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FOREIGN TECHNOLOGY DIVISION

(PART V)

ENCYCLOPEDIA OF CONTEMPORARY ENGINEERING.
STRUCTURAL MATERIALS.

solder thru zircon

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(PART FIVE OF FIVE PARTS)

ENCYCLOPEDIA OF CONTEMPORARY ENGINEERING.
STRUCTURAL MATERIALS.

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SOLDER – a metal or alloy used in soldering for filling the gap between the components to be joined, in order to obtain a monolithic soldered joint. Solder has a complete-fusion temperature lower than the initial melting temperature of the material to be soldered and is capable of forming a strong bond with the latter, of wetting it in the liquid state, and of spreading over it to fill the gap between the surfaces to be joined. The very important characteristic of solder is its ability to dissolve the base metal in the molten state, forming a layer of brittle intermetallides at the contact site, penetrating along the grain boundaries, embrittling the material to be soldered, etc. The technical characteristics of solder vary in accordance with the composition and condition of the material to be soldered. Solders differ in their base, e.g., tin, cadmium, zinc, magnesium, aluminum, copper, nickel, etc. solders, in their characteristic components, e.g., silver, gold, palladium, indium, gallium, etc. solders, in their technological characteristics, e.g., self-fluxing, wide-range, and cermet (consisting of a mixture of powders that partially melt during soldering) solders, in their purpose, e.g., high-hot-strength and acid-fast solders, and in their melting temperature. Only completely meltable solders were formerely used.

Various partially meltable solders have been developed: these include homogeneous solders, which melt over the crystallization-temperature range, and heterogeneous cermet solders, which are employed in the form of mixtures of high- and low-melting powders or are produced by scintering high-melting powders, impregnating them with the low-

melting component of the solder, and then rolling the resultant product.

Completely meltable solders can be homogeneous or heterogeneous. The latter include powdered and laminar materials, whose melting usually involves fusion of the lower-melting component and complete dissolution of the latter in the higher-melting component, as well as eutectic solders, which melt as a result of contact-reactive fusion. Such solders can consist of mixtures of powders, of layers of separate components, or of intermediate alloys. The classification of solders as hard and soft is out-dated and does not correspond to the temperature characteristics of the various classes of solder as they are now defined. The Especially low-melting solders are alloys containing substantial quantities of bismuth, indium, gallium, or mercury and with other elements (tin, lead, cadmium) added. The eutectic Cd-Pb-Sn has the highest melting temperature (145°) in this class. A temperature of 145° is the boundary between this class and the low-melting solders, which are based on tin, lead, cadmium, and zinc. The upper temperature limit of the low-melting solders is 450°, the melting point of the lowest-melting aluminum-based eutectics (Al-Cu-Mg-Si; t°_{pl} 449°). Aluminum-based solders fall into the class of Medium-melting solders, which also includes solders based on magnesium, silver, copper, and certain titanium, palladium, and nickel alloys. The natural temperature limit of the medium-melting solders is 1100°, which corresponds to the melting points of solders based on eutectic alloys of iron-group metals with boron (Ni-B, t°_{pl} 1080°; Co-B, t°_{pl} 1095°) and to the melting point of copper, 1083°. The upper temperature limit of the high-temperature solders can be regarded as falling at the melting point of the lowest-melting of the known eutectics based on high-melting metals (t°_{pl} 1850°). Solders based on high-melting metals with a melting point above 1850°

belong the the high-melting class.

References: See the article entitled Soldering.

N.F. Lashko and S V. Lashko

SOLDER FOR SOLDERING ALUMINUM ALLOYS — solders based on aluminum, zince, or tin. The table shows the compositions of certain solders. Types P300A, P425A, PSr5AKTs, PAKTs, V62, 34A, and P590A are of low plasticity and are used in the form of rods, cast rings, or bars; type 34A is also used in the form of a three-layer foil (silumin + copper + + silumin). The fluxes used for soldering aluminum alloys and their compositions are: 34A flux — 10 ± 1% NaF, 8 ± 2% $ZnCl_2$, 32 ± 3% LiCl, and 45-50% KCl, t°_{pl} ~ 420°; FV3 flux — 40% KCl, 8% NaF, 36% LiCl, and 16% $ZnCl_2$, t°_{pl} = 380-400° (in soldering with zinc solders); F61A flux — 10 ± ± 0.5% zinc fluoroborate, 8 ± 0.5% ammonium fluoroborate, and 82 ± 1% triethanolamine. Type F61A flux is suitable for assembly soldering of aluminum alloys to one another and to steel, copper, etc.; it is active at temperatures of up to ~270° on slow heating and 350° on rapid heating. Type F380 flux, with a composition of 5% NaF, 10% $ZnCl_2$, 38% LiCl, and 47% KCl is used for bath soldering.

On prolonged heating salt fluxes containing $ZnCl_2$ saturate the surface of the alloys to be soldered with zinc, which leads to a sharp reduction in their solderability and to local melting. In soldering massive components in furnaces or in massive assemblies the flux is consequently introduced after preheating the components or rapid heating to the soldering is employed.

Residues of 34A, FV3, F380, and other salt fluxes promote corrosion in soldered joints and they are therefore removed after soldering by washing in hot and cold water (see Soldering of aluminum alloys).

Solders for Soldering Aluminum Alloys

1 Припой	2 Химич. состав (%)							4 Температурный интервал плавления (°С)	5 Температура пайки (°С)	6 Способ пайки и применяемый флюс
	Zn	Cu	Si	Cd	Sn	Al	3 Др. элементы			
7 П200А	10	—	—	—	90	—	—	199—210	260—350	21 Абразивная и ультразвуковая, с флюсом ФЯ1, пайка бесплавленой (ТВЧ, электроконтактный, в электропечах), с П300А — также пайка с флюсом 34А при 440—450°
8 П250А	20	—	—	—	80	—	—	199—235	240—300	
9 ПВ250А	35—39	0,6	—	0,2—0,3	Остальное	—	0,2 Sb	190—245	240—270	
10 П300А	60	—	—	40	10 —	—	—	266—310	340—400	
11 П425А	65	15	—	—	—	20	—	415—425	455—480	22 В пламени паяльной лампы и газовых горелок, ТВЧ, электроконтактный, в электропечах с флюсом ФВ1
12 ПСр5АКЦ	Остальное	—	До 0,15	—	—	2	5 Ag	390—420	450—475	
13 ПАКЦ	Остальное	—	До 0,15	—	—	20	—	420—450	480—500	
14 Припой	—	—	4,5	—	—	Остальное	31Ge	445—485	500—520	
15 В62	20	25±1	3,5	—	—	Остальное	—	20 470 (солид)	495—505	23 В пламени паяльной лампы и газовых горелок, ТВЧ, электроконтактный, в электропечах с флюсом 34А, в ваннах с флюсом Ф380
34А	—	28±1	6	—	—	Остальное	—	[illegible]	560	
16 П575А	30	—	—	—	—	80	—	570—620	620—650	
17 П590А	—	10	1	—	—	89	—	590—625	650—680	
18 Эвтектический силумин	—	—	11,7	—	—	88,3	—	577	600—650	

1) Solder; 2) chemical composition (%); 3) other elements; 4) melting-temperature range (°C); 5) soldering temperature (°C); 6) soldering method and flux used; 7) P200A; 8) P250A; 9) PV250A; 10) P300A; 11) P425A; 12) PSr5AKTs; 13) PAKTs; 14) solder; 15) V62; 16) P575A; 17) P590A; 18) eutectic silumin; 19) remainder; 20) final; 21) abrasive and ultrasonic; with flux F61, flameless heating (with high-frequency current, electrical resistance heating, heating in electric furnaces); with P300A, soldering with 34A flux at 440-450°; 22) in blow torch and gas-burner flames, with high-frequency current, electric resistance, in electric furnaces in FV3 flux; 23) in blowtorch and gas-burner flames, with high-frequency current, electrical resistance, in electric furnaces with 34A flux, in flux baths with F380 flux.

For references see the article entitled Soldering of aluminum alloys.

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SOLDER FOR SOLDERING COPPER: Copper Solder for soldering copper alloys.

SOLDER FOR SOLDERING BRONZE — See Solder for soldering copper alloys.

SOLDER FOR SOLDERING COPPER ALLOYS. Copper alloys are soldered with especially low-melting, low-melting, and medium-melting solders containing no magnesium or aluminum and having a melting temperature below the solidus of the alloy to be soldered. Tin-lead, copper-phosphorus, silver, and copper-zinc solders are most frequently used for copper alloys (see Low-melting solders, Especially low-melting solders, and Medium-melting solders).

In order to prevent evaporation of the zinc from solders of the brass type they are alloyed with small quantities of silicon (LOK59-1--0.3 and LOK62-0.6-0.4 solders). Copper-phosphorus and silver solders containing phosphorus are self-fluxing in soldering copper alloys in air (provided that one employs rapid high-frequency heating, electrical resistance heating, etc.). Phosphorus-containing solders are not self-fluxing in soldering copper alloys of the brass or aluminum-, beryllium-, or silicon-bronze type. Brass is soldered with low-melting solders based on tin, lead, and zinc and with medium-melting solders based on silver and copper and having a liquidus (fusion-termination temperature) lower than that of the alloy to be soldered; copper-rich brasses are soldered with PSr[illegible], PSr[illegible], PSr[illegible], PSr[illegible], PSr12 and PSr[illegible] silver solders, copper-phosphorus solders, and brass solders with a lower melting temperature, such as PMt[illegible], PMt[illegible], PMt[illegible], PF07-[illegible], etc. Type PSr[illegible] silver solder is generally used for zinc-rich brasses (L62, L[illegible]; PF07-[illegible]2 copper solder and PMt[illegible] and PMt[illegible] brass solders can be employed for joints not subject to impact loads or substantial vibration loads. See Soldering of copper alloys.

References: See the article entitled Soldering of copper alloys.

N.F. Lashko and S.V. Lashko

SOLDER FOR SOLDERING HIGH-HOT-STRENGTH ALLOYS. Nickel and palladium solders are most suitable for soldering high-hot-strength alloys. Nickel solders are given low melting points by basing them on eutectic alloys of nickel with bromine, silicon, beryllium, and phosphorus, which have melting temperatures of 1080°, 1150°, 1155°, and 880° respectively, and on alloys containing a continuous series of solid solutions with a minimal melting temperature (e.g., Ni-Mn alloys). Nickel solders based on Ni-B, Ni-Be, and Ni-Si eutectics are brittle and are used in the form of cast bars, powder, and paste (for example, mixed with acrylic resin and R-5 solvent). Such solders, which contain B and Be, intensively dissolve the material to be soldered and have a low hot strength and heat resistance. Addition of chromium, molybdenum, tungsten, aluminum or titanium increases their hot strength and heat resistance. However, addition of aluminum and titanium has a negative influence on the technological characteristics of the solder and the flowability and wettability of the base metal. The heat resistance and hot strength of nickel solders of this type remains considerably lower than that of the materials to be soldered after addition of chromium and molybdenum. The hot strength of joints produced with these solders may be increased by diffusion of the solder components into the base metal on prolonged heating of the soldered components at a temperature near the solidus of the solder (diffusion soldering). Of the aforementioned elements, phosphorus has a greater tendency to diffuse and manganese a lesser tendency.

TABLE 1

Characteristics of Soldered Joints in KHN77TYuR Alloy

1 Припой	2 Система припоя	3 Сопротивление срезу (кг/мм²) при темп-рах (°С)			4 Вид припоя
		20	800	980	
5ПЖ45(67)	Ni – Cr – Mn	72–74	16–20	–	8 Фольга, прутки
6Г40НХ	Ni – Cr – Mn	65–67	16–18	–	9 То же
7ВПр3	Ni – Cr – Si – Ti – (Co)	68–72	41,5–51	9–8	10 Паста, порошок, прутки

1) Solder; 2) solder system; 3) shear resistance (kg/mm^2) at temperature of (°C); 4) form of solder; 5) PZh45(67); 6) G40NKh; 7) VPr3; 8) foil, bars; 9) the same; 10) paste, powder, bars.

TABLE 2

Hot Strength of Joints Soldered in KhN77TYuR Alloy with VPr3 Solder

1 Темп-ра испытания (°С)	2 Телескопическое соединение		3 Стыковое соединение	
	4 напряжение (кг/мм²)	5 время до разрушения (часы)	напряжение (кг/мм²)	время до разрушения (часы)
920	1–1,3 1	100 200	1–1,3 –	100 –
980	0,5–1 0,5	100 300	0,5–0,8 –	200 –

1) Test temperature (°C); 2) telescopic joint; 3) butt joint; 4) stress (kg/mm^2); 5) time to fracture (hr).

Solders based on solid solutions, in which manganese plays an important role, reducing their melting temperature, are relatively plastic (foil can be produced from them by rolling). In this case the hot strength and heat resistance of soldered joints can be increased by alloying the solder with chromium or by alloying the joints themselves with components of the base material during diffusion soldering.

A typical example of solders alloyed with elements that form low-melting eutectics with nickel is nikobreyz (10% Cr, 4% B, 4% Si, 4% Fe, 1% C, and the remainder nickel; soldering t° – 1150-1180°); complex alloying is employed in certain solders, such as SM56 (15% Cr, 3.5% Be,

4.5% Si, and the remainder nickel; soldering t° – 1030°). Examples of solders based on solid solutions include that containing 40% Ni and 60% Mn and solders of this type additionally alloyed with chromium.

There are solders based on high-hot-strength nickel alloys hardened with an intermetallic phase based on $Ni_3(AlTi)$; their melting temperature can be reduced by adding substantial quantities of manganese. These solders have lower technological characteristics and are more brittle than those based on Ni-Cr-Mn alloys.

Nickel solders containing boron, beryllium, and phosphorus are distinguished by an increased tendency to dissolve high-hot-strength alloys during soldering, while those containing boron and beryllium tend to penetrate between the grains of the base material and are unsuitable for soldering thin-walled structures. Solders alloyed with silicon and, especially, manganese have a comparatively low dissolution capacity and no tendency toward intergranular penetration of the base material and consequently can be used for soldering at high temperatures and with long holding times. Soldering with nickel solders is usually carried out with furnace heating and less frequently with high-frequency heating or in gas-burner flames. Other heating methods are also possible, including salt baths, electrical resistance heating, etc. Depending on the composition of the material to be soldered, furnace heating is conducted in various gases or in a vacuum; alloys of type Kh20N80T (EI435) and cobalt alloys are soldered in dry hydrogen with a dew point $\geq -50°$, while alloys of type KhN77TYuR (EI437B) are soldered in a vacuum with a residual pressure of no more than 1 mm Hg. Good soldered joints are obtained when the chamber is preliminarily cleaned with purified argon. Joints in KhN77TYuR alloy soldered with Ni-Cr-Mn solders can function at temperatures of up to 800-850°, while those soldered with Ni-Cr-Si-Co and Ni-Cr-Si-Ta solders can function at up to 980-

1000°. Table 1 shows the shear resistance of joints soldered in KhN77T KhN77TYuR alloy with certain Soviet solders, while Table 2 shows the hot strength of joints soldered in KhN77TYuR alloy.

Assemblies of high-hot-strength and heat-resistant nickel alloys and steel can also be soldered with palladium solders based on Pd-Ni, Pd-Ni-Cr, which has a melting temperature of up to 1250° and forms soldered joints heat-resistant to temperatures above 900°, and Pd-Ag-Mn and Pd-Ag-Cu, which have a lower soldering temperature and form joints heat-resistant to 500-800°. Palladium solders are plastic and have a low dissolution capacity with respect to the base material. High-hot-strength nickel alloys can be soldered with palladium solders in a vacuum or in argon activated with gaseous fluxes (BF_3, etc.). See Solder for soldering steel.

References: Gorokhov, V.A., Skripov, M.I., Vestn. mashinostroyeniya [Herald of Machine Building], 1955, No. 7, page 47; Herrschaft, D.C., The Evolution of Ductile High-Temperature Brazing Alloys, Metal Progr., 1961, Vol. 80, No. 3, page 97; Feduska, W., New Alloys for Brazing Heat-Resisting Alloys, Weld. J., 1960, Vol. 39, No. 7; Perry, E.R., Brasage a haute temperature par apport d'alliages au palladium [

], Bull. Soc. Roy. Belge Electriciens [Bulletin of the Royal Belgian Society of Electricians], 1960, Vol. 76, No. 2, page 171; see also the article entitled Soldering.

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SOLDER FOR SOLDERING HIGH-MELTING METALS AND THEIR ALLOYS — see Soldering of high-melting metals and their alloys.

SOLDER FOR SOLDERING LEADS. Low-melting solders (tin-lead, lead, and cadmium), are used for soldering copper leads, while tin-zinc, cadmium-zinc, and zinc solders are used for aluminum leads. The principle requirements imposed on soldered joints in wire are sufficiently high corrosion resistance, electrical conductivity, and high hot strength. Joints soldered in copper wires with tin-lead solders (TOS30, TOS40, and, less frequently, POS18) exhibit satisfactory corrosion resistance and can function at temperatures of up to ~100°, while those made with silver-lead solders (PSr3, PSr2.5) are hot-strong at temperatures of up to 200-250°; joints made with cadmium solders (PSr3Kd etc.) exhibit the greatest hot strength at temperatures of $\geq$200°. Lead and cadmium solders have lower technological characteristics than tin-lead solders. The wetting power, spreading capacity, and flowability of solders of type PSr3 is somewhat improved by alloying with tin (PSr2.5 solder). Cadmium solders have a tendency toward intensive oxidation, pronounced dissolution of copper, and formation of a layer of brittle intermetallides along the boundary between the seam and the base metal, the latter weakening the joint. In soldering copper wire with cadmium solders there is consequently a danger of extreme tapering of the wire near the chamfer (especially at a wire diameter of less than 0.8-0.7 mm) and a decrease in joint strength. In order to prevent intensive dissolution of copper in cadmium solders, soldering should be conducted as rapidly as possible, without interruption, repetition, or overheating of the solder, using sufficiently powerful regulable electric soldering guns or resistance or induction heating. Thus, for example, in sol-

dering fine copper wire (with a diameter of 0.5-0.8 mm) the time for which it is in contact with the molten solder should not exceed 30 sec and the soldering temperature should be no higher than ~400°. Joints made with PSr3Kd cadmium solder are strongest when heating is carried out with carbon electrodes. In order to ensure sufficiently high corrosion resistance, copper wire is soldered with rosin-alcohol fluxes, LK2 flux, NICO paste, or LTI120 flux; any residue of LK2, NICO, or LTI120 flux is removed by rubbing the joint with waste wetted in ethyl alcohol. Cadmium solders are also used with FK50 flux, in the form of a 30-50% aqueous solution. The residue of FK50 flux is thoroughly removed by subsequent rinsing (see Low-melting solders). Cadmium solders are more conductive (by a factor of 2-1.5) than tin-lead or lead solders.

Aluminum leads are soldered by the abrasive or ultrasonic method with solders containing tin, zinc, silver, cadmium, and aluminum (up to 20% Al) and having a melting temperature of 150-450°. The principal shortcoming of joints made in aluminum wire with solders containing less than 30-35% Zn is their low corrosion resistance; such joints must be protected from humid air and water with lacquer coatings and insulating materials. A higher corrosion resistance is displayed by joints made with solders of type P300A and with solders of compositions A and B: solder A – 55% Zn, 40% Sn, and 1.5-2% Cu, t°_{pl} 400-425°; solder B – 80% Zn, 8% Cu, and 12% Al, t°_{pl} 410°.

References: Apukhtin, G.I., Tekhnologiya payki montazhnykh soyedineniy v priborostroyenii [Techniques for Soldering Fitting Joints in Instrument Building], Moscow-Leningrad, 1957; Maksimikhin, B.A., Payka metallov v priborostroyenii [Soldering of Metals in Instrument Building], Leningrad, 1959; Kromchenko, G.Ye., Soyedineniye i okontsevaniye mednykh i alyuminiyevykh provodov i kabeley [Joining and Finishing of

Copper and Aluminum Leads and Cables], Moscow-Leningrad, 1950.

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SOLDER FOR SOLDERING MAGNESIUM ALLOYS – see Soldering of magnesium alloys.

SOLDER FOR SOLDERING NICKEL ALLOYS — silver, nickel, tin-lead, copper, and brass solders. Aluminum-, magnesium-, and titanium-based solders form brittle joints in nickel alloys and therefore are not employed (see Low-melting solders and Medium-melting solders).

Solder selection is dictated by the purpose for which the alloys and components to be soldered are intended. Low-melting tin-lead solders are suitable for soldering components to function at temperatures of no higher than 100°. These solders are used with LK2, LTI120, NICO, and other rosin-alcohol fluxes. Silver solders are used for soldering alloys with a high nickel content to one another and to other metals and alloys; PSr40 and PSr45 solders are used for soldering temperatures of up to 650-700°. When the soldered joints must satisfy increased requirements for corrosion resistance solder with a higher silver content (≥50%) is used.

Copper and nickel form a continuous series of solid solutions. Considerable dissolution of the base material in the solder consequently occurs when soldering copper, this phenomenon being accompanied by a rise in the melting temperature of the liquid phase, expansion of its crystallization range, and a decrease in its flowability. In soldering copper the solder must be carefully measured out and applied as close as possible to the gap (or introduced into the gap) and heating must be conducted at temperatures near the working soldering temperature.

Components of high-hot-strength and heat-resistant nickel alloys are soldered with special nickel and palladium solders (see Solder for soldering high-hot-strength alloys).

References: See the article entitled Soldering of nickel alloys.

N.F. Lashko and S.V Lashko

SOLDER FOR SOLDERING STEEL — solders based on tin, lead, silver, copper, and nickel. Iron, aluminum, cadmium, and zinc solders are unsuitable for soldering steel. Iron solders have a relatively high melting temperature (≥1250°), while those with lower melting temperatures have a very strong tendency to dissolve steel during soldering. Aluminum and zinc solders form brittle joints that tend to exfoliate; cadmium solders exhibit a poor wetting capacity and flowability.

Solders based on Sn-Pb and Cu-Zn, silver and nickel solders, and copper, with the appropriate fluxes or gaseous media, are used for soldering steel (see Medium-melting solders, Low-melting solders, and Solders for soldering high-hot-strength alloys). Lead solders have low technological characteristics in comparison with tin-lead solders. Silver solders (based on Ag-Cu, Ag-Cu-Zn, or Ag-Cu-Zn-Cd) have a tendency to spread rapidly and to form localized incrustations on the coated surface. Copper as a solder is characterized by an ability to flow into very narrow gaps and to coat the surface to be soldered rapidly, especially when soldering in a furnace with a reducing atmosphere (dry hydrogen, dissociated ammonia). The copper-zinc solders with the greatest ability to spread and to form strong, plastic joints are L62, L68, and LOK59-1-0.3 brasses. Brasses with a higher zinc content (PMts36, PMts48, and PMts54) are of low plasticity and less strong and are rarely used. Addition of tin to L62 or L68 brass improves its spreadability on steel, while addition of silicon prevents evaporation of the zinc.

Copper-manganese solders (>15% MN) with a varying nickel content (10-30% Ni) have a very strong tendency to form pores in the joints

when soldering with 200 or 201 flux in a gas-burner flame and are consequently used principally for soldering in flowing argon or gaseous fluxes in electric furnaces. Addition of several tenths of a percent of lithium or lithium and boron makes copper, copper-manganese, and certain silver solders self-fluxing in pure flowing argon.

When covered with flowing argon the surface of Kh18N9T stainless steel, which is stabilized with titanium, is poorly wetted by self-fluxing silver solders (e.g., PSr72LMN). Activation of PSr72LMN solder by addition of Ti (~0.12%) or Zr (~1%) ensures good wetting, smooth chamfers, and an increase in joint strength under these same conditions (at a soldering temperature of 960-1050°).

Silver and copper solders containing no lithium and nickel solders are suitable for soldering stainless steel in a vacuum, in mixtures of dry argon and gaseous fluxes (BF_3, etc.), or in very dry hydrogen with a dew point of from -40° to -70°. However, solders alloyed with zinc, cadmium, or substantial quantities of manganese are unsuitable for vacuum soldering as a result of their increased evaporability. Addition of small amounts of palladium (1-6%) to Ag-Cu solders ensures compact joints capable of functioning under vacuum conditions.

In vacuum soldering manganese-containing nickel solders are characterized by reduced flowability, a tendency to form convex chamfers and "beads" at the points of solder application, and interdendritic porosity in the joint.

Joints made in high-hot-strength steels with tin-lead solders are capable of functioning for prolonged periods at temperatures of up to ~100°, while those made with silver solders can function at up to ~400-450°; the extremely high-hot-strength silver solder PSr85-15 forms joints that oxidize in air at temperatures above 500°; the copper-nickel-manganese solders VPr2 and VPr4 and the copper-nickel solder

VPrl form joints that can function for brief periods at up to ~600°; joints made with nickel solders alloyed with chromium (10-20%) are hot-strong and heat-resistant at temperatures of up to 800-1000°. Thin-walled structures of stainless and high-hot-strength steels intended to operate for prolonged periods at elevated temperatures are soldered with palladium solders based on Pd-Ni or Pd-Ni-Mn, occasionally with chromium, silicon, beryllium, gold, or aluminum added. Palladium solders melt over a relatively broad temperature range (810-1552°). Pure palladium is used as a solder in some cases.

Palladium solders based on Pd-Ni or Pd-Ni-Cr form heat-resistant joints that can function at temperatures above 900°; solders based on Pd-Ag-Mn or Pd-Ag-Cu have a lower heat resistance (up to 500-800°). Palladium solders are distinguished by low low erosivity and good plasticity. Steels are soldered with palladium solders in a vacuum or an atmosphere of argon activated with gaseous fluxes. High-temperature solders corresponding to the temperature from which the tool is to be quenched after soldering are used for tool steels: copper is employed for carbon steels, while welding powders containing ferrous alloys and fluxes, complex-alloy copper solders, and solders containing nickel, zinc, iron, and silicon (types GFK and GPF) are used for high-speed steels.

References: Kulikov, F.V. and Lekhtsiyer, I.P., Tverdaya payka [Solid Soldering], Moscow-Leningrad, 1959; Feduska, W., New Alloys for Brazing Heat-Resisting Alloys, Weld. J., 1960, Vol. 39, No. 7.

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SOLDER FOR SOLDERING THIN-WALLED STRUCTURES. The quality of soldered joints in thin-walled structures depends principally on the ability of the molten solder to dissolve the base material during soldering. This dissolution can be local or general, reducing the thickness of the material and leading to undercutting or, in certain cases, complete fracture ("eating away") of the component being soldered. Local dissolution can be intergranular, extending into the base material, or superficial. Thin-walled structures are soldered with solders that, when molten, to not tend to dissolve much of the base material under a predetermined soldering regime (temperature and time). Thin-walled structures of stainless austenitic steel can be soldered with copper or copper alloys (VPr1 and VPr2 solders), which do not markedly dissolve the base material, and with solders having compositions of 72% Ag and 28% Cu, Ni-Cr-Mn, and Ni-Cr-Si, which also dissolve little of the steel on severe overheating (to more than 200° above the working soldering temperature for 1 hr). Manganese solder of type G70 and L62 brass are unsuitable for this purpose, intensively dissolving stainless steel. In using these solders they must be carefully measured out and applied as close as possible to the gap (they are best introduced directly into the gap); substantial overheating or prolonged contact between the base metal and the liquid solder is impermissible. Nickel solders alloyed with boron intensively dissolve stainless steel, penetrating deep along its boundaries, and are unsuitable for soldering thin-walled structures. Thin-walled articles of high-hot-strength nickel alloys of types KhN77TYuR (EI437B) and Kh20N80T (EI435) are soldered with Ni-Cr-Mn

solders, although Ni-Cr-Si solders can also be employed. Copper and nickel solders alloyed with boron, beryllium, zirconium, or phosphorus, which tend to dissolve a great deal of the base material, and solders containing boron (and sometimes beryllium), which penetrate between the grains of the base material, are unsuitable for this purpose. Palladium solders, which dissolve little of the material to be soldered, are also used for thin-walled structures of stainless steel and nickel alloys (see Solder for soldering steel). It is dangerous to solder thin-walled structures of copper and its alloy with Ag-Cu silver solders or copper-phosphorus bronze or to solder structures of cupronickel alloys with copper. All these solders intensively dissolve the base material and must be used with the precautions mentioned above. In soldering with low-melting solders, copper has a tendency to dissolve in zinc, cadmium, and tin solders.

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SOLDER FOR SOLDERING TITANIUM ALLOYS. Silver-rich solders are the most suitable for this purpose, forming the comparatively plastic intermetallide TiAg when they react with titanium and its alloys. The soldered joints exhibit fracture of the plastic-shear type along the seam. Aluminum is an alternate base for Medium-melting solders for soldering titanium alloys. Aluminum solders are used for soldering titanium to aluminum alloys (see Soldering of titanium alloys).

Solders for Soldering Titanium Alloys and Shear Resistance of Soldered Joints*

1 Припой	2 Паяемый материал (толщина 8 мм)	3 Покрытие	4 Режим пайки и способ нагрева	5 Среда пайки	6 Сопротивление срезу (кг/мм²)
7 Серебро **	15 ВТ1 (1,5 мм)	—	25 Электропечь; 26 960—980°, 5 мин.	29 Аргон	15—16
8 ПСр90	17 ОТ4 (1,5 мм)	—	980°, 5 мин.	30 Вакуум	9—10
9 ПСр85-15	ОТ4	—	27 1000°, 10 мин.	Аргон	20—22
ПСр85-15	ВТ1	—	ТВЧ, 990°	То же	22
10 ПСр72	ОТ4	—	Электропечь, 900°, 5 мин.	Вакуум	17—20
11 ПСр72ЛМН	ОТ4	—	Электропечь, 880°, 5 мин.	То же	17—19
ПСр72ЛМН	ОТ4	23 Никелевое (химич. способ)	28 Кислородно-ацетиленовая горелка	31 Флюс 209	17—19
12 ПСоМо68-27-5	ОТ4	—	Электропечь, 870°, 5 мин.	—	13—15
13 ПСр50	ОТ4	Никелевое (химич. способ)	Кислородно ацетиленовая горелка	Флюс 209	9—10
ПСр50	18 ВТ3-1	24 То же	То же	То же	19—28
14 ПСр45	ВТ1	—	Электропечь, 680°, 5 мин.	Аргон	19—26
15 ПСр40	ВТ3-1	Никелевое (химич. способ)	Кислородно-ацетиленовая горелка	Флюс 209	17—20
ПСр50	19 ОТ4 и 1Х18Н9Т	То же	То же	То же	9,5
ПСр50	20 ОТ4 и БрХ0,8	•	•	•	5,7
ПСр50	21 ВТ3-1 и 1Х18Н9Т	•	•	•	16,5—18
11 ПСр72ЛМН	19 ОТ4 и 1Х18Н9Т	•	•	•	12—16
ПСр72ЛМН	21 ВТ3-1 и 1Х18Н9Т	•	•	•	14—16
ПСр72ЛМН	20 ОТ4 и БрХ0,8	•	•	•	6—8,5
15 ПСр40	21 ВТ3-1 и 1Х18Н9Т	•	•	•	13—14
ПСр40	22 ВТ3-1 и БрХ0,9	•	•	•	11—13,5

*For the chemical compositions of these solders see the table in the article entitled Medium-melting solders.

**Corrosion resistance in certain media is reduced when silver and titanium are in contact.

1) Solder; 2) material to be soldered (8 mm thick); 3) plating; 4) soldering regime and heating method; 5) soldering medium; 6) shear resistance (kg/mm^2); 7) silver; 8) PSr90; 9) PSr85-15; 10) PSr72; 11) PSr72 LMN; 12) PSrMo68-27-5; 13) PSr50; 14) PSr45; 15) PSr40; 16) VT1; 17) OT4; 18) VT3-1; 19) OT4 and 1Kh18N9T; 20) OT4 and BrKh0.8; 21) VT3-1 and 1Kh18N9T; 22) VT3-1 and BrKh0.8; 23) nickel (chemical deposition); 24) the same; 25) electric furnace; 26) min; 27) high-frequency; 28) oxyacetylene torch; 29) argon; 30) vacuum; 31) flux.

Solders based on zinc, copper, nickel, and many other metals are unsuitable for soldering titanium alloys, since they form very brittle joints and intensively dissolve the base material. The presence of these metals (zinc, copper, nickel, manganese, etc.) in silver or aluminum solders also leads to embrittlement of the joints and intensive dissolution of the titanium in the solder. Thus, for example, the shear resistance of joints made in VT1 alloy with solder containing Ag and 15% Mn amounts to 15-20% of that of the solder, while that of joints made with PSr50 solder amounts to 30-35% of that of the solder. The strength of soldered joints is reduced both by embrittlement of the joint itself and by dissolution of the base metal in the solder and the resultant thinning of the former at the points of solder application, this being especially dangerous in soldering thin-walled structures. Satisfactory joints can be obtained with silver-rich solders when the soldering time and temperature are strictly limited or when diffusion soldering, which involves dispersion of the intermetallide TiAg, is employed. Silver solders alloyed with considerable quantities of copper, cadmium, and zinc can be used with the appropriate fluxes in welding components with an applied intermediate layer, as of nickel (deposited chemically). However, heating should be rapid in this case (employing high-frequency current, gas torches, or the electrical-resistance method), especially in soldering titanium alloys to steel and copper alloys. The table shows the recommended soldering temperatures

and strength characteristics for soldered joints. Tin and POS61 solder are also employed for soldering titanium alloys.

References: Clark, E.J., Vacuum Diffusion Processing of Titanium Components Produces Joint Strength Equla to that of Base Metal, Weld. J., 1959, Vol. 38, No. 6, page 251.

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SOLDERING – inseparable joining of solid materials by filling the gap between them with a relatively low-melting liquid alloy (solder) and forming a strong bond between the soldered joint and the materials being soldered.

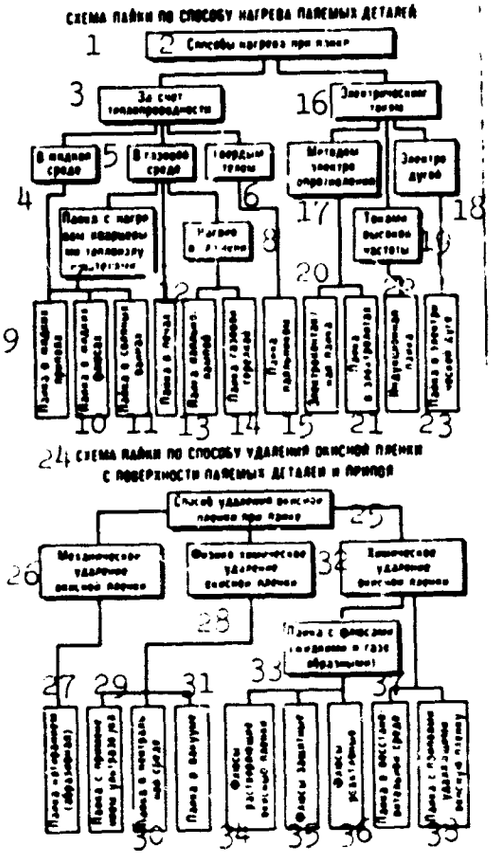
Metallic and nonmetallic (graphite, ceramics, glass, etc.) materials can be joined by soldering. Adhesion in the soldered joint generally results from a physicochemical diffusion reaction between the liquid phase (solder) and the material to be soldered and subsequent crystallization. Before soldering the surface of the components and the solder should be cleaned of oxides, oil, and other contaminants, which hinder contact and development of strong adhesion between the metal to be soldered and the solder. Grease, oil, and other contaminants are removed from the surface of the components to be soldered by wiping or rinsing with solvents or with ultrasound. Oxides are removed by mechanical or chemical means. Mechanical techniques include sand-blasting (for steel) and use of steel or fiber brushes, emery paper, and scrapers. Mechanical surface cleaning is employed for steel, copper and its alloys, and nickel and its alloys. Etching in special solutions is more reliable for aluminum, aluminum alloys, magnesium, and titanium. Etching gives metal surfaces a more favorable microfinish for soldering than does mechanical cleaning. Etching is also more efficient than mechanical cleaning in serial production. In order to remove oxides from the surface of the metal to be soldered and the liquid solder and to protect them from oxidation during soldering special substances (fluxes) are used and soldering is carried out in protective gases or in a vacuum.

II-1P-2

Physicomechanical Characteristics of Pavinols

Показатели 1	Павинол галантерейный (заменитель кожи) (ТУ 796-52) 2		Павинол авиационный 3	
			4 ПА (ТУ 1-59)	5 ПА-1 (СТУ 18-413-62)
Тканевый каркас, артикул 6	Хлопчатобумажная ткань бязь, артикул 36 14	Хлопчатобумажная ткань молескин Д 15	Стеклоткань АП 16	Хлопчатобумажная ткань перкаль А №5 с огнезащитной пропиткой, артикул 4234 17
Ширина (см, не менее) 7	60	58	85	75
Толщина (мм) 8	0.5—0.7	0.6—1.0	0.25—0.45	0.25—0.45
Вес 1 м² (г) 9	550—750	600—900	18 а) Мелкие рисунки 370 ± 50 б) Крупные рисунки 400 ± 50	
Прочность на разрыв полоски 25×100 мм (кг, не менее) 10 — Основа 10a	14	20	30	18
Уток 10b	12	15	30	15
Истирание на приборе Федорова при грузе 500 г (сек, не менее) 11	90	90	90	90
Морозостойкость при температуре −25° 12	19 Покрытие не растрескивается при перегибе образца вокруг стержня диаметром 10 мм			
Горючесть 13	20 Горит	Горит	21 Не горит и не тлеет по удалении источника огня	

1) Characteristic; 2) haberdashery pavinol (leather substitute) (TU 796-52); 3) aviation pavinol; 4) PA (TU 1-59); 5) PA-1 (STU 18-413-62); 6) cloth base, weave; 7) width (cm, no less than); 8) thickness (mm); 9) weight of 1 m^2 (g); 10) tensile strength of strip 25 x 100 mm in size (kg, no less than); 10a) warp; 10b) woof; 11) wear in Fedorov device under load of 500 g (sec, no less than); 12) frost resistance at -25°; 13) combustibility; 14) cotton cloth of byaz' type, weave 36; 15) cotton cloth of moleskin D type; 16) AP fiberglass cloth; 17) percale A-85 cotton cloth impregnated with fire-retardant substance, weave 4234; 18a) small patterns — 370 ± 50; 18b) large patterns — 400 ± 50; 19) coating does not crack when specimen is bent around rod 10 mm in diameter; 20) burns; 21) does not burn or smolder when flame is removed.



Classification of soldering techniques by method of heating the components to be soldered and by method of removing the oxide film from the surface of the components to be soldered and the solder. 1) Classification of soldering techniques by method of heating the components to be soldered; 2) heating method; 3) by thermal conduction; 4) in liquid medium; 5) in gaseous medium; 6) with solid body; 7) heating with quartz heat-radiating elements; 8) flame heating; 9) soldering in liquid solders; 10) soldering in liquid fluxes; 11) soldering in salt baths; 12) soldering in furnaces; 13) soldering with soldering lamp; 14) soldering with gas torch; 15) soldering with soldering iron; 16) with electric current; 17) by resistance heating; 18) electric-arc; 19) with high-frequency current; 20) electrical-resistance soldering; 21) soldering in electrolytes; 22) induction soldering; 23) soldering in electric arc; 24) classification of soldering techniques by method of removing oxide film from surface of components to be soldered and solder; 25) method of removing oxide film; 26) mechanical removal of oxide film; 27) abrasive soldering; 28) physicochemical removal of oxide film; 29) soldering using ultrasound; 30) soldering in neutral medium; 31) soldering in vacuum; 32) chemical removal of oxide film; 33) soldering with fluxes (liquid and gaseous); 34) fluxes that dissolve oxide film; 35) protective fluxes; 36) reactive fluxes; 37) soldering in reducing atmosphere; 38) soldering with solders that remove oxide film.

Fluxes are mixtures or solutions of salts or acids (including organic acids) and are used in the liquid or gaseous state. During their interaction with fluxes, oxides are broken down or removed by chemical exchange or reduction processes (particularly in hydrogen), while in a vacuum they are removed by dissociation. During the soldering of certain metals that act as getters (e.g., titanium and zirconium) surface oxides dissolve in the metal when it is heated in a vacuum or protective gas. Certain solders are self-fluxing during soldering; this is true of Cu-P and Cu-Ag-P solders when soldering copper. Copper- or silver-based solders containing lithium and boron are self-fluxing when soldering stainless steel. Oxides are removed from the surface of aluminum and aluminum alloys during soldering with low-melting solders by the abrasive or ultrasonic method.

The following types of soldering are employed: 1) noncapillary, in which the solder is completely melted and interacts with the material to be soldered without participation of capillary forces; 2) capillary, in which the solder is completely melted and interacts with the material to be soldered with participation of capillary forces; 3) cermet, in which the solder, a mixture of powders, is partially melted during soldering and interacts with the material to be soldered during crystallization and as a result of sintering. Cermet soldering is employed chiefly when the gap between the components is wide or when precise fitting of the components is impossible; 4) contact-reactive, in which a liquid phase is formed as a result of contact-reactive fusion where the soldered components come into contact; 5) diffusion, in which the joint solidifies at a temperature above the solidus of the solder. Capillary soldering is the most common method. The technological features of the soldering process and, as a rule, the lower strength of the solder in comparison with the base material govern the structural charac-

teristics of soldered joints. Lap joints are most frequently encoun tered, butt joints being considerably less common.

The strength of a soldered joint is governed by the strength of the solder, the size of the gap, the method by which oxides are removed from the solder and the surfaces to be joined, the soldering regime, and the structural characteristics of the joint. The soldering-temperature range that insures a high-quality joint is limited by the working temperature, i.e., the minimum temperature at which the liquid phase begins to fill the gap and adhere to the base material, and the maximum soldering temperature, above which the base material intensively dissolves in the molten solder.

Heating during soldering is carried out in electric furnaces, in baths containing molten solder, fluxes, or salts, with high-frequency current, by the electrical-resistance method, in electrolytes, in electric arcs, in the flames of soldering lamps or torches, and with various types of soldering irons. Quartz heat-radiating elements (lamps) are also employed. Heating with plasma, electron beams, and optical quantum generators are promising methods. Soldering techniques are most often classified by the method used to heat the components to be soldered, by the method used to remove oxide films (see Figure), or by the procedure by which the joint is formed. The soldering process can be mechanized and automated, principally with respect to delivery of the components to be soldered to the heating site and control of the soldering-temperature cycle. Soldering is used in the manufacture of various products, ranging from broad-consumption merchandise to special-purpose equipment. Soldering has advantages over fusion welding as a joining method in the manufacture of light thin-walled openwork structures, in joining components that differ greatly in thickness, in the manufacture of products of complex shape, and when structures consist

of alloys with different bases, including nonmetallic materials that cannot be joined to metallic components or to one another by other methods. As a result of the less intensive or more uniform heating (in furnaces) during soldering the structure of the base material and the size and shape of the component or product remain unaltered in many cases. The residual internal stresses in soldered joints are less than those in fusion-welded joints.

References: Lashko, N.F., Lashko-Avakyan, S.V., Payka metallov [Soldering of Metals], Moscow, 1959; Yesenberlin, R.Ye., Payka metallov [Soldering of Metals], Moscow, 1959; Idem, Payka metallov v pechakh s gazovoy sredoy [Soldering of Metals in Furnaces with Gaseous Atmospheres], Moscow-Leningrad, 1958; Lakedemonskiy, A.V., Khryapin, V.Ye., Spravochnik payal'shchika [Solderer's Handbook], Moscow, 1959; Lashko, N.F., Lashko-Avakyan, S.V., O vybore temperatury payki [Selection of Soldering Temperature], Svarochnoye proizvodstvo [Welding], 1961, No. 3; Rukovodstvo po payke metallov [Handbook of Metal Soldering], translated from English, Moscow, 1960.

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SOLDERING OF ALUMINUM ALLOYS – a process utilizing salt and organic fluxes or preliminary cleaning of the surfaces to be soldered by the abrasive or ultrasonic method. Aluminum alloys are not soldered in a vacuum, in argon, or in hydrogen. Soldered joints can be made in the majority of aluminum alloys, except those containing more than 4-5% Mg. Such soldering is carried out with special solders and fluxes (see Solder for soldering aluminum alloys). Before soldering the surfaces of aluminum alloys should be thoroughly cleaned of oil and grease, etched in a 10-20% aqueous solution of NaOH, cleared in 5% HNO_3, washed in water, and dried at 50-70°. Heating is carried out in electric furnaces, in flux baths, with high-frequency current, and in the flames of soldering lamps and torches (except oxyacetylene), being limited by the solidus temperature of the alloys being soldered.

Марка припоя 1	σ_b (кг/мм²) 2						Вид разрушения 8
	соединения, паянные внахлестку 3				соединения, паянные в стык		
	Al	АМц 4	Д16Т 5	Д20 6	АМц 4	Д16Т 5	
П200А 9	6,4	5	4	–	11,5	7,5	Разрушение по паяному шву, УЗ паяка 20
П250А	5,8	5,5	9,5	–	9	11	
П300А 11	5,3	то же	7,5	–	12	10	
ПАКЦ 12	–	4,7	–	– 18	–	–	Разрушение рядом со швом, пайка с флюсом 34А 21
ПСр5АКЦ 13	–	4,5	–	–	–	–	
В62 14	–	–	25	28,8 (в печи)	–	–	
То же 15	–	–	–	23,8 (с горелкой)	–	–	
34А 16	–	9,4	20	20,4 (в печи)	–	–	
Эвтектич. силумин 17	–	–	–	– 19	9,3	–	

1) Type of solder; 2) kg/mm^2; 3) lap-soldered joints; 4) AMTs; 5) D16T; 6) D20; 7) butt-soldered joints; 8) type of fracture; 9) P200A; 10) P250A; 11) P300A; 12) PAKTs; 13) PSr5AKTs; 14) V62; 15) the same; 16) 34A; 17) eutectic silumin; 18) in furnace; 19) with torch; 20) fracture along soldered joint, ultrasonic soldering; 21) fracture parallel to joint, soldering with 34A flux.

Al-Mg-Cu and Al-Mg-Zn alloys hardened by heat treatment and Al-Mg alloys hardened by plastic deformation tend to crack in stressed structures when brought into contact with molten low-melting tin solders. As a result of the overaging and annealing that occur under the action of the thermal and physicomechanical soldering cycles alloys hardened by aging or cold-working lose some of their increased strength in soldered joints, the extent of this phenomenon depending on the heating method and regime.

Lap and butt joints made between aluminum alloys and eutectic silumin with PSr5AKTs, PAKTs, V62, 34A, P575, and P590A solders fracture through the base material or in parallel with the seam under tension.

Quenching of soldered joints in aluminum alloys is greatly hampered by the danger that the joints will melt on reheating. If the design of the structure and the soldering temperature permit, it is best to combine soldering and quenching. When the soldered seam is of low strength (e.g., when soldering with the low-melting solders P200 and P300A) a uniformly strong joint can be obtained by increasing the soldering area.

The table shows the ultimate strength of soldered joints in aluminum alloys.

Soldered joints made with low-melting tin-based solders (P200A or P250A) have a low corrosion resistance under atmospheric conditions and must be protected by painting. The corrosion resistance of soldered joints can be increased by raising the zinc content of the solder (e.g., when soldering with VP250 solder), by soldering anodized components with Sn-10Zn-5Al solder, or by using an intermediate nickel coating preliminarily applied to the surfaces to be soldered by chemical means. Joints soldered with the low-melting solder P300A or the medium-melting solders V62 and 34A have a high corrosion resistance without

protection by painting. The most corrosion-resistant joints are those made with PSr5AKTs and PAKTs solders and eutectic silumin. When aluminum solders not containing large amounts of silicon (P570A or P590A) are used the joints have the same color as the base material after anodizing.

References: Lashko, N.F. and Lashko-Avakyan, S.V., Payka metallov [Soldering of Metals], Moscow, 1959; Idem, Payka alyuminiyevykh splavov [Soldering of Aluminum Alloys], Moscow, 1958; Maksimikhin, B.A., Payka metallov v priborostroyenii [Soldering of Metals in Instrument Building], Leningrad, 1959; Lashko, N.F., Lashko-Avakyan, S.V., Korrozionnaya stoykost' soyedineniy iz alyuminiyevykh splavov, payannykh legkoplavkimi pripoyami [Corrosion Resistance of Joints Soldered in Aluminum Alloys with Low-melting Solders], Svarochnoye proizvodstvo [Welding], 1961. No. 5; Idem, Povysheniye korrozionnoy stoykosti soyedineniy iz alyuminiyevykh splavov, payannykh legkoplavkimi pripoyami [Increasing the Corrosion Resistance of Joint Soldered in Aluminum Alloys with Low-melting Solders], Ibid., 1962, No. 12.

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SOLDERING OF BERYLLIUM – see Welding and soldering of beryllium.

SOLDERING OF BRASS – see Soldering of copper alloys.

SOLDERING OF BRONZE – see Soldering of copper alloys.

SOLDERING OF COPPER ALLOYS. The special features of the soldering of copper and its alloys are dictated by the chemical stability of copper oxides, the fact that they may dissolve or be reduced during heating, their content of readily vaporized elements (zinc, cadmium, and manganese), their high thermal conductivity, the tendency of oxygen-containing copper and certain of its alloys toward hydrogen embrittlement, the high capacity of copper to form brittle intermetallides with other elements, the high capacity of copper and its alloys for dissolution in molten solders, the tendency of such alloys to undergo brittle fracture when brought into contact with molten solders, and the hot-shortness of copper alloys.

The only oxides formed on the surface of copper and low-alloy copper alloys are CuO and Cu_2O, which have a low chemical stability. Oxides of zinc, aluminum, beryllium, and silicon are present on copper alloys alloyed with these elements and are characterized by a high chemical stability and free energy of formation. Especially careful surface cleaning is consequently necessary before soldering brass or beryllium, aluminum, or silicon bronze. Oxides of silicon, beryllium, and aluminum are removed by treatment with hydrofluoric acid or a mixture of sulfuric and nitric acids; the surface of the alloy is then immediately protected with a layer of a sufficiently active flux.

The active flux 38N is used in soldering aluminum and beryllium bronzes with low-melting solders (of the POS type; see Low-melting solder). Fluxes of boron, boron anhydride, fluorides, and fluoborates activated with zinc chloride ($\leq$15%) are suitable for soldering bronze

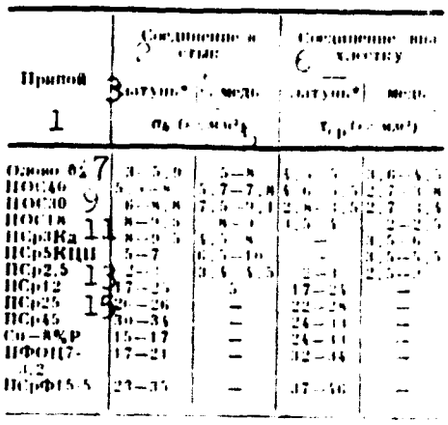
with high-temperature solders, using torches, high-frequency current, or other heating methods. These alloys can also be soldered in neutral-gas atmospheres or a low vacuum in furnaces, using a small amount of salt flux.

When copper alloys containing easily vaporized and easily oxidized elements (zinc and cadmium) are heated with torches, in furnaces, etc., these elements are vaporized and oxidized; active fluxes are consequently used, even when soldering in dry reducing or protective atmospheres or in a vacuum. The cause of the high thermal conductivity of copper heavier soldering irons are used, the components to be soldered are subjected to additional heating with torches, etc.

The tendency of oxygen-containing copper and certain copper alloys toward hydrogen embrittlement when heated in furnaces in a hydrogen atmosphere leads to formation of water vapor and resultant porosity of the metal. Such alloys consequently are not soldered in hydrogen-containing gaseous media. Furnace-soldering of copper and its alloys is generally carried out with fluxes, in an argon atmosphere, with gaseous fluxes, in dry nitrogen, or in a vacuum. Copper is soldered with solders based on bismuth, tin, lead, cadmium, zinc, silver, and copper (see Solder for soldering copper alloys). However, it is necessary to take into account the characteristics of the interaction between the copper alloy and the solder. Copper and copper alloys tend to form intermetallides with aluminum, tin, cadmium, and zinc. The heating of the solder and the time for which copper alloys are in contact with molten solders containing these elements should therefore be minimized.

Copper and copper alloys intensively dissolve in molten silver and copper-phosphorus solders, while copper-nickel alloys dissolve in molten copper, so that soldering must be carried out rapidly in order to avoid overheating of the solder. Copper-nickel alloys (especially those

Strength of Soldered Joints in Copper and L62 Brass



* The substantial scattering of the strength indices of joints soldered in L62 brass with medium-melting solders is due to the porosity of the seams.

1) Solder; 2) butt joint; 3) brass; 4) copper; 5) kg/mm^2; 6) lap joint; 7) type 02 tin; 8) POS40; 9) POS30; 10) POS18; 11) PSr3Kd; 12) PSr5KTsN; 13) PSr2.5; 14) PSr12; 15) PSr25; 16) PSr45; 17) PFOTs7-3.2; 18) PSrF15-5.

containing 10% Ni), copper-silicon alloys, and brasses tend toward brittle fracture when brought into contact with molten low-melting solders, so that they are soldered only in the annealed state. Contact-reactive soldering of copper is possible after application of a layer of silver (5-15 μ thick) to the surfaces to be joined.

Lead brasses, silicon bronzes, tin bronzes, and copper-nickel alloys tend toward hot-shortness and components fabricated from them are consequently not heated through during soldering and are not subjected to severe stresses or loads; heating is carried out rather slowly.

During the soldering of lead bronze (especially with electrical-resistance heating) some lead may escape from the alloy as a result of its low melting point. Heating during soldering may cause a decrease in the mechanical characteristics of joints in age-hardened beryllium bronze.

The table shows the strength of soldered joints made in copper and L62 brass with certain low-melting and medium-melting solders.

References: See the article entitled Soldering.

N.F. Lashko and S.V. Lashko

SOLDERING OF HIGH-MELTING METALS AND THEIR ALLOYS. The soldering of high-melting metals and their alloys entails a number of difficulties associated with their characteristics, since these metals require high soldering temperatures, neutral-gas atmospheres, and production of plastic joints, and with their comparatively low recrystallization temperature, grain growth, and tendency toward embrittlement.

Low-temperature soldering of high-melting metals is employed in exceptional cases, where the joints are intended to function at temperatures of no higher than 100° or such metals are to be joined to aluminum, copper, or steel. Low-temperature soldering of high-melting metals with tin-lead solders is carried out by the techniques usually employed for soldering steel, preliminarily preparing the surfaces to be joined by one of the following methods: 1) mechanical removal of oxides and simultaneous rubbing and tinning with tin-lead solder; 2) heating to a temperature above the point where the oxides begin to volatilize and the surfaces are readily coated with tin; 3) galvonic plating with nickel or copper.

High-melting metals are soldered with solid high-temperature solders in neutral atmospheres (argon, helium) purified of O_2, H_2, and N_2 or in a vacuum with a residual pressure of less than 10^{-4} mm Hg. Heating is conducted in electric furnaces, with high-frequency current, with plasma torches, or by the electrical-resistance method. Before soldering the surfaces to be joined are thoroughly cleaned of contaminants and oxides by chemical or mechanical means.

Inseparable joints can be made in components of Mo, W, and their

Паяемый металл 1	Состав припоя 2	$t_{пл}$ (°C)	Темп-ра испытания паяного соединения 3	$\tau_{ср}$ (кг/мм²) 4
Mo и его сплавы 5	70% Ag, 30% Pt	1205	982	5.1
	80% Ni, 14%Cr, 6%Fe	1392	980	13
	60% Pd, 40% Ni	1260	980	6.6
	Zr	1860	1500	2
Nb и его сплавы 6	Ti	1660	1200	5.5
	29%Ni,2%Si, 1,2% Fe, 0.2% B, остальное— Cu 7	1120	1800	9
	Zr	1860	1200	4
W	98% Cu, 2% Si	1050	–	–
	93% Mo, 7% B	1950	–	–
	97% Mo, 3% B	2400	–	–
	51% Ni, 49% Mo	1315	–	–
Ta	85% Ti, 15% Mo	1800	–	–
Cr	80% Ni, 20% Cr	1450	–	–

1) Metal to be soldered; 2) composition of solder; 3) test temperature for soldered joint; 4) kg/mm^2; 5) Mo and its alloys; 6) Nb and its alloys; 7) remainder Cu.

alloys in areas not heated to temperatures above 300° during operation by soldering with PSr25, PSr45, PSr72, and PSr85 solders and 284 and 209 fluxes. Joints that will function at temperatures of up to 600° can be made in Mo, Nb, Ta, Cr, and their alloys with VPr2, VPr4, and VPr1 solders at soldering temperatures of 1000-1200°, employing general and local heating by the methods described above.

High-temperature soldering of high-melting metals is carried out by rapid heating with high-frequency current or plasma torches or by the electrical-resistance method in argon, helium, or a vacuum.

The table shows the high-temperature solders used and the mechanical characteristics of soldered joints in high-melting metals.

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SOLDERING OF LEAD. The principal difficulties that arise in soldering lead are due to its strong oxidizability when heated in air, to the formation of a dense oxide film, which hampers soldering, and to the low melting point of this metal. Heating is generally carried out with an oxyhydrogen torch, giving the flame an excess hydrogen content sufficient to remove the oxide film from the surface of the metal, with a soldering lamp, or by the friction method. A soldering iron is rarely used for lead components. When soldering in a soldering-lamp flame the component is heated to the temperature at which the bar of solder melts and coats the surface to be soldered when brought into contact with it. Before soldering by the friction method the surface of the component is cleaned mechanically and the area near the joint is coated with grease. The solder is kept from flowing over the component by a layer of soot. Friction soldering is carried out with the aid of a grease-impregnated rag or piece of leather; the solder is applied to the surface of the heated component on the rag or leather. Lead components are soldered with tin-lead solders, most frequently POS30, which have a broad crystallization range and are suitable for soldering by the friction method (see Low-melting solders).

References: See the article entitled Soldering.

N.F. Lashko and S.V. Lashko

SOLDERING OF MAGNESIUM ALLOYS. The special features of the soldering of magnesium and its alloys are dictated by the chemical stability of the oxide, MgO, formed on their surface, the comparatively broad crystallization range of the majority of commercial magnesium alloys, which contain low-melting eutectics or form such eutectics when brought into contact with molten solders, and the low corrosion resistance of magnesium and its alloys when they are brought into contact with iron, aluminum, copper, nickel, or lead or soldered joints alloyed with substantial amounts of these elements.

TABLE 1

Fluxes Used in Soldering Magnesium Alloys

Флюс 1	Температура плавления (°С) 2	Химич. состав (%) 3						
		KCl	NaCl	LiCl	$SrCl_2$	Na_3AlF_6	KF	NaF
8	435	35	35	20	5	—	5	—
12	380	31.5	9	49.5	—	2	—	8
Ф380Мд 4	380	42.5	10	37	—	0.5	—	10

1) Flux; 2) melting temperature (°C); 3) chemical composition (%); 4) F380Mg.

Oxides can be removed from the surface of magnesium alloys only with the aid of sufficiently active fluxes (Table 1).

Residues of these fluxes cause intensive corrosion of the soldered joints and they must consequently be thoroughly removed immediately after soldering by immersing the component for 0.5-1 hr in boiling 2-3% aqueous sodium acetate, which protects magnesium from the corrosive ac-

tion of hot water, and rinsed (for 8-12 min at 20°) in 0.5% potassium dichromate, in 20-30% chromic anhydride, and then in cold and hot water. The principal shortcoming of these fluxes is the fact that they have a higher specific gravity than magnesium-based solders, so that the finished joint may contain residual flux inclusions. Removal of the casting skin from the joints by machining may expose flux-filled pores, in which case the component is again thoroughly rinsed. No fluxes have as yet been developed for soldering magnesium and its alloys at temperatures below 400°.

Ultrasonic soldering of magnesium alloys does not give satisfactory results. Soldering with Low-melting solders is consequently carried through a layer of copper (after chemical zinc-plating), nickel, or silver applied electrolytically to the surfaces to be soldered. The same fluxes employed for soldering with low-melting solders are used for soldering by this method. Tin-zinc, cadmium-zinc, and other lead-free solders are among the low-melting solders employed for soldering magnesium alloys. Lead and tin-lead solders are unsuitable for this purpose, since there is a danger of intensive corrosion between the soldered joint and the base material, which may occur even through pores in the coatings. Soldering with solders of types P300A, P200A, and P170A through coatings is conducted with a soldering iron and LTI120 flux. Magnesium alloys are not softened by soldering with these solders. The only Medium-melting solders used are those based on magnesium. Aluminum solders are unsuitable for this purpose, since they react intensively with magnesium alloys to form brittle, corrosion-susceptible joints. Solders based on other metals (copper, silver, nickel) are unsuitable because of their high melting temperature. In order to reduce the melting temperature of magnesium solders they are alloyed with aluminum, zinc, cadmium, or copper; their corrosion resistance can

be increased by alloying with manganese, while combustion can be prevented by alloying with beryllium. Table 2 shows the composition of certain magnesium solders.

TABLE 2

Magnesium Solders

Припой 1	Темп-ра полного расплавления (°С) 2	Химич. состав (%) 3						
		Al	Zn	Mn	Cd	Cu	Be	Mg
AZ92	595	9	2	—	—	—	0,002	Остальное
AZ125	560	12	5	—	—	—	—	"
1	435	25—27	1—1,5	0,1—0,3	—	—	—	6 "
2	415	21—22	0,2—0,5	0,1—0,3	25—26	—	—	"
3	400	—	—	—	5—15	25—35	—	"
4 П380Мг	560	2—2,5	23—25	—	—	—	—	"
П430Мг 5	600	0,75—1	13—15	—	—	—	—	"

1) Solder; 2) complete-fusion temperature (°C); 3) chemical composition (%); 4) P380Mg; 5) P430Mg; 6) remainder.

TABLE 3

Strength of Certain Solders and Soldered Joints

Припой 1	σ_b припоя в литом состоянии (кг/мм²) 2	МА1	МА8	МА2
		σ_b паяных швов в стык (кг/мм²) 3		
4 П380Мг	10—12	8,5	9,5	8
П430Мг 5	13—15	10,8	9,6	—

1) Solder; 2) σ_b of solder in cast state (kg/mm^2); 3) σ_b of butt-soldered joints (kg/mm^2); 4) P380Mg; 5) P430Mg.

Magnesium solders containing substantial amounts of copper (type 3) or aluminum (types 1, 2, AZ92, and AZ125) have a low corrosion resistance and are capable of intensive dissolution of the base material; it is consequently very difficult to solder thin-walled structures with them. Types P430Mg and P380 Mg solder are technologically the most suitable and are used with induction heating or heating with gasoline-air torches. Type P430Mg solder is suitable for soldering magnesium

and MA1, MA2, and MA8 alloys, while P380Mg solder is used for soldering these alloys and MA3, MA5, and ML5. Soldered joints made with these solders are susceptible to oxidation. When P430Mg and P380Mg solders are used the soldered material undergoes partial softening in the zone of thermal influence parallel to the joint. Table 3 shows the ultimate strength of P380Mg and P430Mg solders and joints soldered with them. Joints made in magnesium shaping alloys by the lap method with P380Mg and P430 Mg solders fracture through the base material, parallel to the joint. Soldered joints in MA1 alloy are softened by ~50%, while those in other shaping alloys are softened by 10-30%.

References: Lasjko-Avakyan, S.V., Lashko, N.F., Payka legkikh metallov (magniya, titan, berilliya) i ikh splavov [Soldering Light Metals (Magnesium, titanium, beryllium) and their Alloys], Moscow, 1958; Maksimikhin, B.A., Payka metallov v priborostroyenii [Soldering of Metals in Instrument Building], Leningrad, 1959.

N.F. Lashko and S.V. Lashko

SOLDERING OF NICKEL ALLOYS. The special features of the capillary soldering of nickel and its alloys are dictated by the difficulty of removing the NiO layer formed on the surface of nickel and certain of its alloys by mechanical means, the high chemical stability and energy of formation of the oxides deposited on alloys containing chromium, aluminum, and titanium, the low melting point of eutectics consisting of nickel and sulfur, arsenic, bismuth, lead, or boron, and the tendency of nickel alloys of the nichrome (Ni-Cr-Fe) and monel (Ni-Cu, Ni-Cu-Al) types toward brittle fracture when stressed and brought into contact with molten solders (see Solder for soldering nickel alloys).

Because of the difficulty of removing NiO from the surface of nickel alloys by mechanical means, etching in special baths no more than 24 hr before soldering is generally employed. In order to prevent formation of an oxide layer during soldering the components are heated in a reducing atmosphere or salt fluxes are employed. Fluxes containing zinc chloride, ammonium chloride, and hydrochloric acid are used for soldering low-alloy nickel alloys, on which oxides based on NiO are formed during heating, with low-melting solders. Soldering of nickel alloys containing chromium, aluminum, and titanium is carried out with the more active fluxes generally employed for soldering steel (see Soldering of steel). However, when boride fluxes of the F201 type are used there is a danger (especially during furnace heating) of erosion of the surface of the material to be soldered as a result of formation of a low-melting boride eutectic. Furnace soldering of nickel and its alloys (nichromes) at temperatures of 1000-1250° is therefore generally

conducted in a dry-hydrogen atmosphere (with a dew point of from -40° to -70°). Alloys containing aluminum and titanium are soldered in a vacuum (of less than $1 \cdot 10^{-3}$ mm Hg) or in mixtures of neutral gases with gaseous BF_3 or NH_4F fluxes; when a vacuum of 1-5 mm Hg is used the surfaces to be soldered are preliminarily subjected to electrolytic plating with nickel or copper or a thin layer of salt fluxes is applied to them.

When nickel reacts with sulfur during heating a low-melting eutectic is formed along the grain boundaries, embrittling the metal. The sulfur content of the protective and reducing gases used in the soldering of nickel and its alloys consequently should not exceed 0.4 mg/liter; residues of oil, paint, greases, and other substances containing sulfur are thoroughly cleaned from the surfaces of the components. Bismuth, arsenic, and certain other low-melting metals have a similar effect on nickel and its alloys. In order to prevent nichrome and monel components from undergoing brittle fracture when stressed and brought into contact with molten solders (especially those containing silver, cadmium, and zinc) soldering is carried out in the annealed state and with no external or internal tensile stresses present. Components to be subjected to subsequent aging are joined with solders whose melting point is below the aging temperature of the material being soldered.

Nickel and its alloys are soldered with the usual heating methods. Torch soldering is carried out in a gentle reducing flame. Soldering can also be conducted by immersion in a salt bath, molten flux, or molten solder. Nickel and nickel alloys are most frequently soldered in special containers, which are evacuated or filled with reducing gases and heated in electric resistance or induction furnaces. The gap between the components should be 0.005-0.12 mm for soldering with fluxes and approximately 0.015 mm for soldering in protective and reducing at-

mospheres.

References: Lashko, N.F. and Lashko-Avakyan, S.V., Payka metallov [Soldering of Metals], Moscow, 1959; Rukovodstvo po payke metallov [Handbook of Metal Soldering], translated from English, Moscow, 1960.

S.V. Lashko and N.F. Lashko

SOLDERING OF STEEL. In selecting a soldering method for steel it is necessary to take into account the stability of the oxide film formed on the surface of the metal, which hampers soldering, the character of the physicochemical interaction between the steel and the solder and the change in the characteristics of the steel under the influence of the soldering heat cycle.

Removal of oxides presents no great difficulty when soldering carbon or low-alloy steel. It is considerably more difficult to remove oxide films from steel alloyed with chromium, aluminum, titanium, or silicon, since stable low-solubility oxides of the Me_2O_3, $Me^1O \cdot Me^2O_3$, etc., types are formed on the surface of such steels during heating. Table 1 shows the methods used for oxide removal in the soldering of steel.

Steel is generally soldered with solders based on tin, lead, silver, copper, nickel, and palladium (see Solder for soldering steel), the majority of which dissolve steel to only a slight extent.

A characteristic trait of certain types of steel is their tendency toward brittle fracture when they come into contact with molten solder; this is true of 30KhGSA steel and tin-lead types POS-40 and POS-60 solder, KhN9T steel and silver, copper, or brass solder, etc. Steels in which tensile stresses (applied or internal) are set up before or during soldering by cold-work, metastable structural transformations, or development of thermal stresses as a result of rapid heating with torches or high-frequency currents or by quenching, plastic bending devices, etc., are especially susceptible to brittle fracture when brought into

TABLE 1

Methods of Removing Oxides in Soldering Steel

Steel	Fluxes and Gaseous Protective and Reducing Atmospheres
Carbon and low-alloys	Organic and inorganic fluxes: chlorides and fluorides of certain heavy and alkali metals and ammonia, hydrochloric acid, and certain boron-containing inorganic compounds. Atmosphere: argon, hydrogen, or dissociated ammonia with a relatively high dew point Copper is also soldered in an atmosphere of the incomplete-combustion products of a mixture of air and high-caloric gases (illuminating gas, generator gas, water gas, propane, and kerosene-pyrolysis products)
Chromium-containing (12-30% Cr)	Fluxes: active organic, rosin-acid containing orthophosphoric acid, fluoride-containing, and boron-containing inorganic compounds (various borates). Atmosphere: sufficiently dry mixtures of argon with gaseous HF or BF_3 flux, hydrogen or dissociated ammonia with a low dew point ($<-40^{\circ}$), or a vacuum
Chromium-containing alloyed with aluminum, titanium, and silicon	Fluxes the same as for soldering chromium-containing steel, but with a higher vacuum; gaseous protective atmospheres with a low dew point.

contact with molten solder. Quenched or low-tempered steel has the greatest tendency toward brittle fracture under these conditions. The danger than stainless steel will undergo brittle fracture during soldering can be reduced by using a solder with a melting point above the recrystallization temperature of the material to be soldered (e.g., copper solder, VPr1, or nickel solders for Kh18N9T steel) or by employing a special heating regime.

Steel may undergo a change in characteristics under the action of the soldering heat cycle as a result of structural changes caused by annealing, austenite-martensite transformations, martensite decomposition, grain growth, and grain-boundary processes that produce temper

brittleness and intercrystallite corrosion. During soldering, especially furnace soldering, it is consequently necessary to avoid temperatures at which temper brittleness or other processes leading to a decrease in mechanical characteristics can occur in the steel.

TABLE 2

Strength of Soldered Joints in Steel and Iron

Припой 1	Флюс или газовая среда 2	Способ нагрева при пайке 3	σ_b (кг/мм²) 4			
			Железо или низкоуглеродистая сталь 5		Нержавеющая сталь Х18Н9Т 8	
			пайка внахлестку 6	пайка в стык 7	пайка внахлестку	пайка в стык
Свинец 9	Канифольно-спиртовой (углеродистая сталь), ЛМ1 (нержавеющая сталь) 25	Паяльником 30	1.4	7.9	–	–
ПОС4-6 10	»	»	4.9	10.3	–	–
ПОС18 11	»	»	5.1	10.5	1.9	–
ПОС30 12	»	»	5	11.5	2.9	–
ПОС40 13	»	»	6.1	10.1	3	–
Олово 14	»	» 31 32	3.8	7.9	3.15	–
Медь М1 15	Водород 26	В печи	17 – 20	35 – 40	–	–
ВПр1 16	Флюсы 200, 201 27	Газовой горелкой, токами высокой частоты	–	–	30 – 48	56
ВПр2 17	Аргон 28	В печи	–	–	25 – 30	25 – 40
ВПр4 18	Аргон	То же 33	–	–	33 – 40	–
Л62 19	Бура 29	Газовой горелкой	27.5	43	–	–
ЛОК62-06-04 20	Бура	»	31.6	43.8	–	–
ПМц48 21	Бура	» 34	20.9	31.3	–	–
ПСр40 22	Флюс 209	В печи	–	–	22–26	–
ПСр45 23	Флюс 209	»	–	–	17 – 20	–
ПСр72 ЛМН 24	Аргон	»	–	–	22 – 24	–

1) Solder; 2) flux or gaseous atmosphere; 3) heating method; 4) kg/mm^2; 5) iron or low-carbon steel; 6) lap soldering; 7) butt soldering; 8) Kh18N9T stainless steel; 9) lead; 10) POS4-6; 11) POS18; 12) POS30; 13) POS 40; 14) tin; 15) M1 copper; 16) VPr1; 17) VPr2; 18) VPr4; 19) L62; 20) LOK62-06-04; 21) PMts48; 22) PSr40; 23) PSr45; 24) PSr72LMN; 25) rosin-alcohol (carbon steel), LM1 (stainless steel); 26) hydrogen; 27) flux; 28) argon; 29) borax; 30) soldering iron; 31) in furnace; 32) gas torch, high-frequency current; 33) the same; 34) gas torch.

During the soldering of unstablized chromium-nickel stainless steel chromium carbides may precipitate along the grain boundaries, so that the steel develops a tendency toward intercrystallite corrosion. In this connection, high-temperature soldering of such steel is carried out with brief heating at temperatures that insure dissolution of the chromium carbides (above 1000°) and subsequent rapid cooling or with stabilizing heat treatment after soldering. Chromium-nickel steel stabilized with titanium or niobium can be soldered at various tempera-

tures and with a longer heating cycle.

Heat-treatable components are soldered with solders that form a joint with the steel having a solidus temperature above the heat-treatment temperature. In certain cases heating during soldering can be combined with heat treatment, as when soldering transition-class steels with VPr2 or PSr93 solder.

In soldering steel it is also necessary to take into account possible warping of the components, which is accompanied by a dimensional change caused by structural transformations. Stresses produced in soldered joints by large differences in the coefficients of thermal expansion of the metals being joined, which lead to fracture of the joint or a decrease in its mechanical characteristics (e.g., when soldering tools), can be relaxed by using reticular or corrugated sheet facings of metals with a coefficient of expansion intermediate between the coefficients of the metals to be joined. In some cases notches 0.15-0.25 mm deep are made in the components for this purpose.

High-hot-strength, heat-resistant, and acid-resistant steels are soldered with solders that have characteristics similar to those of the steel or that form joints with the required properties (e.g., as a result of redistribution of volatile elements between the steel and the solder during diffusion soldering or by evaporation of elements from solders with a high vapor tension). Joints made in stainless ferrite steel with standard silver solders are susceptible to slit corrosion. This steel is consequently soldered with silver solders alloyed with nickel (2-2.5%), which forms a thin layer between the material being soldered and the seam and prevents corrosion. In soldering graphitized steel or cast iron the graphite is preliminarily removed chemically or by combustion. Soldered joints in steel are generally made by the capillary method; contact-reactive soldering is almost never used for

steel. Solder-welding is employed principally in the manufacture of large articles, particularly of cast iron.

In the furnace soldering of steel with high-temperature solders (except copper) the gap between the components to be joined should be 0.05-0.12 mm, while in soldering with copper solder it should 0-0.05 mm. Wider gaps can be used with other heating methods. Steel can be soldered by any of the usual techniques; soldering in gas flames, in furnaces with regulable atmospheres (for mass production), and with induction heating (when local heating is required) are the most widely employed methods. Table 2 presents data on the strength of joints in iron and low-carbon and stainless steels.

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N.F. Lashko and S.V. Lashko

SOLDERING OF TITANIUM ALLOYS. The characteristic features of the soldering of titanium and titanium alloys are dictated by their high chemical activity. As a result of the high superficial solubility of oxygen and nitrogen in titanium a brittle alphirated layer and stable titanium oxides are formed when this metal is heated in air. Hydrogen, which is of low solubility in alpha-titanium, forms titanium hydrides in alpha-alloys, embrittling them; hydrogen is quite soluble in beta-titanium and accelerates eutectoid decomposition in $\alpha + \beta$-titanium alloys. In view of the lack of sufficiently active fluxes for titanium alloys they are not soldered in air and, as a result of the embrittlement caused by hydrogen and nitrogen, they are not soldered in these gases. Titanium alloys can be soldered only after the oxides and alphirated layer have been removed from the surface of the components by mechanical cleaning or chemical etching following water-sand-blasting (e.g., in a solution containing 30 ml HCl, 20 ml HF, and 950 cm^3 H_2O for 4-6 min at 20°). When soldering with silver and Ti-Ni solders the components are heated in circulating pure, dry, neutral gases, most frequently argon. A comparatively low vacuum ($1 \cdot 10^{-2}$-$1 \cdot 10^{-3}$ mm Hg) can also be used. In soldering titanium alloys with aluminum and tin the surfaces to be joined are preliminarily tinned by rapid immersion in tin heated to 600-650° or aluminum heated to 850-900° and then soldered, using the fluxes ordinarily employed for these solders (see Low-melting solders, Solder for soldering aluminum alloys). Type VT1 alloy can also be soldered with tin or POS40 solder in circulating pure dry argon. The fluxes used in the soldering of aluminum alloys are employed

for tinning titanium with aluminum.

Titanium forms brittle chemical compounds with the majority of metals and soldered joints in this material consequently have low plasticity and strength, while the base metal intensively dissolves in the molten solder. When heated to temperatures above 1000° many titanium alloys tend toward severe grain growth and an irreversible deterioration of mechanical characteristics. Soldered joints of higher strength can be obtained in titanium and its alloys by diffusion soldering, as a result of diffusion of the components of the solder (e.g., copper, nickel, silver) into the base metal. This is due to the ability of titanium to form wide-range solid solutions with certain metals (Ag, Ni, Cu).

In order to prevent intensive dissolution of the titanium in the molten solder and formation of layers of brittle intermetallides in the joint, the heating of the components should be restricted with respect to temperature and be as brief as possible, while the solder should be carefully measured out. For this purpose and in order to prevent oxidation of the titanium in air, the surfaces to be soldered are sometimes preliminarily plated with silver or other metals, e.g., nickel (by chemical means, in a layer 10-20 μ thick). In order to improve the adhesion between the nickel plating and the base metal the component is heated at 250° for 2-2.5 hr. Application of intermediate coatings to titanium alloys is obligatory when they are to be soldered to steel or copper alloys or with gas torches or high-frequency current in air. Titanium alloys are soldered in vacuum furnaces or special hermetically sealed containers of materials such as stainless steel, which are preliminarily evacuated or filled with pure dry argon. The components to be soldered are loaded into electric furnaces heated with quartz radiating elements. Soldering in argon is more successful when the compo-

nents are shielded from the argon stream entering the container.

In order to prevent intensive grain growth in titanium and its alloys the working temperature of the solders used should be no higher than 1000° (see Solder for soldering titanium alloys).

References: Goryachev, A.P. et al., Argono-dugovaya svarka i payka titana [Argon-Arc Welding and Soldering of Titanium], Leningrad, 1957; Lashko-Avakyan, S.V., Lashko, N.F., Payka legkikh metallov (Magniya, titana, berilliya) i ikh splavov [Soldering of Light Metals (Magnesium, Titanium, Beryllium) and Their Alloys], Moscow, 1958; Titan i yego splavy [Titanium and Its Alloys], Edited by L.S. Moroz, Vol. 1, Leningrad, 1960; Brazing titanium sandwich, Aircraft and Missiles, 1959, Vol. 2, No. 11, page 22. See also the article entitled Soldering.

N.F. Lashko and S.V. Lashko

SOLID LUBRICANTS – lubricants which when applied to friction surfaces in the solid state reduce their wear and the friction between them. The following solid lubricants are most frequently encountered: 1) laminar solids (graphite, molybdenum and tungsten disulfide, boron nitride, talc, mica, etc.); 2) organic solids (soaps, waxes, fats); 3) sulfide; oxide, phosphate, xanthogenates, etc. films; 4) soft metals (lead, indium, etc.); 5) polymer films. Lubricants with a laminar structure have come into wide use. Graphite and MoS_2 are employed industrially; these materials are resistant to radiation, thermally and chemically stable, insoluble in hot and cold water, and unreactive with the majority of acids, being decomposed only by aqua regia, fuming hydrochloric acid, fluorine, and chlorine. The decomposition temperature of MoS_2 is 450° in air, above 1000° in a vacuum, and 1300° in argon. Graphite decomposes in air at a temperature of 600°. The Moos hardness of MoS_2 is 2, while that of graphite is 1.5. MoS_2 is electrically nonconductive and its lubricating properties are independent of the presence of absorption layers of water, CO_2, or other gases; in contrast to graphite, MoS_2 can thus be used in a high vacuum. All other conditions being equal, the coefficient of friction of MoS_2 is lower than that of graphite. When dry powders are smeared on metallic surfaces the coefficient of friction of MoS_2 ranges from 0.05 to 0.035 and that of graphite varies from 0.19 to 0.11. The coefficient of friction of graphite increases with the load, while that of MoS_2 decreases. MoS_2 is capable of withstanding loads of up to 28.000 kg/$/cm^2$. Solid-lubricant films are formed by smearing the surface with

pastes, briquettes, or dry powders or by applying a [illegible] solid lubricating component in a volatile solvent containing a binder. In the later case the film is deposited by immersion or spraying, depending on the configuration of the component. The metallic surface is specially treated to provide better film adhesion: all metals are thoroughly degreased, carbon steel is sand-blasted and phosphated, stainless steel is sand-blasted or pickled, and aluminum and its alloys are anodized. The instructions for fabricating the component should note whether the film is to be applied by immersion or spraying. Solid lubricants are employed at high specific pressures, which cause siezing, sticking, and increased wear, in dusty atmospheres, aggressive media, and vacuums, at very high or low temperatures, in friction pairs consisting of identical metals (stainless steel and stainless steel, bronze and bronze, etc.), when there is a possibility of fretting, and in rubber-metal friction pairs. Conditions of this type are encountered in almost all branches of industry. In the metallurgical and metal working industries use of solid lubricants is very effective in cold and hot stamping, wire drawing, cutting of metals, knurling, thread cutting, and in the manufacture of plastics and plastic products; in the aviation industry and other branches of technology they are used for lubricating hinges, various types of levers, pivots, grooves threaded pairs, stop cocks, etc. In accordance with their fields of application, solid lubricants are used in different forms: pastes, dry powders, briquettes, film coatings, and as additives to consistent greases and mineral oils. All types of solid lubricants are produced in the USSR. The widely used graphite lubricants include colloidal aqueous and oil suspensions of types RP, VKGS-30, VKGS-1p, V-0, V-1, V-2, and V-3 and dry powders of types S-1, S-2, and S-3. MoS_2 is used as the basis for VNIINP-232 pastes containing mineral oil, VNIINP-2225

III-[illegible]

containing liquid [illegible] ings, VNIINP-209 suspension [illegible] pension for high specific pressures, VNIINP-[illegible] up to 400°, and the consistent greases VNIINP-214, VNIINP-[illegible], VNIINP-242, and VNIINP-255 for rolling-contact bearings, which contain additions of MoS_2 as an antiwear component; the latter four lubricants are used over temperature ranges of −65° to +200°, −60° to +150°, −30° to +120°, and −65° to +90° respectively.

L.N. Sentyurikhina

SOLUBILITY – 1) The ability of a substance to form homogeneous mixtures with other substances, in which it takes the form of individual kinetically stable atoms, ions, molecules, or particles. 2) The solute concentration at equilibrium between the solution and the solid phase at a given temperature and pressure. Solubility is expressed either as a percentage or in units of weight or volume per 100 g or 100 cm^3 of solvent (g/100 g or cm^3/100 cm^3).

S.A. Reytlinger

SOLVENTS – volatile organic liquids or mixtures of such liquids used for dissolving various substances. Solvents are widely employed

1 Растворитель	2 Уд. вес при 20°	3 Температура кипения (°С)	4 Температура самовоспламенения паров в воздухе (°С)	5 Концентрационные пределы поджигания (взрываемости) воздушных смесей (г/м³)		Допустимая санитарная концентрация в воздухе (мг/л)
				6 нижний	7 верхний	8
9 Ацетон технический	0,790—0,794	55—[illegible]	500	60,5	218	0,2
10 Бензин лаковый (уайт-спирит)	0,795	[illegible]—200	633	60,5	218	0,3
11 Бензин-растворитель БР-1 «Галоша»	0,730	80—120	—	—	—	—
12 Бензин экстракционный	0,725	70—95	—	—	—	—
13 Бензол	0,875—0,880	79—80,5	580	48,7	308,0	0,02
14 Бутилацетат	0,870—0,890	116—140	420	15	712	0,2
15 Дихлорэтан	1,255—1,260	80—86	449	—	—	0,01
16 Ксилол (смесь орто-, мета- и пара-изомеров)	0,8629	139,2	553	130,0	330,0	0,05
17 Метилен хлористый	1,320	40	—	—	—	—
18 Нитропропан	1,003	131,6	—	—	—	—
19 Сольвент каменноугольный	0,865—0,885	120—200	250	—	—	0,1
20 Спирт бутиловый	0,808—0,812	115—118	366	—	—	0,2
21 » метиловый	0,793	64—67	475	78,5	478	0,05
22 » этиловый	0,791	78,3	404	65,8	338	1,1
23 Тетрахлорэтан	1,598	146	—	—	—	Не допускается
24 Толуол каменноугольный	0,866	104,5—111	553	48,2	264,0	0,05
25 Хлорбензол	1,112—1,114	132	—	—	—	0,05
26 Четыреххлористый углерод	1,590	75—78	—	—	—	0,001 [28]
27 Этилацетат	0,885—0,905	70—85	484	82,4	403	0,2

1) Solvent; 2) specific gravity at 20°; 3) boiling point (°C); 4) self-ignition temperature of vapor in air (°C); 5) concentration limits of ignition (explosiveness) of air mixtures (g/m^3); 6) lower; 7) upper; 8) permissible sanitary concentration in air (mg/liter); 9) technical acetone; 10) black benzine (white spirit); 11) "Galosh" BR-1 solvent benzine; 12) extraction benzine; 13) benzene; 14) butylacetate; 15) dichloroethane; 16) xylol (mixture of ortho-, meta-, and para-isomers); 17) methaline chloride; 18) nitropropane; 19) coal-tar solvent; 20) butyl alcohol; 21) methyl alcohol; 22) ethyl alcohol; 23) tetrachloroethane; 24) coal-tar toluol; 25) chlorobenzene; 26) carbon tetrachloride; 27) ethyl acetate; 28) impermissible.

in various branches of industry (lacquers and paints, rubber, textiles, plastics, etc.), agriculture, and medicine. They can be subdivided into the following groups in accordance with their chemical nature: hydrocarbons (principally benzene, toluol, and xylol), mixtures of hydrocarbons (BR-1 and BR-2 benzine, white spirit, etc.), chloroorganic compounds (chloroform, carbon tetrachloride, chlorobenzene, methylene

chloride, trichloroethylene, tetrachloroethylene, and dichloroethane), alcohols (methyl, ethyl, isopropyl and butyl), complex and simple ethers, ketones (acetone, methylethyl ketone), and compounds containing nitrogen or sulfur (nitromethane, nitropropane, nitrobenzene, carbon bisulfide, and nitroparaffin). Solvents readily dissolve plant and mineral oils, fats, bitumens, rubber, and many natural and synthetic resins, waxes, and paraffins. They are widely used as diluents (see Diluents) for many lacquers and paints, as well as in extraction; hydrophilic and polar substances, such as complex cellulose esters, shellacs, etc., have low solubility in solvents. Alcoholes are extensively employed as thinners for nitrocellulose and polyacrylic lacquers and enamels and as solvents for certain natural and synthetic resins. Fats, oils, bitumens, and waxes dissolve poorly in alcohol. Addition of alcohols to certain solvents increases their solvent action. Complex ethers are the best solvents for cellulose esters and vinyl, acrylic, and other polymer resins; they are generally mixed with other solvents. The glycol ethers (the monomethyl and monoethyl esters of ethylene glycol) are the most important of the simple ethers, readily dissolving nitrocellulose and acetocellulose and many polar resins. Nitroparaffin solvents, which are obtained by nitrating natural gases (methane, ethane, propane, butane) are often used in mixtures with other solvents to dissolve vinyl resins, esters, cellulose, oils, fats, waxes, rubber, etc.; they are similar to butyl acetate in their solvent action. The overwhelming majority of solvents are toxic, very volatile combustible substances which form explosive mixtures with air. The Table shows the principle constants of certain solvents.

References: Lakokrasochnyye materialy. Syr'ye i poluprodukty [Lacquers and Paints. Raw Materials and Intermediate Products], Handbook, Moscow, 1961; Jordan, O., Khimicheskaya tekhnologiya rastvorite-

ley [Chemical Technology of Solvents], translated from German, Moscow Leningrad, 1934; Drinberg, A.Ya., Tekhnolgiya plenkoobrazuyushchikh veshchestv [Technology of Film-Forming Agents], 2nd Edition, Leningrad, 1955.

I.I. Denker

SORBITE – a structural constituent of steel, a mechanical mixture of ferrite and cementite. It differs from perlite, which is also a mechanical mixture of ferrite and cementite, in the fact that the mixture is finer (more highly dispersed), individual particles being difficult to distinguish under an optical microscope.

As a result of the higher dispersion of the sorbitic structure, a steel in which this structure predominates has a higher strength and plasticity than perlitic steel. The majority of machine components and mechanisms are consequently subjected to heat treatment leading to transformation of the steel to sorbite; this is usually achieved by quenching and high-temperature annealing. As a result of the fact that formation of sorbite materially improves the properties of steel, heat treatment intended to produce sorbite is called refining.

M.L. Berynshteyn

SORBITIZATION OF STEEL – heat treatment consisting of heating the steel to a temperature above the upper critical point As_3, subsequent quenching of the surface layer or part of the cross section, and self-tempering at 450-500°. As a result of sorbitization the steel acquires a Sorbite structure, which improves its mechanical characteristics and durability. Sorbitization is often carried out in conjunction with rolling during the normal flow of work in the rolling shop. A predetermined cooling rate should be created with the aid of a specially selected spraying apparatus. As a result of quenching of the surface layer or part of the cross section of the semifinished product or component, the remainder of the cross section should retain the heat necessary for self-tempering of the quenched layer. Sorbitization is employed for carbon and low-alloy steels, although in principal it can be used for any quenchable steel.

Ya.M. Potak

SPACE METAL SCIENCE considers the behavior of materials in space or in conditions approximating those in space. Several fundamental problems arise in the development and use of the materials.

Evaporation of materials in deep vacuum below 10^{-8} mm Hg. Evaporation is of a selective nature and the loss of the metal from the grain boundaries is approximately an order higher than the evaporation from the grain body. Therefore, in the evaluation of the behavior of materials in the space vacuum we cannot go by only the average evaporation characteristics. Differently oriented grains of the metal will evaporate differently (as a result of the anisotropy of the forces of the interatomic forces in the crystal), which leads to some roughness of the surface. The corpuscular nature of the pressure effects is strongly manifested in space. The free path of the particles is a quantity of the order of several kilometers. For this reason the evaporation components leaving the surface of a spaceship will for practical purposes not not encounter this surface again.

The variation of the gas density with departure from the earth leads to reduction of the pressure, which is associated with the number of molecules or atoms striking the surface of any body. The reduction of the density and the pressure as a function of the distance from the earth is tabulated below. At heights above 6500 km the pressure is taken to be equal to 10^{-12} mm Hg.

Certain metals, zinc and cadmium, for example, which are widely used in engineering as protective coatings against corrosion under conditions of long-term operation in a moist atmosphere will not ensure

operation in a deep vacuum. At a temperature of 450°K, which may characterize the conditions of operation of the skin of satellites in cosmic space, zinc and cadmium have vapor pressures of $5 \cdot 10^{-7}$ and 10^{-4} mm

Density and Pressure as a Function of Flight Altitude

Свойства 1	2 Высота полета (км)				
	160	320	640	1280	2560
3 Плотность (кг/м³)	$\sim 10^{-7}$	$\sim 10^{-10}$	$\sim 10^{-12}$	$\sim 10^{-14}$	—
4 Давление (мм рт. ст.)	$\sim 10^{-4}$	$\sim 10^{-7}$	$\sim 10^{-9}$	$\sim 10^{-10}$	$\sim 10^{-11}$
5 Упругость паров некоторых материалов при 450° К (мм рт. ст.)	Кадмий $\sim 10^{-4}$ (будет испаряться) 6	Цинк $\sim 5 \cdot 10^{-7}$ (будет испаряться) 7	8 Магний $\sim 2 \cdot 10^{-9}$ (будет испаряться)	—	Железо, никель, алюминий, титан, стекло 10^{-14} (не будут испаряться) 9

1) Property; 2) flight altitude (km); 3) density (kg/m^3); 4) pressure (mm Hg); 5) vapor pressure of certain materials at 450°K (mm Hg); 6) cadmium (will evaporate); 7) zinc (will evaporate); 8) magnesium (will evaporate); 9) iron, nickel, aluminum, titanium, glass 10^{-14} (will not evaporate).

Hg respectively, which eliminates the possibility of their use as space materials. The vapor pressure of magnesium at 450°K is equal to 2.10^{-8}, and from other data it is $6 \cdot 10^{-9}$ mm Hg; increase of the temperature to 500°K changes its vapor pressure to $3 \cdot 10^{-7}$ mm Hg. This metal can be used as a space material only under the condition of definite limitations on the temperature and duration of usage. Such metals as iron, nickel, aluminum and beryllium have a vapor pressure at 450°K of the order of or less than 10^{-14} mm Hg (extrapolated data) and at 900°K a value of 10^{-10} to 10^{-9} mm Hg, and are without doubt suitable as bases for the creation of space alloys, although it will be necessary to take account of some evaporation at elevated temperatures which may perhaps limit the temperature ceiling for their use to a greater degree than the possible high-temperature strength. The majority of the refractory metals (Ta, W, Mo and others) behave well in a vacuum even at very high temperatures. An exception is chromium, which evaporates easily at tem-

peratures above 1500-1700°C. Gaseous impurities, naturally, are easily evaporated in a deep vacuum and this effects the metal properties. Evaporation of the volatile components of an alloy is possible only with sufficiently high temperatures when "atomic transport" of the element being vaporized to the surface is realized by means of diffusion. The vapor pressure of any element in an alloy differs from the value of this characteristic for the pure metal.

A very important problem is that of creating nonmetallic materials for operation in a hard vacuum. Many familiar engineering compositions of nonmetals used for particular purposes are unsuitable as space materials because of the evaporation of individual components. Thus, for example, under these conditions certain sealants cease to be pressure tight. In addition, here we must take account not only of the sublimation process which proceeds on the surface, but also the decomposition of the complex compound into simpler compounds which will take place throughout the bulk of the body.

The evaporation of the metallic and nonmetallic materials heated to a definite temperature can be accompanied in close structures by the process of the condensation of the vapors on the cold surface of the components, which alters the physical characteristics of the material (electrical conductivity, thermal conductivity).

Creep and fracture of metals and alloys as a function of severity of the vacuum, temperature and test duration. The process of creep rupture for the majority of the metals proceeds by means of the formation and development of cracks along the grain boundaries. Intensified evaporation of the metal from the grain boundaries in a hard vacuum accelerates the fracture process if the material is operating at high temperature. However, by using special [illegible]ing we can significantly retard the local evaporation from the grain boundaries. With operation of a

material in the region of comparatively low temperatures under terrestrial conditions, when evaporation does not become particularly manifest, a vacuum may even be useful, since oxidation under stress of the metal grain boundaries (in the air) reduces the tensile strength.

A major independent problem is that of the condition of the surface of products operating in cosmic space, since the surface layer of the metal is most subject to damaging residual phenomena after various technological operations. Mechanical working of the high temperature alloys may be the source of two unfavorable phenomena: residual tensile stresses and plastic deformations in the thin surface layer of the metal (depth of 15-20 microns). The residual stresses after mechanical working are associated not only and not so much with the nonuniform plastic deformation in the machining process, as with the nonuniform heating of the products during the time of this operation; the lower the thermal conductivity of the metal, the higher the level of the residual stresses after machining.

Just as in the case of operation under terrestrial conditions, surface work hardening of the parts is undesirable if the temperature and the duration of operation are sufficiently high for the diffusional processes to take place; for parts operating in the region of comparatively low temperatures work hardening is often used as a strengthening technique. Under the influence of the plastic deformation, the activation energy of the diffusion process is reduced by 1.5-2 times and in the surface layer of the metal at elevated temperatures there takes place intense further aging of many heterophase alloys which shortens their operational life. In this connection special requirements are made on the condition of the surface layer of the metal. Of great interest in this regard is the process of electropolishing to the depth of the layer damaged by the plastic deformation. The electropolishing

regime must be chosen so that there is no corroding of the grain boundaries.

In many cases annealing of the parts in a neutral medium is recommended for the relaxation of the residual stresses. The mechanism of the relaxation of the residual stresses which arise in the surface layer during machining has a dual nature: the residual stresses can be relieved with heating as a result of the high diffusional mobility of the atoms in the surface layer (which requires a comparatively low annealing temperature), and by means of plastic deformation or creep under the influence of the residual stresses themselves (which requires higher temperatures). It is desirable that heating prior to rolling and forging be carried out in an inert medium, since the presence of an oxide film can lead to a reduction of the high-temperature strength in the metal layer under the oxide which is depleted of the alloying elements which were used in the formation of the oxide film. The oxidation and phosphatization of the metals, leading to the creation on the surface of the parts of a dense film which is stable in a hard vacuum, retard the evaporation process.

The state of weightlessness and also the absence of aerodynamic forces in cosmic space significantly facilitate the operation of certain structural elements. Of course, the stress state from the action of centrifugal forces, in rotating discs, for example, are the same as in terrestrial conditions; in this case a high specific strength is required. During takeoff from the surface of the earth it is necessary to take into account the high accelerations and vibration. Several structural bays, including the cosmonaut's cabin, are under internal pressure, which makes it desirable to check the materials for sensitivity to the formation and development of cracks in the plane stress state. The need for this sort of testing becomes particularly obvious if we

consider that several aircraft accidents abroad which at first appeared to be due to an explosion of the aircraft fuselage were actually due directly to the rapid development of fatigue cracks under the influence of the internal pressure, which created in the structure a large store of potential elastic energy. The danger of such a failure must be taken into account in the selection of the material and the design of the structure with consideration for possible penetration of a meteorite through the skin of the cosmonaut's cabin.

Effect of extreme cold on materials. In outer space the temperature of an individual element of the structure of flight vehicles can be below -250°, approaching absolute zero. Therefore the questions of cold-brittleness is associated first of all with the purity of the metal in respect to impurities which distort the crystal lattice, which makes it necessary to establish particularly high requirements on the purity of the metal for space materials. The degree of purity of the metal with regard to impurities may vary depending on the "tightness" of the space they occupy in the crystal lattice with account for the fact that many of the impurities are not mechanically embedded inclusions, but atoms and compounds which interact with the ion-electron lattice of the basic metal; certain impurities are particularly dangerous when they are located along the grain boundaries of the polycrystal and in this respect the monocrystal must be less cold-brittle. The "tightness" of the space occupied can be characterized in the first approximation by the lattice period of the basic metal.

Of the metals with a body-centered cubic lattice, niobium has the largest lattice period and is not cold-brittle over a wide temperature range. Nickel, copper and aluminum, having a face-centered cubic lattice, are also not among the cold-brittle metals, however, it has been established that under the influence of neutron irradiation at room

temperature copper becomes brittle at 78°K - here there is manifested the effect of copper atoms imbedded in the interstices of the lattice itself. Among the hexagonal metals beryllium has the "tightest" spacing and it is cold-brittle even with a slight content of certain impurities. In the case of the use of materials in the region of low temperatures, we must take account of their greater sensitivity to stress concentration, particularly in the metals and alloys for which with a reduction of the temperature there is a sharp increase of the yield strength while the plasticity decreases.

Impurities and enlargement of the grain usually reduce the fracture resistance of a metal, which depends only slightly on the temperature. Resistance to plastic deformation increases with reduction of the temperature for those metals which have a "tight space" for the impurities, since thermal compression of the crystal lattice intensifies the influence of the impurities. According to the scheme of Academician A.F. Ioffe, at that temperature when the yield point reaches the value of the tensile strength there occurs the phenomenon of brittle fracture - cold-brittleness.

External friction and wear of materials as a function of hardness of vacuum. With increase of the severity of the vacuum the effect of the lubricating action of the gaseous atoms is lost and between dry surfaces experiencing friction there may occur seizing of the metal, a manifestation of interatomic interaction. A high vapor pressure excludes the use of many lubricants which operate well under terrestrial conditions. Thick lubricants with low vapor pressure and low rate of evaporation can operate for a limited time if the vacuum is not very severe (10^{-6} mm Hg). These features of friction in a hard vacuum present specific requirements on many structures and materials operating in outer space.

Effect of meteorite particles on materials. The nature of this problem is associated with the fact that during an encounter between meteorite particles with the surface of a flight vehicle there takes place the impact phenomenon which is reminiscent of microscopic explosions, since the velocity of these particles relative to the earth is very high (from 10 to 70 km/sec.). We cannot exclude the possibility of surface damage to the flight vehicles, and the dimensions of the damage can exceed considerably the "caliber" of the meteoritic projectile. The dimensions of meteorites vary from fractions of a micron (meteoritic dust) to several tens of kilometers. The probability of encounter with large particles is lower, the larger the particles. The probability of encounter with those meteorites which are capable of penetrating the skin of the spacecraft in near-earth space is small, but it does exist - one case per year if the surface area of the spacecraft is equal to 100 m^2 and the thickness of the aluminum skin is 2 mm. Today it is far from clear what energy the meteorite penetrating the skin will have and what danger it presents for the integrity of the cabin and the survival of the cosmonaut. We must also take account of the fact that spalling on the inner surface of the skin is possible, just as is observed under terrestrial conditions in firing at certain types of armorplate.

The formation of pits and small craters on the surface of the spacecraft will undoubtedly alter its radiative capability. It is known that a rough metal surface radiates heat about twice as strongly as a polished surface. Special coatings which have a high degree of blackness show practically no reaction to small pits if in this case the primary surface of the material with a different radiating capability is not bared. "Bombardment" of glasses by space dust will of course alter their optical properties at the damage locations. The meteorite danger is particularly great for the power plants which have a large

area of radiating coolers.

Effect of solar and cosmic radiation on the structure and properties of materials. By radiation we understand some flux of waves or particles, which may be electrically charged or neutral. Solar radiation constitutes the spectrum of x-ray, ultra-violet, visible and infrared waves, and also the flux of low-energy particles; during chromospheric bursts which cover up to 25 billion square kilometers of the solar surface and which increase by up to 10,000 times the general background of the cosmic radiation, there is not only an increase of the overall brightness of the light by 5-10 times, but there arises a flux of high energy (to 10-20 Mev) particles (protons) commensurate with the energy of the cosmic particles. Cosmic radiation consists of 3 forms of radiation: a) primary radiation consisting basically of protons (about 85%) with energies of 0.1 Bev, α-particles (about 15%) with energies of 0.1 Bev and a small number of nuclei of heavy atoms (nitrogen, oxygen and carbon) with huge energy (10^5 Bev); b) secondary radiation consisting of electrons (250 Mev), positrons (250 ev), neutrons (to 10 Mev), γ-rays (to 120 Mev), x-rays (to 120 kev), mesons (1 Bev); c) the radiation band about the earth, apparently consisting of electrons (to 600 kev) and protons (to 650 Mev).

At the present time it is customary to speak of the following radiation bands: 1) outermost band of particles of low energy (hundreds of kev) which are visitors from the Galaxy, radiation intensity very low; 2) outer band of electrons and protons with energies to 1 Mev; 3) inner band of particles of high energy of the order of 100 Mev, according to certain US data (possibly overestimated) the proton energies can reach 650 Mev; 4) an artificial band which is the result of the explosion of the US hydrogen bomb at high altitude which formed a huge cavern in the magnetic field of the earth and gave rise to particles, primarily elec-

trons, of high intensity and high energy of the order of 1.5 Mev. At high altitude the artificial radiation band can exist for years, while in the dense layers of the atmosphere it can exist only a comparatively short time.

Beyond the limits of the radiation bands there stretches the interplanetary space in which there blows continuously the "solar wind," carrying with it particles with energies of the order of 1 kev. The shortwave (1-20Å) solar radiation leads to very weak displacement of the atoms in materials, radiation with wavelength from 1000 to 2000Å causes ionization of the atoms, and the still longer wavelengths (2000-3000Å) excite the electrons. There is no radiation on the earth with wavelength shorter than 3000Å, it simply does not reach the earth. The thermal balance is determined primarily by the longwave radiation while the wavelengths shorter than 3000Å introduce no more than 1% of the en- into the overall balance. The energy of an individual quantum of radiation with wavelength less than 3000Å is equal to 4 v. The reflection coefficient of the anodized surface of the aluminum alloys may be reduced under the influence of the solar radiation.

Even in terrestrial conditions, where it has considerably less intensity than in space, the solar radiation has a large effect on the structure and properties of the nonmetallic materials which are of primarily an organic nature. This effect is amplified in space, and we must take account not only of evaporation, but also cyclic heating which causes thermal stresses which are favorable to cracking. All the particles which carry energy are of importance in the radiation action on the nonmetallic materials. Regardless of the nature of the radiation, the decisive factor is the amount of energy. The alteration of the chemical, physical and mechanical properties of the nonmetallic materials is associated with two basic irreversible processes taking place

during irradiation: a) decomposition of the molecules, their destruction, here the strength is reduced; b) "crosslinking" of chains of molecules as a result of the appearance of lateral bonds between them, here the strength and thermal resistance are increased while the plasticity is reduced. These two irreversible reactions can proceed simultaneously, with predominance of one of them at a particular stage of the irradiation (for example, the destruction of a material with long-term radiation). The formation of a new form of interatomic bond (lateral bond) in many of the nonmetallic materials can be considered as the result of ionization which appears comparatively easily in these materials with various forms of irradiation.

The primary effects of radiation on the metallic materials are: 1) Ionization of the atoms - the result of the elastic collision of a cosmic particle with the orbital electrons, where the outer electrons are most easily "torn loose." In the structural-type metals ionization is not of essential importance, but in instrument materials, for example, insulators or semiconductors, the displaced electrons can fall in the conductance band, which makes them current conductors.

2) The formation in the crystal lattice of "Frenkel pairs", i.e., vacancies and interstitial atoms, is the result of the elastic collision of a cosmic particle with the nucleus of an ionized atom. This effect has a decisive influence on the properties of the constructional materials. If the particle transfers considerable energy to the metal atom, this atom in its turn can be the source for the formation of a Frenkel pair. The energy of formation of the Frenkel pair is relatively small (about 25 ev) and particles with high energy are capable of causing significant changes in the metal structure. Neutrons, as a result of the absence of a charge, are capable of penetrating far into the depth of the crystal lattice. The protons of the radiation belts and

the protons arising in large numbers during solar flares and having high energy are also capable of penetrating to a comparatively great depth. Many physical and mechanical properties are structurally sensitive. As a result of the appearance of the interstitial atoms and vacancies, the electroresistance of the metals increases and the mechanical properties change in a definite manner: resistance to plastic deformation increases, particularly in its beginning stage (yield limit), and the plasticity decreases; in many cases cold-brittleness of the metals appears (in molybdenum, for example); the probability of brittle fracture is higher, the larger the radiation dose. Thermal treatment reduces the effect of irradiation as a result of the recombination of the Frenkel pairs. Here the diffusional mobility of the atoms, which eliminates the structural defects caused by the radiation, plays a favorable role.

3) The protons with comparatively low energy (of the order of 100 kev), which occur along with the electrons in the radiation which gives rise to the polar aurora, are capable, just as many other particles, of causing atomization of the surface of the spacecraft skin. An atom located on the surface of the materials, under the influence of the impact of cosmic particles, may, losing the bond with its neighbors, not penetrate into the material (which leads to the formation of the Frenkel pairs), but may go into the external medium, tearing away from the material. The rate of this atomization can amount to about 1 micron per year in near-earth space. Atomization as a result of cosmic radiation will alter the physical properties of the material surface and will effect the operation of systems (solar batteries, mirrors, etc.) where the quality of the surface (primarily optical qualities) are of importance. This atomization can be considered as evaporation under the influence of the cmosmic particles, since in both cases there is destruc-

tion of the interatomic bond on the material surface with loss of atoms into the environment.

4) The penetration of a cosmic particle into a body is accompanied by elastic oscillations of the crystal lattice, with which the thermal effect during irradiation is connected. According to the computations of F. Zeitz, during neutron irradiation a local increase of temperature to 10,000°K in a time of the order of 10^{-11} sec is possible. The "thermal peak" along the path of the penetrating particle is similar to a "microatomic explosion" involving millions of atoms. If the atoms are near the surface, their evaporation at the moment of formation of the "thermal peak" is not impossible. Calculations show that metals having self-diffusion activation energy of less than 92,000 cal/g-atom, and this includes most of the metals, can melt in the "thermal peak" zone in a time of 10^{-11} seconds. In this case the recombination of a portion of the Frenkel defects is very probable. Many refractory metals (W, Mo, Ta), in spite of such a high temperature (10^4 °K), simply do not melt and the recombination of the Frenkel pairs is very unlikely for them. It may be that this is one of the reasons why molybdenum is markedly embrittled by irradiation.

5) In the fissionable materials (uranium and others) the result of the inelastic collision of a particle with the nucleus, leading to decomposition of the nucleus, is the formation of new elements. Considering that the energy of the particles of the primary cosmic radiation exceeds by several orders the energy of the neutron radiation in atomic boilers, we would expect that certain cosmic particles not only alter the structure and properties of the metals, but also lead to a nuclear transformation.

The theoretical prediction of the result of the interaction of cosmic particles having high energies of the primary radiation with the

nuclei of the crystal lattice of the various metals without knowing the mechanism of this interaction is very difficult, just as it is difficult to evaluate in this case the possibility of the transformation of certain elementary particles into others, although we must take account of several changes of the surface layer. It is possible that a detailed analysis of the iron meteorites which can be irradiated for very long periods of time in cosmic space by particles of various energies and in differing temperature conditions may be of assistance in the solution of this problem, particularly since the penetration of the earth's atmosphere during entry of the meteorite effects the surface of this celestial body only to a depth of the order of 1 cm. According to certain sources, a considerable number of iron isotopes have already been discovered in the meteorites. Of very great interest is the study of the various lunar materials, since the moon has no atmosphere to absorb the primary impact of the cosmic particles and meteorites as in the case of the earth.

Cosmic radiation apparently does not present major danger for the structural strength of a rocket (comparatively small radiation does). But there is no doubt about the danger of the destruction of certain refractory alloys used in the zone of intense neutron radiation which occurs in atomic power plants.

Effect of aerodynamic heating (surmounting the "thermal barrier"). Aerodynamic heating takes place during both launch and re-entry into the earth's atmosphere. Launch of a flight vehicle is performed in accordance with a definite program which is specified in its design; in this case the problem of aerodynamic heating is resolved in stages, and the flight vehicle reaches high speeds in the upper layers of the atmosphere where the aerodynamic heating is less severe than near the earth. Re-entry into the earth's atmosphere may be accomplished along

a steep trajectory (guided missile) or along a flat trajectory (satellite or manned spacecraft) when the motion in the atmosphere is stretched out over a long time period in order to reduce the aerodynamic heating.

The stagnation temperature on the surface (T_T) of the flight vehicle can be evaluated approximately from the equation:

$$T_t = T_H (1 + 0.18M^2),$$

where: T_H is the absolute air temperature at the flight altitude; M is the Mach number for the given flight speed. Thus, the skin surface temperature is proportional to the square of the Mach number and increases rapidly with increase of the flight speed. Therefore, for flight vehicles returning to the earth it is necessary to have a definite system for thermal protection so that the heat transfer into the structure will not exceed definite values and the material will not overheat. In the case of turbulent flow at a high Mach number, nonuniform heating of the structure and its deformation cannot be avoided.

These conditions in which the space materials operate do not determine all the requirements imposed on this group of materials by any means. Additional specific requirements are imposed on reactor materials, coatings with specific optical and other physical properties, materials for direct energy conversion and many other materials which are necessary for particular flight vehicles, whether these be satellites or spaceships intended for interplanetary flights. Space material science as a new branch of science and engineering is developing under extremely difficult conditions, since we cannot yet calculate theoretically many properties of the materials because of their sensitivity to the structure, and exact experimentation is possible only in space conditions, which are difficult to simulate in earth-bond laboratories.

For the integral evaluation of the effect of the various factors

simulating cosmic space on the behavior of materials, individual instruments and complex designs, use is made of hard-vacuum chambers in which both the test objects and various radiation sources can be placed. The best laboratories for the evaluation of the behavior of materials and complete systems operating in cosmic conditions are artificial earth satellites, particularly when they are returned from space to our planet in accordance with a special program which provides for preservation of the most important structural elements.

S.T. Kishkin

SPALLATION – a type of brittle (without plastic deformation) fracture occurring under the action of tangential stresses. Spallation is never (or very rarely) observed in metals, since tangential stresses sufficient to produce fracture cause plastic deformation. It occurs in glass and other very brittle materials, as on indentation (taking a petalous form). In some cases slight plastic deformation occurs in glass on indentation, e.g., a slight indentation may be produced by the indentor during testing for Microhardness.

Ya.B. Fridman

SPECIAL BRASS is brass which is alloyed with one or more of the following elements: aluminum, silicon, tin, nickel, manganese, iron and lead. These additives improve the corrosion resistance of the brasses, the strength, hardness, fluidity and reduce the grain size, while the lead improves the machinability and the antifriction properties as well. Additional alloying of the aluminum brasses with nickel improves not only the strength and corrosion resistance, but also increases the aluminum and zinc content in the α-copper-zinc alloys, since the nickel broadens the region of the α brasses. The addition of iron to the α brasses strongly refines the grain and raises the recrystallization temperature.

Depending on the purpose, the special brasses are divided into wrought and cast (see Cast Brass). The name of the special brasses comes from the alloying element, for example, the special brass containing aluminum is termed "aluminum brass."

For the effect of each of the forementioned additives on the corrosion resistance of the brasses, see Corrosion Resistant Wrought Brass, for the effect on the structure and other properties, and also the field of application, see Aluminum Brass, Silicon Brass, Manganese Brass, Naval Brass, Nickel Brass, Leaded Brass, Muntz Metal. Nineteen types of special brasses are produced in accordance with GOST 1019-47. They are used for the fabrication of semimanufactures in the form of sheet ribbon, strip, tubes, rods and wire. Widest usage is made of the following special brasses: LNC5-5, LZhMts59-1-1, LMts58-2, L090-1, L062-1, LS59-1 and LK80-3.

II76k1

The LZhMts59-1-1 brass has the following chemical composition (%): 57-60 Cu; 0.1-0.2 Al; 0.3-0.7 Sn; 0.6-1.2 Fe and 0.5-0.8 Mn. The tensile strength of the LZhMts59-1-1 brass in the soft condition is 45 kg/mm^2, the relative elongation is 50%. The physical properties are: γ = 8.5 g/cm^3, $\alpha = 22.10^{-6}$ 1/°C, c = 0.24 cal/cm-sec-°C; ρ = 0.093 ohm-mm^2/m; E = 10,600 kg/mm^2. The melting point is 900°, hot-work temperature is 650-750°, anneal at 600-650°. The LZhMts59-1-1 brass is used for producing strip, rods, wire and tubes.

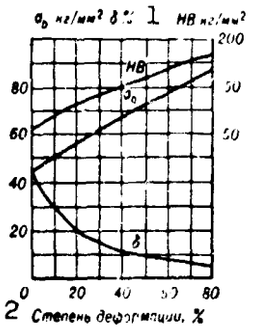

Fig. 1. Variation of mechanical properties of the LZhNts59-1-1 brass with degree of deformation. 1) kg/mm^2; 2) degree of deformation.

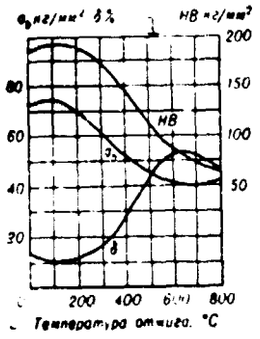

Fig. 2. Variation of mechanical properties of LZhMts59-1-1 brass with annealing temperature. 1) kg/mm^2; 2) annealing temperature.

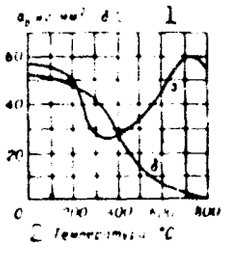

Fig. 3. Variation of mechanical properties of LZhMts59-1-1 brass with temperature. 1) kg/mm^2; 2) temperature.

Figures 1-3 show the variation of the mechanical properties of LZhMts59-1-1 brass with degree of deformation and temperature.

References: Mal'tsev M.V., Barsukova T.A., Borin F.A., Metallografiya tsvetnykh metallov i splavov [Metallography of Nonferrous Metals and Alloys], M., 1960; Smiryagin A.P., Promyshlennyye tsvetnyye metally i splavy [Industrial Nonferrous Metals and Alloys], 2nd ed., M., 1956; Spravochnik po mashinostroitel'nym materialam [Handbook on Machine Construction Materials], Vol. 2, M., 1959.

Ye.S. Shpichinetskiy

SPECIFIC DEEP RESISTANCE ρ – a characteristic of material defined as the ratio of the voltage E of an electric field (the force with which it acts on a unit charge) to the current density I which it produces (the quantity of electricity passing through a unit area perpendicular to the direction of its movement over a unit time):

$$\rho = \frac{E}{I}.$$

It is usually expressed in ohm·cm. In electrical engineering ohm·mm^2/m is used as the unit. The specific deep resistance of different substances found in nature varies within extremely wide limits, from 10^{-6} for highly conductive metals (silver, copper, aluminum) to 10^{16}-10^{18} ohm·cm for high-quality insulating materials (mica, polystyrene, polyethylene).

Materials with a ρ of from 10^{-6} to 10^{-3} (metals and alloys) are referred to as conductors. The specific deep resistance of metals is usually increased by cold drawing and when impurities are present and reduced by annealing. At sufficiently high temperatures the deep resistance of pure metals is roughly proportional to the absolute temperature T. At normal temperatures the thermal coefficient of deep resistance for the majority of pure metals is $3\text{-}6 \cdot 10^{-3}$ degree^{-1}. The specific deep resistance of alloys is generally substantially higher than that of pure metals, while their thermal coefficient of deep resistance is considerably lower. In certain special alloys (constantan, manganin) this coefficient approximates to zero at normal temperatures. At temperatures near absolute zero the specific deep resistance of pure met-

als is roughly proportional to T^5. In the temperature interval 0-10°K a number of metals and alloys suddenly pass into a state of superconductivity, which is characterized by a specific deep resistance of virtually zero.

Materials with a ρ of more than 10^8 ohm·cm are dielectrics. The thermal function of specific deep resistance for dielectrics is often expressed by the formula:

$$\rho = \rho_0 e^{\frac{B}{T}}.$$

Technical electrolytes and semiconductors occupy a position intermediate between conductors and dielectrics. This category includes nonmetallic elements of groups IV, V, and VI of the Mendeleyevian periodic system, inorganic compounds (oxides, sulfides, etc.), certain metallic alloys, and organic dyes. The specific deep resistance of semiconductors drops with temperature. That of electrolyte solutions also decreases with temperature, but passes through a minimum in certain cases.

L.S. Priss

SPECIFIC STRENGTH – generally the ratio of the ultimate tensile strength σ_b of a material is kg/cm^2 to its specific gravity σ in kg/cm^3. This characteristic has the dimension of length (cm) and physically represents the length at which a rod with a cross section of 1 cm^2 fails under its own weight. Specific strength is the principal criterion for selection of materials for components whose tensile fracture load has been computed. In this case the condition $\sigma_b/\sigma_{0.2} \leq f$ should be observed for all comparable materials, where f is the safety factor and $\sigma_{0.2}$ is the tensile yield strength. If $\sigma_b/\sigma_{0.2} > f$, the arbitrary ultimate strength $\sigma_b^1 = \sigma_{0.2}f$ must be used in making a comparative evaluation of the specific strengths of materials. On axial compression the criterion of specific strength is the ratio $\sigma_{0.2szh}/\gamma$. In those cases where the component cross section is selected from the fracture conditions on loss of stability due to compression, shear, bending, etc, the basic criteria of the gravimetric efficiency of a material in a structure are the various indices of Specific rigidity. When a component must operate for prolonged periods at hgih temperatures, where the calculated loads are determined from the creep of the material, the ratio of creep strength to specific gravity is the criterion of specific strength.

S.I. Kishkina-Ratner

SPECIFIC STRENGTH – is a criterion used for the selection of a material ensuring the required strength at a minimum weight of the construction. The specific modulus of elasticity, E/γ is such a criterion within the range of elastic deformations.

The weight of thin-walled metal construction used, for example, in aviation and rocket engineering limits in many cases the requirement of a sufficient local stability. $\sqrt[3]{E}/\gamma$ is the criterion in the case of compression (along the long side), shearing, and transversal bending of thin-walled parts (flat or cylindrical parts with a radius of curvature $R/\delta>3000$, and a ratio of the sides $a/b>3$) (Fig.). The critical load of thin-walled parts, the bending under a transversal load, for example, is proportional to the cylindrical strength $D=E\delta^3/12(1-\mu^2)$. The ratio of the weights (G) of a part with the thickness δ, made from different materials (1 and 2) is equal to

$$\frac{\delta_1}{\delta_2}=\sqrt[3]{\frac{E_2}{E_1}};\ \frac{G_1}{G_2}=\frac{\gamma_1\delta_1}{\gamma_2\delta_2}=\frac{\left(\sqrt[3]{E}/\gamma\right)_2}{\left(\sqrt[3]{E}/\gamma\right)_1}.$$

under the condition that the required strength maintains a fixed value (D = const). In the elastic range, the equation

$$E_1F_1=E_2F_2;\ \frac{G_1}{G_2}=\frac{\gamma F_1}{\gamma_2F_2}=\frac{(E/\gamma)_2}{(E/\gamma)_1}.$$

is valid.

The quantity $\sqrt{E}/\gamma$ serves as a criterion in the case when the critical loads are proportional to $E\cdot\delta^2$, for example, in the case of compression or bending of a long thin-walled cylinder ($l>0.75R$; $R/\delta>100$). Thus, the specific strength is not an unequivocal criterion. The criteria of strength are used together with the criteria of rigidity $\sigma_b/\gamma, \sigma_r/\gamma$) ,

for example) for the determination of the reasonable temperature limits in the use of different alloys.

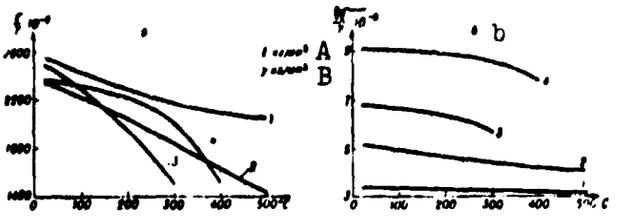

Fig. Comparison of the criteria of strength of certain alloys: a) (E/ /γ) 10^{-6}; b) $\frac{\sqrt[3]{E}}{\gamma}$ 10^{-6} ; 1) Heat-treatable steel ZOKhGSA (γ = 7.85); 2) titanium alloy VT5-1 γ = 4.5); 3) aluminum alloy D16AT (γ = 2.78); 4) magnesium alloy MA13 (γ = 1.8). A) kg/mm^2; B) kg/mm^3.

Ya.A. Disman

SPECIMENS FOR MECHANICAL TESTS. The size and shape of specimens are determined by the method of mechanical testing and the type of component (semifinished product) from which they are prepared. Specimens with working segments of round and rectangular cross-section are the most common.

When specimens for mechanical tests are prepared on metal-cutting machine tools the machining process should not alter the characteristics of the material and heating to temperatures above 50° and cold-working are consequently impermissible. Observation of proper specimen-fabrication technology is especially important for materials with a high sensitivity to surface condition (high-strength steels and alloys). The surface of the working segment of the specimen should be machined to a finish of at least class 6. The size and shape of the heads of the specimen are determined by the manner in which it is fastened in the holding devices of the test machine (directly in the jaws of the machine, with the aid of inserts, through a rod, etc.). The working segment of the specimen passes into the heads in a smooth curve, forming a so-called fillet. The fillets are machined with the same care as the working segment, since a fillet with scores, sharp changes in cross-section, nicks, etc., becomes a site of premature fracture. The dimensions of the working segment are held to predetermined tolerances, but are measured before testing. In specimens for large-scale tests it is best to make the tolerance for the basic size of the working segment quite rigid, so that the test results can be calculated from the nominal size, without measuring each specimen. Flat specimens equal in

thickness to the initial material are cut from sheets and thin strips; the surface layer is left intact.

Small tubes, strips, wire, and cast specimens are generally tested without machining. It is recommended that flat specimens be cut from semifinished products (shapes, stampings, etc.) with elements having a rectangular cross-section. Round specimens are usually cut from semifinished products and large components, the cutting site and direction being stipulated by the technical specifications or plans. In order to produce guaranteed properties specimens are cut from the sites of possible defects in the direction perpendicular to the deformation (rolling, drawing) axis for semifinished products and from the most severely stressed area for finished products. Specimen size and shape affect certain of the mechanical characteristics of materials. Geometric similarity of specimens of different sizes does not always insure that the test results will be comparable. In the majority of materials an increase in specimen size causes a decrease in ultimate plasticity (compression, elongation) and fracture resistance (especially rupture resistance), a considerable drop in durability and resistance to repeated static loading, and a rise in notch sensitivity (see Geometric similarity).

The majority of specimens for mechanical tests are standardized by appropriate GOST and technical specifications. Specimens for Tensile testing at room temperature are described in GOST 1497-61, while those for tensile testing at elevated temperatures are described in GOST 9651-61. Similar specimens are used for determining long-term strength (GOST 10145-62) and creep (GOST 3248-60). Definite specimen-dimension ratios have been established to insure comparability of tensile-test results. The GOST and the standards of the majority of European countries have adopted two specimen ratios: 10-fold, with $l_0 = 10d =$

Fig. 1. Specimen for testing brittle materials.

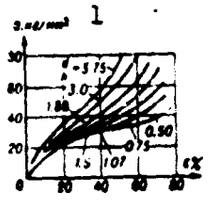

Fig. 2. Graph showing compression of copper as a function of specimen size (G. Sachs). 1) kg/mm^2.

= 11.3 $\sqrt{F}$, and five-fold (shortened), with $l_0 = 5d =$ = 5.65 $\sqrt{F}$, where l_0 is the calculated length over which elongation is measured, d is the diameter of a round specimen, and F is the cross-sectional area (of a flat of round specimen). Ten-fold specimens with a diameter of 20 mm are referred to as "normal," with all other dimensions being proportional. In the U.S.A. tensile tests are conducted with a standard round specimen 0.5 inches (12.7 mm) in diameter and with a calculated length of 2 inches (50.8 mm), i.e.,

$$l_0 = 4d = 4.51\sqrt{F}.$$

The elongation under tension is greatly affected by the ratio $l_0/\sqrt{F}$ and the multiplier (l_0/d) is therefore always indicated by a subscript to the symbol for elongation, e.g., δ_5 for a five-fold specimen. The shorter the calculated length, the higher is the relative elongation, since concentrated deformation plays a larger part in total elongation (δ_5 is always higher than δ_{10}; for steel $\delta_5 \simeq 1.25\ \delta_{10}$). Relative elongation also depends on the cross-sectional shape of the specimen and is lower for a rectangular specimen than for a round specimen of equal cross-sectional area. The elongations of flat and round specimens are approximately the same when the ratio b/a $\leq$ 5 (where b is the width of the flat specimen and a is its thickness). In order to keep the heads (fillets) from affecting the value obtained for elongation it is necessary to satisfy the condition $l - l_0 \geq d$ (where l is the working length, or the distance between the heads, l_0 is the calculated length, and d is the diameter of the working segment). The sizes and shapes recommended for the heads and transition areas by the GOST can be varied in accordance with the test con-

ditions or the characteristics of the material. In order to provide reliable fixation in the test-machine clamps, specimens prepared from sheets of high-strength steels and alloys are made with heads having holes beneath the pegs that fix the specimen on the rod. All flat specimens for tests at high and low temperatures are fabricated with similar heads. In order to prevent warping plates of the appropriate shape can be fastened or welded to both sides of the heads of specimens cut from thin sheets. Specimens with a working segment of varying cross-section (Fig. 1), which follows a radius of large curvature, are used for tensile-testing brittle materials.

Micromechanical tensile tests are conducted on round specimens 0.5-1.2 mm in diameter and flat specimens up to 1 mm thick with a total length of 10-13 mm; these specimens are prepared with special care on watch-making tools. Compression tests are conducted on short round, square, and rectangular specimens, which eliminate the possibility of loss of stability during testing. In preparing compression specimens the faces must be kept strictly perpendicular to the longitudinal axis and carefully machined (to a finish of class 8-9). Specimens in the form of cubes are often prepared from brittle materials (concrete, etc.). The results of compression tests depend on the ratio of the specimen dimensions. For plastic materials an increase in the ratio d/h (where d is the specimen diameter and h is the specimen height) leads to a rise in deformation resistance (Fig. 2), which is associated with an increase in the influence of friction along the faces. Cylinders with concave faces are sometimes used to reduce friction (Fig. 3). Specimens for Torsion tests are described in GOST 3565-58. In addition to bolts, rivets, and wire, peg-like specimens with a diameter corresponding to that of the working aperture of the holding device and a length $l \geq 3d$, where d is the specimen diameter, are subjected to Shear

tests. Bending tests are conducted on rectangular, square, and round specimens. The length of the specimen is generally 40-60 mm greater than the distance between supports, which is taken as 10-20h (where h is the specimen height or diameter, usually 10-30 mm) in order to reduce warping near the supports. Bend-test specimens of cast iron are prepared in accordance with GOST 2055-43. Warping tests of sheets are conducted with rectangular plate-like specimens with holes (Fig. 4). The warping stress depends on the ratio e/d (where e is the distance from the edge of the sheet to the center of the hole and d is the diameter of the hole). The ratio e/d is customarily taken as 1.5 or 2. The warping stress is usually 10-20% higher in a specimen with e/d = 2 than in one with e/d = 1.5. Impact strength is determined on Menage specimens (GOST 9454-60). Specimens of reduced cross-section (5 x 10 mm or 5 x 5 mm) can be used for comparative evaluations.

Fig. 3. Specimen for compression test (α_k = 4 for steel).

Notch sensitivity is determined in static, fatigue, and dynamic tests on specimens with stress concentrators (notches) of various shapes. We can distinguish external notches (annular fluting, grooves, and cuts of predetermined shape) and internal notches (through apertures). The shape of a notch is customarily characterized by its sharpness (the ratio of its radius of curvature at the apex ρ to the width or diameter of the specimen in the notched area d_n) and its depth (the ratio $2v/d_0$, where v is the depth of the notch and d_0 is the width or diameter of the specimen outside the notch). The concentration factor (shape factor) α_k increases as the notch becomes sharper. At a given notch sharpness increasing its depth by up to 50% causes a rise in the concentration factor; α_k drops as the notch depth is further increased. The influence of a notch on specimen strength is determined by its

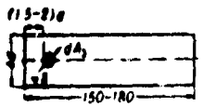

Fig. 4. Specimen for warping test.

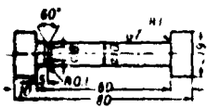

Fig. 5. Grooved specimen for tensile test.

shape (the concentration factor α_k), its location (internal or external), the characteristics of the material (reserve plasticity), and the loading method. Thus, for example, an internal notch (hole) causes a greater decrease in strength on extension than an external notch; this relationship is reversed on bending. The notch sensitivity of materials on static loading is usually evaluated by testing round specimens 10-20 mm in diameter with and without notches, employing a V-shaped transverse groove with an apical radius of ρ = 0.1-0.3 mm and a depth of 25-50% at an angle of 45-60° (Fig. 5 shows the form of the most frequently used "notched" specimen). Notch sensitivity on static bending is evaluated on rectangular specimens (6 x 1[illegible] mm) with a central groove 2 mm deep and having an apical radius of 2 mm or on cylindrical specimens with a circular groove (Fig. 6), which are most frequently used in evaluating high-strength steel. Notched specimens for durability tests are described in GOST 2860-45. Other types of notched specimens can also be employed. In connection with the wide use of sheet materials notch sensitivity is determined on flat specimens with holes or lateral grooves. Specimens with cracks created during preliminary static or vibration loading are quite common. Such cracks simulate internal and superficial defects and make it possible to evaluate the sensitivity of high-strength structural materials to defects of the crack type during subsequent tests.

Specimens for fatigue testing are characterized by high requirements with respect to surface finish and their size and shape depend to a considerable extent on the type of test (type of test machine). In order to obtain durability characteristics unaffected by surface condi-

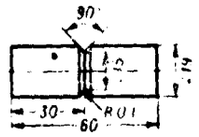

Fig. 6. Notched specimen for bending test.

tion the final operation in preparation of the specimen should be mechanical or electrolytic polishing. Smooth specimens with working segments of two types are used in fatigue tests: 1) with a working segment of constant cross-section; 2) with a working segment of varying cross-section (see Fig. 1). The principal drawback of the first type of specimen is the concentration of stresses at the points where the cylindrical segment passes into the fillets, which leads to preferential fracture near the latter, so that the test results do not characterize the true fatigue resistance of the material. Specimens of types which do not have these shortcomings are now often employed. However, from the standpoint of the statistical factor (the occurrence of different types of weakening in a given volume of material) test results for specimens of the 1st type that fracture in the working segment are more reliable than those for radius specimens, which function under maximum stresses only through one cross-section (that of minimum area). When specimens with a working segment of constant cross-section are used the fillets are polished, which gives them a better surface finish and thus increases the probability that fracture will occur in the working segment. Some durability specimens are standardized by GOST 2860-45. Round specimens are the most common for fatigue testing. Flat as well as round specimens are used for loading by pure bending, bending in one plane, and extension-compression. The ultimate durability of cylindrical specimens is higher than that of flat specimens of the same material. The scale factor (see Scale effect) has a strong influence on fatigue tests; durability decreases substantially as specimen size increases, this phenomenon being particularly pronounced in the region of relatively small diameters (less than 50 mm).

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Static durability is customarily tested on round (7-10 mm in diameter) and flat (with a thickness corresponding to that of the sheet or strip) specimens, which generally have a stress concentrator in the of a circular groove for cylindrical specimens or a hole for flat specimens; the ratio of specimen width to hole diameter is taken as 5-6. The surface of specimens of high-strength steels and alloys for static durability tests is subject to the same rigid requirements as that of specimens for fatigue tests.

References: Drozdovskiy, B.A., Fridman, Ya.B., Vliyaniye treshchin na mekhanicheskiye svoystva konstruktsionnykh staley [Influence of Cracks on the Mechanical Characteristics of Structural Steels], Moscow, 1960; Metally. Metody mekhanicheskikh i tekhnologicheskikh ispytaniy [Metals. Methods for Mechanical and Technological Testing], Moscow, 1963.

N.V. Kadobnova

SPECTRAL ANALYSIS – a physical method for qualitative and quantitative analysis of the composition of substances, based on study of their spectra. Optical spectral analysis is conveniently distinguished by its relative simplicity, its rapidity, the lack of complex preparation of the specimen to be analyzed, and the small amount of substance (10-30 mg) needed for analysis for a large number of elements. Emission spectra are produced by vaporizing the substance and exciting the atoms of its elements by heating them to 1000-10,000°. The radiation of the excited atoms and ions is directed through an optical system to a spectrograph (spectrometer), a device used to resolve the light beam into individual monochromatic beams and to record the resultant spectral lines photographically or photoelectrically. Two types of devices, moderate-dispersion (ISP-28 and ISP-51) and high-dispersion (ISP-51A and various spectrographs with diffraction gratings), are used for spectral analysis. A spark (from an IG-3 spark generator) or an ac arc (from a DG-2 arc generator) is used to excite the spectra in analyzing electrically conductive materials, the sample itself serving as the electrodes. Direct- and alternating-current arcs, pulse (low-voltage and high-voltage) arcs, and cathodic-field discharges are most frequently used in analyzing nonconductive materials. The sample is placed in a hollow in one of the carbon electrodes. Various gas flames, ac arcs with discharge tubes, plasmatron jets, and high-frequency spark discharges are widely used for analyzing solutions. Qualitative and semiquantitative spectral analysis reduces to establishing whether or not characteristic lines are present in the spectrum and evaluating the

content of the elements sought from their intensity. This is done with the aid of a measuring microscope or a spectral projector, using special atlases. Quantitative determination of the content of an element is based on the empirical relationship (at low contents) between the intensity of a spectral line and the concentration of the corresponding element in the sample; this relationship has the form $J = ac^b$, where J is the intensity of the spectral line, c is the concentration of the element, and a and b are coefficients which depend on the characteristics of the excitation source, those of the line, the evaporation rate, and the diffusion rate. The intensity of the spectral lines is measured photoelectrically or by recording them on a photographic plate; in the latter case subsequent photometry with a MF-2 microphotometer is necessary, taking into account the characteristic curve of the film. The Table shows the relative sensitivity with which various elements can be determined in a dc arc (in 10^{-4}%).

1 Элемент	2 Чувствительность	Элемент	Чувствительность	Элемент	Чувствительность	Элемент	Чувствительность
Ag	0.5	F	100	Nb	30	Sr	5
Al	2	Fe	5	Nd	10	Ta	10
As	100	Ga	3	Ni	5	Tb	10
Au	10	Gd	200	Os	50	Te	200
B	10	Ge	5	P	100	Th	100
Ba	5	Hf	100	Pb	5	Ti	10
Be	10	Hg	100	Pd	10	Tl	1
Bi	20	Ho	10	Pr	10	Tu	10
Ca	2	In	1	Pt	50	U	100
Cd	510	Ir	50	Rb	1	V	5
Ce	500	K	2	Re	100	W	20
Co	10	La	10	Rh	10	Y	10
Cr	1	Li	1	Ru	10	Yb	10
Cs	3	Lu	10	Sb	20	Zn	3
Cu	0.5	Mg	2	Se	2	Zr	10
Dy	10	Mn	10	Si	20		
Er	10	Mo	5	Sm	500		
		Na	0.5	Sn	10		

1) Element; 2) sensitivity.

The sensitivity data shown in the Table are not maximal. Use of special excitation sources or physical and chemical enrichment of the sample permits a substantial increase in the sensitivity of spectral determinations. The accuracy of such determinations depends to a considerable extent on the content of the element in the sample and generally varies from 5% to 25%. Multichannel spectrometers or quantometers (DFS-10, ARL) are used to reduce the time required for analysis and to increase the accuracy of the determination to 1-2%. Spectral analysis in the infrared region makes it possible to identify various functional and structural groups

of macromolecules both qualitatively and quantitatively, to get an idea of the orientation of the links and groups in polymer molecules, and to evaluate the regularity of polymers. Spectral analysis in the ultraviolet region can be used to identify individual groups, oxidation and reaction products, etc. This type of analysis employed for quantitative determination of the content of low-molelcular additives in polymers. In some cases, ultraviolet analysis also makes it possible to determine polymer structure. A special field of spectral analysis, magnetic radiospectroscopy, involves analysis in the region of ultra-high-frequency radiowaves, centimeter and millimeter waves. Despite the fact that this region is a portion of the same electromagnetic spectrum, the apparatus used is completely different from that for optical analysis. Radiospectroscopic methods, those of nuclear and paramagnetic resonance, can be employed to determine the state of the protons in polymers, the presence, character, and number of free radicals in polymerization and oxidation processes, etc.

References: Mandel'shtam, S.L., Vvedeniye v spektral'nyy analiz [Introduction to Spectral Analysis], Moscow-Leningrad, 1946; Prokof'yev, V.K. Fotograficheskiye metody kolichestvennogo spektral'nogo analiza metallov i splavov [Photographic Methods for Quantitative Spectral Analysis of Metals and Alloys], Vols. 1-2, Moscow, 1951; Zaydel', A.N. et al., Emissionnyy spektral'nyy analiz atomnykh materialov [Emission Spectral Analysis of Atomic Materials], Leningrad-Moscow, 1960; Poluektov, N.S., Metody analiza po fotometrii plameni [Methods of Flame-Photometric Analysis], Moscow, 1959; Bellami, L., Infrakrasnyye spektry slozhnykh molekul [Infrared Spectra of Complex Molecules], 2nd Edition, Moscow, 1963; Bilmeyer, F.U., Vvedeniye v khimiyu i tekhnologiyu polimerov [Introduction to the Chemistry and Technology of Polymers], translated from English, Moscow, 1958; Keller, A., Sandeman, J., J.

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Polymer Sci., 1955, Vol. 15, No. 179, page 149.

V.V. Korolev and N.N. Lezhnev

SPHALERITE, ZnS – zinc sulfide (zinc blende). Fe (up to 26%), Mn (up 5.8), and Cd (0.8-4%) may be present as isomorphous impurities, while Ga, Ge, and In may be present in small quantities. The melanocratic, iron-rich (7-10% FeS) variety is called marmatite, while the light-colored variety is called kleiophane. Sphalerite crystallizes in cubic syngony. It has a specific gravity of 3.9-4.1. Complete cleavage occurs along the {110} plane. Its average Mohs hardness is 3.5-4. The hardness of the {001} face is 117 kg/cm^2, while that of the {111} face is 212 kg/cm^2 (by the Vickers method). It is usually brown or black in color, although less frequently reddish, yellow, green, or colorless Its luster is greasy or adamantine. It is optically isotropic; n = = 2.36-2.47 (increasing with the Fe content).

The reflectivity of Sphalerite is 18% for red light and 18.5% for orange light. It has piezoelectric, pyroelectric, and weak photoelectric properties. It exhibits pulse conductivity when irradiated with α-particles. Its dielectric constant is 7.9 and its specific resistance 10^8 ohm·cm. Natural sphalerite, especially the cadmium-containing varirties, luminesces blue, yellow, orange, and red in cathode rays. This mineral exhibits diamagnetic characteristics at a content of no more than 0.4%. The varieties containing larger amounts of iron are paramagnetic, raising the Fe content from 0.28 to 15.98% causes the magnetic susceptibility to vary from $0.68 \cdot 10^{-6}$ to $18.9 \cdot 10^{-6}$, SGSM. Sphalerite dissolves in concentrated HNO_3 to liberate S and in HCl to liberate H_2S; it can be dissolved with difficulty in acetic acid. It forms solid solutions with CdS.

The thermal conductivity of sphalerite at 0° is 0.266 watts·cm^{-1}·degrees^{-1}; at 880-1020° it is converted to wurtzite (α-ZnS). It passes into a trigonal modification (γ-ZnS) over the temperature range 660-1200° and sublimates at 1000°. The heat capacity of this mineral is 0.23 at -200°, 0.45 at 0°, 0.53 at 200°, 0.56 at 400°, and 0.587 at 800°. Its melting point under a pressure of 150 atm is 1800-1900°. Its thermal expansion is 0.06 as the temperature is varied from 20 to 100° and 6 as it is varied from 20 to 1000°.

Metallic Zn is smelted from natural sphalerite. Cd, In, and Ga are extracted as byproducts. A considerable amount of sphalerite is used in the paint industry, for the manufacture of zinc white. Finely ground sphalerite (with a particle size of <2 μ) is also employed as a pigment in paint manufacture. The production of chemically pure ZnS, which is used as a luminophore, from natural sphalerite is of ever increasing importance. Luminophore sphalerite activated by Ag or Cu is employed in the manufacture of television kinescopes and screens for radio-locating equipment and oscillographs. Chemically pure sphalerite is used in the production of various fluorescent compounds and paints for instrument building, for masking, in all types of signaling equipment, etc.

References: Mineraly [Minerals], Handbook, Vol. 1, Moscow, 1960; Pshibram, K., Okraska i lyuminestsentsiya mineralov [Coloration and Luminescence of Minerals], translated from English, Moscow, 1959; Lyuminofory [Luminophores], (compiled by L.Ya. Markovskiy and G.M. Eliashberg), Leningrad, 1958.

V.V. Nasedkin

SPODUMENE, LiAl [Si_2O_6] – a mineral belonging to the monoclinic pyroxenes; it forms α- and β-modifications. The natural mineral is the α-modification; α-spodumene is encountered both in large prismatic crystals and lamellar-columnar aggregates and in compact cryptocrystalline masses. It is grayish-white or greenish in color; the reddish and reddish-violet varieties are called kunzite. α-spodumene with an emerald green hue is called hiddenite. Colorless and blue varieties are rarely encountered. This mineral has a vitreous luster. X-irradiation causes it to change color. Distinct cleavage occurs along the 110 plane (at an angle of 87°); parting occurs along the 010 plane and less frequently along the 100 plane. Spodumene has a Mohs hardness of 6–7 and a specific gravity of 3.0–3.2. It is optically positive and biaxial. Its indices of refraction are N_g = 1.676–1.681, N_m = 1.660–1.671, N_p = 1.651–1.668, and $N_g - N_p$ = 0.025–0.013. In cathode rays α-spodumene luminesces a bright red; its luminescence is markedly weaker in ultraviolet light. This mineral has a specific heat capacity (c_p) of 0.90 joules/g at 60°. It has a negative thermal expansion over the temperature range 950–1400°.

Spodumene is used as a luminophore in its native state. The majority of this mineral is used in the production of metallic Li. It is also employed in the manufacture of opal, white, low-melting, heat-resistant, borosilicate, and flint glass, glass or cathode-ray and kinescope tubes, and photosensitive glass.

Addition of spodumene to a glass charge reduces its coefficient of expansion and its tendency toward devitrification and rapid changes in

temperature. The surface of the glass is hardened and its brittleness is reduced. This mineral is used in the manufacture of various types of ceramics: high-voltage porcelain (which is heat-resistant to 550-800° and has a coefficient of thermal expansion of $1.7 \cdot 10^{-6}$), dish ceramics (which have an annealing temperature of 1250-1280°), and acid-resistant ceramics (mixtures of spodumene, alkaline amphibole, and clay). Spodumene ceramic products have a low (near-zero) coefficient of expansion. This mineral is used in the manufacture of glazes and enamels. Kunzite and hiddenite belong to the gem-stone group. Since the ore is easily concentrated, it is primarily monomineral spodumene that is used. Natural ceramic mixtures consisting of spodumene and pegmatite are also employed.

References: Ginzburg, A.N., Tr. Mineralog. muzeya AN SSSR [Transactions of the Mineralogical Museum of the Academy of Sciences USSR], 1959, No. 9; Tumanov, S.G., Maslennikova, G.N., Tr. Gos. issled. elektrokeram. in-ta [Transactions of the State Electroceramic Research Institute], 1957, No. 2; Plyushchev, V.Ye., Simanov, Yu.P., and Shakhno, I.V., DAN SSSR [Proceedingsof the Academy of Sciences USSR], 1959, Vol. 125, No. 2; Winchell, A.N., Winchell, G., Opticheskaya mineralogiya [Optical Mineralogy], translated from English, 2nd Edition, Moscow, 1953.

V.V. Nasedkin

SPONGE RUBBER – a porous material with shock-absorptive, heat- and sound-insulating, and hermetic properties. We can distinguish sponge rubbers with open communicating pores, with closed cells, and with a composite structure. Rubber of the first type is manufactured from latex or solid caoutchouc, while that of the second type is produced only from solid caoutchouc. Sponge rubber manufactured from latex (latex sponge, foam rubber) is gas- and water-permeable as a result of its communicating pores and is characterized by the following properties: bulk weight – 0.08-0.25 kg/cm^3, hardness (the force required to compress a sample to 60% of its initial height) – 0.06-0.5 kg/cm^2, residual deformation after 250,000 compression cycles – less than 7.5%, ultimate tensile strength – 0.2-1.0 kg/cm^2, relative elongation – 100-300%, and pore size – 0.05-2 mm. At an average poor diameter of 0.2-0.4 mm the heat capacity of sponge rubber is 160 kcal/m^3·°C), while its thermal conductivity is 0.08 kcal/m·hr·°C.

The coefficient of frost resistance of natural-latex sponge rubber is 0.95-1.0 at –40°; the distention of divinylnitrile-latex sponge rubber is 7% in gasoline and 50% in benzene. Chloroprene-latex sponge rubber is incombustible.

Latex sponge rubbers are produced in the USSR and abroad in the form of molded articles or sheets 3-30 mm thick. They are used principally as shock-absorbing cushions for the seats of aircraft, automobiles, and trains and in the manufacture of various shock absorbers, padding, soft furniture, mattresses, heat- and sound-insulating materials, inner soles for shoes, prostheses, etc.

Cellular and porous sponge rubbers of solid caoutchouc are characterized by the following properties: bulk weight – 0.15-0.90 g/cm^3, ultimate tensile strength – 0.1-50 kg/cm^2, relative elongation – 20-300%, hardness – 0.5-12 kg/cm^2, and heat capacity – 0.4-0.6 kcal/kg·°C. The frost resistance of cellular and porous natural sponge rubbers is –40°. Sponge rubbers of nairit are fireproof, those of divinylnitrile caoutchouc are oil- and gasoline-resistant, and those of butyl rubber are acid- and alkali-resistant. Siloxane sponge rubber is inert in all chemical media. Sponge rubbers manufactured from solid caoutchouc may have dielectric or conductive characteristics. The electrical resistance of a sponge rubber depends on its composition; moreover, it may vary from 10 to 10^{17} ohm·cm in the same sample, depending on the extent to which it is compressed. Solid-caoutchouc sponge rubbers are produced in sheets and molded and unmolded packings. The latter can be obtained in any length and in widths of from 1 to 50 mm.

References:

SPONGOLITE – a rock consisting principally (more than 50%) of thin elongated particles of hydrated silica (an opaline substance); it is a constituent of the skeleton (spicule) of sponges and generally contains some impurities of argillaceous material. Spongolite is greenish or light gray in color. It is similar in chemical composition, characteristics, and application to Tripoli and Fine kaolin.

P.P. Smolin

SPRING SHAPING BRONZE – bronze intended for the manufacture of various types of springs. Helical and flat springs, elastic elements (membranes and silfons) for precision instruments, and all types of spring components are fabricated primarily from BrOF6.5-0.15, BrOF4-

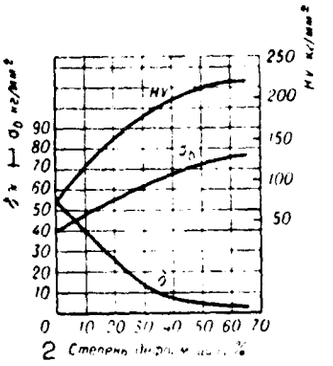

Fig. 1. Mechanical properties of BrKMts3-1 bronze as a function of degree of deformation (bands 1 mm thick). 1) kg/mm^2; 2) degree of deformation, %.

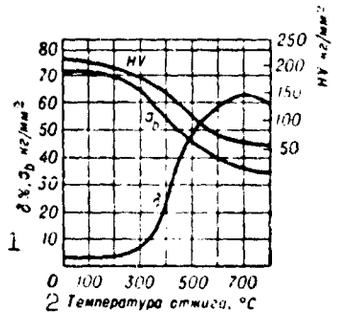

Fig. 2. Influence of annealing temperature on the mechanical properties of BrKMts3-1 bronze (bands 1 mm thick deformed by 50%). 1) kg/mm^2; 2) annealing temperature, °C.

0.25, and BrOTs4-3 tin bronzes, BrA7 Aluminum bronze, BrKMts3-1 silicon-manganese bronze, and BrB2, BrBNT1.9, and BrBNT1.7 Beryllium bronzes. Springs and other electronic components are also fabricated from the nickel-aluminum alloy MNA6-1.5 (see Kudial). Spring shaping bronzes

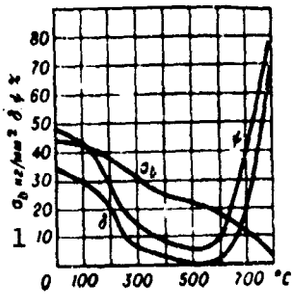

Fig. 3. Mechanical properties of MNA6-1-1.5 alloy at elevated temperatures. 1) kg/mm^2.

are produced in strips and bands 0.15 mm thick and in wire 0.1-12 mm in diameter. Thin-walled tubes of various sizes are produced for the manufacture of Burden manometer springs. With the exception of beryllium bronzes and kunial, the aforementioned alloys are solid solutions and have a homogeneous structure. They have high elasticity and strength when cold-worked. Thus, the strength of strips of BrOF6.5-0.15 bronze is doubled by cold-working to 80%, while their hardness increases from 90 to 200 kg/mm^2 (Tables 1 and 2). The aluminum bronze BrA7 has a strength of 90 kg/mm^2 and a hardness of 200 kg/mm^2 after 70% deformation, which reduces its elongation to 2-3%. Figure 1 shows the change in the mechanical properties of BrKMts3-1 bronze as a function of degree of deformation.

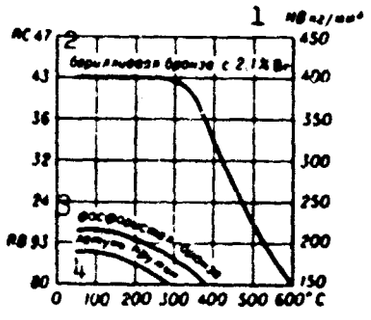

Fig. 4. Loss of hardness in various bronzes at elevated temperatures (holding time – 1 hr). 1) kg/mm^2; 2) beryllium bronze containing 2.1% Be; 3) phosphorus bronze; 4) spring brass.

Heating (annealing) of these alloys causes them to lose the high elasticity, strength, and hardness which they acquire during cold working. In tin and aluminum bronzes this decrease begins after annealing at 270-300° and becomes sharp at 350°. The characteristics of BrKMts3-1 bronze are less severely affected (Fig. 2), but a noticeable drop is

observed at annealing temperatures above 250°. In MNA6-1.5 alloy, which contains 6% Ni and 1.5% Al, a decrease in characteristics occurs only at annealing temperatures above 500°, this resulting both from the considerable nickel content and the ability of the alloy to undergo dispersion hardening (at an annealing temperature of 500°). It also retains a certain strength at elevated temperatures (Fig. 3). Beryllium bronzes are among the dispersion-hardening alloys which are soft and plastic when quenched and hard and highly elastic when annealed. These alloys are worked in the quenched state, up to the final fabrication of the finished product. The finished component acquires high elasticity and strength during annealing, as a result of decomposition of the solid solution. Springs of beryllium bronze have substantially higher characteristics at normal and elevated temperatures than other types of springs (Figs. 4 and 5).

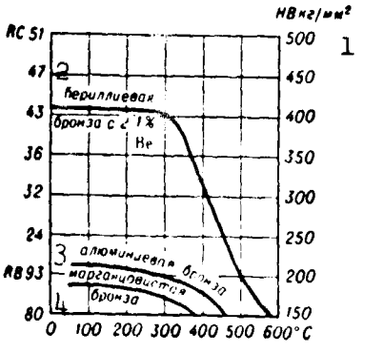

Fig. 5. Loss of hardness in various bronzes at elevated temperatures (holding time – 15 hr). 1) kg/mm^2; 2) beryllium bronze containing 2.1% Be; 3) aluminum bronze; 4) manganese bronze.

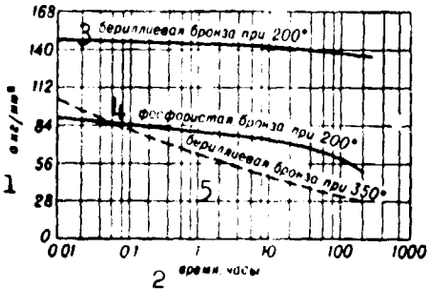

Fig. 6. Long-term strength curves for beryllium and tin bronzes. 1) kg/mm^2; 2) time, hr; 3) beryllium bronze at 200°; 4) phosphorus bronze at

200°; 5) beryllium bronze at 350°.

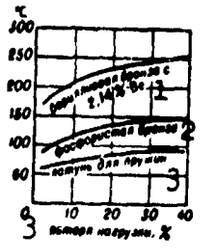

Fig. 7. Loss of tension in certain spring bronzes at elevated temperatures. 1) Loss of tension, %; 2) beryllium bronze containing 2.14% Be; 3) phosphorus bronze; 4) spring brass.

TABLE 1

Mechanical Properties of Spring Shaping Bronzes

1 Сплав	2 Состояние сплава	3 (кг/мм²) E	$\sigma_{пц}$	$\sigma_{0,2}$	σ_b	δ (%)	4 σ_{-1} при 100 млн. циклов	НВ
5 БрОФ6,5-0,15	Твердое 11	11 200	46	65	85	1	—	180—200
6 БрОФ4-0,25	То же	10 500	40	55	65	2	—	160—170
7 БрОЦ4-3	» 12	10 000	—	50	60	2	18	160
8 БрА7	»	12 000	45	60	90	3	19	180—220
9 БрКМц3-1	»	12 000	—	55	90	1	21	200
10 МНА6-1,5	Твердое	—	—	—	65—75	3	—	210

1) Alloy; 2) condition of alloy; 3) kg/mm^2; 4) σ_{-1} at 100 million cycles; 5) BrOF6.5-0.15; 6) BrOF4-0.25; 7) BrOTs4-3; 8) BrA7; 9) BrKMts3-1; 10) MNA6-1.5; 11) hard; 12) the same.

TABLE 2

Physical and Technological Properties of Spring Shaping Bronzes

1 Сплав	2 γ (г/см³)	3 $\alpha \cdot 10^6$ (1/°C) при темп-ре (°C) 20—100	20—200	20—300	4 λ (кал/см·сек·°C)	5 ρ (ом·мм²/м)	6 Темп-ра (°C) горячей обработки	7 отжига	8 закалки	9 отпуска	10 Темп-ра начала рекристаллизации (°C) 11
12 БрОФ6,5-0,15	8.7	17.7	—	—	0.13	0.176	750—780	600—650	—	—	350—360
13 БрОФ4-0,25	7.8	17.6	—	—	0.20	0.091	750—780	600—650	—	—	360—380
14 БрОЦ4-3	8.8	17.6	—	—	0.20	0.087	750—780	600—650	—	—	360—380
15 БрА7	7.8	17.0	17.4	18.2	0.19	0.11	830—880	650—750	—	—	350—380
16 БрКМц3-1	8.4	17.4	17.6	18.1	0.11	0.15	800—850	700—750	—	—	360—380
17 МНА6-1,5	8.7	—	—	—	—	—	850—900	750—800	900	500	—

1) Alloy; 2) g/cm^2; 3) $\alpha \cdot 10^6$ (1/°C) at temperature of (°C); 4) cal/cm·sec·°C; 5) ohm·mm^2/m; 6) temperature (°C); 7) hot working; 8) annealing; 9) quenching; 10) tempering; 11) recrystallization initiation temperature (°C); 12) BrOF6.5-0.15; 13) BrOF4-0.25; 14) BrOTs4-3; 15) BrA7; 16) BrKMts3-1; 17) MNA6-1.5.

TABLE 3

Applications of Spring Shaping Bronzes

Сплав 1	2 Область применения
Бронза оловянистофосфористая БрОФ6,5-0,15 3	Плоские пружины, мембраны и сильфоны приборов и аппаратов, работающие при темп-ре до 80° 11
Бронза оловянистофосфористая БрОФ4-0,25 4	Манометрич. пружины в виде трубок Бурдона 12
Бронза оловянноцинковая БрОЦ4-3 5	Плоские и витые пружины, пружинящие детали, сильфоны 13
6 Бронза алюминиевая БрА7	Плоские пружины и пружинящие детали 14
7 Бронза кремнистомарганцовистая БрКМц3-1	Плоские и витые пружины в химич. и общем машиностроении, в морском судостроении 15
8 Бронза бериллиевая БрБ2 9 Бронза бериллиевая БрБНТ1,9	Плоские и витые пружины, мембраны и сильфоны в точном приборостроении, работающие при темп-рах до 150—200° 16
10 Куниаль МНА6-1,5	Пружины повышенной коррозионной стойкости спец. назначения 17

1) Alloy; 2) application; 3) BrOF6.5-0.15 tin-phosphorus bronze; 4) BrOF4-0.25 tin-phosphorus bronze; 5) BrOTs4-3 tin-zinc bronze; 6) BrA7 aluminum bronze; 7) BrKMts3-1 silicon-manganese bronze; 8) BrB2 beryllium bronze; 9) BrBNT1.9 beryllium bronze; 10) MNA6-1.5 kunial; 11) flat springs, membranes, and silfons for instruments and apparatus which must function at temperatures of up to 80°; 12) Burden-tube manometer springs; 13) flat and helical springs, spring components, and silfons; 14) flat springs and spring components; 15) flat and helical springs in chemical and general machine building and ship building; 16) flat and helical springs, membranes, and silfons for precision instruments which must operate at temperatures of up to 150–200°; 17) special-purpose springs with high corrosion resistance.

The short-term tensile strength and relative elongation of strips and bands 0.25 mm thick have not been established, but their hardness has been determined on a PMT-3 apparatus under a load of 0.2 kg. In determining Vickers hardness thick strips and bands can withstand the following maximum loads:

Толщина полосы или ленты (мм) 1	Нагрузка (кг) 2
0,25—0,35	5
0,4—0,55	10
0,6 и более	30

1) Thickness of strip or band (mm); 2) load (kg); 3) or more.

The tensile strength of BrB2 bronze wire is very little affected by testing at 200° for 100 hr (Fig. 6); BrB2 has a substantially higher long-term strength than tin-phosphorus bronze. Figure 7 shows the relaxation of spring bronzes under thermal stress. Beryllium-bronze springs can function for extended periods at elevated temperatures (up to 150-200°). The applications of spring shaping bronzes are shown in Table 3. Semifinished products of spring shaping bronzes are produced in accordance with GOST 1761-50, 1048-49, 4748-49, 1789-60, 5222-50, 5221-50, 2622-44 and TsMTU 302-41, 315-41, 325-41, 3326-53, and MPTU 4146-53.

O.Ye. Kestner

STABILITY TEST – is a test to evaluate the carrying capacity of an element compressed by a longitudinal force. The relative evaluation of materials destined for structural parts which must be stable is mostly carried out by testing thin-walled rods with diverse shapes of the cross section (pipes, profile iron, pillars). The tests are carried out by a single increasing load in presses and universal machines or by the long-time action of a constant load on machines of the lever type.

Several types of the loss of stability: bending, torsion, torsional bending, are observable in the stability test as well as in service. Total and local loss of stability are discernible. The total loss of stability is frequently accompanied by a local loss of stability.

The rod in the stability test is compressed between the cross beams of the machine. In the moment of bulging, when the sagging increases without a noticeable increase in load, the critical force P_{kr} is recorded and the critical stress $\sigma_{kp} \frac{P}{F}$ is determined, where F is the area of the cross section. Deformation (buckling or sagging) may be measured during the test by means of strain-gauges. Wire strain-gauges are convenient for the measurement of buckling. A series of rods with the same cross section but with different length is, as a rule, tested in order to obtain the curve of the longitudinal stability in the coordinates $P_{kr} = f(l)$ or $\sigma_{kp} = f\left(\frac{l}{i}\right)$, where l is the length of the rod, i is the smallest radius of the inertia of the cross section; the value of σ_{kr} depends on the material properties and on the geometrical conditions (the shape of the cross section and the length) of the rod, the method of fixing the butts, and the quality of the preparation of the

rod (perpendicularity of the end faces to the longitudinal axis, initial buckling). The butts of the rod are fixed for the test in ball or cylindrical supports, but more frequently and simply the rod is resting with the end faces on the plates of the machine.

In the range $\sigma_{kr} < \sigma_{pts}$, where σ_{pts} is the proportional limit for stretching or compression, the experimental stability curves are near to that calculated by Euler's formula

$$\sigma_{kp} = C \frac{\pi^2 E}{\left(\frac{l}{i_{min}}\right)^2},$$

where E is the modulus of elasticity of the rod material; C is the fixing factor (which may change between 0.25 and 4). An experimental determination of σ_{kr} is especially necessary for "short" rods (with $l/i < 10$) because a reliable calculation formula does not exist. Stability tests at high temperatures are carried out in multisection furnaces installed on the test machine (owing to a possible temperature drop caused by the considerable lengtn of the specimens). In addition to short time test, stability tests at high temperatures are also carried out with a continuously acting compressing load. Machines with reserving gears may be used in this case for the long-life stability test. Curves in the "critical stress v.s. time," coordinates, similar to the curves of long-life strength, or curves in "deformation v.s. time" coordinates similar to the creep curves in the tensile test are drawn on the basis of the results.

The conception of the critical time τ_{krl}, the time in which the rod maintains the carrying capacity under the action of a certain constant stress, is introduced to evaluate the stability of a rod working for a long time at high temperatures. Depending on the given conditions, τ_{kr} may be determined by the time in which the deformation reaches a certain fixed value τ_{krl}, or accelerated elongation begins (τ_{kr2}), or

unlimited elongation occurs (τ_{kr3}) (Fig.). In most of the cases, the critical time τ_{kr2} is used.

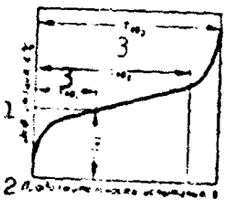

Fig. 1. Deformation; 2) test time; 3) critical.

References: Vlasov V.Z., Tonkostennyye uprugiye sterzhni [Thin-walled Elastic Rods], 2nd edition, Moscow, 1959; Hoff N., Prodol'nyy izgib i ustoychivost' [Longitudinal Bending and Stability], translation from English, Moscow, 1955.

N.V. Kadobnova

STAINLESS BEARING STEEL is stainless steel used to fabricate the races and rolling bodies for bearings. The 9Khl8 high-c rbon, high-chrome steel has found widest application. The chemical composition of the 9Khl8 steel and some of its modifications is shown in Table 1.

TABLE 1

Chemical Composition of Stainless Bearing Steel

Страна 1	2 Содержание элементов (%)					3 Стран
	C		Mn	Si		
4 9Х18, 9Х18Ш*	0.9—1		≤0.7	≤0.8	—	5 СССР
ПХ18Ш*	1.1—1.23		≤0.7	≤0.8	0.6	СССР
6 440B	0.75—0.95		≤1	1	0.75	7 США
440C	0.95—1.2		≤1	1	0.75	США
X 1 CrMoV18	0.85—0.95		≤1	1	1—1.3	8 ФРГ

*High-quality, produced by the arc electroslag resmelting method.

1) Steel; 2) element content (%); 3) country; 4) 9Khl8, 9Khl8Sh*; 5) USSR; 6) PKhl8Sh*; 7) USA; 8) FRG.

A steel differing from the 9Khl8 steel by the addition of cobalt and molybdenum with 4% molybdenum in place of the chrome is also used.

The physical properties of the 9Khl8 steel are: γ = 7.65-7.7; E = = 20,200-21,500 kg/mm^2; $\alpha \cdot 10^6$: 10.2 (20-100°), 10.7 (20-200°), 11 (20-300°), 11.6 (20-400°), 12 (20-500°) 1/°C. The critical points for heating and cooling with a rate of 5° per minute are A_{c1} 815-865°, A_{g1} 765-665°.

Processing properties of 9Khl8 steel. The temperature range for forging and stamping is: begin at 1050-1080°, end at 900°. The heating regime for forging is: slow heating to 800-850°, hold for 30 minutes, then fast heating to 1050-1080°. Slow cooling of the forgings (in ashes, furnace, thermostat). The variation of the mechanical properties of

the 9Kh18 steel as a function of the forging temperature is shown in Fig. 1.

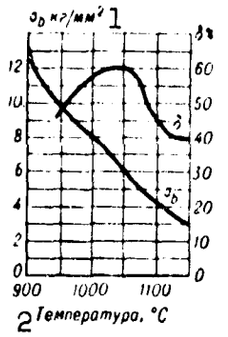

Fig. 1. Mechanical Properties of the 9Kh18 steel as a function of forging temperature. 1) σ_b, kg/mm^2; 2) temperature, °C.

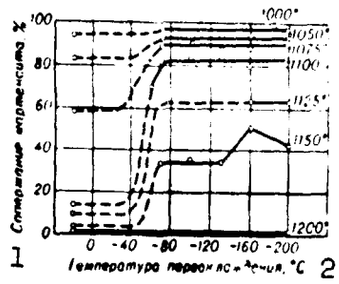

Fig. 2. Effect of quench temperature and degree of supercooling during quench on amount of martensite in 9Kh18 steel. 1) Martensite content, %; 2) supercooling temperature, °C.

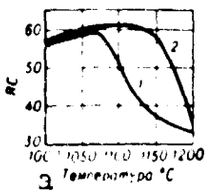

Fig. 3. Effect of quench temperature and cold treatment on hardness of the 9Kh18 steel: 1) without cold treatment; 2) with cold treatment. a) Temperature, °C.

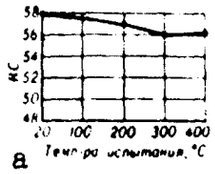

Fig. 4. Hot hardness of tempered type 9Kh18 steel after cold treatment and tempering at 400°. a) Test temperature, °C.

The annealing regime is: slow heating to 850-870°, after soak, cooling at a rate of from 25 to 100° per hour. The mechanical properties of the annealed 9Kh18 steel are: HB = 232-241 kg/mm^2; σ_b = 76 kg/mm^2; δ 13,4%, ψ=30%. The basic heat treatment regime is: preliminary heating to 850°, final heating to 1060°, cooling in oil, temper at 150-160°, microstructure after quench from 1000-1100° is cryptocrystalline (martensite and carbides).

Conversion of the residual austenite into martensite during long-term storage and particularly during operation of the bearing at negative temperatures is accompanied by a considerable increase of its linear dimensions. This takes place in the case when the actual quenching temperature is above 1070°. Additional cold working of the steel is used to stabilize the dimensions and to increase the contact fatigue strength. The martensitic conversion during quench in the quenching temperature range used in practice terminates at −70° (Fig. 2). The optimal heat treatment regime for the 9Kh18 steel, which makes it possible to obtain a high degree of stability of the geometrical dimensions of the bearing parts in the range of operating temperatures from −200° to +150° and which provides for the optimal complex of mechanical properties, consists of preliminary heating to 850°, final heating to 1050-1070°, cooling in oil, and then slow cooling to −70° and tempering at 150-180°.

The following heat treatment regime is used for parts of stainless heat-resistant bearings operating in the temperature range up to 350-400°, to provide the required dimensional stability, optimal mechanical properties and satisfactory corrosion resistance: preliminary heating to 850°, final heating to 1070-1090°, cooling in oil, and then slow cooling to −70°, −80° and double tempering at 400° (3 hours + 2 hours).

Mechanical properties of tempered 9Kh18 steel. The effect of

quenching temperature and cold treatment on the hardness of the steel is shown in Fig. 3. Hot hardness of the steel treated in accordance with the regime for heat-resistant stainless bearings is shown in Fig. 4.

TABLE 2

Impact Strength of 9Kh18 Steel as a Function of Heat Treatment Regimes*

Темп-ра закалки (°С) 1	a_n (кгм/см²) 2		
	3 на квадратных образцах с надрезом	4 на цилиндрич. образцах без надреза	
		без обработки холодом 5	с обработкой холодом 6
1000	1,2	—	—
1050	1	—	5,2
1075	1,3	6,4	6,4
1100	1,6	—	4,4
1125	1,8	—	3,9
1150	2,1	—	—

*Tempering temperature after quenching is 150°.

1) Quenching temperature (°C); 2) a_n (kgm/cm^2); 3) on square specimens with notch; 4) on unnotched cylindrical specimens; 5) without cold treatment; 6) with cold treatment.

The effect of heat treatment regime on the impact strength of 9Kh-18 steel is shown in Table 2.

The wear resistance of the 9Kh18 steel in rolling friction with slip (10%) as a function of tempering temperature is shown in Fig. 5. The endurance of tempered 9Kh18 steel in fatigue testing (alternating bending, stress 98 kg/mm^2) is characterized by the following number of cycles to failure:

$6.8 \cdot 10^6$ with tempering temperature 100°
$6.9 \cdot 10^6$ with tempering temperature 150°
$6.7 \cdot 10^6$ with tempering temperature 200°

The contact endurance of the 9Kh18 steel after quenching and tempering with intermediate cold treatment is considerably higher than after heat treatment without the use of the cold treatment (Fig. 6), which is explained by the considerable difference of the residual aus-

tenite content.

Corrosion resistance of 9Khl8 steel. The corrosion resistance of 9Khl8 steel in sea water as a function of the tempering temperature and

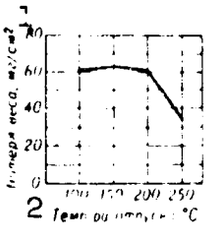

Fig. 5. Weight loss of 9Khl8 steel in rolling friction tests as a function of tempering temperature (basic heat treatment regime). 1) Weight loss, mg/cm^2; 2) tempering temperature, °C.

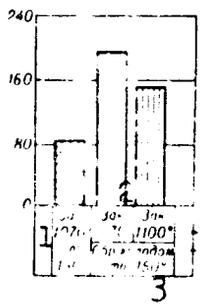

Fig. 6. Contact endurance of 9Khl8 steel in testing long-term rolling of spherical specimens between cylindrical races under load. Number of cycles N = 10^6 along ordinate axis. 1) Quench from 1070°, temper at 150°; 2) quench from –; 3) cold treatment, temper at 150°.

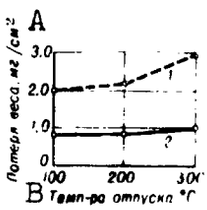

Fig. 7. Corrosion resistance of tempered 9Khl8 steel in sea water as a function of tempering temperature and immersion condition: 1) specimens half-immersed; 2) specimens fully immersed. A) Weight loss, mg/cm^2; B) tempering temperature, °C.

the loading conditions is shown in Fig. 7, the nature of the corrosion resistance in various aggressive media is shown in Table 3.

Cold treatment at –70° and tempering at 150°–400° have no essential effect on the corrosion resistance of the 9Khl8 steel. The resistance of the steel produced in a vacuum arc furnace is considerably

TABLE 3

Resistance of 9Kh18 Steel and Certain Acid-Resistant Steels in Aggressive

Агрессивная среда 1	Сталь 2		
	9Х18 (17% Cr, 1% C) 3	Х17 (17% Cr, 0.1% C) 4	Х18Н9 (18% Cr, 9% Ni, 0.15% C) 5
Воздух морской 6	Х	Х	О
Вода морская 7	У	У	У
Влажный пар 8	О	Х	О
Растворы кислот (при нормальной температуре, концентрация 5—15%):			
10 соляной	П	П	П
11 серной	П	П	П
12 азотной	Х	О	О
13 уксусной	Х	О	О
14 ортофосфорной	У	У	У
15 Растворы щелочей (концентрация 1—20%)	О	О	О
16 Органич. вещества (сырая нефть при 20—200°)	О	О	О

*О) Excellent resistance, Х) good, У) satisfactory, П) poor.

1) Aggressive medium; 2) steel; 3) 9Kh18; 4) Kh17; 5) Kh18N9; 6) sea air; 7) sea water; 8) wet steam; 9) acid solutions (at room temperature, concentration 5-15%); 10) hydrochloric; 11) sulfuric; 12) nitric; 13) acetic; 14) phosphoric; 15) alkaline solutions (concentration 1-20%); 16) organic substances (raw petroleum at 20-200°).

TABLE 4

Chemical Composition of Stainless Steels Used to Fabricate Parts for Special Anti-Friction Bearings

Сталь 1	2 Содержание элементов (%)								
	C	Mn	Si	Cr	Ni	Mo	Co	Be	Ti
3 Х18Н9	4 ≤0.12	1—2	0.8	17—19	8—10	—	—	—	—
329	По 0.1	≤2	≤1	25—30	3—5	1.15—1.65	—	—	—
5 9Х13Н6ЛК4	0.8—1	0.6	0.6	12—14	5.5—6.5	—	4—5	1.1—1.5	0.6

1) Steel; 2) element content (%); 3) Kh18N9; 4) up to; 5) 9Kh13N6LK4.

greater than that of the steel melted by the usual method.

Other stainless steels which belong to the group which are strengthened with the aid of cold plastic deformation and dispersion hardening are used to fabricate races and rolling bodies for ball and roller bearings in special cases; Table 4 shows the chemical composition of some such steels.

References: Spravochnik po mashinostroitel'nym materialam [Handbook on Machine Construction Materials], Vol. 1, Moscow, 1959; Sheyn, A.S., Bashkirov, B.Ya., Tsareva, A.A., Termicheskaya obratotka vysokouglerodistoy khromistoy nerzhaveyushchey stali [Heat Treatment of High-Carbon Chrome Stainless Steel], Moscow, 1956 (AS USSR, Institute of Technological and Economic Information, Theme 5, No. I-56-42); Sheyn, A.S., et al., Nerzhaveyushchiye stali dlya podshipnikov, prednaznachennykh dlya raboty pri povyshennykh temperaturakh [Stainless Steels for Bearings Intended for Operation at High Temperatures], in book: Transactions of the All-Union Scientific Research Design and Technology Institute of the Bearing Industry, Moscow, 1960, No. 4(24); Sheyn, A.S., Gorshkova, V.F., Podshipnik [Bearing], 1952, No. 11, pages 8-11; Podshipniki kacheniya [Anti-Friction Bearings], Moscow, 1961; Mashinostroyeniye. Entsiklopedicheskiy spravochnik [Machine Construction. Encyclopedic Handbook], Vol. 3, Moscow, 1947.

A.S. Sheyn

STAINLESS STEEL is steel containing over 12% chromium which has high corrosion resistance under atmospheric conditions and retains a

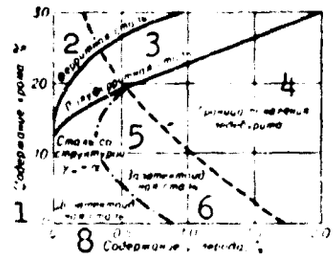

Fig. 1. Schematic division of chrome steels and irons with respect to structural characteristics. 1) Chrome content, %; 2) ferritic steel; 3) semiferritic steel; 4) boundary of ledeburite appearance; 5) steel with structure; 6) hypereutectoid steel; 7) hypoeutectoid steel; 8) carbon content, %.

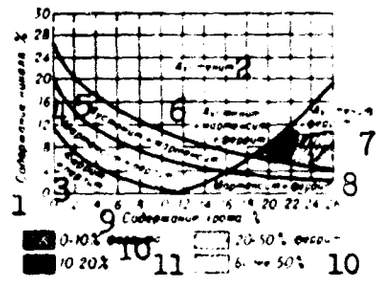

Fig. 2. Structural diagram of chrome-nickel steel with 0.1% C, 0.35% Mn, 0.3% Si. 1) Nickel content, %; 2) austenite; 3) ferrite + pearlite; 4) martensite + pearlite; 5) austenite + martensite; 6) austenite + + martensite + ferrite; 7) austenite + ferrite; 8) martensite + ferrite; 9) chrome content, %; 10) ferrite; 11) more than.

a bright metallic luster, i.e., it has stainless properties. Chromium also improves the corrosion resistance of iron alloys in several other media (primarily oxidative), which is utilized widely in the fabrication of chemical equipment and, in particular, equipment for the production of nitric acid. The good corrosion resistance is explained by the formation on the surface of the steel of a stable oxide film which

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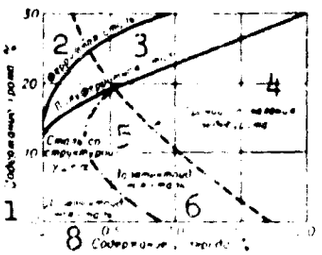

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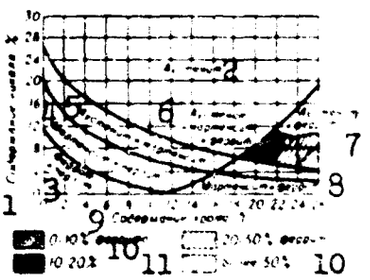

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protects the steel from the activity of the aggressive substances which cause corrosion. Chromium and, to a somewhat lesser degree, nickel, molybdenum, manganese, and silicon facilitate the film formation.

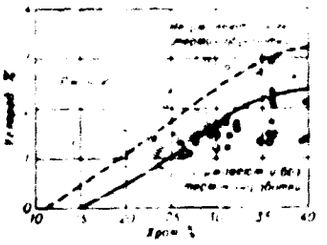

Fig. 3. Effect of carbon and chrome on corrosion resistance of chrome steel in atmospheric conditions. 1) Carbon, %; 2) stainless after heat treatment; 3) rusts; 4) stainless even without heat treatment; 5) chrome, %.

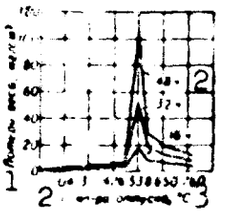

Fig. 4. Effect of tempering temperature on corrosion resistance of 12% stainless chrome steel in 5% nitric acid. 1) Weight loss, mg/cm²; 2) hours; 3) tempering temperature, °C.

In addition to chromium, Ni, Mn, C, Mo, W, Nb and other elements are introduced into steel in order to provide high mechanical properties at high temperatures and special physical properties.

Depending on composition, the stainless steels are divided into chrome, chrome-nickel, chrome-manganese, chrome-manganese-nickel. With respect to structure, the stainless steels are divided into martensitic, semiferritic, ferritic, ferritic-austenitic, austenitic, austenitic-ferritic, ledeburitic (iron). Figures 1 and 2 show the division of the chrome and chrome-nickel steels with respect to structural characteristics.

Martensitic stainless steel contains up to 17% chrome depending on the carbon content and is produced in the following grades: 1Kh13, 2...

13, 4Kh13, Kh18, Kh17N2; several grades of complex-alloyed steel of high heat resistance are also used. The variation of the corrosion resistance under atmospheric conditions with carbon and chrome content in the steel is shown in Fig. 3. In order to avoid reduction of the corrosion resistance, tempering in the temperature range 450-525° is not recommended (Fig. 4). See Martensitic Stainless Steel.

Semiferritic stainless steel has low carbon content (less than 0.08%) with 13-15% chrome (0Kh13) and contains about 0.1% carbon with 15-17% chrome (Kh17, Kh17T). With heat treatment this steel acquires a partial temper, since at high temperatures it consists of δ-ferrite and austenite. The semiferritic stainless steels are used as a corrosion-resistant material (see Ferritic and Semiferritic Stainless Steel).

Ferritic stainless steel contains 18-35% chrome, has low heat-resistance properties, has high tendency to grain growth with heating and welding about 800°. With extended heating or slow cooling from high temperatures (above 800°), this steel becomes coarse grained and brittle at room temperature. In this case the cold brittleness threshold may be above 20°.

Ferritic-austenitic stainless steel usually contains 20-30% chrome and a small amount of the austenite-forming elements: manganese, nickel, nitrogen, carbon. The steel structure contains ferrite and up to 30% austenite. These steels have received restricted application, they are used where somewhat higher strength at high temperature and high resistance in gaseous media containing sulfur (furnace gases) are required. These steels are prone to precipitation of the σ-phase with slow cooling or heating in the range 700-850° and to dispersion hardening at a temperature of about 475°, leading to embrittlement of the steel.

Austenitic stainless steel, which includes the largest number of

grades, has high corrosion resistance in oxidizing media, moderate strength, high plasticity and good weldability (see Austenitic Stainless Steel).

Austenitic-ferritic stainless steel contains 17-25% chrome and the austenite-forming additives nickel or manganese in quantities which form the prescribed two-phase structure with austenite predominant (see Austenitic-Ferritic Stainless Steel).

The resistance of the stainless steels to atmospheric corrosion depends also on the atmospheric conditions themselves. For example, 13% chrome steel has higher corrosion resistance in an uncontaminated atmosphere. In the atmosphere of industrial cities, contaminated with the products of combustion of sulfurous fuel, smoke, soot (see table), the

Effect of Surface Condition on Corrosion Resistance of 13% Chrome Steel

1 Состояние поверхности	Потери в весе в течение 20 суток ($г/м^2$) 2	
	при переменном смачивании и высушивании 3	при обрызгивании соляным раствором 4
5 Прокатанный необработанный материал	194	112.6
6 Обдувка песком	87	90
7 Пассивирование в течение 30 мин. в 10% ном растворе HNO_3	45.6	60.4
8 Шлифование наждачной бумагой № 00	35,7	29

1) Surface condition; 2) weight loss in the course of 20 days (g/m^2); 3) with alternate wetting and drying; 4) with spraying with salt solution; 5) untreated rolled material; 6) sand blasted; 7) passivated for 30 minutes in 10% solution of HNO_3; 8) polished with No. 00 emery cloth.

stainless steels retian their lustrous surface for long periods, but in the course of time they are attacked by pitting corrosion, primarily in the locations of accumulation of deposits of smoke particles. Polishing to provide a smoother surface (periodic cleaning of the surface of parts made from stainless steel) improves the corrosion resistance.

In polishing and treating the surface of parts made from stainless steel, use cannot be made of abrasives or other material containing iron, since adherence of the iron particles leads to the appearance of rust traces on the surface of the stainless steel. Therefore after treatment it is advisable to subject the parts to etching or polishing. Light etching of stainless steel in oxidizing media facilitates the formation on the surface of thin passive films and improvement of the corrosion resistance. Under conditions of marine air which contains very fine particles of chloride and other sales, stainless steel with chrome content of 13% and 17% and the type 18-8 chrome-nickel steel are strongly attacked by pitting corrosion. Under these conditions the type 18-8 chrome-nickel austenitic steel with molybdenum, and particularly with metallic titanium, has the best resistance.

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STAINLESS STEEL FOR CHEMICAL MACHINERY is steel with high corrosion resistance in aggressive media. The corrosion resistance of steel in aggressive media depends on the nature of the base metal, its alloying, the concentration of chemically active reagents in these media, and also on the methods of fabricating the parts of the chemical equipment and machinery. The resistance characteristics of the steel may be affected by the test conditions, the intensity of the stress state, action of aeration, accelerated corrosive action on the interfaces of the liquid and gas phases, etc. Therefore in designing and fabricating chemical equipment it is necessary to take account of these influences, particularly the welding conditions, the corrosion resistance of the weld seams. A wide assortment of stainless steels is used in chemical machinery construction (see table). For the properties and corrosion resistance of these steels see: Austenitic Stainless Steel, Martensitic Stainless Steel, Austenitic-Ferritic Stainless Steel.

In fabricating welded chemical equipment, it is necessary to take account of the tendency of stainless steel to intercrystalline or "pitting" corrosion and turn attention to the corrosion resistance of the weld seams. To avoid intercrystalline destruction of welded equipment in service, for large-scale equipment use is made of chrome-nickel steel with additions of titanium or niobium. However the weld joints acquire the best corrosion resistance in various aggressive media after heat treatment. Therefore, for small-size chemical equipment made from chrome-nickel steel it is advisable after welding to use a quench from 950-1050° with rapid cooling in water or by air blast to obtain the

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Stainless Steels Used in Chemical Machinery Construction

Сталь 1	Марка по ГОСТ 5632—61 2	Назначение 3
4 Полуперлитная 6% хромистая 13%-ная хромистая 7	5 Х5М, Х7СМ, Х6СМ 8 0Х13 (ЭИ496)	6 Детали крекинг-установок, работающие при повыш. темпрах и давлении 9 Детали крекинг-установок и аппаратуры по переработке нефти с высоким содержанием серы
17%-ная хромистая	10 1Х13 (ЖІ), 2Х13 (Ж2), 3Х13 (Ж3), 4Х13 (Ж4) Х17, 0Х17Т	11 Детали аппаратуры, подвергающейся действию слабых агрессивных сред (растворы органич. кислот при комнатной темпре)
	11a	11b Оборудование азотнокислотных з-дов (абсорбционные башни, теплообменники для горячих нитрозных газов и горячей азотной к-ты крепостью не выше 65% при темпре 60—70°, а при кипячении — не выше 56%). Оборудование з-дов пищевой промсти
25%-ная хромистая	11c Х25Т, Х28, Х28АН	11d Детали аппаратуры, работающей в растворах дымящей азотной к-ты, фосфорной к-ты различных концентраций и др. сильно окислит. агрессивных средах
28—34%-ные хромистые чугуны 12	13 Х28, Х34 (ГОСТ 2176—43)	14 Литые детали аппаратуры для перекачки к-т в азотной пром-сти, пром-сти взрывчатых веществ и искусств. удобрений. Детали, стойкие в дымящей азотной к-те и растворах фосфорной и уксусной к-т
Хромоникелевая типа 18-8 15	16 15 0Х18Н10Т (ЭЯ0), Х18Н10Т (ЭИ1Т), Х18Н9Т (ЭИ1Т), 0Х18Н12Б (ЭИ402)	17 Сварной аппаратура, применяемая в производстве азотной к-ты крепостью до 65% при темпре не выше 65° и кипящей кроме того не выше 50% (абсорбционные башни, теплообменники, баки для к-т, трубопроводы). Целесообразная аппаратура для производства различных химич. полуфабрикатов из органич. веществ
Хромоникелевая с молибденом 18	19 0Х21Н6М2Т (ЭИ54), 0Х17Н13М2Т (ЭИ448), 0Х17Н16М3Т (ЭИ580)	20 Детали, работающие в среде повышенной агрессивности, в частности в муравьиной, уксусной, молочной щелочной к-тах (не выше 3%), а также в фосфорной (до 32%), содержащей фтористые соединения, в борной к-те с примесью серной (до 1%), кремнефтористоводородной к-те (до 10%) для темпры не выше 40°
Высоколегированная хромоникелевая с молибденом 21	22 0Х23Н28М2Т (ЭИ628)	23 Детали, работающие в растворах серной к-ты низких концентраций (до 20%) при темпре не выше 60°, в фосфорной к-те, содержащей фтористые соединения, и др. средах высокой агрессивности
Высоколегированная хромоникель-молибденовольфрамовая 24	25 0Х23Н28М3Д3Т (ЭИ943)	26 Детали, работающие в серной к-те всех концентраций при темпре не выше 80°, фосфорной к-те (32—50%), содержащей фтористые соединения, и кремнефтористоводородной к-те повышенных концентраций (до 25%) при темпре не выше 70°
Хромомарганцово-никелевая 27	28 2Х13Н4Г9 (ЭИ100), Х14Г14Н	29 Высокопрочные соединяемые точечной электросваркой элементы конструкций, стойкие против атм. коррозии
То же 30	31 Х14Г14Н3Т (ЭИ711)	32 Сварные конструкции и оборудование, работающие в средах слабой агрессивности—органич. к-тах невысоких концентраций и при умеренных темпрах
	33 Х17Г9АН4 (ЭИ878), Х17АГ14 (ЭП213)	34 Заменитель хромоникелевой стали типа 18-8 в изделиях, работающих в слабоагрессивных средах и в условиях атм. коррозии

1) Steel 2) grade per GOST 5632-61; 3) application; 4) semistainless, 6% chrome; 5) Kh5M, Kh7SM, Kh6SM; 6) parts for cracking plants operating at high temperatures and pressures; 7) -% chrome; 8) OKh13 (EI496); 9) parts for cracking plants and equipment for processing petroleum with high sulfur content; 10) 1Kh13 (Zh1), 2Kh13 (Zh2), 3Kh13 (Zh3), 4Kh13 (Zh4); 11) parts for equipment subjected to the action of weak aggressive media (solutions of organic acids at room temperature); 11a) Kh17, OKh17T; 11b) equipment for nitric acid plants (absorption towers, heat exchangers for hot nitrose gases and hot nitric acid of strength no greater than 65% at temperatures of 60-70°, and with boiling temperatures strength not over 56%). Equipment for foodstuff industry plants; 11c) Kh25T, Kh28, Kh28AN; 11d) parts for equipment operating in solutions of fuming nitric acid, phosphoric acid of various concentrations, and other strongly oxidizing aggressive media; 12) 28-34% chrome irons; 13) Kh28, Kh34 (GOST 2176-43); 14) cast parts for equipment for pumping acids in the nitrogen industry, explosives industry, and artificial fertilizers. Parts which are resistant in fuming nitric acid and solutions of phosphoric and acetic acids; 15) type 18-8 chrome-nickel; 16) OKh18N10T (EYa0), Kh18N10T (EYa1T), Kh18N9T (EYa1T), OKh18N12B (EI402);

17) welded equipment used in the production of nitric acid of strength to 66% at temperatures not over 60° and for boiling acid with strength not over 50% (absorption towers, heat exchangers, acid tanks, piping). Varied equipment for the production of various chemical semimanufactures made from organic materials; 18) chrome-nickel with molybdenum; 19) OKh21N6M2T (EP54), OKh17N13M2T (EI448), OKh17N16M3T (EI580); 20) parts operating in medium of high aggressivity, in particular in formic, acetic, lactic, oxalic acids (not over 5%) and also in phosphoric acid (to 32%) containing fluorine compounds, in boric acid with some sulfuric acid (to 1%), in fluosilicic acid (to 10%) for temperatures not over 40°; 21) highly alloyed chrome-nickel with molybdenum; 22) OKh23N28M2T (EI628); 23) parts operating in solutions of sulfuric acid of low concentrations (to 20%) at temperatures not over 60°, in phosphoric acid containing fluorine compounds, and in other media of high aggressivity; 24) highly alloyed chrome-nickel-molybdenum-copper; 25) OKh23N28M3D3T (EI943); 26) parts operating in sulfuric acid of all concentrations at temperatures not over 80°, phosphoric acid (32-50%) containing fluorine compounds, in fluosilicic acid of high concentration (to 25%) at temperatures not over 70°; 27) chrome-manganese-nickel; 28) 2Kh13N4G9 (EI100), Kh14G14N; 29) high strength structural elements joined by electric spot welding, resistant to atmospheric corrosion; 30) same; 31) Kh14G14N3T (EI711); 32) welded structures and equipment operating in media of weak aggressivity - organic acids of low concentrations and at moderate temperatures; 33) Kh17G9AN4 (EI878), Kh17AG14 (EP213); 34) replacement for the type 18-8 chrome-nickel steel in articles operating in weakly aggressive media and under conditions of atmospheric corrosion.

solid solution; for 17% chrome steel an anneal at 720-760° with air cooling should be used.

In order to economize the expensive stainless steel in equipment operating under pressure, it is advisable to make use of two-layer materials in which only 10% of the metal thickness is stainless steel. At the present time the metallurgical industry has initiated the production of the MSt. 3 two-layer laminated steel (Kh18N9T and 20K) Kh17N13-M2M, and NIIKhIMMASh has developed the technology of welding this steel using electrodes. To economize on nickel it is recommended that the chrome-nickel 1Kh21N5T steel and OKh21N6M2T steel with reduced nickel content be used (see Austenitic-Ferritic Stainless Steel).

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STAINLESS STEEL FOR ELASTIC ELEMENTS – see Heat-Resistant Spring Steel.

STAINLESS STEEL FOR FOODSTUFF INDUSTRY is steel which is nontoxic and corrosion resistant in foodstuff media of the milk, meat, cheese-

TABLE 1

Corrosion Resistance of Stainless Steels for the Foodstuff Industry (data of NIIPRODMASh)

Коррозионно-активные процессы 1	Глубина коррозии (мм/год) 2							
3 Молочная промышленность								
4 (Обработка молочных продуктов при обычной температуре (молоко, сгущенное молоко, сливки, сгущенные сливки, кефир, простокваша, смесь для мороженого плодово-ягодного и молочного))	0,1							
5 Тепловая обработка молочных продуктов с кислотностью от 18° до 120°Т при температуре от 30° до кипения)	0,0005	0,001	0,001					
6 Производство и обработка молочных продуктов, не содержащих поваренной соли (ацидофильное молоко, сметана и творожные массы молочнокислые, ацидофильная паста и др.) с кислотностью от 120° до 400°Т при температуре до 50°	0,0005	0,001	0,001	0,001	0,001	0,001	0,001	0,1
7 Производство сычужных сыров (твердых сыров, содержащих сыворотку, молочных продуктов и полуфабрикатов) с кислотностью от 15° до 120°Т при температуре до 60°	0,0005	0,001	0,001	0,001	0,001	0,001	0,001	0,1
8 Обработка под прессом массы (творожной сыворотки, молочный сахар, сухая сыворотка) с кислотностью от 120° до 250°Т при температуре до 60°	0,0005	0,001	0,001	0,001	0,001	0,001	0,001	0,1
9 Прессование сычужных сыров (твердых, полутвердых сыров, брынзы, мягких сливочных, сыворотки, молочных сгустков) при температуре до 60°	0,0005	0,001	0,001	0,001	0,001	0,001	0,001	0,1
10 Посолочные масла и его обработка (солью, растворами масла поваренной соли и сливочных продуктов, сливочных продуктов с содержанием соли и без соли) при температуре до 50°	0,0005	0,001	0,001	0,001	0,001	0,001	0,001	0,1
11 Хлебопекарная промышленность								
12 Приготовление теста сдобного и разных тестомесильных машин и выпекание при температуре до 250° для изделий по Нейману								
13 Приготовление начинок (кремов) и пропитывание при температуре до 120°								
14 Разбавленные растворы поваренной соли (3%) при температуре от 15 до 25°								
15 Концентрированные растворы поваренной соли (26%) при температуре 15–25°								

*T is the acidity in degrees Traless.

1) Corrosion-active processes; 2) corrosion depth (mm/yr); 3) milk industry; 4) processing of milk products at ordinary temperature (milk, condensed milk, cream, condensed cream, kefir, sour milk, mixture for milk and fruit ice cream); 5) thermal treatment of milk products with acidity from 18° to 120°T* at temperatures from 30° to boiling; 6) production and treatment of milk products which do not contain table salt (acidophilus milk, sour cream, curds and curdled stock, lactic acid leavens, acidophilic paste, etc.) with acidity from 120° to 400°T at temperatures to 50°; 7) production of rennin cheeses (curds, whey, including acidified and purified stock) with acidity from 15° to 120°T at temperatures to 60°; 8) handling cheese stock (curdled whey, whey, milk

sugar, dried whey) with acidity from 200 to 250°T at temperatures to 80°; 9) production of liquid cheeses (pot cheese, skim-milk cheese, brynza, creamery butter, whey, milk spice) at temperatures to 80°; 10) production and processing of butter (pasteurized cream, cow butter, sweet and sour cream, both salted and unsalted) at temperatures to 30°; 11) bakery industry; 12) production of dough (wheat and rye dough, leavened doughs, yeasts and ferments) at temperatures to 32° and acidity to 25° Neumann; 13) production of bakery yeasts (liquid and pressed) at temperatures to 32° and acidity from 15 to 20° Neumann; 14) dilute solutions of table salt (to 3% NaCl) at temperatures from 18 to 25°; 15) concentrated solutions of table salt (20% NaCl) at temperatures of 18-25°; 16) resistant.

making, bread industries, has adequate corrosion resistance in solutions used for washing and disinfecting production equipment - in 0.5% solution of calcined soda, 0.15% solution of caustic soda, bleaching powder solutions containing 200 mg of active chlorine. In fabricating equipment for the foodstuffs industry, use is made of the following grades of stainless steels: 0Kh13 (EI496), 1Kh13 (Zh1), 2Kh13 (Zh2), 3Kh13 (Zh3), 4Kh13 (Zh4), Kh14G14N, Kh14G14N3T, 2Kh13N4G9 (EI100), Kh-17N13M2T, Kh17N4AG9 (EI878), Kh17, Kh17T, Kh17N2 (EI268), 0Kh18N10 (EYa0), Kh18N9 (EYa1), 1Kh18N9T (EYa1T) and Kh27.

With regard to corrosion rate in the media listed, the stainless steels for the foodstuffs industry are divided into the following groups: completely resistant, with corrosion depth no more than 0.0010 mm/yr; satisfactorily resistant - 0.0011-0.003 mm/yr; poor resistance - from 0.003 to 0.005 mm/yr (under the condition of uniformity of the corrosive action). Table 1 gives data on the corrosion resistance of the stainless steels for the foodstuffs industry in various foodstuff media.

With extended contact with disinfectant solutions, the stainless steels for the foodstuffs industry may be attacked by pitting corrosion, therefore after use of disinfectant solutions containing chlorine the parts and equipment should be carefully washed and dryed.

TABLE 2

Corrosion Resistance of Stainless Steels in Foodstuffs Media and in Media Associated with Food Production

Среда 1	2 Температура (°С)	3 1Х18Н9Т	4 Х17	Х18Н9Т, 1Х18Н9Т	5 Х17Н13М2Т	6 7 Х17Н4АГ9
8 Аммиак всех концентраций	10					
9 Аммиак (газ)	Горячий					
Аммиак (раствор)	11					
12 Винегрет						
13 Виноматуральное						
Глицерин 14						
15 Горчица						
16 Гашированная вода						
17 Кровь (из мяса)	холодная					
18 Кетчуп (томатный соус)						
19 Лимонная кислота 5%-ная						
20 Лимонная кислота 5%-ная						
Лимонная кислота 15%-ная	21					
Лимонная кислота 5%-ная	кипящая					
22 Майонез						
23 Масло растительное						
24 Молоко						
25 Молочная кислота 5%-ная						
26 Морская вода						
Мыло 27						
Овощные соки						
28 Пиво 29						
30 Сахар (растворы)						
Сидр 31						
Сода двууглекислая						
32						
233 Сода двууглекислая						
34 Соль поваренная (хлористый натрий) 5%-ная						
35 Уксусная кислота						
36 Уксусная кислота 5%-ная						
20%-ная	21					
30%-ная						
50%-ная	кипящая					
80%-ная						
90%-ная	молодая					
100%-ная						
100%-ная	кипящая					
37 Уксусный антигидрид	кипящий					
38 То же	20					
Формалин 40%						
39 ный						
Фруктовые соки	40					
41 Хлорная вода						
Яичный сидр						
42						

Note: Corrosion resistance is indicated on a 5-number scale: number 1 – material is very resistant, weight loss less than 0.1 g/m^2-hr; number 2 – material is resistant, weight loss from 0.1 to 1 g/m^2-hr; number 3 – material is comparatively resistant, weight loss from 1 to 3 g/m^2-hr; 4 – material has low resistance, weight loss from 3 to 10 g/m^2-hr; number 5 – material is not resistant, weight loss more than 10 g/m^2-hr. *Pitting corrosion in the presence of air.

1) Medium; 2) temperature (°C); 3) 1Kh13, 2Kh13; 4) Kh17; 5) Kh18N9, 1Kh18N9T; 6) Kh17N13M2T; 7) Kh17N4AG9; 8) ammonia of all concentrations; 9) ammonia (gas); 10) hot; 11) ammonia (solution); 12) vinegrette [salad]; 13) natural wine; 14) glycerine; 15) pepper; 16) mustard; 16) carbonated water; 17) blood (from meat); 18) ketchup (tomato sauce); 18) cold; 19) ketchup (tomato sauce); 20) 5% citric acid; 21) boiling; 22) mayonnaise; 23) vegetable butter oil; 24) milk; 25) 5% lactic acid; 26) sea water; 27) soap; 28) vegetable juice; 29) beer; 30) sugar (solutions); 31) cider; 32) soda bicarbonate; 33) 5% soda bicarbonate; 34) table salt (sodium chloride), 5%; 34') 5%; 34") 20%; 35) carbonic acid; 36) acetic acid; 37) acetic anhydride; 38) same; 39) 40% formalin; 40) fruit juices; 41) chlorine water; 42) ethyl alcohol.

Table 2 presents data on the corrosion resistance in various foodstuff media most widely used grades of the stainless steels for the food industry.

For chemical composition and mechanical properties of the foremention steel grades for the food industry see: Stainless Steel, Austenitic Stainless Steel, Austenitic-Ferritic Stainless Steel, Martensitic Stainless Steel, Ferritic and Semiferritic Stainless Steel. In order to save on nickel, it is recommended that primary use be made of the 0Kh-13, Kh17, Kh2; chrome steels, and also the chrome-nickel and chrome-manganese steels with lower nickel content.

F.F. Khimushin

STAINLESS STEEL FOR HEATING ELEMENTS is steel with high ohmic resistance which provides for the release of a large amount of heat with the passage of electrical current.

The alloying elements for this steel are chromium and aluminum. In addition to the high ohmic resistance and slight variation of this resistance at high temperature, this steel has resistance to oxidation in the corresponding media and low temperature coefficient of linear expansion. For the majority of the steels used, the electrical resistivity is in the range of 1.2-1.6 ohms-mm^2/m; the higher the aluminum content, the less the variation of the electrical resistance with tempera-

TABLE 1

Chemical Composition of Stainless Steel for Heating Elements*

Сталь по ГОСТ 1	Заводская марка 2	3 Содержание элементов (%)				
		C	Si	Mn	Cr	Al
Х13Ю4 . 4.	5 ЭИ60	≤0.15	≤1	≤0.7	12–15	3.5–5.5
0Х23Ю5 . .	–	≤0.06	≤0.7	≤0.5	21.5–24.5	4.5–5.5
0Х23Ю5А . .	ЭИ595	≤0.05	≤0.6	≤0.3	21.5–24.5	4.5–5.2
0Х27Ю5А . .	ЭИ626	≤0.05	≤0.6	≤0.3	26–28	5–5.8
1Х17Ю5 . .	ЭИ341	≤0.12	≤1.2	≤0.7	16–19	4.0–6
0Х17Ю5 . .	ЭИ318	≤0.06	≤0.6	≤0.7	16–19	4–6
1Х25Ю5 . .	ЭИ340	≤0.12	≤1.2	≤0.7	23–27	4.5–6.5
0Х25Ю5 . .	ЭИ292	≤0.06	≤0.6	≤0.7	23–27	4.5–6.5

*Composition of first four steels per GOST 9232-59, remainder per GOST 5632-51.

1) Steel per GOST; 2) plant designation; 3) element content (%); 4) Kh-13Yu4; 5) EI.

ture. The chemical composition of the stainless steel for heating element is given in Table 1, and the physical and mechanical properties are given in Tables 2 and 3. Heating of the Kh13Yu4 steel is limited to 1000°, the Okh23Yu5 and OKh23Yu5A steels are resistant to oxidation up

to 1200°.

The OKh25Yu5A steel has the highest resistance to oxidation (to 1300°) and the highest electrical resistivity. Figure 1 shows the vari-

TABLE 2

Physical Properties of Stainless Steel for Heating Elements (wire, strip)*

Сталь 1	2 ρ (ом·мм²/м)	α·10³ / (1/°C)	3 t°пл (°C)
Х13Ю4 4	1,26	0,02	—
0Х23Ю5	1,37	—	—
0Х23Ю5А	1,35	—	—
0Х27Ю5А	1,42	0,06	—
1Х17Ю5	1,2	0,03	1485
1Х25Ю5	1,4	0,06	1493

*Value of ρ, α_ρ and α given at 20°.

1) Steel; 2) ρ (ohm-mm²/mm); 3) $t°_{pl}$ (°C); 4) Kh13Yu4.

TABLE 3

Mechanical Properties of Stainless Steel for Heating Elements

Сталь 1	Состояние 2	3 σ_b (кг/мм²)	δ	ψ	Число гибов на 180° 4
			(%)		
Х13Ю4 5	6 В состоянии поставки	68—74	5—7	50	1—6
	7 После 10 мин. выдержки при 720—740° и охлаждении на воздухе	58	23	48	8—11
1Х25Ю5 8	В состоянии поставки	72	3—8	10—19	0,5
	9 После 10 мин. выдержки при 760° и охлаждении в воде	82	16	52	5

1) Steel; 2) condition; 3) σ_b (kg/mm²); 4) number of 180° bends; 5) Kh-13Yu4; 6) as delivered; 7) after 10 minutes at 720-740° and air cooling; 8) 1Kh25Yu5; 9) after 10 minutes at 760° and water cooling.

ation of the electrical resistivity of the OKh23Yu5A and OKh27Yu5A s steels for single and multiple heatings. The structural changes in the range of temper brittleness at a temperature near 475° has an effect on the values of α and ρ, and are the cause of their large scatter. Long-term soak at temperatures near 450° for 100 hours eliminates this phenomenon, but the heating element becomes brittle.

The effect of tempering temperature for 100 hours on the electrical resistance and the mechanical properties of the OKh27Yu5A steel

which has had a solid-solution quench is shown in Fig. 2. The rate of cooling from high temperatures has an effect on the electrical resistivity and the mechanical properties, with slow cooling they are considerably lower than with rapid cooling. In view of the low high-tem-

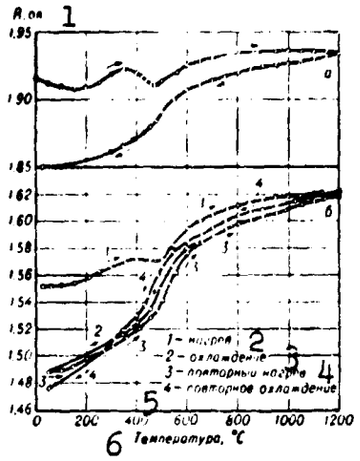


Fig. 1. Variation of electrical resistance with temperature and multiple heatings: a) steel OKh27Yu5A; b) steel OKh23Yu5A (→ heating, ← cooling). 1) R, ohms; 2) heating; 3) cooling; 4) reheating; 5) recooling; 6) temperature, °C.

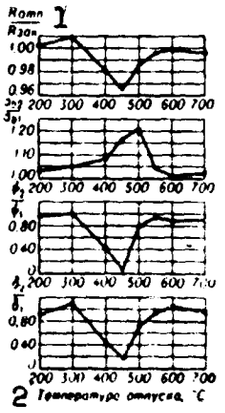


Fig. 2. Effect of tempering temperature for 100 hours on mechanical properties and electrical resistance of quenched OKh27Yu5A steel. 1) R_{otp}/R_{zak}; 2) tempering temperature, °C.

perature strength of the alloys it is necessary to design the furnaces so that the heating elements (spirals) rest on supports and they must be easy to replace. In selecting the steel for specific purposes, it is necessary to take account of the effect of the medium, both gaseous and

solid, i.e., ceramic supports and holders, with which the heating element comes into contact during operation.

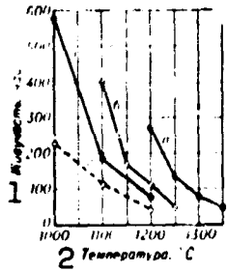


Fig. 3. Variation of life of heating elements with heating temperature in an air atmosphere: a) OKh23Yu5A steel; b) OKh27Yu5A steel; c) nichrome alloy (Kh20N80); d) nichrome alloy (Kh15N60). 1) Life, hours; 2) temperature, °C.

For operation in reducing media where the presence of free carbon is possible and, consequently, carburizing of the heating element is possible, use should be made of a nichrome alloy with lower iron content (Kh15N60 or Kh20N80). In a gaseous medium containing sulfur, the steel with chromium and aluminum operates better. In the case of high mechanical loads at high temperatures, it is better to use alloys based on the γ-solid solution (type 80-20 nichromes). Figure 3 shows the effect of temperature on service life of the OKh23Yu5A and OKh27Yu5A steels.

The Kh13Yu4 steel is used for heating elements of household appliances and rheostats; the 1Kh17Yu5 and OKh17Yu5 steels are used for heating elements of electric furnaces operating at temperatures no higher than 1100γ; the OKh23Yu5, OKh23Yu5A, OKh27Yu5A, 1Kh25Yu5 and OKh25Yu5 steels are used for heating elements of high temperature industrial and laboratory furnaces with operating temperatures up to 1200-1300γ. Steels with the designator "A" have longer service life than the steels without this designation.

References: Kornilov, I.I., Splavy zhelezo-khrom-alyuminiy [Iron-Chromium-Aluminum Alloys], Moscow-Leningrad, 1945 (Zheleznyye splavy

[Iron Alloys], Vol. 1); Semenova, N.V., Zhukov, L.L., Stal' [Steel], 1959, No. 7, page 652; Semenova, N.V., in book: Pretsizionnyye splavy [Precision Alloys], Moscow, 1959 (TsNIlChM. No. 22); Hessenbruch, W., Metalle und Legierungen für hohe Temperaturen [Metals and Alloys for High Temperatures], Vol. 1, Berlin, 1940.

F.F. Khimushin

STAINLESS STEEL FOR MEDICAL USE is steel which is characterized by a high degree of immunity to chemical corrosion which is used to fabricate equipment, appliances, and instruments in medical practice.

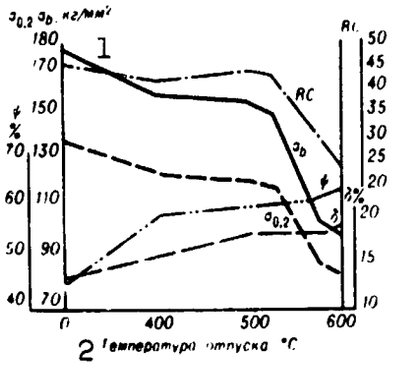


Fig. 1. Variation with tempering temperature of the mechanical properties of 2Kh13 steel, quenched at 1025°. 1) kg/mm^2; 2) tempering temperature, °C.

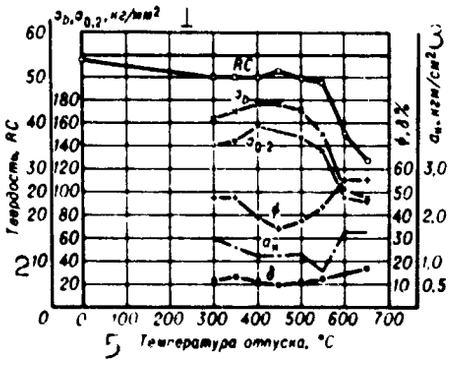


Fig. 2. Variation with tempering temperature of the mechanical properties of 3Kh13 steel, quenched at 1030°. 1) kg/mm^2; 2) hardness, RC; 3) a_n, kgm/cm^2; 4) a_n; 5) tempering temperature, °C.

During use, the medical instruments, and also the majority of medical appliances and equipment are subjected to periodic sterilization, which, as a rule, is a source of the occurrence of corrosion of the base metal of the article. Medical articles are fabricated from the

martensitic class stainless steel (the 2Kh13, 3Kh13, 4Kh13 chrome steel and the EI515 chrome-molybdenum steel), the semiferritic class (Kh17 chrome steel), and the austenitic class (the Kh18N9T, Kh14G14N3T, Kh18-G14AN4 chrome-nickel steels).

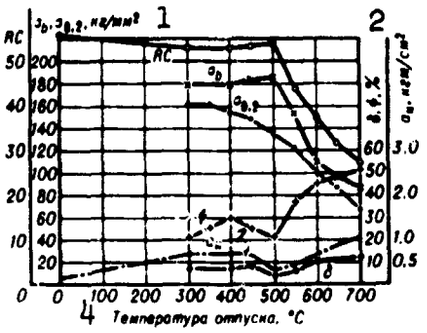


Fig. 3. Variation with tempering temperature of the mechanical properties of 4Kh13 steel, quenched at 1030°. 1) kg/mm^2; 2) a_n, kgm/cm^2; 3) a_n; 4) tempering temperature, °C.

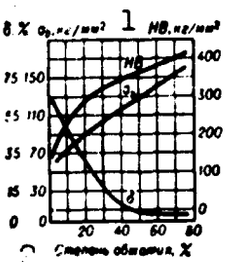


Fig. 4. Variation of mechanical properties of the Kh18N9T steel with degree of reduction. 1) kg/mm^2; 2) degree of reduction, %.

The mechanical properties as a function of the heat treatment are shown in Figs. 1-3.

The 2Kh13, 3Kh13, 4Kh13 chrome stainless steels are used primarily in the heat treated condition (quench temperature above 1000°) with carefully polished surface, which provides high mechanical strength and excellent corrosion resistance. Tempering of the quenched steel at 400-550° is not recommended, since in this case there appears precipitation of the carbides, accompanied by deterioration of the corrosion resistance. Chrome steel has good resistance to the action of the moist atmosphere, tap and sea water, steam, nitric acid, and solutions of salts

and alkalis, blood, alsohol, boric acid, calcium permanganate; it has poor resistance to the action of hydrochloric, hydrofluoric, sulfuric acids, chlorine, bromine, and mercuric chloride solutions (see Martensitic Stainless Steel).

The Kh17 chrome steel is used in the annealed condition and has higher resistance to corrosion than the previously mentioned grades of chrome steel. Heating this steel above 950° and rapid cooling increases the strength, but considerably reduces the plasticity and corrosion resistance. The chrome steels are magnetic in the annealed and quenched conditions (see Ferritic and Semiferritic Stainless Steel).

With respect to corrosion resistance, the Kh18N9T, Kh14G14N3T, Kh18G14AN4 chrome-nickel steels surpass the chrome steels. The mechanical properties of the chrome-nickel steel vary little with heat treatment. This steel has the lowest hardness, very high plasticity, and best corrosion resistance after quenching from high temperatures (1050-1100°). In the quenched condition the steel is nonmagnetic. High hardness and strength are achieved only by means of cold deformation (Fig. 4). The high plasticity of the steel is retained even after considerable strengthening (see Austenitic Stainless Steel).

The EI515 chrome-molybdenum steel has good resistance to the action of atmospheric air, steam and water at variable temperature. Steel quenched from above 1000° has high hardness and wear resistance. Tempering of the quenched steel in the 400-450° range is not recommended, in this case there is observed precipitation of the carbides and reduction of the corrosion resistance.

The basic properties and application of the medical stainless steels are shown in the table.

II-44n3

Basic Properties and Applications of Medical Stainless Steels

Сталь 1	2 Основные свойства	3 Применение
2Х13 (Ж2) 4	5 Удовлетворит. стойкость в слабоагрессивных средах (атмосфера, вода, пар). Наибольшая стойкость достигается после термич. обработки и полировки	6 Детали, не требующие высокой твердости, подвергающиеся ударным нагрузкам и действию слабоагрессивных сред (детали медицинских приборов и аппаратов, винты, штифты, оси)
3Х13 (Ж3) 7	То же 8	9 Детали с повыш. твердостью и упругостью, подвергающиеся действию слабоагрессивных сред (пластинчатые зажимы, щипцы, пинцеты, пластинчатые пружины, пружины)
4Х13 (Ж4) 10	То же 8	Режущий хирургич. инструмент (ножницы, щипцы кусачки, ножи к щипцам, ложки костные, ретракторы) 11
ЭИ515 12	То же 8	Режущий хирургич. инструмент (скальпели, ложки костные, фрезы) 13
Х17 14	Удовлетворит. коррозионная стойкость в средах средней агрессивности. Неудовлетворит. сопротивляемость межкристаллитной коррозии 15	Детали медицинского оборудования, работающие в агрессивных средах и не требующие высокой твердости. Не рекомендуется для изготовления сварных конструкций 16
Х18Н9Т (ЭЯ1Т) 17	Хорошая коррозионная стойкость и очень высокая пластичность. Удовлетворит. сопротивляемость межкристаллитной коррозии 18	Детали, работающие в агрессивных средах и изготовленные методом холодной штамповки, волочения, глубокой вытяжки и сварки (инъекционные иглы, стерилизаторы, автоклавы) 19
Х14Г14Н3Т (ЭИ711) 20	Коррозионная стойкость и пластичность несколько ниже, чем у стали Х18Н9Т. Удовлетворит. сопротивляемость межкристаллитной коррозии 21	Заменитель стали Х18Н9Т для деталей с пониженными требованиями к коррозионной стойкости и пластичности (зеркала) 22
Х18Г14АН4 (ЭИ197) 23	Хорошая коррозионная стойкость и высокая пластичность. Удовлетворит. сопротивляемость межкристаллитной коррозии 24	Заменитель стали Х18Н9Т для деталей, работающих в агрессивных средах и изготовляемых методом холодной штамповки, глубокой вытяжки и сварки (стерилизаторы, автоклавы) 25

1) Steel; 2) basic properties; 3) applications; 4) 2Kh13 (Zh2); 4) satisfactory resistance in weakly aggressive media (water, steam, atmosphere). Greatest resistance is achieved after heat treatment and polishing; 6) parts not requiring high hardness which are subjected to impact loads and the action of weakly aggressive media (parts for medical instruments and equipment, screws, pins, shafts); 7) 3Kh13 (Zh3); 8) same; 9) parts with high hardness and elasticity subjected to the action of weakly aggressive media (elastic clamps, pincers, forcepts, flat springs, hooks); 10) 4Kh13 (Zh4); 11) surgical cutting instruments (scissors, cutting pliers, forcep knives, bone spoons, raspatories); 12) EI515; 13) surgical cutting instruments (scalpels, bone knives, milling cutters); 14) Kh17; 15) satisfactory corrosion resistance in media of moderate aggressiveness. Unsatisfactory resistance to intercrystalline corrosion; 16) parts for medical equipment operating in aggressive media and not requiring high hardness. Not recommended for fabrication of welded structures; 17) Kh18N9T (EyalT); 18) good corrosion resistance and very high plasticity. Satisfactory resistance to intercrystalline corrosion; 19) parts operating in aggressive media and fabricated by cold stamping, deep drawing, wire drawing, and welding (injection needles, sterilizers, autoclaves); 20) Kh14G14N3T (EI711); 21) corrosion resistance and plasticity somewhat lower than for the Kh18N9T steel. Satisfactory resistance to intercrystalline corrosion; 22) replacement for the Kh18N9T steel for parts with lower requirements corrosion resistance and plasticity (mirrors); 23) Kh18G14AN4 (EI1[illegible]; 24) good corrosion resistance and high plasticity. Satisfactory resistance to intercrystalline corrosion; 25) replacement for the Kh18N9T steel for parts operating in aggressive media and fabricated by cold stamping, deep drawing, and welding (sterilizers, autoclaves).

II-44n4

References: Metallovedeniye i termicheskaya obrabotka stali i chuguna [Metal Science and Heat Treatment of Steel and Iron], Handbook, Moscow, 1956; Mashinostroyeniye. Entsiklopedicheskiy spravochnik [Machine Design. Encyclopedic Handbook], Vol. 3, Moscow, 1947; Materialy po obmenu peredovym opytom i nauchn. dostizh. v med. prom-sti [Materials on the Exchange of Advanced Experience and Scientific Achievements in the Medical Industry], 1955, No. 1 (7); 1956, No. 4 (16); Meditsinskaya promyshlennost' SSSR [Medical Industry of the USSR], 1957, No. 9; 1961, No. 12; Shmykov, A.A., Spravochnik termista [Handbook for the Heat-Treating Engineer], 2nd edition, Moscow, 1961.

S.Z. Gol'berg

STAMPED ALUMINUM PIECES – are semifinished pieces obtained by the stamping of aluminum alloys; they have a shape similar to that of the finished pieces. They are used in large-lot production. The size and the shape of the stamped pieces are limited by the potentialities of the forging equipment. According to the TU, the stamped pieces are divided into two classes: small and medium pieces with a weight up to 30 kg, and large pieces with a weight more than 30 kg. The maximum size of the stamped pieces is 2000 x 1500 mm. The maximum weight of the stamped pieces depends on the casting properties of the alloy (allowing large-diameter castings to be obtained) and on the preliminary treatment of the blank before stamping (pressed, forged, or cast blanks). The following types of blanks are used for stamping: machined castings molded by the semicontinuous method; pressed rods; and pieces obtained by forging the casting or the pressed rod. The maximum weight of a stamping piece obtained from a cast blank or a forged casting is greater than that of a piece obtained from a pressed blank. Flaws (scabs, scratches, or clefts) deteriorating the material properties along the thickness may occur on surfaces where the metal flowed with a high rate. These flaws may be determined by the UZ flaw detection. The stamped pieces are delivered in a hardened or aged state and also in a tempered state. When the blanks are delivered in a hardened or aged state, the thickness (the minimum value of three measurements) of the parts must not exceed 125 mm for alloys of the V95 type, 150 mm for alloys of the Duralmin type, and 200 mm for alloys of the AK4-1 type. These dimensions guarantee a high-grade hardening. In the case of tempered

blanks, it must be taken into account that the size (the length and the width is diminished after hardening of the stamped piece. The degree of the shrinkage depends on the composition of the alloy and the shape of the blank and may reach up to 1-2 mm per running meter. The finishing of joints and fits must be carried out after the heat treatment of the piece. The allowances and tolerances of stamped aluminum pieces are quoted in the reference.

References: RTM 37-61. Zagotovki shtampovannyye iz tsvetnykh splavov. Dopuski pripuski [Blanks Stamped from Nonferrous Alloys. Tolerances and Allowances], Moscow, 1962.

Ye.D. Zakharov

Manuscript Page No.

[Transliterated Symbols]

3811 УЗ = UZ = ul'trazvukovyy = ultrasonic

3812 РТМ = RTM = rukovodyashchiye tekhnicheskiye materialy = important technical materials

STAMPED AND FORGED MAGNESIUM PIECES – are manufactured from the MA1, MA2, MA3, and MA5 (AMTU 226-45), VM65-1 (AMTU 425-57) and other alloys according to special technical specifications.

Free forging and hammer stamping is recommended only for the more plastic alloys (MA1, MA2, MA8, VM65-1, MA13). Stamping by means of a hydraulic press is more preferable; all magnesium alloys are treatable by this method. Forged pieces with a weight of up to 400-500 kg are manufactured by free forging, those with a weight of up to 250-300 kg by stamping. Exemplary technological conditions for stamping of alloys (a pressed rod being the blank) are given in the Table.

1 Сплав	Температурный интервал штамповки (°С) 2		Степень деформации за нагрев при осадке (%) 5	
	под молотом 3	под прессом 4	под молотом 3	под прессом 4
6 МА1, МА2, МА8 ..	450–350	420–300	50	70
МА2-1	430–350	400–300	45	65
МА3, МА5, МА10	400–300	380–280	35	60
ВМ65-1	410–340	400–300	50	70
МА13	480–400	450–380	50	70
ВМ17	400–350	420–330	45	65
7 ВМД1	480–400	450–380	40	60

1) Alloy; 2) temperature interval for stamping (°C); 3) on drop forging; 4) on pressing; 5) degree of deformation after heating once at a shrinkage of (%); 6) AM..; 7) VM..; 8) VMD.. .

The allowances for machining and the tolerable deviations in the dimensions of the forged and stamped pieces are fixed by special technological conditions. The surface of the forged and stamped piece oxidizes; preservation and packing must be carried out according to AMTU 420-57. Regarding the use of stamped and forged magnesium pieces see

III-10sh1

Magnesium alloys.

A.A. Kazakov

STAMPED MOLYBDENUM PIECES — see Forged and stamped molybdenum pieces.

STAMPED MOLYBDENUM PIECES (stamped from a sheet). Sheet-metal stamping is one of the principal methods used to obtain objects from molybdenum and its alloys. Molybdenum is poorly stampable in cold state. This is caused by the small interval between σ_b and $\sigma_{0.2}$ ($\sigma_{0.2}/\sigma_b \simeq$ $\simeq$ 0.8-0.9) and the low values of δ_{10} (18-22%), δ uniform ($\simeq$9-10%) and ψ (20-35%).

The resistance to deformation is lowered, and the material's ability to be stamped (the ability to be drawn, flanged, bent, pressed, etc.) is increased when heated to 350-450°. The effect of the temperature on the parameters of the molybdenum to be stamped such as maximum drawing coefficient $K_{vyt.pr}$, maximum flanging coefficient $K_{otb.pr}$, maximum coefficient of plane stamping $K_{vyd.pr}$ (plosk.), and the minimum bending radius r_{min} are shown in the figure. At the quoted temperatures, the ability of molybdenum sheets to be stamped is similar to that of aluminum alloys and carbon steels in a cold state.

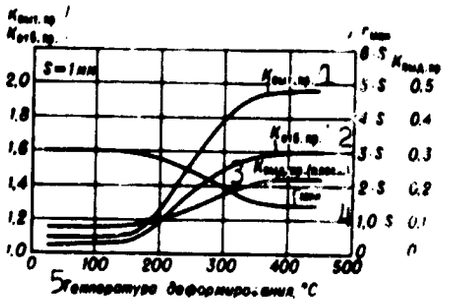
The following must be taken into account when stamping molybdenum sheets:

1. Molybdenum is more quickly heated and colled than steel, owing to its high heat conductivity and low specific heat.

2. The ampability of the material to be stamped increases with increasing deformation rate.

3. Special solid-film lubricants with a sufficient heat-resistance (colloidal aqueous graphite preparation according to GOST 3645-50) and also special materials for the manufacture of stamps (aluminum bronze, graphitized steel, hard cermets, heat-resistant steel EI736) must be

used to guard against the adhesion of particles to the stamped material on the stamps, the formation of ribs and notches on the stamped pieces, and also to provide antifrictional conditions during complex of stamping operations (drawing, flanging, etc.).



Effect of the deformation temperature on the ability of Molybdenum to be stamped. 1) $K_{vyt.pr.}$; 2) $K_{oth.pr.}$; 3) $K_{vyd.pr.}$ (plosk.); 4) r_{min}; 5) deformation temperature, °C.

Sheet molybdenum with a deformed structure possesses the best stamping properties after removal of the stress. Such a material has a fine-fibriform structure and may be better stamped than totally recrystallized coarse-grained molybdenum. The annealing temperature recommended to relieve the stress in molybdenum and sheet alloys is 1000-1100°. Not only the rolled sheets destined for stamping, but also the finished stamped pieces must be annealed at the mentioned temperatures because residual stress may cause cracking. The production of stamped molybdenum parts offers no difficulty and may be carried out by the usual equipment in stamping shops when the above mentioned peculiarities are taken into account.

Yu.P. Davydov and G.V. Pokrovs[illegible]

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[Transliterated Symbols]

3816 выт.пр. = vyt.pr. = vytyazhka predel'naya = maximum drawing

3816 отб.пр. = otb.pr. = otbortovka predel'naya = maximum flanging

3816 выд.пр. = vyd.pr. (plost.) = vydavleniye predel'noye (ploskoye) = maximum (plane) stamping

3816 мин = min = minimum = minimum

STAPLE POLYAMIDE FIBER – chemical fiber from polyamides in the form of thin untwisted strands of fibers cut into stacks (staples) of a specified length. It is produced in the cut form and in the form of clusters.

Staple polyamide fiber is distinguished by high wear resistance (higher than polyester, viscose and polyacrylonitrilic fibers by a factor of 4, 10 and 70, respectively), to multiple deformations (by a factor of 50 higher than the resistance of polyester fiber), dimensional stability (as a result of reversibility of elongation after the load is removed, and of low shrinkage), ability to take a variety of dyes. The differences and similarities between staple polymer fibers capron, nylon 66 and enant are seen by comparison of their properties. Thus, the specific weight of capron is 1.14 (1.14, 1.14) (numbers in parentheses pertain to nylon 66 and enant, respectively). The moisture content under standard conditions is 3.5-4% (4.0-4.5, 2.2-2.8), at 95% relative humidity it is 7.0-8.0 (6.0-8.0, 2.6-2.8). Softening temperature 196° (225, 205); melting temperature 216° (250, 225). The specific heat of caprone is 0.3-0.4 cal/g·°C (0.3-0.4, 0.4-0.5); the thermal conductivity varies from $5.4 \cdot 10^{-4}$ to $2.0 \cdot 10^{-4}$ cal/cm·sec·°C ($2.2 \cdot 10^{-4}$; –). Staple polyamide fibers (in comparison with polyester and polyacrylonitrilic fibers) are characterized by lower resistance to heat and light (particularly capron); are resistant to the action of alkalis, oxidizers, reducers, organic acids (with the exception of concentrated formic acid) and micro-organisms. Capron and nylon 66 are soluble in mineral acids. The rupture length of capron is 36-53 km (36-75, 39-45), strength losses

in the wet state 15-20% (12-15, 2-5); in the loop 8-15% (7-18, 10-13). Ultimate tensile strength 36-53 kg/mm^2 (47-74, 43-50).

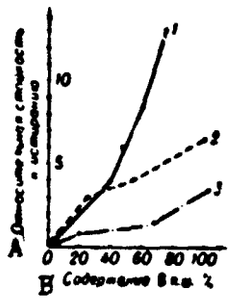
Comparative Properties of Certain Profiled and Ordinary Fibers

Вид и форма волокна 1	Уд. вес 2	Уд. объем (см³/г) 3	Разрывная длина (км) 4	Удлинение при разрыве (%) 5	Потеря прочности в петле (%) 6	Число изгибов до разрушения 7	Число истираний до разрушения 8	Жесткость (кг) 9
10								
Моноволокно 11								
обычное (круглое)	1.14	0.877	50	30	—	2000	670	1.06
профилированное, звезда (10 зубцов)	1.14	0.877	50	30	—	1850	350	1.07
12								
пустотелое	1.025—1.070	0.935—0.976	—	—	—	6000	1250	1.91—1.69
13								
Филаментный шелк 14								
обычное (круглое)	—	—	40	30	—	410	—	—
профилированное, звезда (10 зубцов)	—	—	40	30	—	220	—	—
Штапельное волокно 15								
обычное (круглое)	—	—	35	90	5	—		—
профилированное пустотелое 16	—	—	30	85	15	—	—	

1) Kind and shape of fiber; 2) specific weight; 3) specific volume (cm3/g); 4) rupture length (km); 5) rupture elongation (%); 6) strength losses in the loop (%); 7) number of flexures to failure; 8) number of rubbings to failure; 9) rigidity (kg); 10) monofiber; 11) ordinary (round); 12) profiled, star (10 teeth); 13) hollow; 14) filament rayon; 15) staple fiber; 16) profiled hollow.

Rupture elongation in the dry state 40-60% (16-42, 50-65), in the wet state 50-65% (18-45, 51-54). Modulus of elasticity from 175 to 300 kg/mm^2 (150-400, 200-250). The degree of restoration one minute after removal of load 88.1% (—, 89.0), after 30 minutes it increases to 94.5% (—, 96.0). For other properties see Capron, Nylon-66, Enant. Staple polyamide fibers have a round cross section and smooth surface, which make its processing difficult and which is conducive to the creeping out of fibers at the surface of products. Staple polyamide fibers are used in the pure form but more frequently mixed (15-25%) with viscose staple fibers, wool, cotton (to increase their service life). The effect of addition of staple polyamide fibers to other fibers on the wear resistance is seen from the figure. Staple polyamine fibers are used for the production of filters, cloth, dyeing and washing sacks, packing

and thermal insulation materials, felt for paper finishing machines and also (matted fiber) for consumer goods.



Dependence of the relative wear resistance of various yarns on their content of staple polyamide fiber. 1) Mixture of viscose with polyamide staple fibers; 2) mixture of wool and polyamide staple fibers; 3) mixture of cotton with polyamide staple fiber. A) Relative wear resistance; B) content of polyamide staple fibers, %.

References: Klare, G., Khimiya i tekhnologiya poliamidnykh volokon [The Chemistry and Technology of Polyamide Fibers], translated from German, Moscow, 1956; Hoppf, G., Müller, A. and Wenger, F., Poliamidy [Polyamides], translated from German, Moscow, 1958; Moncruiff, R.W., Chemical Fibers, translated from English, Moscow, 1961; Fibers from Synthetic Polymers, edited by R. Hill, translated from English, Moscow, 1957.

E.M. Ayzenshteyn

STAPLE VISCOSE FIBER – artificial cellulose hydrate fiber from natural cellulose. It is produced in the form of a cluster of known length or in the form of a bunch which is subsequently cut into clusters. Standard, and higher-strength, lustrous, mat and dyed in mass staple viscose fibers are produced. The number of an elementary standard fiber is 1500-600, of higher strength fiber it is 3000-7000 (the numbers in parentheses for other indicators pertain to the higher-strength fiber), specific weight 1.5 (1.53), moisture absorption capacity under standard conditions 13.5% (13.4), at 95% relative humidity, correspondingly 27.0% (33.0). For other physicochemical indicators see Viscose Rayon.

The rupture length of standard staple viscose fiber comprises 15.2-20 km (22.5-32.0); wet strength loss 50-60% (35.0-45.0), in the loop 50-60% (50-70). The ultimate tensile strength for standard fiber comprises 23.1-30.4 kg/mm^2 (34.2-42.0), elongation in the dry state 20.0-25.7% (12-20.5), in the wet state 20.3-29.1% (18.3-30.5). The degree of fiber restoration one minute after compressive load was removed is 38.8% (51), after 30 minutes it is, respectively, 62.5% (72.5). The longevity (number of double flexures to rupture at a load of 10 kg/mm^2) of ordinary staple viscose fiber comprises [illegible], the wear resistance, respectively, [illegible] (45.7).

A higher-strength staple viscose fiber is a fiber such as teramomen, which is distinguished by a smaller, in comparison with other fibers, elongation and swelling in water; its initial modulus exceeds by magnitude the initial modulus of viscose rayon; this fiber is deformed less

under the action of moderate loads, which arise on its processing. Staple viscose fiber in the pure form, and also mixed with cotton or wool is used extensively in the textile industry and for engineering purposes as a heat-insulating material. To reduce the wrinkling of staple viscose fiber articles they are treated by melamineformaldehide resins, products of condensation polymerization of polysaccharides and ketones with formaldehides and other compounds.

References: Dem'ina, N.V. [et al.], "KhV," No. 5, page 40, 1960; Bandel', V, Zametki o novykh metodakh formirovaniya viskoznykh volokon. Polucheniye volokon s novymi svoystvami [Remarks on New Methods of Viscose Fibers Spinning. Obtaining Fibers with New Properties]. "KhiTP," No. 7, page 56, 1961.

G.G. Finger

STATIC ENDURANCE – resistance to failure under repeated loads of moderate frequency and comparatively high level. Many structures loaded by static loads are periodically subjected to overloads which determine the service life of the structure. An aircraft, whose static load is determined by its weight, is subject to periodic overloads from wind gusts, on maneuvering, landing, takeoff, etc.; for a ship these repeated overloads are produced by wave impacts on the hull; for an automotive vehicle these are due to traveling on rough roads, etc. Static endurance tests can be performed on standard general-purpose failure-testing machines, equipped with electromagnetic devices which make it possible to automatically load and unload the specimen in accordance with a preselected loading regime, or on fatigue testing machines equipped with reducing devices which make it possible to apply loads at moderate frequencies (10-20 cycles/min). Static ensurance is most frequently evaluated by testing of notched specimens by repeated loads which are applied with a frequency of 5-20 cycles/min. The stress level is selected in the interval of 0.3-0.7 of the ultimate strength of a smooth (sometimes notched) specimen. Under these stresses the static endurance curve usually embraces an interval up to $5 \cdot 10^4$-$5 \cdot 10^5$ cycles along the abscissa axis. At high stresses (0.7-0.8 σ_b) failure in static endurance tests can ensue after 1000-2000 loading cycles. Here it is possible to see in the fracture, as in the case of fatigue tests with a frequency of 25-50 cps, a light matted zone of gradual failure in repeated loads and a darker zone of the additional fracture, which is similar in appearance with brittle fracture-due to a static

load (Fig. 1). Most extensively used tests are those using pulsating or asymmetric (r = 0.1) tension loading of flat specimens with a hole (the ratio of the width of the specimen to the diameter of the hole b/d = 0.5, α_k = 2.4). At each stress level 5-10 specimens are tested to failure. The test results are depicted in the form of static endurance curves in the (σ_{max}, N) (Fig. 2a) or (K, N) (Fig. 2b) coordinates, where K = σ_{max}/σ_b (or σ_{max}/σ_{bn}) is an indicator characterizing the possibility of using the ultimate strength of the material in structures subjected

Fig. 1. Fracture of a notched specimen from 30 KhGSNA steel (σ_b = 90 kg/mm^2) which has failed in reversed (r = 0.1, n = 8 cycles/min) flexure after 1800 cycles with σ_{max} = 50 kg/mm^2.

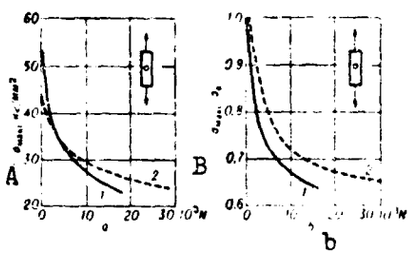


Fig. 2. Static endurance in asymmetric (r = 0.1, n = 8 cycles/min) tension loading of aluminum alloys (3 mm thick sheet). 1) V95AT (σ_b = 53 kg/mm^2); 2) D16AT (σ_b = 46 kg/mm^2). A) σ_{max}, kg/mm^2; B) σ_{max}/σ_b.

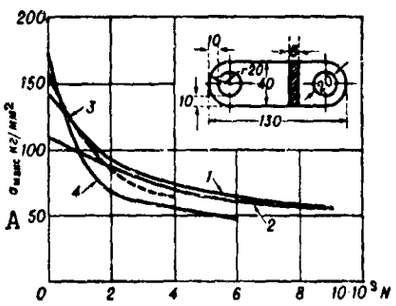


Fig. 3. Static endurance in asymmetric (r = 0.1, n = 5 cycles/min) tension loading of steel eye-bars. 1) 30KhGSNA (σ_b = 157 kg/mm^2); 2) 30KhGSA (σ_b = 125 kg/mm^2); 3) 30KhGSNA (σ_b = 172 kg/mm^2); 4) EI643 (σ_b = 215 kg/mm^2). A) σ_{max}, kg/mm^2.

to repeated static loads. Frequently materials with a higher ultimate strength exhibit lower static endurance in comparison with less strong materials. The V95 aluminum alloy which has a higher static strength and at the beginning has a higher resistance to repeated loads, starting with some instant (on Figs. 2a, and b – after 4000 cycles), loses its advantages and becomes inferior, by its static endurance, to the D16 alloy. The same can be observed when comparing static endurance

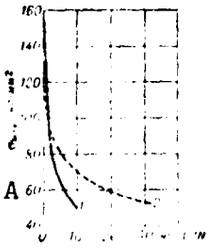


Fig. 4. Static endurance in repeated asymmetric (r = 0.1, n = 8 cycles/min) tension loading of M8 × 1.25 bolts from the VT6 titanium alloy. 1) Quenched from 950° and aged at 480° (σ_b = 125 kg/mm^2); 2) annealed at 800° (σ_b = 97 kg/mm^2). A) σ_{max}, kg/mm^2.

curves of high-strength and medium-strength steel, (Fig. 3), titanium alloys of varying strength (Fig. 4). Thus, tension elements with stress raisers used in designs subjected to repeated stresses are frequently more desirably made from materials with a somewhat lower static strength, for example, from the D16 rather than from the V95 alloy, from 30KhGSNA steel (σ_b = 160-180 kg/mm^2) and not EI643 (σ_b = 190-210 kg/mm^2), etc. In tension elements in the absence of stress concentrations as well as in elements subjected to compression and shear, the advantage of high strength is retained also under repeated static loads. The relative position of static endurance curves of various materials frequently does not conform not only to the relationship between their endurarce limits, but to the position of the left-hand upper sections of the fatigue curves. This nonconformance is due to the time dependence of strength under repeated loads, that is, it is due to a relation-

ship which for a long time has not been taken into consideration, since it was assumed on the basis of tests at comparatively high frequencies

TABLE 1

Effect of the Loading Frequency on the Endurance of Smooth Specimens in Symmetric Flexure

Материал 1	Амплитуда напряжения σ_a (кг/мм²) 2	Частота нагружений n (цикл/мин) 3	Число циклов до разрушения (N) 4
Алюминиевый сплав Д16 (σ_b=58 кг/мм²) 5	41	7.5	2320
		130	2980
		2250	3400
		4750	3420
	30	7.5	15755
		130	20726
		2250	40100
		4750	40570
	23.2	7.5	83170
		130	105538
		2250	445500
		4750	432470
Алюминиевый сплав В95 (σ_b=64 кг/мм²) 6	43.6	7.5	2102
		130	2357
		4750	3040
	31.1	7.5	14988
		130	17614
		4750	26220
	24.9	7.5	69432
		130	77200
		4750	172320
Сталь 30ХГСА (σ_b=172 кг/мм²) 7		7.5	8870
		130	9740
		4750	14150
	90	7.5	25200
		130	31620
		4750	55070
	81	7.5	67103
		130	79800
		4750	206340
Сталь 30ХГСА (σ_b=120 кг/мм²) 8	85.4	7.5	4322
		130	5070
		4750	5770
	73.2	7.5	13070
		130	16020
		4750	19000
	61	7.5	31288
		130	40470
		4750	54850

1) Material; 2) stress amplitude σ_a (kg/mm^2); 2) loading frequency n (cycles/min); number of cycles to failure (N); 5) D16 aluminum alloy (σ_b = 58 kg/mm^2); 6) V95 elumiNum alloy (σ_b = 64 kg/mm^2); 7) 30KhGSNA steel (σ_b = 172 kg/mm^2); 8) 30 KhGSA steel (σ_b = 120 kg/mm^2).

(from 10 to 1000 cps) that the strength in reversed repeated loads is independent (or weakly dependent) on the frequency and, consequently,

on the time during which the load acts (see Fatigue). Investigations showed that when using frequencies lower by an order of 2-3 it is no longer possible to disregard the time dependence of strength in repeated loads. The time dependence of the static endurance manifests itself differently for different materials (Table 1). It manifests itself the more strongly the higher the stress concentration, the higher the test temperature and the higher the level of prevailing stresses. According to certain data, a straight-line depence prevails between the number of cycles to failure N and the frequency n, plotted in the (lgN, lgn) coordinates.

The static endurance of a given material depends on its structure, the process by which the semifinished products are manufactured and the surface finish. The coarser the grain, the lower the static endurance (Fig. 5), although the static strength does not change much here. Steel in the state of temper brittleness has a lower static endurance than the same steel which was rapidly cooled after high tempering (Fig. 6). The ultimate limits being equal, high-strength steel with a lower carbon content will have an advantage (Table 2). Pressed semifinished products from aluminum alloys which exhibit the press-effect phenomenon (see Press Effect of Aluminum Alloys), have a higher static endurance

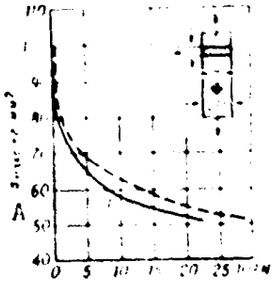


Fig. 5. Static endurance (r = 0.1, n = 8 cycles/min) of the VT5 titanium alloy worked to produce coarse (1) and fine (2) grain. (The ratio of the average grain diameters is 3:1, the ultimate strengths, respectively, are 92 and 95 kg/mm^2). A) σ_{max}, kg/mm$_2$.

than rolled articles. Surface workhardening improves the static endurance of steels and nonferrous alloys (Figs. 7 and 8). A soft cladding

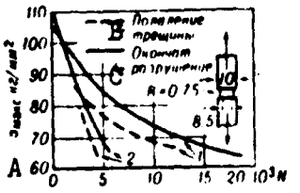


Fig. 6. Static endurance in asymmetric (r = 0.1, n = 8 cycles/min) tension loading of manganese steel after rapid (σ_b = 80 kg/mm^2) and slow (σ_b = 83 kg/mm^2) cooling from the tempering temperature. 1) Cooling in water; 2) furnace cooling. A) σ_{max}, kg/mm^2; B) appearance of a crack; C) final failure.

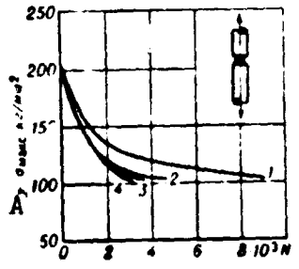


Fig. 7. Effect of the surface finish on the static endurance in tension (r = 0.1, n = 8 cycles/min) of 30KhGSNA steel (σ_b = 160 kg/mm^2). 1) Shot peening; 2) sand blasting; 3) polishing; 4) decarburization. A) σ_{max}, kg/mm^2.

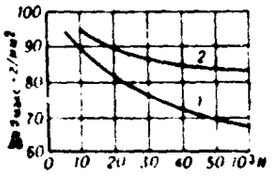


Fig. 8. Effect of the surface finish on the static endurance in tension (r = 0.1, n = 10 cycles/min) of smooth specimens of the VT3-1 titanium alloy. 1) Starting state; 2) shot peening. A) σ_{max}, kg/mm^2.

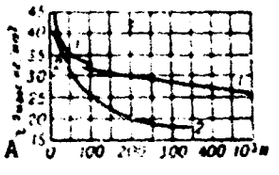


Fig. 9. Static endurance in tension (n = 20 cycles/min, σ_{min} = 2 kg/mm^2) of sheets from the D16AT alloy. 1) Sheet with the coating layer removed; 2) sheet with the coating layer. A) σ_{max}, kg/mm^2.

layer of pure aluminum reduces the static endurance of aluminum sheets (Fig. 9), thick (10-20 microns) electric deposition films also have a negative effect (Fig. 10). Zinc coating reduces the static endurance of structural steel; cadmium and phosphate coatings practically do not effect it (Table 3). Surface flaws reduce the static endurance of high-strength materials. Hence special requirements to the surface finish,

TABLE 2

Effect of the Carbon Content of 30KhGSNA Steel on the Service Life Under Repeated Loads*

C (%)	σ_b (kg/mm^2)	$\sigma_{макс}$ (kg/mm^2)	Число циклов до разрушения (N)
0,29	175	124	5000
0,32	174	123	3500
0,34	173	121	2350

* Flat specimens with a hole with b/d = 5 were tested.

1) (kg/mm^2); 2) σ_{max} (kg/mm^2); 3) number of cycles to failure (N).

such as absence of notches, scratches, dents, etc., are presented to these materials in structures subjected to repeated static loads in service.

TABLE 3

Effect of Electroplating and Phosphate Coating on the Static Endurance in Tension of Notched (α_k = 2.4) Specimens of Isothermally Quenched 30KhGSNA Steel (σ_b = 160 kg/mm^2)*

$\sigma_{макс}$ (kg/mm^2)	1	2	3	4	5	6
103	3671	3224	2940	2687	3256	3528
124	1764	1503	1462			
145	1171	1114	1138	1000	1122	1100

* Average of testing 3-4 specimens.

1) σ_{max} (kg/mm^2); 2) number of cycles

to failure N after:; 3) finish turning; 4) cyanide-zinc method; 5) cyanide-zinc method and tempering at 200°; 6) acid [sulfate] zinc plating; 7) cadmium plating; 8) cold phosphate plating.

The presence of stress raisers perceptibly reduces the static endurance, it is here found that high-strength materials are particularly sensitive to notching (Fig. 11). For this reason the shape of a struc-

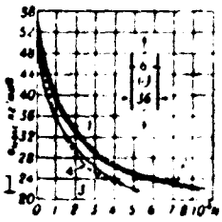


Fig. 10. Static endurance in alternating (r = 0, n = 10 cycles/min) tension of the V95 alloy with various thicknesses of the electroplated film (2 mm thick sheet). 1) Polished specimens; 2) specimens with a 5-7 micron film; 3) specimens with a 10-12 micron film; 4) specimens with an 18-20 microns film. A) σ_{max}, kg/mm^2.

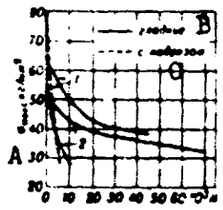


Fig. 11. Notch sensitivity in asymmetric (r = 0.1, n = 10 cycles/min) tension loading of round specimens without and with notches (α_k = 2.2). 1) The V95T alloy; 2) the D16T alloy. A) σ_{max}, kg/mm^2; B) smooth; C) notched.

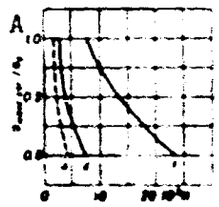


Fig. 12. Static endurance in multiple flexure (r = 0.1, n = 5 cycles/min) of flat specimens from 30KhGSNA steel (σ_b = 150 kg/mm^2). 1) Welded specimens with the reinforcement removed. 2) welded specimens with reinforcement; 3) notched specimens (α_k = 2.3) on the tensioned side. A) $\sigma_{max\ izg}/\sigma_b$.

tural element frequently predetermines the feasibility of using materials with a high ultimate strength. In welded designs the stresses are

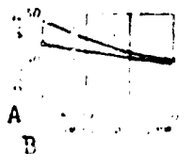


Fig. 13. Effect of the absolute size of geometrically similar notched (α_k = 2.2) specimens on the strength when N = 2400 cycles in asymmetric (r = 0.1, n = 5 cycles/min) tension loading of pressed alloys D16T (σ_b = 54 kg/mm^2) and V95T (σ_b = 64 kg/mm^2). 1) The D16T alloy; 2) the V95T alloy. A) σ_{max}, kg/mm^2; B) specimen diameter, mm.

concentrated at the welded seam reinforcement, removal of the reinforcement improves the static endurance (Fig. 12). Static endurance depends on the dimensions of the specimen or component, decreasing as the latter increase. The Scale Effect becomes amplified as the ultimate strength of the material increases (Fig. 13). As all the other factors, the scale has a substantially greater effect on the service life than

Fig. 14. Comparison of curves of static endurance (1) and creep strength (2) in tension loading of specimens with a hole (α_k = 2.4) from the D16AT alloy (sheet thickness 3 mm, σ_b = 46 kg/mm^2). a) Test temperature 125°; b) test temperature 200°. A) σ_{max}, kg/mm^2; B) time in hours.

on the strength in static endurance tests. A reduction, for example, of the diameter of a smooth specimen from the V95 alloy from 25 to 8 mm increases the strength by 15-20% and the service life by 200-300%. As the temperature becomes higher the static endurance decreases; however, to a lesser extent that the strength under a continuously applied load, so that, starting with a certain temperature, which is different for dif-

ferent materials, the creep strength can become lower than the strength under repeated loads (Fig. 14a and b). The relationship between static

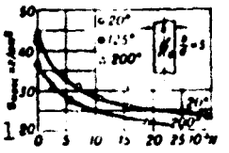


Fig. 15. Effect of the test temperature on the static endurance in asymmetric (r = 0.1, n = 10 cycles/min) tension loading of the V95AT alloy (sheet thickness 3 mm, σ_b = 53 kg/mm^2). 1) σ_{max}, kg/mm^2.

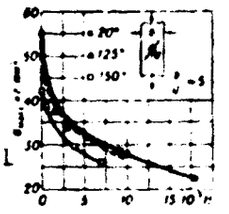


Fig. 16. Effect of the test temperature on the static endurance in asymmetric (r = 0.1, n = 10 cycles/min) tension loading of the D16AT alloy (sheet thickness 3 mm, σ_b = 46 kg/mm^2). 1) σ_{max}, kg/mm^2.

endurance and the static creep strength as a function of temperature or time is determined by both the loading conditions (presence of stress raisers, kind of stressed state, degree of asymmetry of the cycle, and the properties of the material. The static endurance of the D16 alloy

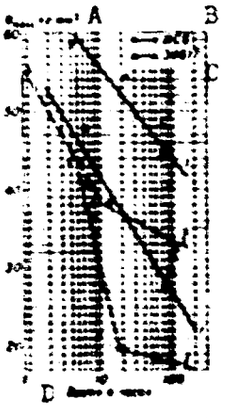


Fig. 17. Static endurance in asymmetric (r = 0.1, n = 10 cycles/min) tension at 850° of smooth (1) and notched (2) specimens of ZhS6 and EI617 heat-resistant alloys. A) σ_{max}, kg/mm^2; B) ZhS6; C) EI617; D) time in hours.

in the presence of stress concentrations changes less upon an increase in the temperature than that of V95 (Figs. 15 and 16). The static endurance of heat-resistant alloys at high temperatures can drop appreciably in the presence of a notch (Fig. 17). The static endurance of butt-

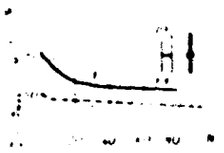


Fig. 18. Static endurance in asymmetric (r = 0.1, n = 8 cycles/min) tension of welded specimens from the VT5-1 titanium alloy (1.2 mm thick sheet). 1) Test temperature of 20°; 2) test temperature of 350°. A) σ_{max}, kg/mm^2.

Fig. 19. Static endurance in asymmetric (r = 0.1, n = 8 cycles/min) tension of M12 × 1.5 bolts from the VT5 titanium alloy. 1) Test temperature of 20°; 2) test temperature of 350°. A) σ_{max}, kg/mm^2.

welded titanium alloys OT4 and VT5-1 in tension is reduced, when the temperature is increased to 350°, by approximately 20% (Fig. 18); bolts from titanium alloys exhibit an appreciably greater (by 35-45%) strength reduction under the same conditions when subjected to repeated static loads (Fig. 19). The surface workhardness, which has a favorable effect at room and moderately elevated temperatures, can be found to have a negative influence at high temperatures.

References: Marin, N.I., "Tekhnika vozdushnogo flota" ["Airline Technology], No. 5, page 1, 1947; Ratner, S.I., Razrusheniye pri povtornykh nagruzkakh [Failure Under Repeated Loads], Moscow, 1959.

S.I. Kishkina-Ratner

STATISTICAL THEORY OF STRENGTH – the results of studying various problems of deformation and fracture on the basis of the concepts and methods of mathematical and physical statistics, taking into account the nonuniformity of these processes. In this case the determinate resistance (fully defined in magnitude and direction) of a body is replaced by the concept of random values for mechanical characteristics as a result of the compositional and structural nonuniformity of all real solids. Measured mechanical characteristics consequently display a fundamentally unavoidable scattering, which is quite considerable in many cases (see Scattering of mechanical characteristics).

According to the statistical theory of strength, it is impossible to make a precise evaluation of the useful life or strength of an individual specimen or component; one can only determine the probability of fracture under a given load. This theory infers relationships governing the mean value and distribution function of microscopic strength and certain other mechanical characteristics, proceeding from consideration of the corresponding microscopic regularities and the probability distribution of stresses and characteristics in different zones and directions.

The statistical theory of strength studies both average (macroscopic) and microscopic relationships. In addition to the usual concepts of deformation and fracture of a body or of zones commensurate with its dimensions, this theory attempts to take into account the microscopic processes governing fatigue, brittle, and other types of fracture. No effort is made to investigate the individual microscopic

processes of deformation and fracture, which would be both virtually impossible (since real bodies contain many thousands of grains) and inexpedient (since the behavior of a large number of individual grains is so similar that there is no need to suppose that there are fundamental differences between them). The statistical theory of strength studies these mechanisms in a statistical manner, determining the distribution of characteristics and stresses over the grains; equal macroscopic characteristics may correspond to different microscopic-characteristic distribution curves.

The first statistical theories of strength were based on the assumption that the strength of a specimen is governed by that of its weakest element or, in other words, the most dangerous nonuniformity (fracture occurring along the "weakest link").

According to this theory, the Scale effect results from an increase in the probability that extremely dangerous defects will appear conjoined with an increase in absolute size. However, this effect also depends on other factors (see Reserve elastic energy), as well as on differences in production technology and structure in large and small specimens (see Mechanical similarity). It was subsequently proposed that fracture along the "weakest link" be generalized to fracture along a "critical link" in order to conform more closely to the behavior of polycrystalline materials.

The statistical theory of strength makes it possible to compute the macroscopic modulus of elasticity of a polycrystal if one knows the elasticity constants of the corresponding monocrystal and the orientation distribution of the various grains. This theory can also be employed for selecting a "tolerance" in determinations of elastic limit and yield strength.

In S.D. Volkov's statistical theory of strength the conditions for

macroscopic fracture (the transition from microcracking to macrocracking) are governed by the permissible number of microcracks. The average stress only determines the instant at which the relative number of cracks (microcrack density) reaches the critical value characteristic of the material in question.

In the case of fatigue fracture the statistical theory of strength is employed to evaluate the durability of nonuniformly fractured materials and to explain the observed distribution function of fatigue life.

References: Kontorova, T.A., Frenkel', Ya.I., Zhurnal tekhnich. fiziki [Journal of Technical Physics], 1941, Vol. 11, No. 3, page 173, Afanas'yev, N.N., Statisticheskaya teoriya ustalostnoy prochnosti metallov [Statistical Theory of the Fatigue Strength of Metals], Kiev, 1953; Volkov, S.D., Statisticheskaya teoriya prochnosti [Statistical Theory of Strength], Moscow-Sverdlovsk, 1960; Strunin, B.M., FMiM, 1962, Vol. 13, No. 1, page 33; Freidenthal, A., Gumbel, E., in collection: Problemy mekhaniki [Problems of Mechanics], translated from English, No. 2, Moscow, 1959, page 161; Weibull, W., Ingenioersvetenskapsc kad. handl. [Transactions of the Science and Engineering Academy], 1959, No. 151.

Ya.B. Fridman

STEEL – an iron-carbon alloy with metallurgical impurities of manganese, silicon, sulfur, and phosphorous. Ordinary, so-called carbon steel contains 0.05–1.5% C, 0.1–1% Mn, up to 0.4% Si, up to 0.08% S, and up to 0.1% P. When the impurity content is high or when other special impurities are added the steel is called alloy steel. Steel can be manufactured from pig iron by partial removal of its carbon by oxidation; this method is widely employed in contemporary metallurgy. Another possible technique for production of steel consists in reduction of iron ore to iron and addition of the requisite quantity of carbon and other impurities. Steel can be obtained in the liquid, semiliquid, and solid states.

The oldest method for producing steel in the liquid state is the crucible process, which involves melting of small pieces of pure soft steel and pure pig iron in small refractory (graphite or firebrick) crucibles with a capacity of 20–45 kg. The advantage of the crucible process, which reached the peak of its development at the beginning of the 19th century (now having been almost completely displaced by electrosmelting), is that is permits production of high-quality steel; its principal drawbacks are its high cost and cumbersomeness.

In converter processes steel is produced in converters with capacities of from 0.5 to 60–100 t by oxidation of molten pig iron with oxygen supplied by compressed air (ordinary atmospheric air or oxygen-enriched air) forced into the metal through an opening in the bottom or wall of the converter or through a nozzle inserted through the lid of a deep-bottomed converter. The converter lining can be acidic (Dinas

brick), in which case the so-called Bessemer process takes place, or basic (dolomite brick), in which case the so-called Thomas process occurs.

At present the principal manufacturing method, accounting for more than 80% of the steel smelted throughout the entire world, is the open-hearth process, which consists in production of cast steel by melting a charge containing pig iron and steel scrap in open-hearth furnaces with an acidic or basic lining. Both ordinary and high-quality open-hearth steels are produced in furnaces of widely varying tonnage (from 1 to 500 t).

Smelting of steel in electric furnaces has developed rapidly since the end of the 19th century. At present 7% of the total world steel output is produced in electric arc or induction furnaces. Induction furnaces adapted for vacuum smelting are of special importance.

When certain special technical and economic conditions obtain it is expedient to utilize combined steel-smelting processes, which are conducted sequentially in several units: a) duplex processes: Bessemer-Thomas, Bessemer – open-hearth, Thomas – open-hearth, two basic open-hearth furnaces, a basic open-hearth furnace and an acidic open-hearth furnace, or an open-hearth furnace and an electric furnace; b) triplex process: converter – open-hearth furnace, electric furnace.

The most important duplex process involves a converter (Bessemer or Thomas) and a basic open-hearth furnace, combining the high productivity of converter processes with the high quality of open-hearth steel.

Production of solid steel (or, more precisely, iron) by reduction of iron ore at 750-1050° is employed on a small scale; sponge iron, which is a very pure intermediate product, serves as the initial material for smelting high-quality steel in open-hearth or electric furnaces.

The principal component of steel is iron and the atoms of other elements are consequently oriented along its crystal lattice. Steel displays the polymorphism inherent in iron, a phenomenon characterized by changes in lattice structure on heating or cooling. Pure iron is known to have a cubic body-centered crystal lattice, so-called α-iron (δ-iron at high temperatures), and a cubic face-centered lattice, so-called γ-iron. The temperature of the transition from one iron lattice to the other (910° and 1390°) is called the critical point. Impurities (primarily carbon) have the effect of shifting the critical point along the temperature scale, its position depending on the chemical composition of the alloy. The critical points of steel were discovered by the Russian scientist D.K. Chernov, who developed the principles of modern metallography.

The principal impurity in steel, which is responsible for all its valuable characteristics, is carbon. The interaction of carbon with α- or γ-iron leads to formation of interstitial solid solutions by insertion of carbon atoms into the free areas of the crystal lattice. Carbon has a very low solubility in the body-centered α-Fe lattice (less than 0.008% at room temperature); this solution is called ferrite. The carbon of steel is very soluble in the face-centered high-temperature γ-Fe lattice (having a maximum solubility in γ-Fe of 2%), forming a solution called austenite. Since the carbon content of commercial steels exceeds its solubility in α-Fe, the excess carbon atoms not included in the ferrite form a chemical compound, iron carbide (Fe_3C) or Cementite, with the iron atoms.

Thus, the structure of steel at room temperature consists of ferrite and cementite particles, which are present either in the form of separate inclusions (so-called structurally free ferrite or cementite) or in the form of a fine mechanical mixture, which is called perlite.

The phase diagram of iron-carbon alloys gives general information on the temperature and concentration limits of the different phases (ferrite, cementite, perlite, and austenite).

The quantity of ferrite, cementite, and perlite in the structure of steel depends chiefly on its carbon content; the different properties of these phases govern the diverse characteristics of steels.

The properties of steel can be varied within wide limits by heat treatment, which is an aggregate of heating and cooling operations resulting in changes in the structure and thus the characteristics of the alloy; the principal types of heat treatment are annealing, normalization, quenching, and tempering.

Exceptionally diverse characteristics can be achieved in steel by adding different alloying elements: Mn (more than 1.0%), Si (more than 0.4%), Cr, Ni, Mo, W, V, Ti, Nb, Co, Cu, B, etc. Atoms of these alloying elements enter the crystal lattice of the ferrite or austenite and alter its characteristics in conformity with the natural properties of the elements added. Moreover, formation of solid solutions and chemical compounds between the iron (the base of steel) or the carbon (the principal impurity in steel) and the alloying elements also alters the characteristics of the steel; these compounds may be hard, strong, chemically stable, hot-strong, etc., and the properties of steel containing them are accordingly altered. See also the articles on stainless steels and spring steels, the group of articles on structural steels, etc.

References: Metallovedeniye i termicheskaya obrabotka stali [Metalworking and Heat Treatment of Steel], handbook, 2nd Edition, Vol. 1, Moscow, 1961; Gudremon, E., Spetsial'nyye stali [Special Steels], translated from German, Vol. 2, Moscow, 1960; Meskin, V.S., Osnovy legirovaniya stali [Principles of the Alloying of Steel], Moscow, 1959; Chalmers,

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B., Fizicheskoye metallovedeniye [Physical Metallography], translated from English, Moscow, 1963.

M.L. Bernshteyn

STEEL CARBIDE – is the chemical composition of the elements, present in steel, with carbon. The formation of carbides occurs, as a rule, not following the valency rule; the carbides have a special lattice structure, on base of which, in turn, limited solid solutions are formed. In addition to iron which forms the carbide Fe_3C, the cementite, many other elements of the IV-VIII groups of the IV, V, and VI periods form so-called special carbides. Manganese carbide, Mn_3C, has the same orthorhombic space lattice as cementite, the chromium carbides Cr_7C_3 and $Cr_{23}C_6$ also have a constant ratio of metal and carbon atoms. Most of the carbide-forming elements (vanadium, titanium, molybdenum, tungsten, hafnium, etc.), whose ratio of the carbon atom radius to the atom radius of the element is lower than (or equal to) 0.59, form interstitial phases. Typical interstitial phase are the carbides VC; TiC; NbC; ZrC; TaC; WC; Mo_2C, and others. Most of the carbides have a high hardness (more than 8 on the Mohs scale), which is explained by the presence of double bonds and bonds of different nature between the metal atoms themselves and between the metal and carbon atoms.

M. L. Bernshteyn

STEEL PIPES – are made from carbon, alloy and high-alloy steels and from almost 300 brands of iron alloy with standard (GOSTs 380-60, 1050-60, 4543-61, 5058-57 and partially 801-60, 5632-61) and nonstandard chemical composition; the composition of the latter is established by special technical specifications. Steel pipes are made seamless, electrically welded, welded, soldered, laminated (bimetallic), cast, etc. Steel pipes are used extensively in all fields of the national economy.

M.L. Bernshteyn

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[Transliterated Symbols]

3844 ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = All-Union State Standard

STEEL SHEET is divided into 3 basic groups: thick sheet, thin sheet, wide strip. The thick sheet includes rolled stock of thickness 4-160 mm, width 600-5000 mm and length 2-12 mm; in exceptional cases the length reaches 18-20 m.

The 4-6 mm thick steel sheet is delivered with intervals of 0.5 mm, 6-30 mm with intervals of 1 mm, 30-60 mm with intervals of 2 mm, over 60 mm with intervals of 2-5 mm. With regard to application, the steel sheet in the form of thick sheets is divided into the following basic groups: boiler-furnace steel (see Boiler Steel), steel for auto and tractor construction, aircraft steel, shipbuilding steel, bridge construction steel, armor steel, special usage steel, ordinary carbon and high-quality constructional steel (see Case-Hardening Constructional Steel). The technology for the rolling of thick steel sheet is determined by the chemical composition and the technological characteristics and requirements made on the properties and the dimensions. Depending on these requirements, there is established the heating regime of the metal prior to rolling, the magnitude and number of reuuctions, the sheet cooling conditions and the heat treatment conditions.

The thin sheet includes rolled stock of thickness from 0.2 to 3.75 mm and width from 600 to 2200 mm. Rolled stock of width less than 600 mm wound into rolls is classified as strip. With regard to application, the steel in the form of thin sheet is divided into the following basic groups: constructional steel, decorative steel, roofing iron, transformer steel. The most advanced method of rolling thin steel sheet is the reel rolling method.

Wide strips are rolled on special mills in which the stands have vertical rolls for working the side edges. Strips are produced in thickness from 4 to 50 mm, width 200-1050 mm and length 5-18 m. The wide strip has a finished side edge after rolling, while the thick and thin sheets are edged after shearing. There are GOST for all the varieties of steel sheet which establish the required technical specifications (sizes, mechanical properties, surface, processing samples, etc.).

V.F. Kalugin

STEEL WIRE. Depending on its purpose, wire is manufactured from various types of steel in diameters (thicknesses) of from 0.005 to 16 mm. Steel wire is classified (GOST 2333-57) according to cross-sectional shape (in addition to the shapes shown in the table, certain types of wire may be oval, segmental, trapezoidal, Z-shaped, etc. in cross section). size, chemical composition, final heat treatment (as delivered), mechanical characteristics, type of surface, type of plastic deformation, and application. The table shows the classification of steel wire.

M.L. Bernshteyn

Classification of Steel Wire

1 Назначение	2 Классификационная характеристика проволоки: по форме поперечного сечения (3): 4 круглая; 5 плоская; 6 квадратная; 7 прямоугольная. 8 по размерам (мм): 9 особо толстая > 8,0; 10 толстая 8,0–6,0; 11 средняя 6,0–1,6; 12 тонкая 1,6–0,4; 13 гончайшая 0,4–0,1; 14 ниточнайшая < 0,1. по механич. свойствам σ_b (кг/мм²) (15): 16 низкой прочности < 40; 17 пониженной прочности 40–80; 18 нормальной прочности 80–125; 19 повышенной прочности 125–200; 20 высокой прочности 200–320. по виду поверхности 21: 22 светлая; 23 оцинкованная; 24 другие. 25 по покрытию: 26 оцинкованная; 27 лужёная; 28 омеднённая; 29 другие покрытия. 30 по виду изделия, для которого предназначена: 31 хлопчатобумажная или хлопчатобумажная; 32 горячепрессованная или горячекатаная
33 Общего назначения	+ | | | + | | + | + | | + | + | | + | | | + | | |

Notes. 1) A plus sign (+) indicates that wire indented for the application in question has the classificational characteristics of the group in question.
2) Simple coatings include brass-, cadmium-, bronze-, and tin-plating, enameling, painting, etc.
3) in accordance with standards or by arrangement, the wire can be coated with a neutral anticorrosion grease that does not cause the turns of the coil to stick to one another.

1) Application; 2) classificational characteristics of wire; 3) cross-sectional shape; 4) round; 5) flat; 6) square; 7) rectangular; 8) size (mm); 9) especially thick; 10) thick; 11) medium; 12) thin; 13) very thin; 14) extremely thin; 15) mechanical characteristics, σ_b (kg/mm^2); 16) low strength; 17) reduced strength; 18) normal strength; 19) elevated strength; 20) high strength; 21) type of surface; 22) bright; 23) oxidized; 24) black; 25) coating; 26) zinc-plated; 27) tinned; 28) copper-plated; 29) simple coatings; 30) type of plastic deformation; 31) cold-drawn or cold-rolled; 32) hot-drawn or hot-rolled; 33) general-purpose; 34) welding and filler; 35) power-line; 36) soldering and ligature; 37) splint; 38) screen; 39) nail and chain; 40) polygraphic; 41) fastener; 42) bolt and screw; 43) steel-aluminum leads; 44) cable; 45) armored cable; 46) banding; 47) multiconductor iron leads; 48) slate; 49) card; 50) heald; 51) comb; 52) needle; 53) garnet; 54) peg; 55) wire rod; 56) spoke; 57) semaphore; 58) various types of spring wire; 59) spring washers; 60) musical-instrument strings; 61) shoe screws; 62) laminated; 63) watch; 64) automatic equipment; 65) ball-bearing; 66) tool; 67) low-carbon wire for reinforced-concrete structures; 68) carbon wire for prestressed reinforced concrete structures; 69) corrosion-resistant products; 70) heating elements and resistors.

STELLITE – a hard alloy based on nickel (cobalt, iron) and used for casting machine, machine-tool, and instrument components in order to increase their wear resistance. The distinguishing feature of stellite is its lack of allotropic transformations; it is not forgible an cannot be cut in the usual manner. It is employed in the cast or deposited form without heat treatment. It is produced in cast sheets for subsequent soldering, finish castings, and cast welding bars with d = = 3-8 mm. Tables 1-3 show the chemical composition of this alloy. Types VKhN1, V3K, and V2K stellite are produced by metallurgical plants in the form of welding bars satisfying the technical specifications set by AMTU 291-57. Other types of stellite are generally produced to the customer's requirements. In most cases only the hardness of the alloy is prescribed. Table 4 shows the hardness of stellite.

TABLE 1

Chemical Composition of Cobalt Stellite

Стеллит 1	Содержание элементов* (%)								
	C	Si	Cr	W	примеси (не более)				
					Ni	Fe	Mn	S	P
4 В3К	0,9–1,3	1,75–2,75	28–32	4–5	2	2	0,5	0,07	0,03
5 В2К	1,75–2,25	1,0–2,0	28–32	14–17	2	3	0,5	0,07	0,03

*The remainder is cobalt.

1) Stellite; 2) content of elements (%); 3) impurities (no more than); 4) V3K; 5) V2K.

The other mechanical characteristics of the softest stellites are shown in Table 5. Table 6 shows the α of stellites.

Cobalt- and iron-based stellites have good hot strength at temper-

TABLE 2

Chemical Composition of Nickel Stellite

Стеллит 1	2 Содержание элементов * (%)							
	C	Si	Cr	W	3 примеси (не более) Fe	Mn	S	P
ВХН1 4	0,5—1,2	1,5—2,5	35—40	—	5	0,5	0,07	0,03
Смена1 5	4—5	0,5—1,0	28—31	18—20	25	1,0	0,07	0,03
Смена2 6	3,8—4,8	0,5—1,0	28—32	18—22	8	1,0	0,07	0,03

*The remainder is nickel.

1) Stellite; 2) content of elements (%); 3) impurities (no more than); 4) VKhN1; 5) Smena1; 6) Smena2.

TABLE 3

Chemical Composition of Iron Stellite

Стеллит 1	2 Содержание элементов* (%)						
	C	Si	Cr	Ni	W	Mn	V
В1Ж 3	1,7—2,0	2,5—3,5	28—34	4—5	3,5—4,5	0,5—1,0	0,5—1,0
4 Сормайт	2,5—3,5	2,5—3,5	28—35	3—5	—	1,0—1,5	—
В2Ж 5	1,8—2,2	0,5—1,0	16—19	0,5—1,0	Mo 14—16	0,3—0,5	1,2—1,6

*The remainder is iron.

1) Stellite; 2) content of elements (%); 3) V1Zh; 4) Sormayt; 5) V2Zh.

TABLE 4

Hardness of Stellite

Стеллит 1	RC	
	2 в литом виде	после наплавки 3
5 В3К 4	40—45	37—42
В2К 5	47—50	45—48
ВХН1 6	25—30	20—25
Смена 1 7	60—63	48—53
Смена 2 8	57—60	46—50
В1Ж 9	45—50	38—42
Сормайт 10	55—60	47—52
В2Ж 11	60—62	58—60

1) Stellite; 2) in cast form; 3) after fusion; 4) V3K; 5) V2K; 6) VKhN1; 7) Smena 1; 8) Smena 2; 9) V1Zh; 10) Sormayt; 11) V2Zh.

atures of up to 1000°, while nickel-based stellites have good hot strength at temperatures of up to 1100°.

The hot strength of stellites (on compression testing) approximates that of alloys with intermetallide hardening. Figure 1 shows the hardness of V3K and VKhN1 stellites. Stellites exhibit considerably higher

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TABLE 5

Mechanical Characteristics of Stellite

Сталлит 1	$\sigma_в$ кг/мм² (20°)	δ (%)	ψ (%)	$\sigma_в$ кг/мм² (500°)	δ (%)	ψ (%)
ВЗК 3	58	2	6.5	33	1	1
ВХН1 4	59	0.5	-	26	1	1.5

1) Stellite; 2) kg/mm^2; 3) V3K; 4) VKhN1.

TABLE 6

Coefficient of Linear Expansion of Stellite

Сталлит 1	$\alpha \cdot 10^6$ (1/°C)
ВЗК 2	14.5 (600–1000), 16 (100–1000)
ВХН1 3	9.5 (900)
Смена1 4	11.2 (100), 12.8 (900)
Сормайт 5	9.1 (100), 12.3 (900)

1) Stellite; 2) V3K; 3) VKhN1; 4) Smena 1; 5) Sormayt.

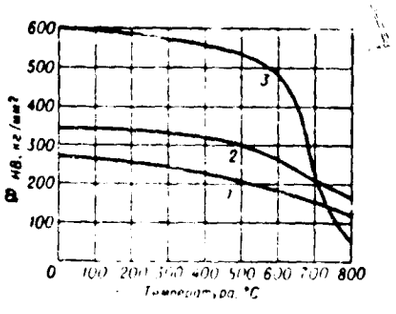

Fig. 1. Hardness of VKhN1 (1) and V3K (2) stellites and RF1 steel (3) at elevated temperatures. a) kg/mm^2; b) temperature, °C.

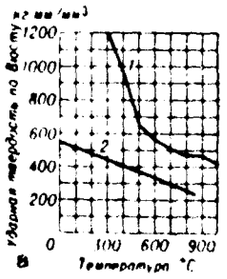

Fig. 2. Impact hardness of V1Zh stellite (1) and EI69 steel (2) at elevated temperatures. a) Wust impact hardness; b) kg-mm/mm^3; c) temperature, °C.

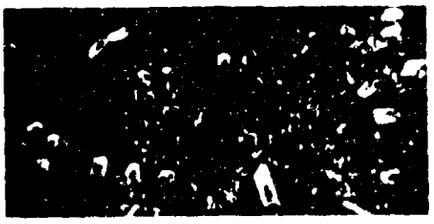

Fig. 3. Microstructure of V2K stellite.

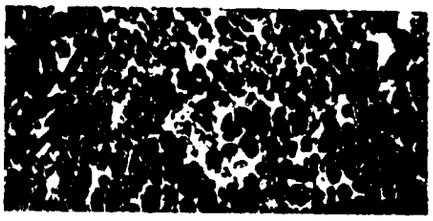

Fig. 4. Microstructure of V3K stellite.

Fig. 5. Microstructure of fused area in stellite deposited on austenitic steel.

hardness than RF1 high-speed steel or 3KhV8 die steel, beginning at temperatures of 700°.

The Wust impact hardness of stellites is materially higher than that of austenitic valve steel of type EI69 (Fig. 2). The wear resistance of stellites is higher than that of any known steel and is exceeded only by that of hard cermet and powder-deposition alloys.

Structurally, stellites consist of a complex eutectic of carbides and a solid solution, as well as structurally free hypereutectic carbides (Fig. 3). An exception is hypoeutectic V3K stellite, whose structure consists of solid-solution dendrites and eutectics (Fig. 4). Types VKhN1, V3K and V1Zh stellite are used for building up the valve faces, headers, and seats of internal-combustion engines; types V2K and V2Zh are employed for sealing and building up dies or punches, valve stocks, contacts, and the various friction surfaces of instruments; Smena 1, Smena 2, and Sormayt are used for building up lathe centers, shoes, worms, nozzles, components of agricultural equipment and machine tools, and other friction components operating without lubrication.

Building up of stellite is carried out with oxyacetylene torches in a reducing flame (with an excess of acetylene). This process usually deposits a layer 3-5 mm thick. Polishing reduces the thickness of the

built-up layer to 1.5–2 mm. The stellite should not be completely mixed with the base metal during building up (Fig. 5), since this reduces its hardness and wear resistance.

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V.P. Grechin

STICKY ADHESIVE – is a compound composed of the basic component substances (polyisobutylene, ethyl cellulose, synthetic rubbers), which impart the stickiness (rosin ester, hydrogenized colophony, coumarone-, alkyd-, and toluene sulfonamide formaldehyde resins), plasticizers (methyl abietate, alkyd- and coumarone-indene resins, dibutyl phthalate, tricresyl phosphate, nondrying oils), and modifiers (hydrogenized wax, animal or mineral waxes). Sticky adhesives do not dry for a long time, they adhere to any surface when weakly pressed on and are characterized by a constant adhesion of the adhesive film. Sticky adhesives based on polyisobutylene adhere well to metals; the disadvantages of these adhesives (the fluidity of the polyisobutylene at lower temperatures, the degradation of the polymer under the action of light) are partially remediable by certain additions; these adhesives are used in combination with synthetic rubbers. The sticky adhesive based on polyvinylmethyl ester adheres well to plastics and other materials; superfluous bits can be washed off easily with water. Sticky adhesive based siliconorganic elastomers is heat-treated at 150-250° to increase the adhesion. High-strength glass fabric covered with nondrying siliconorganic varnish is capable of withstanding temperatures from −60° to 200°; this adhesive is used in radio electronics, aviation and electrical engineering industries. Depending on the composition of the adhesive, the sticky adhesives are applied by a wet or a dry method. In the former method, the components of the adhesive are mixed in the usual resin-mixer without solvent, then heated up to the softening point of the resin and calendered onto the carrier material. The second (wet) method is more wide-

spread. The adhesive is applied to the [illegible] tape, and the coated tape is dried in hot air, by infrared lamps or in long ovens before it is rolled up. Sticky papers covered with adhesive are used to temporarily preserve metal sheets from damage during transport and storage.

Sticky adhesives are widely used for medical purposes (adhesive plasters, dressings, and ligatures); as adhesive labels and wrappers on basis of paper or metal; and as insulating, tightening and preserving tapes. The insulation tape from foamed polyurethane joined with a transparent waterproof and elastic film, covered with sticky adhesive, adheres readily on any surface of machines and devices and is used to damp oscillations, to protect brittle parts from impacts, and to offer protection from moisture and dust. When parts are to be joined with hot-curing adhesives, they can be wrapped in a sticky cellophane film; the cellophane contracts during the heating and produces a considerable pressure in the bond area, thereby preventing the joined parts from shifting.

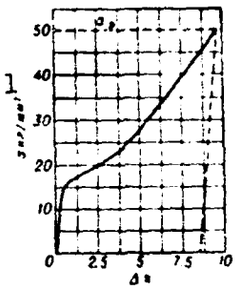
D.A. Kardashev

STRAIN FIGURES – are lines on the surface of distorted bodies, which are directed obliquely to the stress directions. The strain figures are detectable by the following manners: observation of the previously polished surface; investigation of the type of destruction of brittle layers (cinder, for example); heating and subsequent treatment with pickling agents; method of "schlieren photographs" of the surface relief, etc. The direction of the strain figures sometimes coincides with the direction calculated on the basis of the Plasticity theory (see Lueders-Chernov lines).

Ya.B. Fridman

STRAIN HARDENED MAGNESIUM ALLOYS are mill priducts made from magnesium alloys which have been subjected to strengthening by plastic deformation (strain hardening) at a temperature below their crystallization temperature. Under the action of the plastic deformation the hardness (HB), yield strength ($\sigma_{0.2}$) and ultimate strength (σ_b) of the alloys in tensile test increase, while the relative elongation (δ) and the transverse reduction (ψ) diminish. This variation of the properties, most intense at the beginning of the process and diminishing toward the end, takes place up to the instant of fracture of the alloy. For the majority of the alloys (copper, aluminum, etc.) the strain hardened condition is created by cold deformation (at shop temperature), and the required relationship of the strength ($\sigma_{0.2}$ and σ_b) and plasticity (δ and ψ) characteristics of the mill products is achieved by a varying degree of deformation or duration and temperature of the subsequent anneal. The degree of strain hardening of the alloys is determined by the relation of the strength and plasticity characteristics. The strain hardened state is the name given to the temper in which the alloy has the minimal acceptable value of δ with corresponding maximal values of $\sigma_{0.2}$ and σ_b. In the annealed temper, on the other hand, the alloy has minimal values of $\sigma_{0.2}$ and σ_b with a maximal value of δ. The intermediate temper, when the alloy has some average values of the mechanical properties between their values in the fully annealed and fully strain hardened tempers, is termed semi-strain-hardened. For the alloys which admit large degrees of cold deformation prior to fracture, we can differentiate more detailed fractional degrees of deformation, for example,

1/4H, ½H and 3/4H, wher H denotes the strain hardened condition. The limited number of slippage planes in the hexagonal crystal lattice of the magnesium alloys at room temperature leads to a low degree of cold deformation for these alloys.



Compression diagram for the VM65-1 alloy (extruded strip in the aged at 170° for 10 hours temper) 1) kg/mm^2.

The figure shows the compression diagram for the VM65-1 alloy. The low plasticity margin (degree of deformation < 10%) at room temperature eliminates the possibility of strain hardening of the magnesium alloys by cold deformation. Cold rolling is possible only for the low-alloy magnesium alloys with 0.5% Th or with 0.2% mischmetal and 0.4% Zr. In practice, use is made of partial strain hardening of the more plastic sheet alloys by rolling them in the hot condition with a temperature of 150-200° at the termination of rolling with subsequent partial anneal. The table presents the mechanical properties of sheet made from the MA8 and MA2-1 alloys after rolling and annealing at different temperatures. Directly after rolling in the strain hardened condition the alloys have the maximal strength characterisics, but excessively low plasticity, therefore, sheets are not used in this condition. Annealing of the MA8 alloy in the temperature range 250-300° for 30 minutes provides high strength with adequately high plasticity (semi-strain-hardened condition). Maximal plasticity with a small reduction of the strength is achieved with full anneal of the MA8 alloy (temperature 350°, duration 30

minutes). Further increase of the annealing temperature leads to grain growth and reduction of the strength and plasticity of the alloy.

Mechanical Properties (Typical) of MA2-1 and MA8 Alloy Sheet of 2-3 mm Thickness After Anneal for 30 Minutes at Various Temperatures

1 Состояние материала	2 Сплав МА8			2 Сплав МА2-1		
	$\sigma_в$	$\sigma_{0,2}$	δ (%)	$\sigma_в$	$\sigma_{0,2}$	δ (%)
	3 (кг/мм²)			3 (кг/мм²)		
4 После прокатки	28	22	8	32	28	4
5 Отожженный при 200° в течение 30 мин.	–	–	–	30	24	10
Отожженный при 250° в течение 30 мин.	26	18	12	28	19	16
Отожженный при 300° в течение 30 мин.	26	18	14	–	–	–
Отожженный при 350° в течение 30 мин.	24	16	18	26	16	16

1) Material condition; 2) alloy ; 3) (kg/mm^2); 4) after rolling; 5) annealed at for 30 minutes.

In the MA2-1 alloy the simi-strain-hardened condition is reached by annealing at 170-200° for 30 minutes, and the fully annealed condition is reached by annealing at 250-280° for the same time.

References: see article Wrought Magnesium Alloys.

A.A. Kazakov

STRAIN-TEMPERATURE CURVE – one of the characteristics of the mechanical properties of a solid body (usually of a polymer) in a wide temperature range. Strain-temperature curves are usually obtained by measuring the deformation of the material being tested: 1) when the specimen is heated at the constant rate dT/dt under a given load, 2) at a given temperature and subjected to a constant stress during a specified time interval δt. The second method is more exact. The location of the strain-temperature curve depends on the magnitude of the time δt or the heating rate. The strain-temperature curve for polymers is displaced in the direction of higher temperatures with a reduction in δt and increase in dT/dt.

A stress-temperature curve for a crystalline body is shown in Fig. 1. Below T_{pl} the crystal's metlting temperature, the deformations are small and do not increase signficantly with an increase in temperature; they are reversible in short duration tests. In tests of long duration metals and other crystalline bodies exhibit creep and residual deformations which are the greater, the higher the temperature. Above T_{pl} on transition to the liquid state, the deformation is almost entirely viscous. The strain-temperature curves for low-molecular glass are depicted in Fig. 2 (curves 1-3). The deformations change monoton ically with the temperature, below T_g the vitrification temperature, they are small and reversible, above T_g they are large and irreversible. The range of transition from the solid to the liquid state practically occupies a certain temperature interval.

The strain-temperature curves of polymers are more complex in

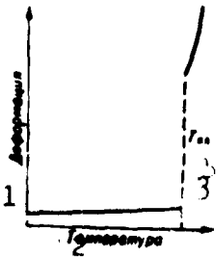


Fig. 1. Strain-temperature curve of a crystalline material. 1) Deformation; 2) temperature; 3) T_{pl}.

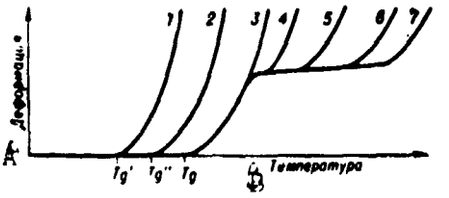


Fig. 2. Strain-temperature curves for low-molecular glass (1-3) and high polymers (4-7). Higher curve numbers correspond to an increase in the degree of polymerization. A) Deformation; B) temperature.

shape (Fig. 2, curves 4-7). A substantial increase in the deformation, which remains reversible, takes place above T_g. Then the deformation changes little with the temperature, up to the yield temperature T_f, after which it becomes irreversible. A hyperelastic state is situated between the vitreous and viscous flow states, in the interval from T_g to T_f (see Hyperelastic Deformation). The high-elasticity range of certain linear polymers is characterized by several plateaus on the strain-temperature curve. This is due to an ensemble of various secondary crosslinkages between the macromolecules; here the weakest of them are destroyed at lower temperatures, then the mor stronger ones, etc. As a result, the material is partially destroyed at certain temperatures and the deformation increases in a jump. The sharp rise in deformation after T_f is due to the viscous flowing of the polymer. For a given polymer-homologous series the strain-temperature curves change in such a manner with an increase in the molecular weight that T_g is displaced (Fig. 2) into the region of higher temperatures but, starting with a certain molecular weight, which corresponds to the transition from low-molecular to high-molecular systems, T_g reamins constant, while T_f increases with an increase in the molecular weight. The T_g-T_f high elas-

ticity region is the wider, the higher the molecular weight of the polymer.

The thermomechanical method of polymer testing has come into extensive use. It consists in obtaining the strain-temperature curve under a certain simple loading regime. For example, in mass testing of polymers use is usually made of a constant rate of temperature increase under a given stress. As a result of simple calculations it is possible to rapidly obtain primary data on the mechanical properties of polymers in a wide temperature range in order to then, using more exact physicomechanical methods, study the individual temperature regions. The thermomechanical method is used to study the effect of the molecular weight, plasticizers, fillers, irradiation, medium and other factors on the mechanical properties of polymers, and also for the production control of the stability of various batches of technical polymers, etc. This method makes it possible to judge about the mechanism of the effect of all these factors, about the feasibility of modifying the properties of polymers and about the temperature fields of their application.

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G.M. Bartenev

Manuscript Page No.

[Transliterated Symbols]

3861' пл = pl = plavleniye = melting

STRAY MAGNETIC FIELD is a magnetic field which appears about a magnetized ferromganetic body. Structural inhomogeneities or discontinuities of the material cause anomalies in the distribution of the stray magnetic field, which makes it possible with the aid of various indicators to detect defects in products made from the ferromagnetic matierials (see Magnetic Defectoscopy).

S.M. Rozhdestvenskiy

STRENGTH – is characterized by increasing deformation under the increase of the load. Usually strength is determined within the range in which Hooke's law is valid, and in this case the strength is a constant of the system (it does not depend on the magnitude of the deformation). In the case of stretching (or compression) the strength is equal to

$$\frac{E \cdot F}{l}, \quad \Delta l = \frac{l}{E \cdot F} \cdot P.$$

where P is the force, Δl is the absolute elongation (or contraction); E is Young's modulus; F is the cross section, and l is the length of the specimen.

In the case of bending, the strength of the cross section is equal to $E \cdot I$, and in the case of torsion it is equal to $G \cdot I_p$, where I is the moment of inertia of the cross section, I_p is the polar moment of inertia of the cross section, and G is the modulus of strength.

The lower the deformation of the system (body), the higher the strength, the other conditions remaining constant. In an absolutely hard body is $E = \infty$; $G = \infty$, and the strength is infinite; the strength of rubbers is very low. The magnitude inverse to strength is termed pliability. ∞

Ya. B. Fridman

STRENGTH – the resistance of a body to deformation and fracture under the action of mechanical loads. This factor is usually evaluaed from the mean stresses corresponding to a definite instant in the development of deformation or fracture. It is the most important characteristic of structural materials. Strength depends on the mechanical characteristics and structure of the material, the size and shape of the body, the ambient medium, and the character of the variation in loading with time, particularly the load duration. The concept of strength includes many different characteristics, which may vary in accordance with different (sometimes contradictory) laws; for example, as the σ_t of a material increases its static strength may rise while its fatigue strength drops. See Strength of structural materials, Theoretical strength, Dynamic strength, Mechanical strength, Specific strength, Ultimate strength.

Ya.B. Fridman

STRENGTHENING OF TEXTILE MATERIALS BY MEANS OF ADHESIVES – is a widely used method to join fabrics together or with other materials. The adhesives used in strengthening textile materials must be highly adhesive to the fabrics, flexible, wash-fast and weatherproof; it must also possess great strength and elasticity, must dry and cure quickly and be harmless in work. The following adhesives are used for strengthening textile materials: polyvinylchloride, polyamide, BF-6, films from dibutyl phthalate and zinc or calcium oxide, adhesives based on polyvinyl butyral, solution of chloranil and vinylidene chloride in ethyl acetate, etc. The strengthening of textile materials by means of adhesives must provdide wear-resistant and elastic seams, but only when the adhesive is repeatedly applied to the bond areas, and the intermediate layers are dried. These adhesives are resistant to low temperatures and to dry-cleaning, but they are insufficiently stable in water, especially in boiling soapy water.

Polyurethane adhesive (PU-2) is used to cement (without heating) wool, glass, cotton or synthetic fabrics to wood, plastics and metals.

D.A. Kardashev

STRENGTH OF POLYMERS — a characteristic closely associated with deformation properties, which depend on the structure and physical state of the polymer. A polymer is subject to different types of deformation and fracture in different physical states and its strength varies accordingly. At small deformations crystalline polymers behave like solids, while on severe extension they undergo a structural transformation from their initial unoriented phase to an oriented crystalline phase, where the chains in the crystals are arrayed predominantly along the axis of extension. The structural transformation is accompanied by a rapid change in specimen length at the critical force F_{kr}, which depends on the temperature. Uniform low-magnitude extension of the specimen occurs during the first stage of loading, followed by sudden development of a "neck," which gradually extends over the entire specimen during the second stage of extension. As its molecular weight is reduced the strength of a crystalline polymer decreases, sometimes to below F_{kr}, in which case the polymer is subject to brittle fracture without any phase transformation. Severe deformation of high-molecular crystalline polymers, almost to the point of fracture, is highly elastic (see Highly elastic deformation), since it is associated with a change in the configuration and orientation of the polymer chains and packets. During tensile testing crystalline polymers yield the temporal strength function shown in Fig. . Only brittle fracture is observed at low temperatures, in the AB region. Beginning at the orientation temperature T_{or}, at which a neck is formed and the material becomes capable of orientation, the specimen has two strengths, depending on whether

fracture occurs in the wider segment or in the neck. Above the embrittlement temperature T_{khr} fracture occurs only after the entire specimen has necked and undergone considerable elongation.

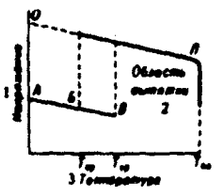

Fig. 1. Temporal strength (stress) function. 1) Stress; 2) extension region; 3) temperature.

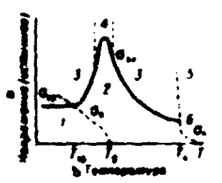

Fig. 2. Diagram of deformation-strength characteristics: 1) Elastic deformation; 2) highly elastic deformation; 3) operating region; 4) extension region; 5) transformation region; 6) irreversible deformation. a) Stress (true); b) temperature.

Crystalline, synthetic, and artificial polymers are often employed in the manufacture of fibrous materials. A preliminarily oriented polymer (fibrous material), is a high-strength material at any temperature below its melting point (the OP region). The operational-temperature region for crystalline fibers lies below the melting point, while the technological elongation region is bounded by T_{khr} and the melting point.

In amorphous polymers, such as gum rubbers and many plastics, the brittle and plastic regions are separated by two new temperature regions (Fig. 2), a forced-elastic region between T_{khr} and T_g and a highly elastic region between T_g and the plasticity temperature T_n. These two regions are separated by T_g. While a polymer undergoes brittle fracture below T_{khr}, at temperatures above this point fracture is preceded by highly elastic deformation, which develops at stresses exceeding the

Limit of forced elasticity σ_b. At temperatures above T_g, in the high-elasticity region, fracture is also preceded by highly elastic deformation, but the latter begins to develop as soon as the load is applied. Above T_n, on passing tnrough the yield-strength point σ_n, residual deformation develops until the material suffers a loss of creep resistance, necks, and fractures. As a rule, when the deformation rate is increased and the loading time reduced the temperature boundaries of the various regions are displaced toward higher levels. Especially severe displacement is observed under impact loads. It can be seen from the graph of deformation-strength characteristics (Fig. 2) that a polymer may undergo elastic, highly elastic, or residual deformation, depending on the temperature, stress, and deformation rate. Its strength varies accordingly.

Three physical states of polymers (vitreous, highly elastic, and viscous) are noted under small stresses. Under large stresses the deformation of polymers acquires a number of new qualitative characteristics, which affect strength and fracture mechanism. This influence is especially manifest during the extension of solid polymers (crystalline and amorphous), where cold elongation is observed. An oriented structure develops in this case, greatly hardening the material. In the majority of cases fracture of polymers occurs when they are in an oriented state, either as a result of preliminary processing (fibers) or during tensile testing, i.e., all other types of fracture, with the exception of brittle fracture, are preceded by highly elastic deformation. The brittle strength of a given polymer can vary widely in accordance with its degree of preliminary orientation.

In the vitreous state, in which plastics are found at ordinary temperatures and gums and rubbers at low temperatures, extension of an amorphous polymer occurs in superficially the same manner as for a crys-

talline polymer. At loads below σ_b specimens are basically subject to elastic deformation. Above σ_b highly elastic deformation beings to develop under the action of external forces (cold flow). After the entire specimen has necked fracture of the workpiece of altered shape takes place in the oriented state, which leads to an increase in strength; at low tensile deformations rupture has the same character as in the brittle state, while at high deformations the specimen undergoes brittle-fibrous fracture. Tensile fracture of a solid polymer at temperatures above T_{khr} has a complex character. Deformation takes place during the transition through σ_b and the specimen then fractures, separating into pieces. The first process is distinguished from the second by the fact that it occurs without disruption of the integrity of the material and leads only to a change in specimen shape. The mechanisms of this process consists in displacement and orientation of the links of the polymer molecules under the action of external forces. The mechanism of the second process consists in crack propagation in the oriented material. The σ_b of the material, which is an analog of the yield strength of solids, increases as the temperature drops and the deformation rate rises. At T_{khr} it exceeds the strength of the polymer and the latter undergoes brittle fracture before σ_b is reached (Fig. 2). As molecular weight decreases a point is reached at which T_{khr} coincides with T_g.

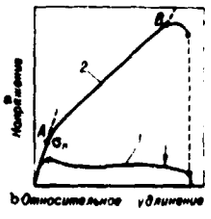

Fig. 3. Graph of extension of polymers. a) Stress; b) relative elongation.

A polymer becomes highly elastic above T_g. The fracture of a highly elastic material differs from that of a brittle material in the fact that it is preceded by more severe deformation, which is associated with orientation and straightening of the polymer chains. In addition, just as in brittle fracture, the specimen cross-section retains its preloading shape after fracture and shrinkage, the fracture surface usually lying perpendicular to the tensile forces. However, the mechanism of prolonged fracture differs in these two cases. Highly elastic polymers fracture by propagation of tears, which are analogous to cracks in brittle bodies. In this case the slow and rapid stages of fracture correspond to the reverse of the zones of the fracture surface in brittle solids.

Plastic fracture is observed at high temperatures (above T_n), where the yield strength of the material drops below its strength. The transition from plastic to highly elastic fracture may occur both when the temperature or deformation rate changes and when the polymer structure is altered. The latter phenomenon forms the basis for rubber technology, since the transition from a plastic rubber mass to a highly elastic material is accompanied by a sharp increase in yield strength. At all temperatures below the chemical-decomposition limit the three-dimensional network of a reticular polymer (rubber) has a high yield strength, which exceeds its rupture strength. In this case T_n coincides with the network-decomposition temperature in practice.

Above T_n a polymer is a plastic material with a characteristic extension diagram (Fig. 3). Below point A the polymer undergoes highly elastic deformation almost exclusively. The stress corresponding to point A is the yield strength. At stresses exceeding σ_n residual (irreversible) deformation occurs simultaneously with the highly elastic deformation. Uniform development of residual deformation along the speci-

men and through its cross-section proceeds until necking takes place (point B). The stress then increases principally in the neck (the dashed curve in Fig. 3, which rises sharply) and fracture ensues. Rupture during a definite stage of necking results from the fact that flow during this process is not unlimited, since the orientation of the molecules leads to a rise in the viscosity of the material in the neck.

The strength of polymers depends on the type of stressed state. For example, during the transition from extension to compression of a solid polymer, its brittle strength and σ_b rise, the former increasing to a larger extent. Under the same conditions a polymer may consequently undergo forced-elastic deformation on compression and brittle fracture on extension. The strength of polymers depends to a large extent on the loading regime (see Time function of strength and Fatigue of materials). Since the strength of such materials in any deformed state is governed by the weakest portion of the structure or the presence of detrimental defects (cracks, tears), the static theory of strength is applicable to polymers.

If it is sufficiently high (more than 50,000 in practice) the molecular weight of linear and reticular polymers has no influence on their strength. Polymer structure (molecular orientation, degree of "cross-linking" and packing for reticular polymers, etc.) has a material influence on strength.

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G.M. Bartenev

STRESS is the characteristic of the unit mechanical loading of a given section. Stress is measured in kg/mm^2 or kg/cm^2. Since a multitude of planes of various orientation passes through every point of a body, at a given point of a given body ghere act various stresses depending on the orientation of the section to which the force is referred. The aggregate of all the stresses for all the planes passing through a point is termed the stress state at the given point. In the general case it is characterized by six quantities (stress tensor). In engineering, most often use is made of the maximal normal and tangential stresses. The majority of the strength characteristics (elastic limit, yield point, ultimate strength, fatigue and creep strengths, etc.) are expressed in terms of stress. See True Stress, Normal Stress, Residual Stress, Thermal Stress, Unit Stress.

Ya.B. Fridman

STRESS CONCENTRATION – is the increase of stresses in the vicinity of openings, fillets, key grooves, and other Stress Concentrators at points where the surface of the concentrator has the largest curvature. The degree of the concentration is the most essential factor within the range of elasticity; it is characterized by the concentration coefficients α_σ for the normal, and α_τ for the tangential stresses. The coefficients α_σ and α_τ are determined theoretically and experimentally as the ratio of the maximal stress (α_{maks}, τ_{maks}) caused by the concentration, to the nominal stress (α_n, τ_n) at the same point:

$$\alpha_\sigma = \frac{\sigma_{макс}}{\sigma_н} \qquad \alpha_\tau = \frac{\tau_{макс}}{\tau_н}$$

The magnitude of α_σ and α_τ is not related to the properties of the material, it depends on the shape of the stress concentrator, of its sharpness, its absolute size and its size relative to the whole piece, and also on the type of deformation and of the stressed state. The effective concentration coefficients K_σ for the normal, and K_τ for the tangential stresses are characteristics for the effect of the stress concentration on the endurance limit. The coefficients K_σ and K_τ are determined experimentally as the ratio of the endurance limit of the smooth specimen (σ_{rg}, τ_{rg}) to the endurance limit of the speciment with a stress concentrator (σ_{rk}, τ_{rk}):

$$K_\sigma = \frac{\sigma_{гг}}{\sigma_{гк}} \qquad K_\tau = \frac{\tau_{гг}}{\tau_{гк}}$$

In the case of asymmetrical cycles, K_σ and K_τ are determined as the ratio of the ultimate amplitude of the smooth specimen to the ultimate amplitude of the specimen with a concentrator, the other conditions

being equal.

In contrast to the concentration coefficients α_σ and α_τ, the magnitude of the effective coefficients K_σ and K_τ depends on the material and its state: these coefficients are lower in a cast state in a deformated state, and higher in a hardened than in a tempered state; they become reduced after chemical and heat treatment and surface-hardening; they drop with a rising stress gradient; they increase when the size of the crystalline grains is reduced; K_σ and K_τ are the higher, the more homogeneous the structure; they frequently rise together with growing hardness and strength characteristics of the material; they increase as the absolute dimensions increase, even when the geometrical similarity is maintained. The effective coefficients K_σ and K_τ are connected with the concentration coefficients α_σ and α_τ by the relations

$$K_\sigma = 1 + q_\sigma(\alpha_\sigma - 1) \qquad K_\tau = 1 + q_\tau(\alpha_\tau - 1),$$

where q_σ and q_τ depends upon the shape and the sharpness of the stress concentrator, on the absolute and relative sizes, and on the type of load. The distribution of stresses in a stretched lamella having an opening is shown in the Fig.

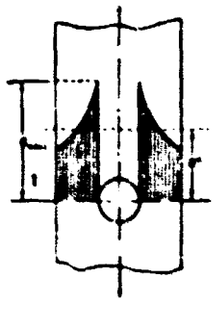

Fig. 1) Max.

G. T. Ivanov

STRESS CONCENTRATOR – is the source of a Stress Concentration. Transversal openings, threads, key grooves, concave chambers, concave corners, fillets and other forms of design, further, the microrelief of the surface with traces of machining, pores, cracks, nonmetallic inclusions and other internal flaws in the material, cracks caused by fatigue under a long-time effect of static load, etc., all play the part of stress concentrators.

G.T. Ivanov

STRESS CYCLE – is the series of the subsequent values of alternating stresses during one period of their change; the stresses of the cycle are expressed by the functions $\sigma = \sigma_m + \sigma_a \cdot f(t)$, and $\tau = \tau_m + \tau_a \cdot f(t)$, where σ_m, τ_m is the mean stress of the cycle, and σ_a, τ_a is the amplitude of the cycle; $f(t)$ is a continuous periodic function characterizing the form of the cycle, alternating within the limits $-1 \leq f(t) \leq +1$. The function $f(t)$, as a rule, must be almost cycloide, when fatigue tests of specimens are carried out. The stress cycle is represented graphically.

G.T. Ivanov

STRESS-CYCLE AMPLITUDE – see Stress-cyle range.

STRESS-CYCLE AMPLITUDE – the greatest value of the alternating portion of the complete stress cycle in repeated alternating stresses; it equals the algebraic mean of the maximum and minimum stresses of the cycle:

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}, \quad \tau_a = \frac{\tau_{max} - \tau_{min}}{2}.$$

G.I. Ivanov

STRESS-CYCLE ASYMMETRY – inequality of the absolute maximum and minimum stresses of the cycle under repetitively alternating loads. The average stress in an asymmetric cycle is not zero. Many components operate under asymmetric conditions: the blades of gas turbines, in which centrifugal forces govern the mean stress of the cycle and deflection oscillations the stress amplitude; connecting bolts, in which the mean normal stresses result from preliminary tightening; valve springs in piston engines, in which the mean tangential stresses result from preliminary compression of the spring, etc. The index which characterizes the degree of stress-cycle asymmetry is the so-called coefficient of cycle asymmetry; it equals the algebraic ratio of the minimum stress in the cycle to the maximum stress:

$$r = \frac{\sigma_{мин}}{\sigma_{макс}}; \quad r = \frac{\tau_{мин}}{\tau_{макс}}.$$

G.T. Ivanov

STRESS RANGE OF A CYCLE – is the algebraic difference between the maximum and minimum stress of a cycle; it is equal to the doubled amplitude of the stresses of the cycle:

$\sigma_{maks}-\sigma_{min} = 2\sigma_a$; $\tau_{max}-\tau_{min} = 2\tau_a$.

G.I. Ivanov

STRESS-STRAIN DIAGRAM – graphical representation of the relationship between stresses and deformations. A distinction is made between conventional and true stress-strain diagrams. Conventional stress-strain diagrams are usually constructed on the basis of results of mechanical tests in the coordinates "conventional stress (the normal stress σ or the tangential stress τ – conventional strain (elongation δ, reduction in area ψ, relative shear γ)", which sufficiently accurately describe the process of deformation in the region of small elastic and elasto-plastic deformations. The characteristic points of conventional stress-strain diagrams for tension (Fig. 1) are the proportionality limits σ_{pts}, yield points σ_s (for materials which have on the diagram a yield-point plateau or projection) and the ultimate strengths σ_b (for materials which neck out under tensile loads). Stress-strain diagrams in the coordinates "true normal stress S – reduction in cross-sectional area ψ" have come into extensive use. These stress-strain diagrams are called curves of trues stresses (Fig. 2), the end point on which characterizes the rupture strenth, that is the true ultimate limit S_k for an area reduction ψ_k. For large deformations the linear relationship $S = f(\psi)$ is approximately assumed. The continuation of the rectilinear segment of the diagram to the left of the ordinate axis ($\psi = 0$) marks off on this axis a magnitude which is close to the ultimate limit σ_b. Extrapolation of the diagram to the right to the value $\psi = 100\%$ cuts off on the ordinate axis twice the value of the true stress S_b, which corresponds to maximum tensile

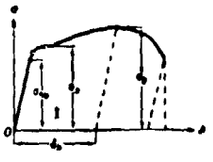

Fig. 1. Conventional stress-strain diagram. 1) Pts.

load of specimens which undergo necking out. On the basis of this qualitative governing laws were proposed on a number of methods for constructing curves $S = f(\psi)$ and empirical formulas of the relationship between the true and conventional stresses:

$$S_k = \sigma_b(1+1{,}35\psi_k) \text{ for } \psi_k < 0{,}15 \text{ and}$$
$$S_k = \sigma_b(0{,}8+2{,}06\psi_k) \text{ for } \psi_k \geq 0{,}15.$$

Using the true stress curves of a material it is possible, in stress calculations of elements to approximately determine the values of bending and twisting moments in the region of large deformations. Thus, the greatest (breaking) bending moment is $M_{maks} = W[S_k + \sigma_b(k-1)]$, where S_k is the true rupture strength, σ_b is the ultimate strength, W is the section modulus, k = 2A/W (A is the static moment of one-half of the cross section with respect to the neutral axis); for a rectangular bar k is 1.5, for a round bar it is 1.7. For materials which fail by shear in tension or twisting, the greatest twisting moment is $M_{kr_{maks}} = 0{,}47 \cdot W_0[S_k + \sigma_b(k_1-1)]$, where W_0 is the section modulus in torsion, $k_1 = A_1/W_0$ (A_1 is the static polar moment), for a round cross section $k_1 = 4/3$. In elasticity and plasticity theories true stress-strain diagrams are considered in the coordinates "stress intensity σ_i (or octahedral stress intensity $t_n = \frac{\sqrt{2}}{3}\sigma_i$) – deformation intensity e_i (or octahedral deformation intensity $g_n = \sqrt{2}\, e_i$)." Use is sometimes made of "true normal stress S – true elongation e" curves. It is assumed that, in the region of small elastoplastic deformations for the case of a simple load, when the directed stress and strain tensors are equal, the "t_n-g_n" curves are independent of the mode of the stressed state, which has been confirmed experimentally for a sufficient number of metals and their alloys. However, for many metals (for example, magnesium alloys, certain grades of bronze, high-strength steels, etc.) the resistance to plastic deformation, and in particular, yield points which are expressed in terms of true stresses, differ for different modes of stressed states. In the region of sub-

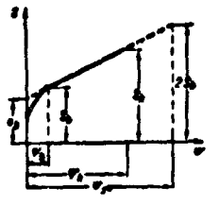

Fig. 2. The true stress curve.

stantial plastic deformations the true stress-strain diagram for the majority of materials depends on the kind of loading. Satisfactory agreement is given by stress-strain diagrams only for pure metals, steels and alloys which have been annealed or highly tempered; here a perceptible divergence in the values of limiting plasticity is observed even for pure metals.

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N.V. Kadobnova

STRIATION OF ALUMINUM ALLOYS is a defect having the form of a series of parallel stripes on the surface of sheet. Striation is formed as a result of friction (with vibration) of turn on turn with insufficient tension of rolls after hot rolling. Striation has no effect on the mechanical and corrosional properties of the sheets, but deteriorates their external appearance markedly. This is an unacceptable defect for sheets which are to be used for articles with high requirements on decorative appearance.

Ye.D. Zakharov

STRING – see Cordage.

STRUCTURAL CEMENTABLE STEEL – steel intended for the manufacture of components with cementable (very hard, wear-resistant) surface layers. Table 1 shows the chemical composition of these steels. In certain cases (e.g., in the manufacture of cemented gears) the C content is raised to 0.25–0.30%. This ensures high core hardness, makes it possible to reduce the thickness of the cemented layer, and consequently curtails the cementation time.

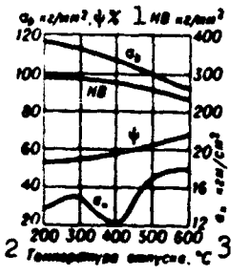

Fig. 1. Influence of tempering temperature on the mechanical characteristics of 15KhA steel (quenching from 900° in oil). 1) kg/mm^2; 2) tempering temperature, °C; 3) kg-m/cm^2.

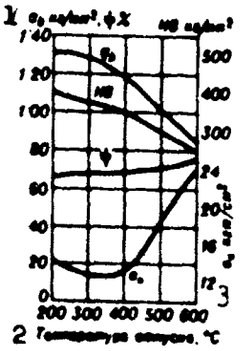

Fig. 2. Influence of tempering temperature on the mechanical characteristics of 12KhN3A steel (quenching from 900° in oil). 1) kg/mm^2; 2) tempering temperature, °C; 3) kg-m/cm^2.

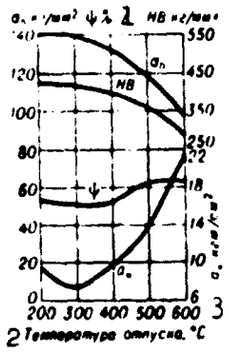

Fig. 3. Influence of tempering temperature on the mechanical characteristics of 12Kh2N4A steel (quenching from 900° in oil). 1) kg/mm^2; 2) tempering temperature, °C; 3) kg-m/cm^2.

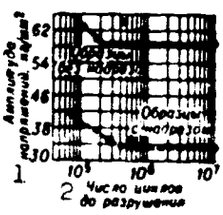

Fig. 4. Durability of 15Kh2GN2TRA steel on cantilever bending (quenching from 860°, tempering at 200° with preliminary normalization at 950°). 1) Stress amplitude, kg/mm^2; 2) number of cycles to fracture; 3) unnotched specimens; 4) notched specimens.

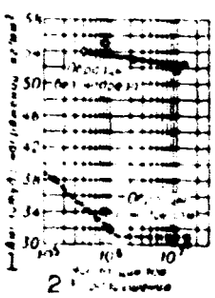

Fig. 5. Durability of 12Kh2NVFA steel on cantilever bending (quenching from 900° in oil, tempering at 550°). 1) Stress amplitude, kg/mm^2; 2) number of cycles to fracture; 3) unnotched specimens; 4) notched specimens.

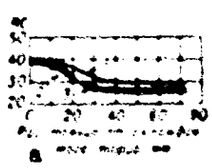

Fig. 6. Hardenability of 15Kh2GN2TRA steel: 1) 0.13% C, 1.0% Mn, 0.13% Si, 1.7% Cr, 0.11% Ni, 0.003% B; 2) 0.13% C, 1.0% Mn, 0.13% Si, 1.7% Cr, 1.61% Ni, and 0.003% B; 3) 0.13% C, 1.0% Mn, 0.13% Si, 1.7% Cr, 1.61% Ni, and 0.004% B. a) Distance from cooled end, mm.

The steels most commonly used for cementation are 15KhA, 18KhGT, 15Kh2GN2TRA, 20KhGNR, 12KhN3A, 12Kh2N4A, 18KhNVA, 12Kh2NVFA (EI712), 15Kh2GN2VFA (EP176, DI3A), and 19KhGN2VMF (DI2).

After annealing or normalization and tempering the Brinell hardness of cementable structural steel (d_{otn}) $\geq$ 4.0 mm. Figures 1-3 show the influence of postquenching tempering on the mechanical characteristics of these steels, while Figs. 4-5 represent their durability. Table 2 shows the forging and heat-treatment regimes and applications of these steels. The mechanical characteristics of certain types of cementable structural steel are given in Tables 3-4, while their physical characteristics are given in Table 5 and their critical points in Table 6.

The modulus of elasticity of cementable structural steels is 20,000 kg/mm^2. The modulus of elasticity varies as the temperature is raised in the same manner as for carbon steel (see Carbon structural shaping steel). Figures 6-7 show the hardenability of cementable structural steels.

The core structure is governed by the composition of the treated steel and the heat-treatment regime adopted, principally the quenching temperature. The core of a component of high-alloy steel (12KhN3A, 12Kh2N4A, 18KhNVA, etc.) consists of ferrite and martensite. Structurally, the cemented layer consists of finely aticular martensite and excess carbides in the form of globules; precipitation of these carbides in the form of a network or coarse aggregates is not permissible.

When high-alloy steel of this type is quenched the cemented layer retains a large quantity of residual austenite, which considerably reduces its hardness. In order to increase its hardness it is subjected to cold treatment (at -70°) immediately after quenching (Fig. 8). The residual austenite can also be eliminated by high tempering. In addi-

TABLE 1

Chemical Composition of Cementable Structural Steels

Сталь 1	2 ГОСТ или ТУ	3 Содержание элементов (%)					4 Прочие элементы
		C	Mn	Si	Cr	Ni	
5) 15ХА 6	15) ГОСТ 4543-61	0,12–0,17	0,40–0,60	0,17–0,37	0,70–1,00	до 0,30	
7) 15Х2ГН2ТРА	16) ЧМТУ 5590-58	0,12–0,18	1,20–1,60	0,17–0,37	1,40–1,80	1,40–1,80	0,02–0,10 Ti; 0,02–0,10 V
9) 12Х2Н3А 10	17) МПТУ 2333-49	0,10–0,16	0,30–0,60	0,17–0,37	0,60–0,90	2,75–3,25	0,02–0,10 Ti
11 18ХНВА	ГОСТ 4543-61	0,16–0,22	0,40–0,70	0,17–0,37	1,00–1,40	1,00–1,40	0,80–1,20 W; 0,15–0,30 V
12) 12Х2НВФА (ЭИ712)	ЧМТУ 5590-58	0,09–0,16	0,25–0,50	0,17–0,37	1,60–1,90	1,40–1,80	0,35–0,50 W; 0,15–0,30 V; 0,02–0,10 Ti
13) 15Х2ГН2ВФА (ЭП176, ДИ3А)	ЧМТУ 320-60	0,13–0,18	0,90–1,20	0,17–0,37	1,40–1,80	1,40–1,80	0,80–1,20 W; 0,15–0,30 V; 0,02–0,10 Ti
14) 19ХГН2ВМФ (ДИ2)	–	0,16–0,22	0,60–0,90	0,17–0,37	1,00–1,50	1,80–2,30	0,30–0,50 Mo; 0,80–1,20 W; 0,15–0,30 V

1) Steel; 2) GOST or TU; 3) content of elements (%); 4) other elements; 5) 15KhA; 6) 18KhGT; 7) 15Kh2GN2TRA; 8) 20KhGNR; 9) 12Kh2N3A; 10) 12Kh2N4A; 11) 18KhNVA; 12) 12Kh2NVFA (EI712); 13) 15Kh2GN2VFA (EP176, DI3A); 14) 19KhGN2VMF (DI2); 15) GOST; 16) ChMTU; 17) MPTU.

TABLE 2

Forging, Cementation, and Heat-Treatment Regimes and Application of Cementable Structural Steels

Сталь 1	Температура ковки	Предварительная термическая обработка на металлургическом заводе	Температура цементации	Окончательная термическая обработка на заводе-потребителе	Применение
15ХА	1150–800°	Нормализация при 900–930°	890–920°	Закалка в масле с отпуском при 150–180°	Шестерни, валики и т.п.
18ХГТ	1200–900°	Нормализация при 950–970°	900–930°	Закалка в масле с отпуском при 180–200°	Шестерни, валики и т.п.
15Х2ГН2ТРА	1180–850°	Нормализация при 930–940°	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
20ХГНР	1150–850°	Нормализация при 900–920°	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
12Х2Н3А	1150–850°	Нормализация при 880–900°	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
18ХНВА	1180–850°	Нормализация при 920–940° или улучшение (закалка в масле с 880–900° и отпуск при 650–680°)	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
12Х2Н4А	1180–850°	Нормализация при 880–900° или улучшение (закалка в масле с 850–870° и отпуск при 650–680°)	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
12Х2НВФА (ЭИ712)	1180–850°	Нормализация при 920–940° или улучшение (закалка в масле с 880–900° и отпуск при 650–680°)	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
15Х2ГН2ВФА (ЭП176, ДИ3А)	1180–850°	Нормализация при 920–940° или улучшение (закалка в масле с 880–900° и отпуск при 650–680°)	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках
19ХГН2ВМФ (ДИ2)	1150–850°	То же	900–930°	Закалка в масле с отпуском при 180–200°	Ответственные детали, работающие при ударных нагрузках

1) Steel; 2) forging temperature; 3) preliminary heat treatment at producer plant; 4) cementation temperature; 5) final heat treatment at consumer plant; 6) application; 7) 15KhA; 8) 18KhGT; 9) 15Kh2GN2TRA; 10) 20KhGNR; 11) 12Kh2N3A; 12) 18KhNVA; 13) 12Kh2N4A; 14) 12Kh2NVFA (EI712); 15) 15Kh2GN2VFA (EP176, DI3A); 16) 19KhGN2VMF (DI2); 17) normalization at 920–940°; 18) normalization at 880–900°; 19) normalization at 930–950°; 20) normalization at 880–900°; 21) normalization at 880–900°; 22) normalization at 880–900° [illegible] forged products); 23) normalization at 880–900° [illegible] temperature at 650°; 24) normalization at 880–900°, high temperature; 25) normalization at 850°, high temperature; 26) [illegible]; 27) quenching from 880° in oil, [illegible] tempering at 150–180°; 28) quenching from 880–900° in oil, [illegible] from 880° in oil, tempering at 150–180°; 29) quenching from 880–900° in water or oil, [illegible]

from 850° in oil, tempering at 160-180°; 31) quenching from 860° in oil, tempering at 170°; 32) quenching from 860° in oil, quenching from 780-810° in oil, tempering at 150-170°; 33) quenching from 900° in air, quenching from 850-860° in air, tempering at 150-170°; 34) quenching from 760-810° in oil, tempering at 150-170°; 35) quenching from 850° in oil, tempering at 250°; 36) quenching from 820-860° in oil, tempering at 170-190°; 36) quenching from 820-860° in oil, tempering at 170-190°; 37) small components up to 30 mm thick; 38) gears, load-bearing components; 39) stressed gears, shafts, double gears; 40) double gears, shafts; 41) gears, cam shafts, axles, rollers; 42) shafts, cam shafts, stressed gears; 43) stressed gears, double timing gears, elastic-transmission gears, shafts, roller axles; 44) transmission gears to operate at up to 280°; 45) heavily stressed gears, double timing gears, transmission gears to operate at up to 250°; 46) stressed gears, shafts.

TABLE 3

Mechanical Characteristics of Cementable Structural Steels (no less than)

1 Сталь	2 ГОСТ или ТУ	3 Состояние контрольных образцов	σ_b (кг/мм²)	$\sigma_{т.т}$	δ (%)	ψ	5 $a_н$ (кгм/см²)	HB ($d_{отп.}$, мм)
6 15ХА	ГОСТ 4543-61	Нормализация при 940°, закалка с 860° в воде или масле, закалка с 770-820° в воде или масле, отпуск при 150-170°	75	60	14	45	8	—
7 18ХГТ	ГОСТ 4543-61	Нормализация при 970°, закалка с 880° в масле, закалка с 970° в масле, отпуск при 200±10° в воде или масле	115	85	10	50	8	—
8 15Х2ГН2ТРА	ЧМТУ 5390-58	Нормализация при 980°, закалка с 800-850° в масле, отпуск при 160-180°	105	—	12	55	11	3.45-3.15
9 20ХГНР	ЧМТУ 1780-58	Нормализация при 950°, закалка с 860° в масле, отпуск при 170°	130	120	10	50	9	3.6-3.1
10 12ХН3А	МПТУ 2333-49	Нормализация при 860-880°, закалка с 860° в масле, закалка с 780-810° в масле, отпуск при 150-170°	95	70	12	55	12	3.65-3.15
11 12Х2Н4А	МПТУ 2333-49	Нормализация при 880°, закалка с 780-810° в масле, отпуск при 150-170°	100	80	12	55	10	3.55-3.1
12 18ХНВА	ГОСТ 4543-61	Нормализация при 920-980°, закалка с 950° на воздухе, закалка с 850-860° на воздухе, отпуск при 150-170°	120	90	10	45	10	3.25-3.1
13 12Х2НВФА (ЭИ712)	ЧМТУ 5390-58	Нормализация при 920°, закалка с 850° в масле, обработка при -70°, отпуск при 250°	105	80	15	45	7.0	3.6-3.1
14 15Х2ГН2ВФА (ЭП176, ДИ3А)	ЧМТУ 320-60	Нормализация при 950°, закалка с 820-860° в масле, отпуск при 170-190°	100	80	12	55	10	3.55-3.1
15 10ХГН2ВМФ (ДИ2)	—	Нормализация при 950°, закалка с 820-860° в масле, отпуск при 160-200°	115	85	11	45	10	3.4-3.15

1) Steel; 2) GOST or TU; 3) state of control specimens; 4) kg/mm^2; 5) kg-m/cm^2; 6) 15KhA; 7) 18KhGT; 8) 15Kh2GN2TRA; 9) 20KhGNR; 10) 12KhN3A; 11) 12Kh2N4A; 12) 18KhNVA; 13) 12Kh2NVFA (EI712); 14) 15Kh2GN2VFA (EP-176, DI3A); 15) 10KhGN2VMF (DI2); GOST; 17) ChMTU; 18) MPTU; 19) normalization at 940°, quenching from 860° in water or oil, quenching from 770-820° in water or oil, tempering at 150-170°; 20) normalization at 970°, quenching from 880° in oil, quenching from 970° in oil, tempering at 200 + 10° in water or oil; 21) normalization at 980°, quenching from 800-850° in oil, tempering at 160-180°; 22) normalization at 950°, quenching from 860° in oil, tempering at 170°; 23) normalization at 840-880°, quenching from 860° in oil, quenching from 780-810° in oil, tempering at 150-170°; 24) normalization at 880°, quenching from 780-

810° in oil, tempering at 150-170°; 25) normalization at 920-980°, quenching from 950° in air, quenching from 850-860° in air, tempering at 150-170°; 26) normalization at 920°; quenching from 850° in oil, treatment at −70°, tempering at 250°; 27) normalization at 950°, quenching from 820-860° in oil, tempering at 170-190°; 28) normalization at 950°, quenching from 820-860° in oil, tempering at 160-200°.

TABLE 4

Mechanical Characteristics of Certain Cementable Structural Steels at Elevated Temperatures (no less than

Сталь 1	2 Термич. обработка	Темп-ра (°С) 3	σ_b	$\sigma_{0,2}$	δ	ψ	$a_н$ (кгм/см²) 5
			4 (кг/мм²)		(%)		
18ХНВА 6	Закалка с 860° в масле, отпуск при 560° 9	300	122	107	16	—	12,2
		400	109	88	14	—	10,7
		500	90	83	14	—	10,2
12ХН3А 7	Закалка с 880 — 900° в масле, отпуск при 500° 10	300	82	74	14	61	—
		400	64	60	17	75	—
		500	50	46	18	75	—
12Х2НВФА (ЭИ712) 8	Нормализация, отпуск при 500° 11	300	102	98	14	52	—
		400	105	92	15	60	—
		500	102	92	12	58	—

1) Steel; 2) heat treatment; 3) temperature (°C); 4) kg/mm^2; 5) kg-m/cm^2; 6) 18KhNVA; 7) 12KhN3A; 8) 12Kh2NVFA (EI712); 9) quenching from 860° in oil, tempering at 560°; 10) quenching from 880-900° in oil, tempering at 500°; 11) normalization, tempering at 500°.

TABLE 5

Physical Characteristics of Cementable Structural Steels

Сталь 1	α·10⁶ (1 °C)	λ (кал/см·сек·°С) 2
15ХА 3	11,0 (20—400°), 13,0 (20—300°); 14,5 (20—600°)	0,12 (100°), 0,091 (500°); 0,088 (600°)
12ХН3А 4	11,0 (20—400°), 14,0 (20—600°)	0,085 (20°)
12Х2Н4А 5	11 (20—100°), 14,0 (20—600°)	—
18ХНВА 6	11,7 (20—100°), 14,7 (300—400°)	0,085 (100°), 0,083 (400°)
15Х2ГН2ТРА 7	11,8 (20—100°), 13,5 (200—300°)	0,096 (20°)
12Х2НВФА (ЭИ712) 8	11,9 (20—100°), 14,2 (400—500°)	0,090 (20°), 0,085 (400°)
15Х2ГН2ВФА (ЭП176, ДИ3А) 9	10,8 (20—100°), 15,3 (500—600°)	0,092 (20°), 0,086 (500°)
19ХГН2ВМФ (ДИ2) 10	11,0 (20—100°), 15,3 (500—600°)	—

1) Steel; 2) cal/cm·sec·°C; 3) 15KhA; 4) 12KhN3A; 5) 12Kh2N4A; 6) 18KhNVA; 7) 15Kh2GN2TRA; 8) 12Kh2NVFA (EI712); 9) 15Kh2GN2VFA (EP176, DI3A); 10) 19KhGN2VMF (DI2).

tion, subsequent quenching makes it possible to obtain homogeneous finely acicular martensite containing uniformly distributed dispersed austenitic areas and ensures a very high durability.

Cemented steels are readily welded by any method (in the uncemen-

TABLE 6

Critical Points of Cementable Structural Steels

Сталь 1	Критич. точки (°С) 2			
	A_{c_1}	A_{c_3}	A_{r_1}	A_{r_3}
3 15ХА 4	735	870	720	—
18ХГТ	740	825	650	730
5 12Х2Н3А 6	719	830	659	726
18ХНВА	700	810	—	—
12Х2Н4А 8	710	820	—	—
7 15Х2ГН2ТРА	710	775	620	670
12Х2НВФА	775	840	650	700
9 15Х2ГН2ВФА 10 (ЭП176, ДИ3А)	750	800	470	400
11 19ХГН2ВМФ (ДИ2)	740	800	495	425

1) Steel; 2) critical points (°C); 3) 15KhA; 4) 18KhGT; 5) 12KhN3A; 6) 18KhNVA; 7) 12Kh2N4A; 8) 15Kh2GN2TRA; 9) 12Kh2NVFA; 10) 15Kh2GN2VFA (EP176, DI3A); 11) 19KhGN2VMF (DI2).

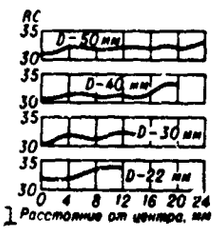

Fig. 7. Hardenability of 12Kh2NVFA steel after normalization at 910° and tempering at 550° (0.13% C, 1.90% Cr, 1.10% Ni, 1.03% W, and 0.15% V). 1) Distance from center, mm.

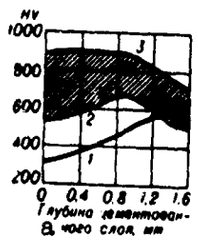

Fig. 8. Hardness of cemented 18KhNVA steel: 1) Hardness after cementation; 2) hardness after cementation and quenching from 780° in oil; 3) hardness after supplemental cooling to −70°. a) Depth of cemented layer, mm.

ted zone). Those areas of the component containing severe stress concentrators must be protected against cementation; areas subject to substantial tensile stresses should also be left uncemented.

Types 12KhN3A, 18KhNVA, 12Kh2N4A, 12Kh2NVFA, 15Kh2GN2VFA, and 19KhGN2VMF steel can also be used as uncemented structural steels for

components intended to operate at 300-500°.

References: Kontorovich, I.Ye., Termicheskaya obrabotka stali i chuguna [Heat Treatment of Steel and Pig Iron], Moscow, 1950; Minkevich, A.N., Khimikotermicheskaya obrabotka stali [Chemical-Thermal Processing of Steel], Moscow, 1950; Spravochnik po mashinostroitel'nym materialam [Handbook of Machine-Building Materials], Vol. 1, Moscow, 1959.

M.F. Alekseyenko

STRUCTURAL CERAMICS – are ceramic materials used in machine building as structural elements with an elevated chemical, thermal, mechanical, and electrical stability. Depending on the requirements, structural ceramics may have diverse physiocochemical properties and consist of the following materials: a) sintered oxides (Al_2O_3; MgO; BeO; ZrO_2; ThO_2, etc.); b) sintered silicates and aluminates (porcelain, mullite, steatite, spinel, corundo-mullite, etc.); c) sintered carbides, nitrides, borides, etc.; d) sintered cermets. The heatproofness of ceramic materials surpasses, as a rule, 1300° and reaches up to 4000° (hafnium carbide, for example). Structural ceramics are characterized by a high inertness to oxidation (apart from carbides, sulfides and phosphides) and a low specific gravity in comparison with metals and their alloys. (For a comparison of the thermomechanical properties of some types of ceramic materials see the Table in the article Ceramics). Besides the high thermomechanical porperties, the structural ceramics are characterized by a high hardness (up to 92-93 according to Rockwell) and a good resistance to abrasion, which explains their use as wear-resistant parts and tools. The change of the hardness of corundum (TsM-332) and metallic (R18, VK15, T15K5, T30K4, VK2, and VK6) tool materials as a function of the temperature is shown in the Figure.

Structural ceramics are used for the production of cutting tools, gages, bearings, spinnerets, dies, thread guides, abrasion-resisting supporting pieces, nozzles, turbine blades, in rocket engineering and nucleonics. The application of structural ceramics is especially important in modern engineering where high requirements are presented to the

materials concerning the thermomechanical and corrosion properties. The outside of the first American satellite Explorer, for example, was coated with a layer of corundum ceramic. Uncooled jet-engine nozzles may be made from a high-refractory ceramic of the Chromal type. Sintered beryllia is used as a moderator in nuclear reactors, and sintered thoria as fuel elements of reactors. The fields of the successful application of structural ceramics in machine building are yet not fully clarified. The brittleness of the ceramics is the main hindrance for their wide application.

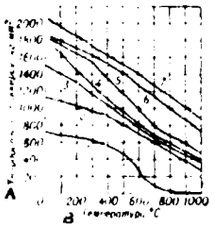

Fig. Change of the hardness of tool materials as a function of the temperature: 1) R18; 2) VK15; 3) VK6; 4) T15K6; 5) T30K4; 6) VK2; 7) TsM322. A) Vickers hardness, kg/mm^2; B) temperature, °C.

Ya.M. Pavlushkin

STRUCTURAL PLASTICS – nonmetallic materials based on natural or synthetic polymers and suitable for the manufacture of instrument and machine components and various finished products and structures. There are also technological plastics (ion-exchange resins, materials for casting models, movie film, etc.). Structural plastics should not be regarded as identical to polymers, since the former are compositions of various components, including nonpolymer materials.

Classification of Plastics

Plastics are classified in accordance with composition, structure, characteristics, production variety, processing method, functional purpose, and field of application.

There is no unified terminology of and classification for plastics. The term structural plastics is sometimes used to mean machine-building plastics, which are employed in instrument and machine building and classified as architectural plastics, which are used in stationary structures. Plastics which need not satisfy high requirements for mechanical characteristics (heat-insulating, decorative, and other materials) are often excluded from the category of structural plastics. The majority of plastics serve several functions in finished products, giving them both the requisite strength and rigidity (or deformability) and special characteristics (electrical-insulating properties, acid-resistance, optical transparency, etc.). Such plastics are accordingly referred to as electrical-insulating, acid-resistant, transparent, etc. Materials from which finished products are fabricated should have the minimum permissible physicomechanical characteristics and technological

and economic indices. It is consequently best not to distinguish an arbitrary class of structural plastics, but to evaluate the feasibility of using a given plastic as a standard structural material.

The Committee of Standards, Measures, and Measuring Instruments of the Council of Ministers USSR has recommended that plastics be classified by the chemical composition of their principal component, the binder, which gives the composition its ability to become plastic, be molded, and set, fixing the desired shape. In many cases plastics consist of several organic and inorganic substances, including a binder, a filler, plasticizers, stabilizers, dyes, hardeners, thickeners, and other additives. The composition and structure of a plastic (particularly the character of the binder, whether it is a thermal or reactive plastic) govern the methods that can be used to fabricate components from it and the physicomechanical characteristics of the finished product. We can distinguish unfilled plastics, which include organic glass, films, etc., and filled plastics; addition of fillers to the latter increases their mechanical strength, hardness, rigidity, and thermostability, reduces their creep, intensifies their frictional or antifrictional characteristics, and sometimes reduces their cost. Filled plastics are classified by: 1) the composition of the filler (glass plastics, asbestos plastics, wood plastics, etc.); 2) by the form, size, and structure of the filler (plastics with an unoriented structure, which have more or less uniform characteristics in all directions, plastics with an oriented structure, which are distinguished by severe anisotropy of properties, and gas-filled plastics, such as plastic foams and cellular plastics). Plastics with an unoriented structure include: a) plastic foams, amino plastics, etc., which contain powdered fillers (sawdust, finely ground minerals); b) plastics with lumpy fillers (pieces of cloth or plywood, flakes of mica); c)voloknits with ran-

domly arrayed short fibers of cellulose (volcknit), glass (glass volok-nit), asbestos, etc. Fibrous and powdered fillers are combined to increase the flowability of the finished plastic during pressing, reduce its shrinkage, and improve its appearance. Plastics with an oriented structure include: a) laminated plastics, such as textolite, glass textolite, asbestos textolite, delta-wood, getinaks, SVAM with a glass veneer coating, etc.; b) plastics with a unidirectional structure consisting of parallel fibers, threads, or coarse linen (SVAM, AG-4s).

Plastics containing no fillers but subject to uniaxial or planular tension may also have an oriented structure. Plastics based on tensioned untwisted fibers (as in cloth) can be uniformly strong in two directions or in all directions in a given plane. Such plastics differ from textolites in their higher modulus of elasticity and lower tensile elongation.

General Evaluation of Plastics as Structural Materials

Plastics are characterized by diverse and specific physicochemical and mechanical properties, ease of processing, and availability of raw materials. Table 1 shows a comparison of the typical characteristics of plastics and other structural materials.

The principal advantages of plastics are low specific gravity, satisfactory strength, high specific strength, friction and antifriction characteristics, damping capacity, chemical stability, dielectric characteristics, and heat-insulating properties, optical transparency (in certain types), good appearance, low labor consumption in the manufacture of finished products, and low cost.

The most important advantage of plastics is the fact that components of complex configuration can be fabricated by high-productivity automated plasticizing processes (pressing, pressure casting, extrusion, rolling, etc.) without laborious machining and loss of material

TABLE 1

Characteristics of Various Structural Materials (+ Characteristic Present, - Characteristic Absent)

1 Свойства	2 Пластмассы	3 Резины, эластики	4 Металлы, сплавы	5 Керамика, силикатные стекла
6 Физико-химические				
7 Малый объемный вес	+	+	—	—
8 Теплоизоляционные свойства	+	+	—	+
9 Работоспособность при высоких (300–500° и выше) температурах длительная	—	—	+	+
10 Стойкость к тепловым ударам	+	+	+	—
11 Электроизоляционные свойства	+	+	—	+
12 Радиопрозрачность	+	+	—	+
13 Оптическая прозрачность	+[1]	—	—	+[1]
14 Неподверженность коррозии	+	+	—	+
15 Биостойкость	+[1]	+	+	+
16 Высокая атмосферостойкость	—	—	—	+
17 Механические	18			
18 Высокая прочность при растяжении	+[1]	—	+	—
19 при сжатии	+[1]	—	+	+
21 Высокая жесткость и твердость	—	—	+	+
22 Отсутствие хрупкости	+	+	+	—
23 Способность к большим обратимым деформациям	—	+	—	—
24 Ползучесть	+	—	+	—
25 Высокое сопротивление ударам	+	+	+	—
26 Малая чувствительность к концентрации напряжений	+	+	+[1]	—
27 Высокая демпфирующая способность	+	+	—	—
28 Уплотняющая способность	+	+	—	—
29 Технологические				
30 Легкая обрабатываемость резанием	+	+	+	—
31 Способность к холодной обработке давлением	—	—	+	—
32 Свариваемость	+[1]	—	+	—

Notes: 1. Certain types. 2. Glass. 3. Perpendicular to the reinforcement plane in laminated plastics. 4. Thermal plastics.

1) Characteristic; 2) plastics; 3) rubbers, elastic materials; 4) metals, alloys; 5) ceramics, silicate glasses; 6) physicochemical; 7) low bulk weight; 8) heat-insulating properties; 9) ability to function for prolonged periods at high (300-500° or more) temperatures; 10) resistance to thermal shock; 11) electrical-insulating properties; 12) radio transparency; 13) optical transparency; 14) noncorrosibility; 15) biological resistance; 16) high atmosphere-resistance; 17) mechanical; 18) high strength; 19) on extension; 20) on compression; 21) high rigidity and hardness; 22) lack of brittleness; 23) ability to undergo severe reversible deformation; 24) creep; 25) high impact strength; 26) low sensitivity to stress concentrations; 27) high damping capacity; 28) sealing ability; 29) technological; 30) good cutability; 31) capacity for cold pressure working; 32) weldability.

as waste.

Plastics are lighter than aluminum alloys by an average factor of 2 and than steel, cast iron, or copper alloys by a factor of 5; the bulk weight of plastic foam is less than one-tenth that of metals.

The principal drawbacks of plastics are limited heat resistance (depending on their composition, most plastics can function satisfactorily only at temperatures of 60-400°), susceptibility to aging (irreversible changes in structure and composition leading to loss of valuable technical characteristics), hygroscopicity (in certain types), and mechanical characteristics highly sensitive to changes in temperature.

Many of the shortcomings of plastics can be overcome by selection of an appropriate technological process, proper designing, and correct selection of the type of material to be used, taking into account the conditions under which the finished product is to operate and the modifications of plastics.

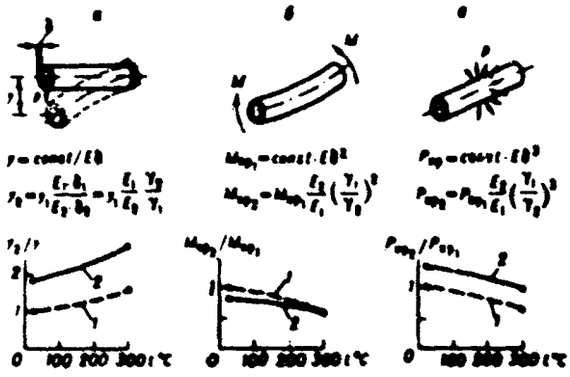

Fig. 1. Rigidity and strength of thin-walled cylinders of equal weight ($\delta_1\gamma_1 = \delta_2\gamma_2$) fabricated from duralumin (1) and glass textolite (2): a) Cantilever bending under concentrated stress; b) loss of strength during bending; c) loss of strength under external pressure. M_{kr} and P_{kr} are the critical bending moment and critical bending force.

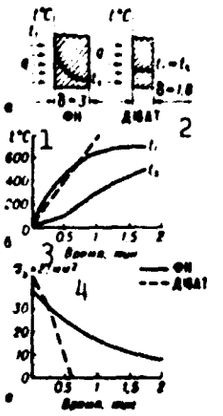

Fig. 2. Tensile strength on brief unilateral heating (q = 20 kcal/m^2·sec, coefficient of heat transfer ~150 kcal/m^2·hr·degree of FN sheet glass textolite (δ = 3 mm) and D16AT duralumin (δ = 1.8 mm) of equal weight (4.85 kg/m^2): a) temperature distribution over cross-section W [t_g is the temperature on the "hot" (heated) side and t_{kh} the temperature on the "cold" side]; b) variation in temperature with time; c) tensile stress as a function of heating time. 1) FN; 2) D16AT; 3) time, min; 4) kg/mm^2.

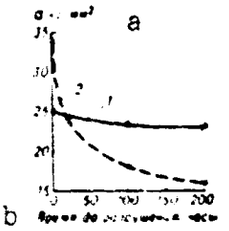

Fig. 3. Long-term tensile strength of FN glass textolite (1) and D16AT duralumin (2). a) kg/mm^2; b) time to fracture, hr.

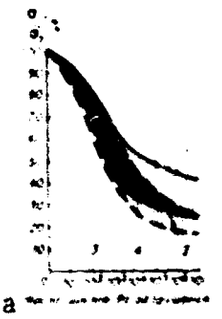

Fig. 4. Fatigue strength (σ_{-1}) in % of static strength (σ_b) for glass plastics and metals: 1) FN glass textolite; 2) EF-32-301 glass textolite; 3) D16AT; 4) 30 KhGSA. a) Number of cycles to fracture.

Whether or not a given plastic can be used principally for load-bearing components is determined primarily by its mechanical characteristics. The basic mechanical characteristics of plastics, certain alloys, cast iron, and steels are shown in Table 2.

The short-term strength of plastics ranges from 1 to 10,000 kg/cm^2, but is generally lower than that of structural metallic alloys (except for certain reinforced plastics). Gravimetric strength strength is sometimes more important than absolute strength, the former being the length at which a filament or rolled sheet fails under its own weight, $L_{razr} = \sigma_b/\gamma$ (measured in km if σ_b is in kg/mm^2 and γ is in g/cm^3); also important is the number of revolutions required for a propeller blade to fail under the action of centrifugal forces, $n = \sqrt{\sigma_b/\gamma} \cdot F(R, S)$, where F is a function of the radius of the blade R and its cross-sectional area S, etc. The specific strength (σ_b/γ) of unfilled isotropic plastics is equal to or slightly less than that of metals; the specific strength of anisotropic plastics with oriented reinforcement is 2-3 times that of metals. A high specific strength does not always mean that a material is structurally advantageous, since its rigidity is also important. Plastics of low rigidity are undesirable because of the large changes in the size and shape of loaded components and their low efficiency when operating in combination with metals. For example, the σ_b/γ of synthetic fibers is higher than that of steel, but their E is lower by a factor of 30-150, so that when they are used for basket coverings for steel vessels subjected to high internal pressure the metal is only slightly deloaded during deformation of the vessel walls; tight winding is better, but the stresses in the polymer relax with time and the hardening resulting from surface pressure disappears. The high elasticity or plasticity of plastics reduces their sensitivity to stress concentrators and increases their fracture resistance under im-

pact loads. Some plastics have a tensile elongation and impact strength lower than those of metals, while in others these indices are higher. Nylon propellers are more resistant to corrosion and to breakage on striking the ground or ice than bronze or brass propellers; they are now being successfully used on small craft. Glass plastics and unfilled plastics in the vitrified state have no flowability base (reserve plasticity), so that their capacity for stress redistribution under short-term loads is lower than that of metals. Large notches are more dangerous in glass textolite than in metals on rapid loading; conversely, on prolonged static or cyclic loading (when relaxation of stresses is possible) the sensitivity of glass textolite to stress concentrations is lower than that of metals (by a factor of 1.5-3, depending on the magnitude of the stresses, the temperature, and the direction of the forces). Plastics have a lower modulus of elasticity than metals, although the E of glass plastics may exceed that of magnesium alloys. The tensile and compressive moduli of elasticity are similar for the majority of materials. The range over which E and especially E/γ vary is narrower (by a factor of up to 50 ... than for σ_b. The extension-compression rigidity of laminated wood plastics approximates that of metal, while glass plastics may have a still higher rigidity. The index E/γ is important for components such as rotating compressor blades: the elongation $\Delta\ell = (\gamma/E)\cdot F(R, S, n) < \Delta H$, where ΔH is the gap between the end of the blade and the housing wall.

Figure 1 shows the values of E and γ for the deformability and strength of thin-walled cylinders.

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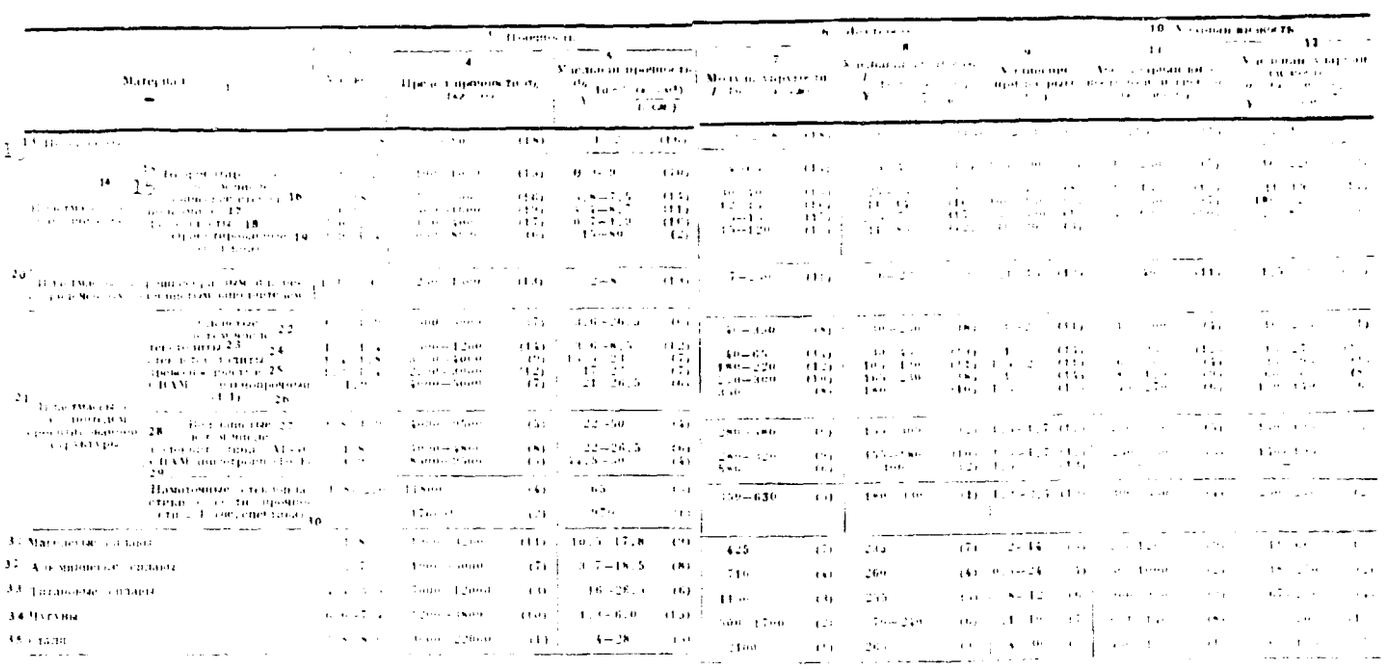
TABLE 2

Principal Mechanical Characteristics of Plastics in Comparison with Those of Certain Alloys, Cast Iron, and Steel*



NOTES AND KEY TO TABLE 2

Notes: 1. Typical values are 0.9-1.4. 2. Typical values are 1.1-2.0. 3. Up to 50% in etrols. 4. Unidirectional.

* Note: These indices were obtained by standard test methods for the materials in question. The number in parentheses indicates the place of the material in decreasing order with respect to the characteristic under consideration. The strength values given are for extension; those for anisotropic plastics are for loading in the plane of the layers or fibers in the direction of greatest strength. The compressive strength of laminated plastics and oriented voloknits (parallel to the reinforcement) is lower than their tensile strength, while that of press-powders, cast iron, and certain other materials is higher.

1) Material; 2) specific gravity; 3) strength; 4) ultimate strength σ_b (kg/cm^2); 5) specific strength $(\sigma_b/\gamma)\cdot 10^{-2}$ $(kg/cm^2)/(g/cm^3)$; 6) rigidity; 7) modulus of elasticity $E\cdot 10^{-3}$ (kg/cm^2); 8) specific rigidity $(E/\gamma)\cdot 10^{-3}$ $(kg/cm^2)/(g/cm^3)$; 9) tensile elongation (%); 10) impact strength; 11) absolute impact strength on bending α $(kg\cdot cm/cm^2)$; 12) specific impact strength (α/γ) = $(kg\cdot cm/cm^2)/(g/cm^3)$; 13) plastic foams; 14) unfilled plastics; 15) unoriented plastics, including; 16) organic glass; 17) polyamides; 18) fluorine-containing plastics; 19) oriented plastics (fibers); 20) plastics with powdered or unoriented fibrous fillers; 21) filled plastics with an oriented structure; 22) laminated plastics, including; 23) textolites; 24) glass textolites; 25) laminated wood plastics; 26) uniform-strength SVAM (1:1); 27) fibrous plastics, including; 28) type AG-4S voloknit; 29) anisotropic SVAM (10:1); 30) wound glass plastics with a strength ratio of 2:1 (prospective); 31) magnesium alloys; 32) aluminum alloys; 33) titanium alloys; 34) cast iron; 35) steel.

As the temperature falls (the range down to -196° has been most thoroughly studied) the static strength and modulus of elasticity of the majority of plastics increase, their impact strength and fatigue strength remain essentially the same, and their long-term strength and creep are improved. This increase in characteristics is more pronounced in thermal than reactive plastics and in unfilled than filled plastics.

The mechanical characteristics of plastics decrease at elevated temperatures, but they are capable of operating in combination with metals under these conditions (see Table 3).

Plastics function better than metals on brief, intensive unilateral heating (Fig. 2). Nonuniform temperature gradients through the

thickness of the component, which are due to differences in the thermal conductivity, heat capacity, and degree of blackness of the material and nonlinearity of the temperature function of σ_b on uniform heating, play a role in this phenomenon.

Figure 3 shows the long-term tensile strength of a heat-resistant glass plastic and of duralumin on heating to 200°. Table 4 shows the fatigue characteristics of glass textolites with phenolic and epoxy binders (along the warp) and of duralumin.

TABLE 3

Influence of Temperature on the Mechanical Characteristics of SK-9F Glass Textolite (1) and D16AT Duralumin (2)

1 Показатели	2 Материал	3 Температура (°C) 20	100	200	300
4 σ_b (кг/см²)	1	37	36	34	31
	2	44	41	33	15
5 σ_{-1}/γ $\frac{(кг\cdot см^3)}{(мм^2\cdot г)}$	1	21,8	21,2	20	18,2
	2	15,8	14,7	11,9	5,3
E (кг/мм²) 6	1	2220	2200	2170	2050
	2	2900	6350	5350	4150
$\frac{E}{\gamma}$ $\frac{(кг\cdot см^3)}{(мм^2\cdot г)}$	1	1300	1290	1270	1200
	2	2480	2300	1930	1500
$\sigma_{0,2}$ (кг/мм²)	1	12,5	12,5	12,5	9,2
	2	29	27,5	25,5	11,5
$\frac{\sigma_{0,2}}{\gamma}$ $\frac{(кг\cdot см^3)}{(мм^2\cdot г)}$	1	7,4	7,4	7,4	5,3
	2	10,4	9,8	9,1	4,1

1) Characteristic; 2) material; 3) temperature (°C); 4) kg/cm^2; 5) (kg·cm^3)/(mm^2·g); 6) kg/mm^2.

The fatigue strength of glass plastics and metals varies similarly as a function of the number of fatigue cycles (Fig. 4). Glass textolites have a lower durability than D16AT or 30KhTSA, but their sensitivity to cyclic loads (the ratio σ_{-1}/σ_b) is approximately the same as that of these materials.

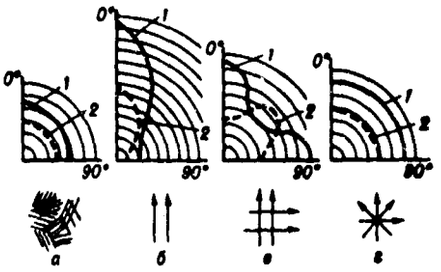


Fig. 5. Anisotropy of ultimate bending strength (1) and impact strength during bending (2) of glass plastics with fibrous reinforcement; a) isotropic; b) oriented glass plastic; c) laminated glass plastic; d) uniformly strong laminated glass plastic.

TABLE 4

Durability of Glass Textolites and Duralumin*

Материал 1	Температура (°С) 2	σ_{-1} (кг/мм²) 3	$\frac{\sigma_{-1}}{\gamma}$ $\frac{(кг \cdot см^3)}{(мм^2 \cdot г)}$ 4
Стеклотекстолиты	20	8,5—9,5	4,7—5,2
	150	9—10	5,0—5,6
	250	3,5—5,0	1,9—2,8
Дуралюмин 5	20	14,0	5,0
	150	12,8	4,5
6	250	10,0	3,6

* Based on 10^7 cycles (coefficient of cycle asymmetry r = -1).

1) Material; 2) temperature (°C); 3) kg/mm²; 4) (kg·cm³)/(mm²·g); 5) glass textolites; 6) duralumin.

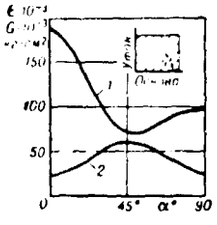


Fig. 6. Modulus of normal elasticity (1) and shear modulus (2) as a function of direction (angle α) of deformation parallel to layers for KAST-V glass textolite. a) kg/cm²; b) woof; c) warp.

Plastics with an oriented filler exhibit severe anisotropy of physicomechanical characteristics. The tensile and shear strengths of laminated plastics are 2-10 times higher perpendicular to the layer-bonding plane than along it. Figures 5 and 6 show the variation in the strength and elasticity of laminated plastics as a function of the direction of deformation parallel to the layers.

Plastics are subject to considerable scattering of mechanical characteristics (especially durability). The scattering of ultimate strength and modulus of elasticity is characterized by an average variation factor of 7-15%.

Special-Purpose Plastics

Antifriction plastics. Many plastics (polyamides, fluorine-containing plastics, textolites, and laminated wood plastics) have good antifriction characteristics (a low coefficient of friction, $f = 0.02$-0.10, and high wear resistance).

Polyamides are equivalent to babbitts and bronzes in load-bearing capacity, coefficient of friction, and wear resistance. When lubricated with oil they can operate at $pv \leq 500$ (henceforth the pressure p is in kg/cm^2 and the sliding speed v in m/sec); they can function at $pv \leq 250$ with water lubrication and at $pv \leq 10$ without lubrication, their wear being less than that of bronze by a factor of 10 or more in the latter case. Their permissible working parameters include $p \leq 100$ kg/cm^2 and $t \leq 80$-100°. In order to increase the load-bearing capacity of thermal plastics they are filled with graphite (for poor lubrication conditions) or powdered MoS_2 (for dry-friction units).

Fluoroplast-4 has a coefficient of friction $f = 0.04$-0.10 for dry friction over metals or fluoroplasts and $f = 0.02$ when lubricated with liquids. It provides smooth sliding at temperatures of up to 260-330°, depending on p. Its load-bearing capacity is limited by the permissible

residual deformation (~1%). Under normal conditions $p < 30$ kg/cm^2. This material is employed in friction units intended to operate in aggressive media ($pv \leq 0.5$) or at elevated temperatures without lubrication.

Graphitized fluoroplast (FUG-3) is added to porous materials to improve their antifriction characteristics. When $pv \leq 0.5$ (dry friction) or $pv \leq 5$ (water lubrication) cheaper high-density polyethylene bushings ($f = 0.06$-0.13 and 0.03-0.17) can be used, having a maximum working temperature of 100°. Bearings of thermal plastics are insensitive to impact loads and choking with solid particles, this being especially important in conveyors and agricultural machinery. Use of a thin facing on the shaft journal instead of a plastic bushing reduces wear (which occurs over the entire cylindrical surface rather than just in the area where the shaft is in contact with the bushing) and increases load-bearing capacity by intensifying heat removal.

Heavily loaded ($p \leq 300$-500 kg/cm^2) sliding bearings intended to operate with copious lubrication are fabricated from glass textolite and laminated wood plastics. The butt of the material is its working surface in the latter case. With water lubrication the coefficient of friction of laminated wood plastics ($f = 0.005$-0.08) is lower than that of other materials at high values of p and low values of v. Textolite and laminated wood plastics can be effectively used in shaft bearings subjected to impact loads and not requiring high precision (the bearings of rolling stands, crankshaft presses, and gantry cranes). Bearings of laminated wood plastics are cheaper than those of textolite (by 100%) or bronze (by 50%), reduce the loss of power due to friction by 20-30%, and have a service life 2-4 times that of metal bearings.

Plastics and rubbers are reliable antifriction materials for marine bearings intended to operate in water (as a result of the low viscosity of water, a "lubricant wedge" is not produced in metal deadwood

bearings and friction occurs under semidry conditions).

Use of laminated wood plastics or textolite (high p) and polyamides (low p) for facing the bench guides of planing and grinding machines and for the support surfaces of lathe tail stocks reduces pulling forces and eliminates grabbing.

Friction plastics. Certain plastics have a high coefficient of friction ($f = 0.2-0.6$) coupled with high wear resistance and are used as friction materials. Special types of asbestos-filled plastics are widely employed in braking devices. They are distinguished by a high ($0.2 < f < 0.5$), stable (at various p and v) coefficient of friction and low susceptibility to wear. The principal drawbacks of asbestos-rubber friction materials are the sharp drop in f at elevated temperatures and their low heat resistance.

The valuable operational characteristics of friction plastics are due to: their rather high mechanical strength on heating; their capacity for rapid running-in (the softness and elasticity of plastics facilitates repeated deformation and holding of solid friction particles); the absence of grabbing during and after braking, which results from the difference in the type of atomic and molecular bonding in plastics and metals used as friction-pair elements; the sharp temperature gradient over the component cross-section, which is due to the low thermal conductivity of plastics; the formation of an intermediate lubricating layer under forced regimes as a result of melting of wire incorporated into the plastic.

The asbestos-rubber materials 6KKh-1 and 6KV-10, press-materials of the KF type, and other materials are suitable for use in the brakes and clutches of automobiles, tractors, and other machines where the temperature reaches 120° for prolonged periods and 200° for brief periods at $p \leq 8$ kg/cm^2. Retinaks can withstand temperatures of up to 400-

TABLE 5

Logarithmic Oscillation Decrement ($\delta \cdot 10^3$) for Various Materials

Материал 1	2 Температура (°С)			
	20	100	200	300
Стеклотекстолит ВФТС: 3 а) по основе	29	87	84	61
б) под 45° к основе	63	244	253	187
Пенопласт ФК-20-А20 4	248	109	108	104
5 Ситалл	1.2	1.2	1.4	1.6
Стекло силикатное 6	6.6	7.4	9.6	9.6
Сталь 7 аустенитная	0.15	0.14	0.13	0.11

1) Material; 2) temperature (°C); 3) VFTS glass textolite; a) along warp; b) at angle of 45° to warp; 4) FK-20-A20 plastic foam; 5) sitall; 6) silicate glass; 7) austenitic steel.

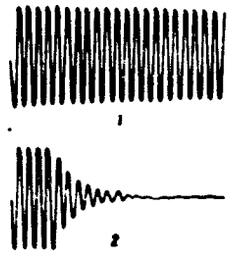


Fig. 7. Damping of free oscillations: 1) Duralumin 2 mm thick (δ = = 0.02); 2) duralumin sheet faced on one side with 8-mm layer of plastic foam (δ = 0.89). Damping decrement for panels δ = 0.34.

500° for extended periods and 1000-1100° for short periods at $p \leq 50$-60 kg/cm^2; type FK-16L is used in aircraft wheel brakes and type FK-24A is employed for the brake shoes of caterpillar excavators and oil-drilling winches.

Promising materials for heavily loaded brakes (t = 1000°) are porous cermets impregnated with synthetic resins, which lack the shortcomings of cermets of the FMK-8 type, particularly grabbing at low temperatures.

Certain plastics are used in ship building for deck coatings in order to eliminate slipping.

Vibration-insulating and sound-absorbing plastics. Shock absorbers (pliable elastic elements that reduce the true frequency of the system) are used to reduce shock and insulate objects from sources of vibration. Shock absorbers with low rigidity can be produced by selecting appropriate structural elements (springs, which can be fabricated from steel or oriented glass plastics) and using a material with high elasticity (packings of elastomers) and an appropriate macrostructure (foam compounds: $E < 1000$ kg/cm^2).

If the frequency of the disturbing forces is variable and the possibility of operation under resonance regimes cannot be excluded (highway jolting, locking, the starting and speed-up periods of machines, etc.), external and internal frictional forces are quite important in damping oscillations. Mechanical energy is dissipated during damping, often being converted to thermal energy. Damping in polymers results from hysteresis losses due to phase shifts between the stress and the deformation and to viscous resistance during diffusion or chemical flow. Mechanical losses due to a change in vibration frequency pass through a maximum when the deformation period equals the relaxation time (plastics have a broad range of possible mechanical-equilibrium times) and depend on the temperature.

Plastics exhibit an internal friction 10-1000 times that of metals (Table 5). This is important in raising the fatigue strength of resonant components and increasing passenger comfort (replacing spring seats with polyurethane-foam seats, reducing the acoustical radiation of vibrating elements, etc.).

Replacing thin metal facings with plastic facings or gluing plastic foams or isols to them promotes damping of oscillations (Fig. 7)

and attenuation of noise. Pairing polyamide gears with metal gears reduces noise level by 6-12 db (a decrease in loudness of 50-75%).

Porous materials with a low acoustical resistance (2-20,000 acoustical ohms) are highly sound-absorbent. The sound-absorption coefficient of plastic foams is 10-60% at 100-300 cps and 60-95% at 300-1500 cps. Plastic foams with open pores have a higher sound-absorption capacity than those with isolated pores. Fiber mats, plastic foams, and other sound-absorbing plastics are used to reduce echoes, especially in metal structures (the holds of ships, the compartments of submarines, etc.), and to lower the acoustical conduction of partitions.

Heat-insulating and heat-protective plastics. The thermal conductivity of plastics is less than that of metals by a factor of several hundred (see Table 6). This is generally a great advantage of plastics, but in some cases (chemical heat-exchange equipment, friction pairs, jet-engine nozzles, etc.) it is a drawback easily eliminated by addition of an appropriate filler (graphite, powdered metals, wire grids, etc.).

The thermal conductivity of plastic foams is lower than that of monolithic plastics by an average factor of 10. Heat transfer in porous materials with thin partitions is due to a considerable extent (50-70%, depending on the structure of the material and the temperature, which determines the proportion of radiated heat) to the thermal conductivity of air. Heat transfer by gaseous convection is hampered by small closed pores. Plastic foams with $\gamma = 0.05$-0.2 g/cm^3 are consequently excellent heat insulators at low and moderately high temperatures (up to 150-250° and up to 300-400° for silicoorganic foams). At higher temperatures they are replaced by fiberglass, asbestos, or ceramic insulation. These materials are less vibration-resistant and more difficult to fix in structures.

TABLE 6

Thermophysical Characteristics of Plastics and Other Materials

Материал 1	2 Теплопроводность (ккал/см × сек · град)	3 Удельная теплоемкость (кал/г · град)	4 Температуропроводность (см² сек)	Коэффициент линейного расширения 5 $\alpha \cdot 10^6$ (1/°C)
6 Пенопласты ($\gamma \approx 0.2$)	$(1.1-1.6)\ 10^{-4}$	0.4 —0.5	$(1.2-1.7)\ 10^{-3}$	20—80
7 Полимеры ненаполненные	$(0.2-0.5)\ 10^{-3}$	0.25—0.7	$(0.6-1.1)\ 10^{-3}$	75—180
8 Стекло- и асбопластики	$(0.8-1.4)\ 10^{-3}$	0.2 —0.4	$(1.5-3.0)\ 10^{-3}$	1—10
9 Дуралюмин	0.3	0.22	0.5	22
Сталь	0.17	0.11	0.2	12
10 Стекло силикатное	$(0.1-3.2)\ 10^{-3}$	0.08—0.2	$(0.1-1.0)\ 10^{-3}$	0.5—12
11				

1) Material; 2) thermal conductivity (cal/cm·sec·degree); 3) specific heat capacity (cal/g·degree); 4) temperature conductivity (cm^2/sec); 5) coefficient of linear expansion $\alpha \cdot 10^6$ (1/°C); 6) plastic foams (γ = = 0.2); 7) unfilled polymers; 8) glass and asbestos plastics; 9) duralumin; 10) steel; 11) silicate glass.

TABLE 7

Heat Absorbed (q) and Relative Volume (v) of Gas Liberated on Heating Various Substances from 20 to 4700° (Rough Values)

1 Вещество	2 q ккал/кг	3 v моли/кг
4 Водород	4700	1.00
5 Предельные полимеризованные углеводороды	1.0	0.1
6 Непредельные полимеризованные углеводороды	0.5	0.1
7 Политетрафторэтилен	0.5	0.05
8 Графит	0.5	0.05
9 Бериллий	0.5	0.05
10 Двуокись кремния	0.5	0.02

1) Substance; 2) kcal/kg; 3) moles; 4) hydrogen; 5) saturated polyhydrocarbons; 6) unsaturated polyhydrocarbons; 7) polytetrafluorethylene; 8) graphite; 9) beryllium; 10) silicon dioxide.

Plastic foams (mipor, PS-1, PS-1U, PKhV-1, PU-101, etc.) are used for heat insulation in refrigerators and for heat and sound insulation in aircraft cabins, automobile bodies, railroad cars, and ships.

Plastics have a heat capacity 4–6 times that of metals and this, in conjunction with their lower temperature conductivity, improves their heat-insulating characteristics on nonstationary heating.

Plastics can successfully be employed as a heat-protective struc-

tural material in the manufacture of external shielding elements for rocket nose cones, which are subject to intensive aerodynamic heating for brief periods (from seconds to minutes) during re-entry (the braking temperature reaching 10,000-15,000° and the thermal flux 5500 kcal/m^2·sec), and of internal heat shielding for jet-engine chambers. In such cases the plastic undergoes Ablation. A considerable portion of the heat conducted away is expended in endothermal sublimation, evaporation, and pyrolysis; the protective gas layer formed (Table 7) and the material itself accumulate a great deal of heat and the low thermal conductivity of plastics keeps these large thermal fluxes from penetrating the structure.

Different types of plastics, ceramics, honeycomb ceramics, ceramic plastics, and other materials vary in effectiveness under different heating conditions (gas-flow rate and pressure, temperature, gas composition, degree of gas dissociation, presence of abrasive combustion-product particles, etc.). Plastics are generally more resistant to thermal shock and vibration, but less erosion-resistant. When some variation in aerodynamic contours is permissible phenolic plastics reinforced with polyamide, asbestos, glass, or ceramic cloth or fiber is usually the best shielding material for protection against external heating.

Electrical and radio-engineering plastics. As a result of their high dielectric characteristics, satisfactory heat resistance, and high strength, plastics have come into wide use in electrical engineering and radio-electronics as electrical-insulating and radio-transparent materials.

Phenolic, aniline, and melamine materials and other plastics having a deep resistance of 10^{9}-10^{14} ohm·cm and a breakdown voltage of 4-20 kv/mm are good dielectrics for high-current applications. Amino

plastics are less water-resistant than phenolic plastics, but have a higher arc-resistance and are used in conjunction with silicoorganic plastics (K-41-5, KMK-218, K-71, etc.) in electrical ignition systems for internal-combustion engines, high-voltage switches for arc-extinction chambers, contactors, etc. Silicoorganic insulation is resistant to prolonged heating at 200° and can briefly withstand heating to 250° or above; it is used for the windings of electric motors intended to operate under water. Polyvinyl chloride, polyamides, epoxy resins (sealing compounds), polyurethanes, acetals, and polyethyle terephthalate are used as low-frequency insulation for transformers, leads, and cables.

The best dielectrics for high-frequency engineering are polystyrene, polyethylene, fluoroplast-4, etc. These materials have a dielectric-loss angle whose tangent ranges from $2 \cdot 10^{-4}$ to $5 \cdot 10^{-4}$ at 10^6 cps, a dielectric permeability of 1.9-2.6, an electric strength of 20-40 kv/mm and a deep resistance of 10^8-10^{15} ohm·cm. A high dielectric permeability is undesirable when alternating current is used, since it increases dielectric losses; on the other hand, the capacitance of radio capacitors increases with this index. In plastics the value of ε is regulated by the degree of porosity (reaching 1.01 in plastic foams) and the filler content and composition. Different types of polymer and inorganic materials or combinations of such materials are employed, depending on the voltage, frequency, temperature, humidity, mechanical load, and technological and structural characteristics of the system. Radiotransparent materials (plastic foams, cellular materials, and glass textolite) are used in the manufacture of radar detectors and antennas for aircraft and rockets, the latter absorbing aerodynamic and thermal loads and insuring a high pass coefficient for electromagnetic waves while leaving their direction unchanged. There are also radio-

absorbing materials with a low reflectivity for e ctromagnetic waves. The good electrical-insulating characteristics of getinaks, polyethylene, fluoroplasts, etc. (with a skin resistance $\rho_s = 10^{10}$-10^{18} ohms) permits their use as bases in the manufacture of printed circuits.

Plastics with nonmagnetic properties (having a magnetic permeability $\mu < 1$ and independent of the intensity of the applied field) are used in the construction of mine sweepers, ships for studying the earth's magnetic field, etc. Plastics are employed in the production of magnetodielectric cores (a resin and a powdered metal) with low losses due to eddy currents and hysteresis and stable magnetic characteristics.

Plastics with optical properties. Many thermal plastics are transparent in visible light, as is organic glass based on polymethylmethacrylate, etc. Plastics with high transparency (equivalent to that of quartz) and atmosphere resistance, which are used for windows and in the production of lenses, are easily distinguished from silicate glasses by their low specific gravity, lack of brittleness (down to temperatures of -60° or below), and resistance to mechanical and thermal shocks; they are readily molded into articles with complex curves, are cutable, and can be reliably welded and glued. Organic glass has a lower working temperature (up to 100-200°) and abrasion resistance than silicate glass and is more combustible. This material passes the ultraviolet portion of the solar spectrum (up to 320-340 mμ), which is blocked by ordinary silicate glass. Preliminary orientation (planular drawing) or orientation during molding increases the "silvering resistance" and plasticity (impact strength) of organic glass by a factor of 2, raises its tensile elongation by a factor of 2 or more, reduces its sensitivity to stress concentrations, and increases the localization of fracture on bending.

Thermostabilized and new heat-resistant plastics are used for glazing the lights of high-speed aircraft; double windows and safety glass are also employed, the latter being a laminated glass bonded with a clear elastic polyvinylbutyral or silicoorganic film, giving it protective characteristics and reducing the danger of decompression of the cabin. Organic glass is used in the manufacture of face-guards for cosmonauts' helmets, components for illuminating equipment, watch glasses, light-conduction devices, and optical lenses (with an index of refraction of 1.489-1.547). Plastics with a high optical stress coefficient (10-130 brewsters), including celluloid, ED-6 resin, styrene-alkyd mixtures, gliftamal, viskhomlit, cast resite, etc., are used as models in studying stresses by photoelasticity methods.

Chemically stable plastics. The covalent nature of the chemical bonding among polymer atoms causes the majority of plastics to be more resistant to liquid (water, salt solutions, acids, alkalis, etc.) and gaseous media than are metals or silicate glasses. Polystyrene, polyethylene, fluoroplasts, and pentaplasts are the most water-resistant (their gain in weight over 24 hr being less than 0.01%). Urea-formaldehyde plastics with cellulose fillers, ether-cellulose plastics, and laminated wood plastics exhibit high water absorption. Absorption of moisture is associated with changes in weight and size, development of internal stresses, deterioration of electrical-insulating and radio-engineering characteristics, and loss of strength, although the coefficient of friction decreases (this is important for laminated wood plastics). The majority of plastics, with the exception of polyethylene, polyisobutylene, and vinyl plastics, are resistant to mineral oils, gasoline, and kerosene. Fluoroplast-4 is chemically more stable than gold or platinum; it is absolutely resistant to acids, alkalis, and organic solvents, even when heated to 150-250°. Fluoroplast-3 is less

stable in fuming sulfuric acid, mixed hydrochloric and nitric acids (3:1), chlorsulfonic acid, and certain solvents (benzene, toluol, etc.) at elevated temperatures.

Among the plastics suitable for use in various highly aggressive media (other than oxidizing acids) are polyethylene, polypropylene, polyisobutylene, polystyrene, copolymers based on fluorine and chlorine derivatives of ethylene, vinyl plastics, epoxy plastics, polyurethane, pentaplast, faolite, asbestos vinyl, phenolite, dekorrozit, asphalt-pitch mixtures, etc. These plastics are used in the manufacture and lining of tanks, pipes, fittings, fixtures, baths, rectification-column components, and other components and units of equipment for the chemical, petroleum-refining, wood-pulp, and textile industries and other branches of technology.

Plastics with characteristics that provide protection against penetrating radiation. Organic plastics contain large amounts of hydrogen (the volumetric hydrogen concentration in polyethylene is 16% higher than that in water), have a low residual activity and satisfactory radiation resistance, and are employed for biological shielding against neutron radiation. Polyethylene retains its mechanical characteristics on neutron irradiation at levels of up to 10^{17} neutrons per cm^2.

Capture γ-radiation can be absorbed when boron is added to plastics. Polyethylene slabs in combination with lead sheets are used for shielding atomic reactors. Plastic foams with barium fillers are employed in x-ray equipment. Plastics are also used in individual protective devices for working with radioactive substances.

Methods for Converting Plastics to Finished Products

These materials are produced in the form of semifinished products (press-powders, granules, casting compounds), which are subjected to further processing, or working plastics, which are molded from mixtures

of the appropriate composition (sheets, slabs, rods, films, and other finished materials) and converted to finished products by stamping, pneumatic forming, cutting, gluing, welding, etc. Selection of a method for fabricating plastic products is dictated by the purpose for which the product is intended, its design and dimensions, the production scale, the type of initial plastic, the filler, and the binder. The parameters of the technological process are determined principally by the binder. The principal methods of forming plastics are: 1) pressing, used primarily for reactive plastics (see Pressing of plastics); 2) casting pressing of plastics with powdered fillers (this method is suitable for components which must be dimensionally precise or which have through reinforcement or deep small-diameter holes). Typical processing regimes entail a pressure of 70-500 kg/cm^2 (depending on the type of filler, a fibrous filler requiring a higher pressure) and a temperature of 130-180° for phenolic plastics and 140-210° for press-materials based on silicoorganic resins; 3) pressure casting (injection pressing); this method is distinguished by a short process cycle (the plastic is preliminarily heated) and does not require tableting, pressing, or removal of burrs; it is not recommended for thick-walled (3-4 mm) components or components with a varying wall thickness. Table 6 shows guideline regimes for pressure-casting plastics. Methods 1, 2, and 3 are used for producing small and medium components weighing 5-10 kg; 4) free (simple) casting of thermoreactive (with or without hardeners) and thermoplastic resins in molds; this method is used for manufacturing clear plastic sheets with high optical characteristics and for producing blanks and finished products from phenolic plastics (cast resite), capromide, and other plastics; 5) extrusion of material compacted and heated until plastic in worm or plunger machines. This method is employed for sheathing insulated leads; 6) stamping of three-di-

mensional components from sheet materials, principally unfilled thermal plastics and plastics with powdered and fibrous fillers. Because of their low ductility (3-5% for glass textolite) laminated plastics, even those with low-viscosity thermoplastic binders, cannot be deep-drawn. This method permits fabrication of large articles without using high-power hydraulic presses (a stamping pressure of 0.7-5.0 kg/cm^2 is employed). Stamping can be carried out with a rigid punch and matrix in a closed die, with a rigid punch having a pressure plate or ring, and by vacuum or pneumatic forming in a die; 7) blowing, which is widely employed in the production of hollow products (bottles and other containers) of polyethylene and other thermal plastics. Units consisting of an extruder, which gives a tubular blank, and a vertical automatic machine with several interchangeable molds, in which the hot blank is inflated with compressed air under a pressure of 1.5-3 kg/cm^2 and then cooled, are highly efficient; 8) vacuum forming ($p = 0.5-0.8$ kg/cm^2), which is used for plastics with "contact" binders that harden without liberating gaseous products. The vacuum promotes removal of volatile substances from the material; 9) pneumatic forming ($p = 1-5$ kg/cm^2) in pressforms (the component is placed in the closed space between the rigid and elastic portions of the form), which insures production of high-quality monolithic articles with the majority of binders. This method is employed in the production of multilayer articles with an intermediate layer of cellular plastic or plastic foam, such as antenna deflectors. In the former case the outer shell (usually of glass textolite) is molded, the cellular plastic and inner shell are placed on it, and the entire article is pressed at once; in the latter case, for instance when using a polyurethane filler, two shells of glass plastic are molded and the space between them is filled with a polyester isocyanate mixture, which is then frothed and hardened. High-quality ra-

dio-engineering products of glass plastics are obtained by placing a blank between a punch and a pressform matrix, hermetically sealing it, and pumping binder into it under a vacuum. The autoclave molding method (with a pressure of 5-25 kg/cm^2) is expedient for production of large batches of massive or complex components. Subterranean tanks, cylindrical containers, radar deflectors, and other fiberglass products with round or elliptical cross-sections can be fabricated on centrifugal equipment; 10) winding, which is employed for producing pipes and other products. By varying the angle at which the fibers, thread, braiding, or strips are wound, the relationship of the longitudinal layers, or the direction of the warp and woof in cloth it is possible to obtain a desired strength ratio in different directions. Glass plastics have a high strength (σ_b = 6000 kg/cm^2) in wound products. This method is employed in the manufacture of high-pressure balloons, the housings of powder-fueled rocket engines, etc.

TABLE 8

Guideline Regimes for Pressure-Casting Plastics

1 Материал	2 Темп-ра на выходе из сопла цилиндра (°С)	3 Темп-ра пресс-формы (°С)	4 Удельное давление ($кг/см^2$)	5 Выдержка под давлением в пресс-форме (сек.)
6 [illegible]	[illegible]—200	25-60	800—1500	От 10 до 180
7 полистиров	150—215	25—60	800—15[illegible]	10 и зависимости от толщины стенки деталей и др. усло-
8 Полиэтилен	175—260	45—80	100-[illegible]	
9 Полиамиды	200—280	50—135	150-800	

1) Material; 2) temperature at discharge from cylinder nozzle (°C); 3) pressform temperature (°C); 4) pressure (kg/cm^2); 5) holding time under pressure in press-form (sec); 6) etrols; 7) polystyrene; 8) polyethylene; 9) polyamides; 10) from 10 to 180, depending on the wall thickness of the component and other factors.

Plastic semifinished products and components are manufactured by: calendaring; production of finished articles from plastizols (particularly polyvinyl chloride pastes) by centrifugal casting (hollow balls, life preservers, etc.), immersion, or smearing the paste on a mold;

tableting and sintering of components in molds; casting films on continuous strips and other processes. A new method for processing plastics (based on caprolactam, polyesteracrylates, etc.) that uses oligomer compounds has been developed and perfected. In contrast to methods for molding finished thermal plastics (high-molecular compounds), this procedure does not require high temperatures or pressures, permits casting with virtually no shrinkage, and makes it possible to mold articles with improved physicomechanical characteristics. A promising technological variant involves filling molds with liquid intermediate products, which are converted to the desired polymer directly in the mold.

In pressing large articles (automobile bodies, boat hulls, the skin of aircraft wings or fuselages, etc.) the pressure is transmitted to the surface of the component through an elastic (usually rubber) jacket. The manufacture of large articles from fibrous or laminated plastics consists in producing a filler blank, impregnating it with binder, and pressing it. Laminated materials (cloth, laminated glass, etc.) or fiber mats are laid out by the "wet" method, in which the binder is applied during positioning of the filler blank (in which case it is difficult to obtain a uniform binder distribution), or by the "dry" method, in which the filler is impregnated beforehand with binder and dried (in which case it is difficult to lay out complex forms). In laying out and positioning the materials one should attempt to insure that the component is uniformly strong or, conversely, to reinforce it in the requisite directions. Cut-fiber blanks are obtained by building-up in air, dispersion, or suction in water. Pressing is carried out in press-forms of the negative type, which yield products with a smooth outer surface, or in simpler press-forms of the positive type, which permit production of articles with a smooth inner surface. Press-forms

of the first type are used for products that must have high aerodynamic characteristics (aircraft radar deflectors, outside antennas, other aircraft and rocket components, cutter hulls, etc.). Positive press-forms are more efficient, facilitate arrangement of the fillers, and are more convenient for producing reinforced shells.

Small series of large, lightly loaded components are molded by contact pressure. Materials based on cold-setting polyester or epoxy resins are rolled while being laid out; setting occurs without pressure, often at the ambient temperature. This method is quite simple, but its productivity and the quality of the finished product are low. See also Machining of plastics.

Methods of Joining Plastic Components

The principal methods for joining plastic components are gluing and welding. Gluing (see Gluing of plastics) is a general-purpose method for reliable inseparable joining of components of any plastic to one another and to other materials. Thermal plastics can be strongly butt- or lap-welded by various methods, which differ in the procedure employed for heating the surfaces to be joined. The most common techniques are contact thermal welding (with a heated tool) and gas-thermal welding (not recommended for fluorine-containing plastics; nitrogen must be used instead of air for polyethylene and polyamides). Other welding methods involve high-frequency current (except for polystyrene and other nonpolar polymers), ultrasound, infrared light, ionizing radiation, and (less frequently) friction, flames, or a molten additive material. The induction-contact method is quite promising for metal-reinforced plastic components. Plastics with a narrow thermoplasticity range ($T_{destruction} - T_{softening}$) are best welded in a compressed-gas atmosphere. The elements of large glass-plastic structures are produced by molding: the edges of the hardened components are joined with a

strip of resin-impregnated cloth or the components are stacked and the ends of the cloth filler are pressed. The first method is employed in mending holes and performing other repairs, while the second is used to produce butt and corner joints. Each of the two joiner strips should have a thickness equal to no less than 0.6 of that of the components to be joined, but should be 25 times as long. Laminated plastic sheets can be joined to one another and to other materials by riveting (see Glued-riveted joints). Soft plastics (polyethylene, fluorine-containing plastics) are unsuitable for riveting. Sealers are employed to make riveted joints hermetic. Threaded joints are preferable to riveted joints for unfilled and powdered plastics. Plastic components are occasionally fastened with bolts, but care must be taken to avoid local overloads in tightening them; it is recommended that the bolt head and nut be twice the normal diameter. Instead of using a rigid bolted joint, the clear plastic of aircraft lights is often held in place with a flexible fastening; for this purpose strips of lavsan or capron are glued to both sides of the plastic or a metal grid is polymerized into it, resting against a retaining ring.

Threaded joints are used principally for joining medium and large plastic components to metal components. Considering the low resistance of laminated plastics to shear parallel to their layers, load-bearing threads must be trapezoidal in shape and have a broad base. It is recommended that threads in fibrous-plastic components be made by molding rather than machining (cutting the fibers). A number of metal-plastic components are joined by press-fitting (pressing in plastic bushings, pressing toothed rims of plastic on metal gear blanks).

Plastic components can be fastened in the same manner as metal components, utilizing metal reinforcing and fastening elements molded into them.

TABLE 9

Use of Plastics in the Manufacture of Machine Components and Units and Technological Equipment

1 Детали и узлы машин, технологическая оснастка	2 Условные номера видов пластмасс	Детали и узлы машин, технологическая оснастка	Условные номера видов пластмасс
3 Зубчатые и червячные колеса	1, 9—11, 16, 17[1], 20, 21	16 Износоустойчивые покрытия металлических изделий	1, 3[3], 8
4 Шкивы, маховички, ступицы	4, 9, 11, 12[1], 14—18, 20	17 Кожухи, крышки, резервуары, корпусы редукторов	1, 2, 6, 7, 10, 11, 15, 16, 20—22 (4, 12, 13, 17)[1]
5 Ролики, катки, бегуны	1, 2[1], 4, 11, 13[1], 14—23	18 Рукоятки, штурвалы; кнопки, колпачки	4, 6, 7, 11—14, 16, 18
6 Подшипники скольжения (вкладыши, втулки), буксы, полуники, подпятники	1, 3, 11, 12[2], 14, 17, 18, 20, 21, 23	19 Детали точной механики часов, счетных машин, реле времени, измерительных и регулирующих приборов, автоматов	9, 10, 11
7 Направляющие станков	1, 11, 14, 20, 21	20 Болты, гайки, шайбы слабонагруженные	1, 4, 10, 11 24, 25
8 Детали шарикоподшипников	1, 9, 11	Пружины, рессоры	
9 Тормозные колодки и накладки, ленты и диски сцепления	15, 22	22 Кулачковые механизмы, клапаны и др. детали аппаратуры	
10 Облицовка грузоподъемных барабанов, шкивов трения	15, 20, 22	23 машин, воспринимающие удар ные нагрузки	1, 6[2], 11, 14
11 Трубы, фитинги, детали арматуры	1, 2, 4, 7, 9, 15, 16, 19[2], 24, 25	Крупногабаритные элементы конструкций, несущие нагрузки, корпусы, емкости, лотки и т. д.	20, 23—25
12 Фильтры, вентили и др. детали масляных и водных систем	1—7, 9, 12, 13, 18[3]	24 Электроизоляционные детали, панели, щитки, корпусы приборов	1—14, 16, 17, 19, 21—25
13 Рабочие органы вентиляторов, насосов и др. гидромашин	1, 2, 4, 9, 11, 25	25 Светопропускающие и оптические детали (линзы, смотровые стекла и др.)	7, 10 (1, 4, 6, 13, 25)[2]
14 Уплотнения (манжеты, прокладки, сальниковые набивки), мембраны	1—3, 5, 11	26 Копиры, контрольные шаблоны	12[2], 17, 19, 21, 23, 25
15 Антикоррозионные покрытия металлических деталей, облицовка химической аппаратуры	1—5, 8, 9	27 Холоднолистовые штампы	16, 20, 23, 25 (18, 12)[2]
		28 Литейные модели	8, 12, 25

Footnotes: 1. For lightly loaded components. 2. Special compositions. 3. For water-free media.

Arbitrary Designations: 1) Polyamides; 2) polyethylene, polypropylene, and other ethylene-based plastics; 3) fluorine-containing plastics; 4) rigid vinyl plastics; 5) plasticized vinyl plastics; 6) polystyrene and its copolymers; 7) acrylic plastics; 8) epoxy plastics; 9) pentaplast; 10) polycarbonates; 11) polyformaldehyde; 12) phenolic press-powders, 13) carbamide press-powders; 14) voloknit and cordovoloknit; 15) asbestos voloknit; 16) glass voloknit; 17) textolite press-powder; 18) wood press-powder; 19) getinaks; 20) laminated wood plastics; 21) textolites; 22) asbestos textolites; 23) glass textolites; 24) oriented glass plastics of the SVAM type; 25) glass-plastic sheets wound from glass mats with contact-type binders.

1) Machine components and units, technological equipment; 2) arbitrary numbers designating types of plastic; 3) gears and worms; 4) pulleys, flywheels, hubs; 5) casters, rollers, travelers; 6) sliding bearings (bushings) axle bearings, sliding contacts, footstep bearings; 7) machine-tool guides; 8) ball-bearing components; 9) brake shoes and linings, clutch bands and discs; 10) winch-drum facings, friction pulleys; 11) pipes, fittings, and reinforcement components; 12) filters, valves, and other oil- and water-system components; 13) working elements of ventilators, pumps, and other hydraulic machinery; 14) sealing elements (cups, gaskets, packing glands), membranes; 15) anticorrosion coatings for metal components, linings for chemical equipment; 16) wear-resistant coatings for metal components; 17) casings, lids, tanks, reduction-gear housings; 18) handles, steering wheels, nobs, caps; 19) precision components for watches, computers, time relays, measuring and monitor-

KEY TO TABLE 9 (continued)

ing instruments, and automatic machinery; 20) lightly loaded bolts, nuts, and washers; 21) springs; 22) cam mechanisms, valves, and other machine and equipment components subject to impact loads; 23) large load-bearing structural elements, housings, tanks, trays, etc.; 24) electrical-insulation components, panels, switchboards, instrument housings; 25) light-transmissive and optical components (lenses, inspection windows, etc.); 26) copies, control patterns; 27) cold-sheet dies; 28) casting models.

Principal Trends in the Use of Structural Plastics in Technology

The Soviet and world production of plastics and their proportion in the output of structural materials is continually increasing. Table 9 shows the uses of plastics in the manufacture of machine components and units and technological equipment. Introduction of plastics into the national economy is one means of technical progress. Their wide utilization will permit: 1) solution of the fundamentally new problems raised by modern technology (rocket and aircraft building, atomic energy, radio-electronics, etc.); 2) improve the technical and operational characteristics of machinery (reduce its weight, increase its durability and reliability, etc.), which will in turn improve the flight and running characteristics of aircraft, seagoing and river vessels, automobiles, and other means of transportation (increasing their ceiling, speed and maneuverability and reducing the wear on paved highways and railroad tracks); thus, for example, use of retinaks in aircraft wheel brakes permits an increase in their loading and a reduction in landing run. Turbine-drill veins of capron or polypropylene are cheaper than veins of other materials by a factor of 10-15 and increase drill efficiency by 10-15%; in the hydraulic mining of coal glass-plastic conveyors are 50% lighter and cheaper than metal conveyors; 3) reduction of the labor consumed in manufacturing finished products; 4) reduction of the cost of finished products; 5) curtailment of production-cycle time;

when ferrous metals are replaced by cast plastics the labor consumption of production processes drops by a factor of 5-6 and their cost is reduced by a factor of 2-6. The cost of large loaded glass-plastic structures is equal to or somewhat higher than that of steel structures, but this is compensated for by the operational advantages of glass plastics; 6) a savings in scarce ferrous and nonferrous metals and semifinished products (tubes, thin sheets) by substitution of polymer materials, which affords a simultaneous decrease in cost by a factor of 4-9; 7) simpler replacement of worn friction-unit and other components; 8) an improvement in working conditions (a reduction in noise when plastic is used for machine transmission gears, a reduction in the weight of manual electrical and pneumatic tools; replacement of lead printing type with plastic type eliminates an occupational health hazard).

The heat-insulating characteristics and sanitary-hygienic advantages of plastics (ease of dust removal, passage of ultraviolet light, etc.) make them promising decorative and trim materials (for the appointments of railroad passenger cars, steamship staterooms, and aircraft cabins, household articles, etc.).

The selection of a given type of plastic for a specific application is governed by the conditions under which the plastic or compnents fabricated from it are to function (air, vacuum, water, steam, aggressive media, solar radiation, temperature range, stress level, loading regime, transparency, erosion-resistance, and special requirements with respect to hermeticity). The selection of a material, the designing of the component, and the fabrication method should be interrelated. Thus, in glass-plastic structures the reinforcing elements should be arranged in such fashion as to insure maximum strength in the direction of maximum stresses; for wound components intended to function under internal pressure the angle at which the threads or strips are wound and the

number of threads or strips in different directions must be selected in accordance with the conditions to be encountered. Among the promising procedures are the new high-efficiency processes for fabricating finished products from filled plastics, including those with unwoven fiberglass reinforcing materials (continuous drawing of shapes in automated production lines, etc.), as well as those for molding large components without heating or use of high pressures (employing oligomers, etc.).

So-called "composite" polymer materials, which are combinations of polymers with metallic, silicate, or ceramic materials in various proportions and spatial arrangements (in the form of particles, fibers, ovoids, layers, etc.), have come into wide use. They include different types of filled plastics, ceramic plastics, safety glass consisting of organic and silicate glass (with an elevated impact resistance), terials (metal-plastics, which consist of a rolled metal sheet with a thin layer of plastic applied to one or both sides), lined pipes, surface-metallized films and cloth (laminar vacuum insulation in cryogenic engineering, shielding against electromagnetic fields), sandwich panels, and filled sheathing. In such panels the external facings are made of thin high-strength materials, such as metal, glass textolite, etc. Between them and glued to them is an intermediate layer of a light filler (plastic foam, honeycomb paper, cloth, or metal foil). The filler should insure that the thin facings work together and prevent loss of stability on compression. The structure consequently has high strength and rigidity combined with low weight. Laminated panels with a porous filler are used as heat and sound insulation. In conjunction with film materials they can be employed to shield spacecraft from damage by micrometeorites.

In contrast to synthetic fibers, which serve principally as semi-

finished products, polymer films of polyvinyl chloride, polystyrene, polyethylene, and other plastics have important independent uses. Films are necessary for protecting machinery, for insulating structural elements from wastes, as containers in the foodstuffs industry, in the manufacture of capacitors, and in the production of gas-impermeable elastic materials for inflatable structures, balloons, parachutes, and soft floating containers for transporting petroleum. Film materials based on polycarbonates, fluorine-containing plastics, and polyacrylates can be employed as movie film and for sound-recording tape.

The creation of plastics with given characteristics for specific components and units and the development of reliable methods for modifying their physicomechanical and technological characteristics by methods available to commercial enterprises are pressing problems. Work on the synthesis of new polymers with high heat resistance and semiconductive characteristics, which are based on changes in chemical composition (elemental-organic compounds, chelate polymers, etc.), is of great importance; attempts to regulate structure at the molecular and supermolecular levels (stereospecific polymerization, production of grafted and unitized copolymers, changes in degree of orientation and crystal habit, etc.) are also extremely valuable.

The technological and especially the operational characteristics of plastics are improved and stabilized by addition of substances that prevent destruction by heat, light, or thermal oxidation, increase water resistance (dressing of glass fillers), raise toxicity for microorganisms, reduce combustibility, etc.

The advances made by chemistry and technology in improving existing materials and developing new types of plastics and new processing methods are opening up prospects for still wider and more effective utilization of these materials in diverse structures.

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STRUCTURAL RADIO-ENGINEERING GLASS TEXTOLITE – laminar plastics based on glass cloth and polymer binders; they have good radio-engineering characteristics (low dielectric losses at high electromagnetic frequencies and stable dielectric permeability). Polyester, modified phenol-formaldehyde, and silicoorganic resins are most frequently employed as binders, epoxy resins being used less frequently. The glass cloth for these materials is produced from glass with an alkali content of no more than 0.7%.

TABLE 1

Basic Physical Characteristics of Radio-Engineering Glass Textolites

Свойства 1	2 Марка		
	3 СТ-911а	4 ВФТ-С	5 ФН
Удельный вес 6	1.71	1.7–1.8	1.54–1.59
Предел прочности (кг/см²) 7 при растяжении			
по основе 9	4300	4000	3500
по утку 10	–	2600	1950
при сжатии вдоль слоев 11	1535	1715	1070
при изгибе 12	2700	3375	2135
Модуль упругости при растяжении (кг/см²) 13			
по основе	210000	217000	188500
по утку	161000	–	98800
Удельная ударная вязкость (кг·см/см²)			
по основе 14	525	105	180
по утку	–	45	–
Водопоглощение за 24 часа (%) 15	1.2	1.15	1.55
Теплостойкость по Мартенсу (°С) 16	270–290	260	220–320

1) Characteristic; 2) type; 3) ST-911A; 4) VFT-S; 5) FN; 6) specific gravity; 7) ultimate strength (kg/cm^2); 8) on extension; 9) along warp; 10) along woof; 11) on compression along layers; 12) on bending; 13) modulus of elasticity on extension (kg/cm^2); 14) impact strength (kg·cm/cm^2); 15) water absorption over 24 hr (%); 16) Martens thermostability (°C).

In order to make the radio-engineering and mechanical characteristics of these materials more stable at elevated humidities glass cloth treated with compounds that form chemical bonds between the glass fi-

TABLE 2

Dielectric Characteristics of Various Types of Glass Textolites (at 100 100° cps).

Свойства 1	Марки 2		
	3 СТ-911а	4 ВФТ-С	ФН
Тангенс угла диэлектрических потерь	5		
в нормальных условиях 7	0.023—0.025	0.01—0.02	0.018—0.020
при 170° 8	0.021—0.025 (200 час.)	–	–
при 200°	–	0.022—0.03	0.018
при 240°	10	0.025—0.036	–
при 250°		–	0.021 (5 час.)
при 300°	–	–	0.018 (5 час.)
Диэлектрическая проницаемость			
в нормальных условиях 9	4.25—4.5	4.25—4.5	3.80—3.95
при 170°	4.2—4.6 (120 час.)	–	–
при 200°	–	4.5—4.8	–
при 240°	–	4.6—4.8	–
при 250°	–	–	4.05 (5 час.)
при 300°	–	–	3.81 (5 час.)

1) Characteristic; 2) type; 3) ST-911A; 4) VFT-5; 5) FN; 6) tangent of angle of dielectric loss; 7) under normal conditions; 8) at; 9)dielectric permeability; 10) hr.

bers and the binder are employed for special chemically active compounds are added to the binder. The dielectric characteristics of glass textolites for radio engineering depend on the type of binder and filler, the presence of special additives, and production technology. The binder content is 28-33%, which ensures the optimum mechanical properties necessary for structural materials and sufficiently stable radio-engineering characteristics.

Table 1 shows the basic physicomechanical characteristics of radio-engineering glass textolites.

The dielectric characteristics of these materials (Table 2) vary with the frequency of the electromagnetic field, the temperature, and the humidity.

Type VFT-S structural radio-engineering glass textolite has dielectric characteristics that vary relatively little at elevated temperatures and humidities, especially when it is produced at high pres-

sures. All glass textolites of this type exhibit a tendency toward an increase in dielectric permeability and tangent of angle of dielectric loss as the temperature is raised. The drop in these characteristics under the initial action of high temperatures is caused by a decrease in the density of the material resulting from destruction and elimination of low-molecular setting products.

Finished products are fabricated from structural radio-engineering glass textolite by contact, vacuum, and autoclave forming, in press chambers, and by hydraulic pressing. Textolites obtained by contact and vacuum forming, which are carried out under pressures of up to 1 kg/cm^2, have the lowest density. Articles fabricated in press chambers or by the autoclave method have a monolithic character and are distinguished by increased water and moisture resistance. Extremely high-quality large components are produced by forming with a rigid punch and die; when these are assembled they form a closed cavity, in which the glass cloth is placed and into which the binder is forced. Structural radio-engineering glass textolites are used in the manufacture of radio locating reflectors, various types of antennas, housings for radio equipment, load-bearing structural elements with radio transparent characteristics, etc.

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B.A. Kiselev

STRUCTURAL SHAPING BRONZE – a bronze used in the manufacture of load-bearing components which must simultaneously be corrosion-resistant and have special physical properties. These alloys include tin-free and tin shaping bronzes and are produced as various semifinished products: pressed and drawn round, square, and hexagonal bars (see

TABLE 1

Properties of Heat-Treated Specimens of Certain Structural Shaping Bronzes

Свойства и режимы термич. обработки 1	БрКН1-3 2	МНА13-3 3
Темп-ра закалки (°С) . .	850	900
Темп-ра отпуска (°С) 5	450	500
Время выдержки (часы) 6	2	2
$\sigma_в$ (кг/мм²) . . 7	70	100
δ (%)	20	5
HB (кг/мм²)	175	260

1) Properties and heat-treatment regimes; 2) BrKN1-3; 3) MNA13-3; 4) quenching temperature (°C); 5) annealing temperature (°C); 6) holding time (Hr); 7) kg/mm^2.

Bronze bars), pressed tubes with outside diameters of 50-200 mm, thin-walled tubes (see Bronze tubes), sheets, strips, bands, and wire (see Bronze wire, Bronze strips, Bronze sheets, and Bronze bands).

Semifinished products of aluminum bronzes alloyed with iron, nickel, and manganese are distinguished by high strength coupled with sufficiently high plasticity and impact strength. These alloys also have a high corrosion resistance, which makes them irreplaceable materials for load-bearing components in various types of chemical apparatus, ship building, aviation, and general machine building. Silicon-manganese (BrKMts3-1) and silicon-nickel (BrKN1-3) bronzes are also corrosion-

TABLE 2

Mechanical Properties of Structural Shaping Bronzes at Elevated Temperatures

Свойства 1	Температура (°С) 2				
	100	200	300	400	500
3 БрАЖ9-4					
σ_b (кг/мм²) 4	55	54	52	—	20
δ (%)	21	17	19	28	32
НВ (кг/мм²)	120	105	100	85	70
$a_н$ (кгм/см²) 5	6,3	5,5	3,1	—	2,7
6 БрАЖМц10-3-1,5					
σ_b (кг/мм²)	62	58	50	35	25
δ (%)	20	18	14	30	40
НВ (кг/мм²)	130	125	120	80	60
$a_н$ (кгм/см²)	5	5	—	5	4,5
7 БрАЖН10-4-4					
σ_b (кг/мм²)	65	65	55	50	30
δ (%)	10	10	10	8	15
σ_{100} (кг/мм²)	27	25	23	—	20
НВ (кг/мм²)	190	180	170	—	80
$a_н$ (кгм/см²)	4	4	4	—	2,5
8 БрКМц3-1					
σ_b (кг/мм²)	50	48	38	28	16
δ (%)	40	38	30	26	29
9 БрКН1-3					
σ_b (кг/мм²)	54	50	48	43	32
δ (%)	23	22	19	12	4

1) Property; 2) temperature (°C); 3) BrAZh9-4; 4) kg/mm^2; 5) kg-m/cm^2; 6) BrAZhMts10-3-1.5; 7) BrAZhN10-4-4: 8) BrKMts3-1; 9) BrKN1-3.

TABLE 3

Creep of Certain Structural Shaping Bronzes

Сплав 1	Полуфабрикат 2	Температура испытания (°С) 3	Предел ползучести (кг/мм²) за 1000 часов при удлинении (%): 4			
			0,001	0,01	0,1	1
Оловянно-фосфористая бронза (5,5% Sn, 0,24% P) 5	Прутки деформированные, d = 16 мм 8	200	—	—	9	—
		250	—	—	1,7	—
	Проволока тянутая, d = 32 мм (80% деформации) 9	150	3,5	22,5	—	—
		200	—	5,3	—	—
		250	—	1,9	—	—
Кремнемарганцовистая бронза (2,84% Si, 1,25% Mn) 6	Прутки тянутые, отожженные при 450°, d = 19 мм 10	200	—	5,6	10	—
		250	—	2,6	4,5	—
Алюминиевая бронза (7% Al)	Прутки деформированные 11	300	—	—	—	7
		400	—	—	—	2,1

1) Alloy; 2) semifinished product; 3) temperature (°C); 4) yield strength (kg/mm^2) over 1000 hr under tension (%); 5) tin-phosphorus bronze (5.5% Sn, 0.24% P); 6) silicon-manganese bronze (2.84% Si, 1.25% Mn); 7) aluminum bronze (7% Al); 8) deformed bars, d = 16 mm; 9) drawn wire, d = 32 mm (80% deformed); 10) drawn bars annealed at 450°, d = 19 mm; 11) deformed bars.

resistant and have rather high mechanical properties. As a result of the high plasticity of annealed BrKMts3-1 bronze it is used in the manufacture of thin sheets (0.05 mm thick). This alloy is cold-worked during rolling, acquiring high elasticity. The silicon-nickel bronze BrKN1-3 and the nickel-aluminum bronze MNA13-3 are dispersion-hardening alloys; their hardness and strength is raised by quenching and annealing (Table 1).

Aluminum-iron bronzes, especially BrAZhN10-4-4, and BrKN1-3 bronze have high hot strengths (Tables 2 and 3) and are consequently used in the production of components which must function at high temperatures (nuts, bolts, and other fasteners, guidesleeves, valve seats, etc.). The nickel-aluminum alloy MNA13-3, which contains 13% Ni and 3% Al, has an extremely high hot strength; its ultimate strength slowly decreases as the temperature rises, amounting to no less than 30-40 kg/$/mm^2$ at 600°. The strength of all these alloys increases when the temperature is reduced to −180°C), their plasticity also rising slightly. See Durable shaping bronze, Tool shaping bronze, Spring shaping bronze, and High-hot-strength shaping bronze.

O.Ye. Kestner

STRUCTURAL STEEL – low-carbon hot-rolled steel for welded and riveted structural assemblies.

TABLE 1

Classification of Rolled Steel by Thickness

Вид проката 1	Толщина (мм) 2		
	1-й разряд 3	2-й разряд 4	3-й разряд 5
Прутки 6 . .	До 40 9	40—100	100—250
Профили . . .	До 15	15—20	Свыше 20 10
Листы и широкие полосы 7 8	4 -20	20—40	40—60

1) Type of rolled product; 2) thickness (mm); 3) 1st category; 4) 2nd category; 5) 3rd category; 6) bars; 7) shapes; 8) sheets and broad strips; 9) up to; 10) more than.

TABLE 2

Mechanical Characteristics of Structural Steels

Сталь 1	$\sigma_т$ (кг/мм², не менее) по разрядам проката 2			$\sigma_в$ (кг/мм²) 3	δ_{10} (%), не менее 4	δ_5 (%), не менее 5	Загиб на 180° в холодном состоянии* 6
	1-й	2-й	3-й				
Ст. 0 7	—	—	—	не менее 32	18	22	$d=2S$
Ст. 2, 8							
Ст. 2 кп	22	20	19	34—42	26	31	$d=0$
Ст. 3 кп	24	22	21	38—40	25	27	
				41—43	22	26	$d=0,5S$
10				44—47	21	25	
Ст. 3 11	24	23	22	38—40	23	27	
				41—43	22	26	$d=0,5S$
				44—47	21	25	
Ст. 4, 12							
Ст. 4 кп	26	25	24	42—44	21	25	
				45—48	20	24	$d=2S$
13				49—52	19	23	
Ст. 5 14	28	27	26	50—53	17	21	
				54—57	16	20	$d=3S$
				58—62	15	19	

*S – specimen thickness,
d – straightening diameter.

1) Steel; 2) $\sigma_т$ (kg/mm², no less than) according to classification of rolled product; 3) kg/mm²; 4) δ_{10} (%), no less than; 5) δ_5 (%), no less than; 6) 180° bending in cold state; 7) St.0; 8) St.2; 9) St.2kp; 10) St.3 kp; 11) St.3; 12) St. 4; 13) St. 4 kp; 14) St. 5; 15) no less than.

Structural steel is produced in types St.0, St.2, St.3, St.4, and St.5 (according to GOST 380-60). Type St.3 is the most widely employed; it has high plasticity, which permits redistribution of stresses as a result of residual deformation, is susceptible to substantial cold working, has a low sensitivity to local heating and severe cooling, and welds well. Structural steel is produced in bars, sheets, and broad strips, which are classified by thickness as shown in Table 1.

These steels are subdivided into groups in accordance with the requirements which they satisfy:

A – steels which satisfy requirements imposed on their mechanical properties (St.0, St.2, St.2 kp, St.3, St. 3 kp, St.4, St.4 kp, St.5).

B – steels which satisfy requirements imposed on the chemical composition (M St.0, M St.2 kp, M St.3 kp, M St.3, M St.4 kp, M St.4, M St.5, B St.0, B St.3 kp, B St.3, B St.4 kp, B St.4, B St.5). For the chemical composition of structural steels smelted in open-hearth furnaces and Bessemer converters see GOST 380-60.

C – steels which satisfy requirements imposed on both their mechanical properties and chemical composition (V St. 2 kp, V St.3 kp, V St.3, V St.4 kp, V St.4, V St.5).

Converter steel has come into use (GOST 9543-60). Oxygen-converter steels are designated by the same trademarks, adding the letter K, e.g., VKSt.3 in group V and KSt.3 in group B.

Structural steels can be classified as killed, rimmed, or semikilled, depending on the extent to which they are deoxidized. Killed open-hearth steel has the highest characteristics (for type St. 3), is less cold-short, has a lower tendency to age after cold working, and welds better; its critical brittle-transition temperature, as determined on standard notched impact specimens, is considerably lower than for rimmed steel. To designate semikilled steel the letters ps are added to

the trademark, e.g., MSt.3ps and VSt.3 ps. Semikilled steel meets the norms shown in Table 2 for killed steel.

Killed St.3 steel satisfying group C requirements is used in welded structures which must function under very severe conditions (at low temperatures and under alternating dynamic loads). Table 3 shows the impact strength of rolled articles of this steel 12-25 mm thick.

TABLE 3

Impact Strength of St.3 Steel (no less than)

Вилы проката 1	Образец 2	a_n (кгм/см²) 3
Лист . 4	Поперек прокатки 7	7
Широкая полоса 5	Вдоль прокатки	8
Пруток, профиль 6	Вдоль прокатки 8	10

1) Type of rolled article; 2) specimen; 3) α_n (kg-m/cm^2); 4) sheets; 5) broad strips; 6) bars, shapes; 7) across article; 8) along article.

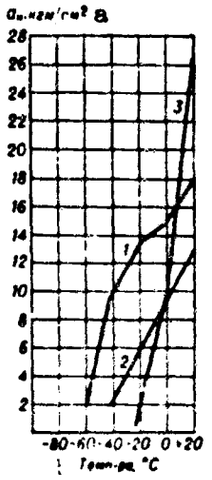

Fig. 1. Change in the impact strength of St.3 steel smelted by various methods as the temperature decreases: 1) Killed open-hearth steel; 2) rimmed open-hearth steel; 3) rimmed Bessemer steel. a) kg-m/cm^2; b) temperature, °C.

The impact strength of sheets of VSt.3 steel 12-20 mm thick should be no less than 3 kg-m/cm^2 after mechanical aging at 20° or in the as-delivered state at 20°.

Bessemer steel is the least reliable, especially when rimmed. It

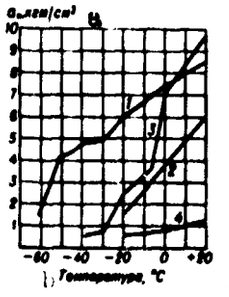

Fig. 2. Change in the impact strength of St.3 steel in various states as the temperature decreases: 1) Killed open-hearth steel in as-delivered condition; 2) killed open-hearth steel after cold-working and aging; 3) rimmed open-hearth steel in as-delivered condition; 4) rimmed open-hearth steel after cold-working and aging (10% cold working by extension, aging at 250° for 1 hr). a) kg-m/cm^2; b) temperature, °C.

TABLE 4

Chemical Composition of M St.T Steel

1 Содержание элементов (%)						
		Si			S	P
C	Mn	2 кипящая сталь	3 полуспокойная сталь	4 спокойная сталь	5 не более	
0,09–0,22	0,30–0,50	Следы 6	До 0,17 7	0,12–0,30	0,055	0,045

1) Content of elements (%); 2) rimmed steel; 3) semikilled steel; 4) killed steel; 5) no more than; 6) trace; 7) up to.

TABLE 5

Mechanical Characteristics of MSt.T Steel (for transverse specimens)

Толщина листа или полосы (мм) 1	$\sigma_т$ (кг/мм²)	$\sigma_в$ (кг/мм²)	δ_5 (%)	Загиб на 180° в холодном состоянии* 2
6–25	30	44	22	$d = 2S$
26–40				$d = 3S$

*S – sheet thickness, d – straightening diameter.

1) Thickness of sheet or strip; 2) kg/mm^2; 3) cold bending through 180°.

has an increased cold-shortness and a tendency to age, so that it can be used only under static loads in noncritical structures intended to function in regions with a rather mild climate.

Structural steel has a stronger tendency to age after cold working (deformation aging); its ultimate and yield strengths rise, its plasticity decreases, its impact strength drops sharply, and its tendency toward brittle fracture is increased.

Oxygen-converter steel is similar in its characteristics to open-hearth steel.

Figure 1 shows the variation in the impact strength of St.3 steel smelted by different methods as a function of decrease in temperature. The variation in this characteristic as a function of temperature for St.3 steel in various states is shown in Fig. 2. With a symmetric stress cycle the durability of St.3 steel (σ_{-1}) amounts to 17-20 kg/mm^2, while for notched specimens it drops to 13-17 kg/mm^2.

Structural steels are used principally in the hot-rolled state, but a tendency has developed to raise their strength by heat treatment. Heat-treated type MSt.T structural steel is produced in accordance with GOST 9458-60 (Tables 4 and 5).

The principal method of protecting structural steels from corrosion is careful painting of the structure after proper preparation of its surface. Zinc plating and phosphating are employed in certain cases, as is aluminum plating (sometimes with subsequent painting).

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E.Sh. Volokhvyanskaya

STRUCTURAL STRENGTH – the strength of a material realizable in a structure. In some cases structures of a material having a higher static (e.g., ultimate) strength or dynamic (e.g., fatigue) strength when laboratory specimens are tested fracture under lower loads after a shorter operational time than structures of materials less strong under laboratory conditions (see Table 1). This noncorrespondence between the strength and structural strength of materials is due primarily to the following peculiarities of structures in comparison with laboratory specimens: 1) A structure is generally considerably larger (Scale effect). As the size of a loaded body increases at a constant stress level its reserve elastic energy rises. It has been demonstrated theoretically that it is possible for internal cracks or defects to develop if the accumulated potential energy of deformation exceeds or equals the work required to create a new surface of separation in the zone adjacent to the origin of a crack. The transition from viscous to macrobrittle fracture has been observed experimentally on many occasions in a single material (even one as plastic as low-carbon steel) when the reserve energy of elastic deformation is raised by an increase in component size or a change in the flexibility of the entire stressed system. Hence it follows that the tendency toward brittle fracture and development of fine cracks or defects with time (so-called "delayed" fracture) is governed both by the characteristics of the material and by those of the structure itself. In evaluating the role of the scale factor it must be taken into account that individual structural elements may be considerably smaller than the laboratory specimens used

to determine the characteristics of the material, as is the case for many modern miniaturized devices. Filamentous crystals with a strength close to the theoretical limit can be used in a number of cases. 2) The geometric complexity of a structure (the presence of various types of stress concentrators in the form of substantial drops in rigidity, small radii of curvature, etc.) and the diverse systems of real external loads acting on it, which often lead to pronounced nonuniformity of stressing in the components. By virtue of this phenomenon, plastic deformation is severely localized in the components, while in laboratory tests the basic mechanical characteristics of the material are determined after considerable plastic deformation of the material as a whole (e.g., during extension of smooth specimens) or in a rather large volume (e.g., during extension of notched specimens, impact bending, etc.). In many cases, even when the components are comparatively simple in shape and there is no material local stressing, the character of the stressed state itself hampers plastic deformation and facilitates development of various types of defects. For example, in a thin-walled cylinder terminating at either end in a smooth transition to a hemisphere and loaded under internal pressure (biaxial extension) the changes in size are concentrated in a single direction, through the walls, which is in accord with theories which take into account the role of defects; the strength of such a cylinder on brittle fracture may be 30% less than its strength on uniaxial extension. If there are annular pieces of relatively large cross-section at the joints between the hemispheres and the cylindrical portion of the shell considerable additional bending stresses develop at these points and free deformation in the marginal-effect zone becomes still more difficult. When there is a marked nonuniformity of stressing crack formation and propagation at the action points of the largest stresses can be prevented

only by a high capacity for local plastic deformation under severe conditions. In this connection such characteristics of a material as strength of notched specimens on simultaneous extension and bending (see Notch sensitivty) or narrowing at the base of a sharp notch during tensile testing, although not directly utilizable in structural culations, are very important indices for preliminary evaluation of structural strength. 3) The presence of internal "technological" tensile stresses, often rather large, in the structure after welding, machining, heat treatment, straightening, bending, etc. The negative effect of these stresses is sometimes intensified by assembly stresses, as at points where components press against one another or in separate joints held together with bolts, etc. Residual stresses are a source of elastic energy even in the absence of external loading and thus promote brittle fracture. In addition, in many structures they extend and intensify the nonuniformity of the stressed state, as a result, plastic deformation at the sites of greatest stress concentration, which leads to redistribution and equalization of the stresses, is hampered and brittle fracture is thus facilitated. d) The specific condition of the component's surface, which is associated with: a) the presence of a substantially larger number of surface defects (which are potential foci of brittle fracture), both by virtue of the larger surface area of components in comparison with laboratory specimens and as a result of the fact that it is often rather difficult under production conditions to protect components from numerous minor superficial injuries. Surface defects are more detrimental (twice as detrimental according to Griffiths) as internal defects and, from this standpoint, a structure will always be subject to less favorable conditions than a laboratory specimen; b) the need in many cases to subject components to degreasing, pickling, and application of various coatings to provide corrosion

protection and to give them special surface characteristics (see Galvanization of steel, Hydrogen brittleness of steel). In some cases formation of microcracks (e.g., as a result of hydrogen absorption by steel during pickling or galvanization) or development of residual tensile stresses (e.g., during nickel- or chromium-plating of steel) may occur during these processes; c) changes in the chemical composition and structure of the surface layer as a result of heat treatment or operation at high temperatures (oxidation, decarbonization, combustion of volatile elements, etc.) 5) The often complex conditions obtaining in the ambient medium, whose complex action it is frequently hard to reproduce in laboratory tests, including tropical conditions, which involve the joint action of humidity, temperature, and microorganisms, or the conditions of outer space, which involve such factors as low temperature, high degrees of atmospheric rarefaction, cosmic and solar radiation, and meteoric particles (see Preparation of materials for astronautic applications).

TABLE 1

Comparison of Ultimate Strengths of Base Material (σ_b) and Welded Joint (σ_{bsv}) on Uniaxial Extension of Laboratory Specimens with Ultimate Strengths of Thin-walled Welded Cylindrical Shells (σ_{bk}) Exhibiting No Special Thickening of Base Material in Welded Joint or Around-the-Weld Zone

1 Материал	2 Состояние	σ_b	$\sigma_{bсв}$	Прочность конструкционная $\sigma_{bк}$ (кг/мм²)	5 Диаметр корпуса d и толщина стенки h (мм)
		3 (кг/мм²)			
6 Алюминиевый сплав АМг6	10 Отожженное при 325°	32	30	34	d=600, h=3
7 Сплав системы Al—Mg—Zn	11 Естественно состаренное	42	38	37—39	d=380, h=3
8 Сталь ВЛ1Д	12 Закаленная и отпущенная при 230°	160	150	160—170	d=200, h=1,5
9 Сталь легированная Cr, Ni, W, Mo, V, содержащая 0,45% C	13 Закаленная и отпущенная при 270°	200	180	190—180	d=200, h=1,5

1) Material; 2) state; 3) kg/mm^2; 4) structural strength σ_{bk} (kg/mm^2); 5) shell diameter d and wall thickness h (mm); 6) AMg6 aluminum alloy; 7) Al-Mg-Zn alloy; 8) VL1D steel; 9) steel alloyed with Cr, Ni, W, Mo, and V and containing 0.45% C; 10) annealed at 325°; 11) naturally aged; 12) quenched and tempered at 230°; 13) quenched and tempered at 270°.

The absence of an unambiguous relationship between the mechanical characteristics of a material, as determined by laboratory testing of specimens, and the behavior of a finished structure is most frequently manifested when using high-strength materials, i.e., steel with $\sigma_b >$ > 120 kg/mm^2, aluminum alloys with $\sigma_b >$ 40-45 kg/mm^2, or titanium alloys with $\sigma_b >$ 85 kg/mm^2, although in individual cases a decrease in the σ_b of medium-strength materials, which is accompanied by an increase in plasticity, rupture resistance, impact strength, etc., may lead to a rise in structural strength.

The increased tendency of high-strength materials toward brittle fracture is due primarily to the fact that they have, as a rule, a reduced capacity for local plastic deformation. The heat treatment or thermomechanical processing employed in order to obtain high strength leads to development of internal macrostresses and microstresses (see Internal stresses). High-strength materials also have a reduced Rupture resistance. Microcracks are usually formed earlier and propagate more rapidly as the structural nonuniformity of the material increases. A reduction in the structural nonuniformity of high-strength materials leads to a rise in structural strength. The presence of nonmetallic inclusions and brittle intermetallides is especially detrimental to such materials.

For better practical evaluation of the structural strength of materials it has recently become more and more common to utilize new test methods under laboratory conditions; these techniques involve determination of such characteristics of the material as the propagation rate of a fine crack (or the time to fracture for a specimen with a crack of predetermined size) under the prolonged action of static or repetitive loads, the work required to fracture a specimen containing a fine crack, or the time to fracture for a specimen subjected to a given load but

with different elastic-energy reserves in the specimen – loading-device system. The comparison of certain structural materials with respect to sensitivity to fine cracks and to reserve elastic energy on the one hand and with respect to such widely utilized characteristics as ultimate strength, elongation, and impact strength on the other, a comparison shown in Table 2, indicates that these new characteristics may lead to a totally different evaluation of materials than the standard indices of strength and plasticity. Operational experience has confirmed the enormous importance of the sensitivity of the material to fine cracking and to reserve elastic energy in the strength and reliability of many structures. For example, in aircraft building use of isothermal quenching of 30KhGSNA steel to σ_b = 160-180 kg/mm^2 instead of low-temper 30KhGSA steel, which is of equal strength but requires only one-third as much work to fracture a cracked specimen (see Table 2), made it possible to materially increase structural reliability. The high propagation rate of fine cracks in V95 alloy in comparison with D16 alloy makes it unwise to use V95 for tensioned aircraft-skin elements, despite its higher strength and sufficiently high plasticity (elongation) on static fracture of smooth specimens.

Structural strength is not dependent solely on the characteristics of the material. It is governed to a lesser extent by the efficiency of the structure, its technological level, and the operating conditions. According to the data of the London International Conference on Metal Fatigue (1956), there were only two cases of structural fatigue fracture (out of several hundred) in which the cause of fracture was defects in the material. In the majority of instances fatigue fracture under operational conditions resulted from structural deficiencies that produced large stress concentrations, from machining defects, or from incorrect assembly. A combination of metallurgical, design, and techno-

logical measures ensures increased structural strength. The design measures essentially reduce to planning of components without substantial drops in rigidity, to location of welded joints at a sufficient distance from the sites of greatest stress concentration, to a reduction in the flexibility of the entire structure (a decrease in reserve elastic energy), and to use of deloading notches, rounding-off of sharp edges, etc.

TABLE 2

Strength, Plasticity and Sensitivity to Fine Cracking of Certain Aluminum Alloys and Steels

1 Материал	2 Состояние	σ_b (кг/мм²) 3	$\sigma_{0,2}$ (кг/мм²) 3	δ (%)	$a_н$ $\left(\frac{кгм}{см^2}\right)$ 4	Работа разрушения образца с трещиной 5 $a_т$ $\left(\frac{кгм}{см^2}\right)$	Время до разрушения образца (в %) при одноосных исходных нагрузке и запасе упругой энергии системы *6
7Алюминиевый сплав Д16 (лист)	14 Естественно состаренное	44	30	16	—	1,24	100
	15 Искусственно состаренное	46	39	7	—	0,6	—
8Алюминиевый сплав В95 (лист)	Искусственно состаренное	51	43	9	—	0,35	58
9Алюминиевый сплав АК4-1 (лист)	Искусственно состаренное	38	33	7	—	0,88	—
10Алюминиевый сплав ВАД23 (лист)	Искусственно состаренное	56	51	5,5	—	0,19	—
11Сталь 12Х5МА	16 Закаленное с 950° и отпущенное при 200°	142	—	—	10,2	2,34	—
	17 Закаленное с 950° и отпущенное при 540°	126	—	—	10,3	0,65	—
12Сталь 30ХГСА	18 Закаленное с 890° и отпущенное при 225°	165	125	7	6,4	0,89	40
	19 Закаленное с 890° и отпущенное при 510°	114	103	8	8,9	4,8	—
13Сталь 30ХГСНА	20 Изотермическая закалка в селитровой ванне при 250°	165	120	8	8,2	2,9	100

*For the aluminum alloys the initial load and reserve elastic energy were P_n = 2.4 t and A_{un} = 7.2 kg-m, respectively; for the steels P_n = 3.6 t and A_{un} = 17.3 kg-m.

1) Material; 2) state; 3) kg/mm^2; 4) kg-m/cm^2; 5) work required to fracture cracked specimen, σ_t (kg-m/cm^2); 6) time to fracture of specimen (in %) on uniaxial initial loading and reserve elastic energy of system; 7) D16 aluminum alloy (sheet); 8) V95 aluminum alloy (sheet); 9) AK4-1 aluminum alloy (sheet); 10) VAD23 aluminum alloy (sheet); 11) 12Kh5MA steel; 12) 30KhGSA steel; 13) 30KhGSNA steel; 14) naturally aged; 15) artificially aged; 16) quenched from 950° and tempered at 200°; 17) quenched from 950° and tempered at 540°; 18) quenched from 890° and tempered at 225°; 19) quenched from 890° and tempered at 510°; 20) isothermally quenched in potassium nitrate bath at 250°.

The effectiveness of many metallurgical and technological measures depends on the conditions under which the structure functions (brief or prolonged loading, static or fatigue loads, component-operation temperature regime, ambient medium, etc.). Some measures are useful under certain conditions but may have a negative effect under others. Thus, production of a fine-grained structure, which increases the rupture resistance of high-strength materials, raises their structural strength under static loads at room and low temperatures, as well as their fatigue strength. Conversely, when the metal is subject to brittle fracture along the grain boundaries (e.g., during the operation of components under prolonged static loads at high temperatures) increasing the grain size proves helpful within certain limits. Superficial cold-working, which increases fatigue strength at room and moderately elevated temperatures and raises corrosion resistance in loaded components, has a negative influence on long-term strength at high temperatures as a result of its acceleration of diffusion processes, which cause over-aging of the material. High impact strength and notch plasticity raise the structural strength of components under static and impact loads; in addition, components subject to fatigue and wear must be cemented and nitrided, although this reduces their plasticity and viscosity to a negligible level. Controlled pickling has little effect on static strength and short-term fatigue, but substantially reduces service life under prolonged fatigue loads. A very thin soft surface layer (produced by decarbonization of high-strength steel or plating of high-strength aluminum alloys with aluminum) increases structural strength under static loads at room temperature and reduces structural strength in components subject to Fatigue. Such metallurgical and technological measures as increasing the purity of the metal (by vacuum smelting), which basically promotes a decrease in the scattering of mechanical

characteristics pertaining to strength (see Problem of reliability of materials), careful finishing of the surface during machining, reduction of the residual stresses produced by welding, heat treatment, and machining, etc., are very effective in raising structural strength under the most diverse component-operation conditions.

While attaching great importance to such characteristics as sensitivity to fine-crack propagation and reserve elastic energy, tendency toward delayed fracture, notch plasticity, and strength on combined extension and bending, it must be emphasized that any final evaluation of structural strength should be based on natural or seminatural testing.

References: Fridman, Ya.B., Mekhanicheskiye svoystva metalov [Mechanical Characteristics of Metals], 2nd Edition, Moscow, 1952; Drozdovskiy, B.A., Fridman, Ya.B., Vliyaniye treshchin na mekhanicheskiye svoystva konstruktsionnykh staley [Influence of Cracks on the Mechanical Characteristics of Structural Steel], Moscow, 1959; Potak, Ya.M., Khrupkiye razrusheniya stali i stal'nykh detaley [Brittle Fracture of Steel and Steel Components], Moscow, 1955; Nekotoryye problemy prochnosti tverdogo tela [Certain Problems in the Strength of Solids], collection of articles, Moscow-Leningrad, 1959; Ustalost' i vynoslivost' metallov [Fatigue and Durability of Metals], collection of articles, edited by G.V. Uzhika, Moscow, 1963; Nemetz, Ya., Raschety prochnosti sosudov, pabotayushchikh pod davleniyem [Calculation of the Strength of Vessels Functioning under Pressure], translated from Czech, Moscow, 1964.

S.I. Kishkina-Ratner

STRUCTURING – the combination of two or more chain molecules of a high-molecular substance by formation of cross-bonds, which produces three-dimensional structures, or "lattices." This process, just as destruction, greatly influences the physical characteristics of polymers. It is utilized in technology to produce new materials (rubbers from gum rubber by vulcanization, which is essentially structuring, three-dimensional resins and other plastics, etc.). Structuring can be induced by physical agents, such as heat and radiant energy (particularly ultraviolet, x-, and γ-rays), and by chemical additives, vulcanization, etc. It can also result from secondary cracking processes, oxidation, radiolysis, etc., since the free radicals produced in such cases may cause chain or nonchain reactions involving bonding, or "linking," of chain molecules. This type of structuring is one of the factors responsible for the change in the characteristics of materials during aging. Structuring is also observed in polymers under the action of mechanical factors, being the result of secondary processes caused by destruction.

In colloid chemistry the term structuring also refers to the formation of three-dimensional gel aggregates in dispersed systems. Such structuring differs from the chemical structuring described above in the fact that it is caused by intermolecular forces.

References: Alfrey, T., Mekhanicheskiye svoystva vysokopolimerov [Mechanical Characteristics of High-Polymer Materials], translated from English, Moscow, 1952; Barg, E.I., Tekhnologiya sinteticheskikh plasticheskikh mass [Technology of Synthetic Plastics], Meningrad, 1954;

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Dogadkin, B.A., Khimiya i fizika kauchuka [Chemistry and Physics of Gum Rubber], Moscow-Leningrad, 1947.

N.N. Lezhnev

STYROFLEX – see Polystyrene fiber.

SULFIDING OF STEEL – a process involving surface saturation of steel with sulfur in order toincrease the seizing and wear resistance of the friction surfaces of machine and equipment components. In the opinion of the majority of researchers, sulfur does not form solid solutions in α-iron. The following sulfides are formed when iron reacts with sulfur: FeS, Fe_2S_3, and FeS_2. Other elements also react with the sulfiding reagent, certain of them, e.g., Mn, Al, and Zn, forming highe ergy bonds with sulfur than Fe.

Sulfiding of steel is carried out in solid, gaseous, and liquid media. Sulfiding in solid media is based on production of active sulfur and its diffution into the layers of the components being treated. The sulfer-bearing medium has the following composition; ferric sulfide, 94%, ammonium chloride or potassium ferrocyanide – 3%, and graphite – 3%. A mixture with this composition can be used repeatedly, 20% of fresh mixture being added each time. For solid sulfiding of fully treated components of high-speed steel or cast iron the heating temperature should be 560-570°; when sulfiding components to be subjected to subsequent quenching the heating temperature should be 900-930°.

Gas sulfiding is carried out in a stream of hydrogen sulfide at 200°.

The following are the most widely used baths for liquid sulfiding. 1) Minsk Automobile Plant bath: 17% NaCl, 25% $BaCl_2$, 38% $CaCl_2$, 3.4% Na_2SO_4, 13.2% FeS, and 3.4% $K_4Fe(CN)_6$; working temperature – 560°; treatment time – 3 hr. 2) NIIKhIMMASh (All-Union Scientific Research and Design Institute of Chemical Machine Building) bath: 4.16% KCl,

51% Na_2SO_4, 5.6% $Na_2S_2O_3$, and 1.8% NaCNS; working temperature – 570°; treatment time – 2 hr. 3) ENIMS (experimental scientific Research Institute of Metal Cutting Machine Tools) bath: 73% $K_4Fe(CN)_6$, 17% NaOH, and 10% $Na_2S_2O_3$; working temperature – 570°; treatment time – 2 hr.

The first two baths ensure increased seizing resistance by creating a layer of ferric sulfide on the surface of the metal. A considerably more effective increase in the wear resistance of steel can be obtained by depositing a thick nitrogen- and carbon-enriched layer (0.1-0.2 mm) under a thin sulfide layer (0.03-0.05 mm).

In France, England, and Czechoslovakia sulfiding of steel is carried out in baths consisting of 95% sodium cyanide (NaCN) and 5% sodium sulfate ($Na_2S_2O_3$). This process is more correctly called sulfocyaniding.

References: Kostkin, V.V. et al., Sul'fidirovaniye poverkhnostey treniya [Sulfiding of Surface Cracks],Moscow, 1954 (In-t tekhniko-ekonomicheskoy informatsii [Institute of Technical-Economic Information], Report 13, No. K-54-178); Povysheniye iznostoykosti i sroka sluzhby mashin [Increasing the Wear Resistance and Service Life of Machinery], Vol. 2, Kiev, 1960.

A.G. Andreyeva

SUPERDURALUMIN – an aluminum alloy containing 4% Cu, 0.4% Mg, 0.7% Mn, and 1% Si. Its chemical composition differs from that of type D1 duralumin in its higher silicon content, which considerably hardens the alloy during artificial aging (see Aging of aluminum alloys). Superduralumin has higher yield and ultimate strengths: σ_b = 45–49 kg/mm^2, $\sigma_{0.2}$ = 35–39 kg/mm^2, and δ = 8–14%. Type AK8 superduralumin is used in the USSR, being produced in bars, forgings, and stampings (see Aluminum forging shaping alloys); it is not used for sheets because of its high tendency toward intercrystallite corrosion (see Corrosion of aluminum alloys).

O.S. Bochvar, K.S. Pokhodayev

SUPERINVAR – see Invar.

SUPERMALLOY – see High-permeability soft magnetic alloy.

SURFACE HARDENING OF ALUMINUM ALLOYS – treating the surface of aluminum alloy products (shot peening, rounding up, etc.) which results in workhardening of a thin surface layer of metal in order to increase the fatigue strength.

Ye.D. Zakharov.

SVAM – see Glass-filled plastics.

SWEATING MATERIAL – a pure metal or cermet alloy containing a considerable number of small pores (up to 60%). These materials are so designated as a result of their ability to pass liquids, which appear at the surface of the article as drops or vapor. They are produced in the form of sheets, sleeves, cones, etc. The most widely employed sweating materials are nickel, nichrome, and stainless steel. The table shows the characteristics of sweating materials based on nickel with porosities of 20% and 50%.

Characteristics of Certain Types of Nickel-Based Sweating Materials

1 Свойства	2 Пористость	
	20%	50%
3 Плотность (г/см³)	6,6—6,8	3,9—4
HB (кг/мм²) 4	68—70	10—11
$\sigma_в$ (кг/мм²)	34—35	4,7—6,5
σ_{-1} (кг/мм²)	180—200	110—115
$\sigma_{изг}$ (кг/мм²)	60—70	6,5—9,6
E (кг/мм²)	5000	2200
$a_н$ (кгм/см²) 5	0,6—0,7	0,17—0,2
λ (кал/см·сек·°С)6	0,022—0,057	0,011—0,024
$\alpha \cdot 10^6$ (20—800°) (1/°С)	12,8—16,5	12,8—16,3

1) Characteristic; 2) porosity; 3) density (g/cm^3); 4) kg/mm^2); 5) kg-m/cm^2); 6) cal/cm·sec·°C.

One of the most important operational characteristics of sweating materials is their permeability, which depends principally on their porosity and the pressure at which the coolant is supplied. Sweating-material products are manufactured from powders by pressing in steel press forms or by rolling into sheets and strips and subsequent sintering. Such products are not as yet widely used, but are very promising in connection with the development of the new technology.

References: Campbell, J.B., Porous Metal Sheets, Mater. and Methods, 1955, Vol. 41, No. 4, pages 98-101; Lenel, F.V., Powder Metallurgy Now, Proc. Amer. Soc. Test. Mater., 1955, Vol. 55, pages 655-688; Mater. and Methods, 1956, Vol. 43, No. 4.

V.S. Rakovskiy

SWELLING is the absorption of fluid by a gel or solid high-molecular substance accompanied by increase of the volume of the swelling body. In the swelling process the molecules of the low-molecular fluid penetrate into the high-molecular substance and cause extension of the links and bonds of the high polymer. We differentiate unlimited and limited swelling. In unlimited swelling the high polymer first absorbs the fluid and then, at the same temperature, gradually dissolves, forming a monophasic, homogeneous system. Limited swelling is characterized by the presence of a limited extent to which the high polymer absorbs the fluid, regardless of time. With temperature increase, some of the limited swelling polymers dissolve in the fluids (gelatin). The high polymers, having a three-dimensional structure, swell to a limited extent, forming gelatins in the swollen state. Swelling is characterized by the degree of swelling α, computed from the relation

$$\alpha = m\text{-}m_0/m_0,$$

where m_0 is the polymer weight prior to swelling, $\underline{m}$ is the polymer weight after swelling. In certain cases we substitute in place of $\underline{m}$ and m_0, respectively, V_0 and V – the high polymer specimen volumes prior to and after swelling. Thus, α is numerically equal to the weight (grams) or volume (cm^3) of the fluid absorbed by 1 gram and 1 cm^3 of the high polymer.

Swelling plays an important role in the technological processes of working with the polymers. The degree of swelling is used to define the stability of the high polymers to the action of fluids and vapors.

References: Tager A.A., Rastvory vysokomolekulayrnykh soyedineniy

(Solutions of High Molecular Compounds), M., 1951; Voyutskiy S.S. Rastvory vysokomolekulyarnykh soyedineniy (Solutions of High Molecular Compounds), 2nd edition, M., 1960; Tager A.A., Fiziko-khimiya polimerov (Physico-Chemistry of Polymers), M., 1963.

S.A. Reytlinger

SYMMETRIC STRESS CYCLE – a cycle in which the maximum and minimum stresses are equal in magnitude but opposite in sign:

$$\sigma_{макс} = -\sigma_{мин}, \quad \tau_{макс} = -\tau_{мин}.$$

In a symmetric cycle the average stress equals zero and the coefficient of asymmetry r = –1. See Fatigue.

G.T. Ivanov

SYNOXAL – a ceramic material based on aluminum oxide. Its name is composed of the initial letters of the words "synthesis," "oxide," and "aluminum." In addition to aluminum oxide synoxal contains certain other compounds formed principally by the synthetic mineralizers added to the mineral mixture; it also includes the impurities present in the initial alumina. Several types of synoxal are produced, varying in the quantity of mineralizer used and ranging from M-0 to M-10 (the numeral indicates the % of mineralizer). Synoxal with an index of 7 is the most widely used and is known as "synoxal 49."

TABLE 1

Properties of M-7 Synoxal

Свойства 1	Единица измерения 2	Показатели свойств 3
4 Механич. прочность:	13	
при сжатии . . . 5. .	кг/см²	10300
6 при растяжении . . .	"	1000
при изгибе . . . . . 7.	14 "	3200
8 Пробивной градиент . .	кв/мм	10.7
9 Уд. объемное сопротивление при 700°	мегом·см	70*
10 Диэлектрич. потери при частоте 1 мгц . .	15 $tg\delta \cdot 10^4$	5.4
11 $\alpha \cdot 10^6$ в интервале:		
0—300°	1 °C	6.44
0—500°	"	7.76
12 Температурный коэфф. (ТК) в интервале от 20 до 80° при частоте 0.5–5 мгц	—	$103 \cdot 10^{-4}$

*More than 1000 megohms·cm for synoxal of types M-1 through M-5.

1) Property; 2) unit of measurement; 3) value; 4) mechanical strength; 5) on compression; 6) on extension; 7) on bending; 8) breakdown gradient; 9) deep resistance at 700°; 10) dielectric loss at 1 mc; 11) $\alpha \cdot 10^6$ over the following ranges; 12) temperature coefficient (TK) over the range 20–80° at 0.5–5 mc; 13) kg/cm^2; 14) kv/mm; 15) megohms·cm.

Articles are produced from synoxal in the following manner. The initial mineral mixture is plasticized with paraffin or paraffin-based mixtures in a hot mixer (converter). The thermoplastic mass thus obtained has a regulable viscosity and readily undergoes various types of molding (pressure and open-mold casting, press drawing, lamination, welding, etc.). Reworking of the thermoplastic mass into a press powder and subsequent molding into synoxal products by hydraulic pressing (hydrostatic pressing) has become quite common. Articles are sometimes produced by machining pressed or cast blanks. Products molded by any of these methods are annealed, an operation utilizing absorbants in the form of loose materials (charges) or solid (porous) shaped bodies (dryers). Adsorbants facilitate removal of the organic plasticizer constituents from the annealed article and also protect it against possible deformation. The annealing temperature varies with the index of the synoxal and ranges from 1580 to 1730°. The annealed products are polished and sometimes glazed.

Synoxal is used primarily as a high-temperature dielectric in spark plugs and as a structural material for machine components.

References: Abramson, I.D., DAN SSSR [Proceedings of the Academy of Sciences USSR], 1946, Vol. 53, No. 4; Abramson, I.D., Keramika dlya aviatsionnykh izdeliy [Ceramics for Aviation Products], Moscow, 1963.

I.D. Abramson

SYNTHETIC ADHESIVE – is a compound, based on organic and inorganic substances, by which – owing to the forces of cohesion and adhesion – different materials (metals, wood, plastics, glass, procelain, ceramics, resin, leather, fabrics, paper, etc.) can be joined together. The mechanism of the bonding process has not been totally clarified. It was discovered that the adhesive properties of polymers depend not only on the structure of the macromoleculaes, but on the molecular weight, on the conditions for the formation of a film and on the physicomechanical properties of the film, on the addition of filler, and on the preparation of the surfaces of the materials to be joined. The adhesive must be selected according to the type of the material (polar materials must be bonded by polar adhesives). Thus, for example, joints of different strengths result when different metals are bonded with the same adhesives (the ultimate shearing strength for a joint bonded by epoxy adhesive is 340 kg/cm^2 in the case of steel, and 210 kg/cm^2 in that of Duralumin; these values are 405 and 200 kg/cm^2, respectively, for phenol-rubber adhesive). Solutions in organic solvents or in the monomers of the substances to be joined and adhesives based on polyurethanes, polyepoxies and on several of the polyacrylic derivatives are effective for the large majority of plastics (molded phenol aldehyde plastics, for example, can be joined by a solution of phenol resin; rubber materials – by rubber solutions).

Extremely difficult is the problem of bonding some nonpolar thermoplastics, polyethylene, polytetrafluoroethylene, etc. The polarity of the plastic may be changed in these cases by means of a special chemi-

cal treatment; the materials can then be bonded by means of the usual polar adhesives. Considerable difficulties also arise in the joining of plastics based on polymers with a different polarity. Mixtures of both polymers, each with a different polarity and combined in a solvent or in an emulsion, are practicable in certain cases.

Difficulties may also arise when plasticized or colored thermoplastics are to be joined for, owing to the penetration of the solvent of the adhesive into the joint, the plasticizer enters into the bond layer and this, in turn, results in a weakening of the joint or in an undesirable discoloration.

Phenol- and urea-formaldehyde resins, polyurethanes, polyepoxies, polyvinyl acetate emulsions, solutions of polyamide resins and several other materials are the best adhesives for joining cellulose materials (wood, veneers, etc.). Plasticized polyvinyl butyral, phenol formaldehyde resins modified by butadiene-acrylonitrile rubber give good results in bonding silicate glass.

The state of the surface of the materials which are to be joined also considerably affects the bonding process. At first, contaminations on the surfaces to be joined must be carefully removed by degreasing and other methods. A treatment of aluminum alloys by electrochemical methods. A treatment of aluminum alloys by electrochemical methods or by acid baths is widely used to prepare metal surfaces, results in the formation of a polar oxide layer on the metal surface which favorably effects the strength of the joint. Steels, magnesium alloys, copper, brass, etc., require special methods of treatment. The surface of nonmetallic materials is usually degreased, a roughing is not always necessary. The adhesives are usually subdivided into classes according to the chemical type of their basic component (adhesives on the basis of thermosetting polymers, thermoplasts, or elastomers). Adhesives based

on thermosetting polymers (phenol formaldehyde, epoxy, carbamide, siliconorganic, polyurethane adhesives, etc.) form strong, heat-resistant joints and are used for the assembly of units from metals or nonmetallic materials which work under stress (Table 1).

TABLE 1

Adhesives on the Basis of Thermosetting Polymers

1 Полимер	2 Основное назначение	3 Темп-ра склеивания (°С)	4 Свойства клеевого соединения			
			5 предел прочности при 20° (кг/см²)		8 термич. стойкость (°С)	9 водостойкость
			6 при сдвиге	при равномерном отрыве		
10 Фенолформальдегидная смола	Склеивание древесины, пенопластов и др. пористых материалов 11	Нормальная 12, 50—60	До 130 13 (при скалывании древесины) 14	13	До 100 13	Хорошая 15
16 Фенольнокаучуковый	Склеивание металлов 17	150—200	200	200	До 250	Высокая 18
19 Фенольнополивинилацетальный		140—200	200	До 400	До 350	Хорошая 15
Полиэпоксиды	Склеивание металлов и неметаллич. материалов 20	Нормальная, 12 120—200	200—300	До 800	До 200	Удовлетворительная 21
22 Полиуретаны		Нормальная, 12 100	150	До 200	До 60	Хорошая 15
23 Кремнийорганич. соединения		150—250	90—100	—	До 1000	Удовлетворительная 21
24 Мочевиноформальдегидная смола	Склеивание древесины и фанеры 25	Нормальная	До 130 (при скалывании древесины) 14	—	До 100	Слабая 26

1) Polymer; 2) main purpose; 3) bonding temperature (°C); 4) properties of the adhesive joint; 5) ultimate strength at 20° (kg/cm^2); 6) in shear; 7) in uniform peeling; 8) heat resistance (°C); 9) waterproofness; 10) phenol formaldehyde resin; 11) bonding of wood, foamed plastics and other porous materials; 12) normal; 13) up to; 14) (cleaving test of wood); 15) good; 16) phenol rubber; 17) bonding of metals; 18) high; 19) phenol polyvinyl acetal; 20) bonding of metals and nonmetallic materials; 21) sufficient; 22) polyurethanes; 23) siliconorganic compounds; 24) ureaformaldehyde resin; 25) bonding of wood and plywood; 26) poor.

Adhesives based on thermoplasts (polyisobutylene, polyamides, polyvinyl acetates, arylates, etc.) are characterized by a low heat resistance and are mainly used for non-metallic joints which are not under stress (Table 2). Adhesives based on elastomers (rubbers, mainly) have a high elasticity and are used to bond rubber with rubber and rubbeer with metals.

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There are one-component (delivered in ready state) and multicomponent adhesives; the latter are prepared from the components at the place of their application; such adhesives may be stored for a relatively long time. The greatest number of adhesives are solutions of diverse polymers and of their mixtures (polyisobutylene, rubbers, phenol formaldehyde resins, polyvinylchloride, polymers of vinyl ethers, polyvinyl acetate, polyacrylates, polyamides, polyepoxies, solutions of phenol formaldehyde resins combined with polyvinyl acetals, polyamides, etc.) in organic solvents. The dissolution of the polymers is carried out without heating in stainless steel or enameled devices provided with mixers and reflux condensers. The resulting adhesive solution is filtered through a metallic sieve or a fabric and then the adhesive is tested according to GOST or TU. In some cases, the polymers are dissolved in their monomers, the so-called reactive solvents. Appropriate stabilizers are added to these adhesives in order to avoid polymerization.

TABLE 2

Adhesives Based on Thermoplastic Polymers

1 Полимер	2 Основное назначение	3 Температура склеивания (°C)	4 Свойства клеевого соединения			
			5 предел прочности при 20° (кг/см²)		8 теплостойкость (°C)	9 водостойкость
			6 при сдвиге	при равномерном отрыве 7		
10 Полидиметилвинилэтинилкарбинол (карбинол)	—	Нормальная 11	100	150	До 60 12	Слабая 13
14 Полиамиды	Склеивание неметаллич. материалов и металлов 15	150	150	300	До 60	Слабая
16 Полиизобутилены	Липкие клеи и ленты 17	Нормальная	—	—	До 50	Хорошая 18
19 Полиакрилаты 20	Склеивание неметаллич. материалов	60—80	150	—	До 60	Удовлетворительная 21
22 Хлорированный поливинилхлорид	Склеивание пластич. масс 23	Нормальная 11	~2	—	До 60	То же 24

1) Polymer; 2) main purpose; 3) bonding temperature (°C); 4) properties of the adhesive joint; 5) ultimate strength; 6) at shearing; 7) at uniform peel; 8) heat resistance (°C); 9) waterproofness; 10) polydimethyl vinyl ethinyl carbinol (carbinol); 11) normal; 12) up to; 13) poor; 14) polyamides; 15) bonding of nonmetallic materials and of metals; 16) polyisobutylenes, 17) sticky adhesives and tapes; 18) good; 19) polyacrylates; 20) bonding of nonmetallic materials; 21) sufficient; 22) chlorinated polyvinylchloride; 23) bonding of plastics; 24) the same.

D.A. Kardashev

SYNTHETIC FIBER – fiber from synthetic high-molecular compounds (polymers) which are products synthesized from simple chemical substances (monomers). The starting raw material for most synthetic fibers is petroleum, coal and natural gas. The majority of synthetic fibers has advantages over natural and artificial fibers consisting in high dry and wet strength, resistance to the effect of chemical reagents and microorganisms and a small specific weight. Synthetic fibers are classified as carbon-chain and netero-chain. The most widely used synthetic fibers, that is capron (nylon 6) Nylon 66 (Anid), Terylene (lavasan), Orlon (nitron), etc., are produced as standard and high-strength thread, staple fiber and monofiber. They are extensively used by the industry and for consumer goods.

References: Rogovin, Z.A., Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fiber Production]. 2nd edition, Moscow, 1957; Fibers from Synthetic Polymers, edited by R. Hill, translated from English, Moscow, 1957.

E.M. Ayzenshteyn

SYNTHETIC ISOPRENE RUBBER – is the product of the catalytic polymerization of isoprene. It is obtained using lithium or the complex Ziegler type catalysts; it contains neozon D, Santovar O, white Age-Rite, Santoflex VKh, diphenyl-para-phenylene diamine and combinations from them as antioxidants. The following experimental and commercial grades of synthetic isoprene rubbers are produced: SKI, SKI-3 (USSR), Corall, Ameripol SN, and Natsine (U.S.).

SKI-3, Ameripol SN and Corall give an x-ray pattern characteristic for natural rubber, this fact points to an extreme similarity of the crystal structure of both these rubbers. SKI may crystallize only when it is considerably stretched. Synthetic isoprene rubbers show a high tendency to oxidative degradation due to the high proportion of 1.4-links in the chain. SKI-3 and Ameripol SN have a lower molecular weight than SKI and Corall, hence, SKI-3 and Ameripol SN have a high plasticity and do not require a premastication. With regard to their technological properties, SKI-3 and Ameripol SN are similar to masticated NK. They are easily miscible with ingredients. Compounds of these rubbers with carbon black are easily calenderable and sprayable, they have the same good stickiness as the NK compositions.

SKI has lower technological properties and not stickiness. As well as NK, the synthetic isoprene rubbers are characterized by a high tensile strength in nonfilled compounds. The thermal stability of SKI-3 is similar to that of NK and surpasses that of SKI. The elasticity of SKI-3 is insignificantly lower than that of NK. Carbon-black filled stocks of synthetic isoprene rubber are characterized by high mechanical pro-

perties. The frostproofness of carbon-black filled SKI-3 rubbers is equal to that of NK rubbers and surpasses that of SKI rubbers. The elasticity of carbon-black filled SKI-3 and Ameripol SN rubbers at 20°, and especially at 100°, is somewhat lower than the elasticity of NK and SKI rubbers.

Tests of truck tires, produced totally from SKI and SKI-3 in the USSR, and from Corall and Ameripol SN in the U.S., have proved a tire-run near to that of NK tires. Synthetic isoprene rubbers are rubbers for general purposes. They can replace NK in tires and other rubber products. The properties of synthetic isoprene rubbers are given in the Tables 1-3.

TABLE 1

Structure and Properties of Synthetic Isoprene Rubber

Каучук 1	Содержание звеньев (%) 2				Температура стеклования (°C) 3	Растворимость в бензоле (%) 4	Содержание непредельных (%) 5
	2a цис-1,4	2b транс-1,4	1,2	3,4			
НК 6	97,8	0	0	2,2	−70	100	96
СКИ-3 7	92—99	0—4	0—2	1—3	−70	97—99	94—98
Америпол SN 8	97	0	0	3	−70	97	94
СКИ 9	60—70	20—30	1—2	5—7	−68	—	—
Корал 10	94	0	0	6	−68,5	90,4	98

1) Rubber; 2) content of links (%); 2a) cis; 2b) trans; 3) vitrification temperature (°C); 4) solubility in benzene (%); 5) proportion of non-saturated links (%); 6) NK; 7) SKI-3; 8) Ameripol SN: 9) SKI; 10) resilience (%).

TABLE 2

Properties of Nonfilled Synthetic Isoprene Rubbers

Показатели 1	НК 2	3 СКИ-3	Америпол SN 4	5 СКИ	6 Корал
7 Прочность на разрыв (кг/см²)					
при 20°	250—350	250—300	250	230—320	238
8 при 100°	200	170—200	—	80—100	—
9 Относительное удлинение (%)					
при 20°	800—850	850	850	1100—1200	780
8 при 100°	1000	950—1000	—	1000—1100	—
10 Эластичность по отскоку (%) 10	70—72	66—69	68	65—70	—

1) Characteristics; 2) NK; 3) SKI-3; 4)

Ameripol SN; 5) SKI; 6) Corall; 7) tensile strength (kg/cm^2); 8) at ...; 9) relative elongation (%); 10) resilience (%).

TABLE 3

Properties of Synthetic Isoprene Rubbers Filled with 30 Parts by Weight of Channel Carbon Black

Показатели 1	НК 2	СКИ-3 3	4 Америпол SN	СКИ 3
5 Прочность на разрыв (кг/см^2)				
при 20°	325—350	314	350	300—350
6 при 100°	200	200	167	110—150
7 Относительное удлинение (%)				
при 20°	750—850	750	790	950—1050
6 при 100°	900	850	930	900—1000
8 Эластичность по отскоку (%)				
при 20°	50	48	46	50
6 при 100°	67	55	53	64

1) Characteristics; 2) NK; 3) SKI-3; 4) Ameripol SN; 5) tensile strength (kg/cm^2) 6) at ...; 7) relative elongation (%); 8) resilience (%).

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M. D. Gordin

SYNTHETIC RUBBER (SK) – is a high-polymer rubberlike material destined for the production of rubbers. Synthetic rubber is usually obtained by the copolymerization of diverse unsaturated compounds; polycondensation of appropriate bifunctional hydrocarbon derivatives is also used to obtain certain synthetic rubbers. The initial monomers, which give synthetic rubber by polymerization or polycondensation, are frequently termed rubbergens, Butadiene, styrene, isoprene, chloroprene, isobutylene, acrylonitrile, α-methylstyrene, etc., are used as rubbergens. The polymerization of the rubbergens is carried out either in the bulk of the monomer (or a mixture of monomers) or in emulsion. In the latter case, the rubber is obtained at first in the form of a latex and is separated from it by coagulation. Similar to natural rubber, the synthetic rubbers have long macromolecular chains, which are branched sometimes, with an average molecular weight of hundreds of thousands and even millions. The macromolecular chains are composed from repeating groups which correspond to the monomer used to obtain the synthetic rubber. In the most cases, the polymer chains of synthetic rubbers have double bonds which form a spatial network during vulcanization and provide the physicomechanical properties characteristic for rubbers. Some types of synthetic rubbers (polyisobutylene, siloxane rubber, etc., for example) are completely saturated compounds; their vulcanization, therefore, is carried out by methods differing from the usual sulfur vulcanization (addition of organic peroxides, amines, etc.). Certain types of synthetic rubber surpass considerably the natural rubber with regard to a number of technical properties (in the resistance to aggressive media,

and solvents, in thermal stability, resistance to abrasion, gasproofness, resistance to light and ozone, etc., for example). The rubbers with a regular structure, synthesized lately, are comparable to natural rubbers with regard to their elastic properties. The production of synthetic rubbers, in contrast to that of natural rubber, is characterized by a high operating efficiency, better working conditions, and independence of climatic and geographic conditions. In contrast to the natural rubber, which contains natural preservatives, special substances, antioxidants, inhibiting oxidative processes which cause degradation or crosslinking of the polymer, must be added during the manufacturing of the synthetic rubber. The majority of the known synthetic rubbers (apart from cis-isoprene, chloroprene, butyl rubber and some other rubbers) give vulcanization products with a low mechanical strength (up to 50 kg/cm^2) when they are not filled. Active fillers reinforcing the mechanical strength of the vulcanizates must be added to obtain synthetic rubbers with good physicomechanical properties. The elasticity is inevitably reduced in this way. Fine-disperse substances with a highly developed surface: carbon blacks, active silica (silica gel, aerosil), active aluminum oxide, kaolin, chalk, etc., are used as active fillers. Synthetic rubbers with regularly structurated molecular chains containing regularly alternating links, and with prevalent presence of the cis-form as in the natural rubber, are necessary (for the greater part of synthetic rubbers) when rubbers with a high strength and without active fillers are to be obtained.

The synthetic rubbers are subdivided into two large classes: 1) universal rubbers for general purposes, for the production of wholesale rubber products: motorcar tires, conveyor belts, hoses, rubber footwear and a number of technical rubber products; 2) rubbers with special technical properties, used for the production of rubber products which must

work under special conditions: in solvents or aggressive media, at high temperature, under the action of ozone and ultraviolet rays, etc. Monomers preponderantly of the vinyl series containing polar groups (acrylonitrile, vinylidene dichloride, methyl vinyl pyridine, etc.) are used (generally in copolymerization with butadiene) to obtain rubbers with special properties. Some rubbers of this class are also obtained from one or several monomers which contain polar atoms also (chloroprene, dimenthyl dichlorosilane, vinylidene fluoride, hexafluoropropylene, etc.). Butadiene alone or combined with styrne or α-methylstyrene is used as a rubbergen for the production of wholesale rubber products. The importance of isoprene has increased in the last few years owing to the successful synthesis of the isoprene rubber whose elastic properties are near to that of natural rubber. The following universal rubbers for general purposes have achieved an industrial importance: sodium-butadiene rubber obtained by polymerization in bulk in presence of alkali metals, and butadiene-styrene rubber, obtained by copolymerization of butadiene and styrene or α-methystyrene in an aqueous emulsion. The lately-synthesized stereoregular rubbers, the isoprene and the cis-polybutadiene rubber, and the copolymer of ethylene and propylene belong also to this class of rubbers. Radical polymerization results in the formation of polymers with some degree of branching, with double bonds in the side-chains, which deteriorate the elastic properties of the rubbers. In contrast to this, the stereospecific polymerization with complex catalysts makes it possible to control and to obtain a desired spatial structure of the links in the macromolecules of the polymer with a preponderant formation of linear structures with cis-configuration. High mechanical strength of the rubbers without application of active fillers is the characteristic peculiarity of the stereoregular synthetic rubbers. Frostproof, oilproof, gasolineproof and heat-

resistant rubbers, rubbers stable to the effect of ozone and aggressive media, rubbers with reduced permeability for gases, with increased resistance to abrasion, etc., belong to the synthetic rubbers with special technical properties. Frostproof synthetical rubbers are obtained on butadiene basis. Its polymerization in bulk with special catalysts, prepared using alkali metals, results in a rubber with the vitrification temperature of −70°. Copolymerization of butadiene with small quantities of styrene (10%) in aqueous emulsion gives a rubber with a vitrification temperature of −75, -80°. Chloroprene, butadiene-nitrile, polysulfide (see Thiokols), and butadiene-methylvinyl pyridine rubbers are resistant to the effect of oils and gasolines. Siloxane fluoro-rubbers belong to the heat-resistant synthetic rubbers. Fluorosiloxane elastomers also possess stability to heat and gasoline. These rubbers, maintaining all the properties of silicon-organic rubbers with respect to the thermal stability and frost-proofness, also possess a good stability to the effect of fuels and oils. Fluoro-rubbers are exclusively stable to the action of diverse aggressive media. Butyl rubber has a reduced permeability for gases and a high chemical stability. It is characterized by an increased resistance to ultraviolet rays, ozone, chemical reagents, and also by a stability to thermal aging in air or in oxygen medium. Polyisobutylene, the product of the polymerization of isobutylene, has a still higher chemical stability. Sulfochlorinated polyethylene belongs to the chemically stable elastomers which are able to vulcanize and to form rubbers with good physicomechanical characteristics. Polyurethane elastomers are characterized by an exclusively high resistance to abrasion which largely surpass the resistance to abrasion of the natural rubber (see Urethane Rubber).

Synthetic latexes in which the polymers are present in a high-disperse state obtain more and more importance and are applied for mani-

fold purposes. The use of elastomers in the form of latexes permits the solving of complicated engineering problems, considerably improves in many cases, the physicomechanical properties of rubbers and simplifies the technology of the production of rubber products.

References: Lebedev S.V., Zhizn' i trudy [His Life and His Works], Leningrad, 1938; Dogadkin B.A., Khimiya i fizika kauchuka [Chemistry and Physics of Rubber], Moscow-Leningrad, 1947; Smirnov N.I., Sinteticheskiye kauchuki [Synthetic Rubbers], 2nd edition, Leningrad, 1954; Litvin O.B., Osnovy tekhnologii i sinteza kauchukov [The Principles of the Technology and the Synthesis of Rubbers], Moscow, 1959; Borodina I.V., Nikitin A.K., Tekhnicheskiye svoystva sovetskihk sinteticheskikh kauchkukov [The Technical Properties of Soviet Synthetic Rubbers], Leningrad-Moscow, 1958; Sinteticheskiy kauchuk [Synthetic Rubber] edited by G. Whitby, translated from English, Leningrad, 1957; Fedorenko N.P., Savinskiy E.S. Ocherki po ekonomike khimicheskoy promyshlennosti SSSR [Essays on the Economica of the Chemical Industry of the USSR], Moscow, 1960, pages 220-221; Ullmanns Encyklopädie der technischen Chemie [Ullmann's Encyclopedia of the Technical Chemistry], 3rd edition, Vol. 9-B. München, 1957, pages 321-[illegible].

A.K. Nikitin

TALC – mineral, a member of the magnesium hydrosilicate group. Chemical composition: $Mg_3[Si_4O_{10}]\ [OH]_2$. MgO = 31.7%, SiO_2 = 63.5%, H_2O = = 4.8%; the magnesium is sometimes isomorphically replaced by iron (up to 2-5%), negligible admixtures of Cr_2O_3, Fe_2O_3, CaO, CO_2, Na_2O, K_2O. Talc crystallizes in the monoclinic system. Has perfect cleavageability along (001). The color is apple white – green, sometimes white with a yellowish or greenish tinge. The optic sign is negative. N_g = 1.575-1.590, N_p = 1.538-1.545. The hardness is very low (it is unity on the Mohs scale). It has a greasy feel. It is hydrophobic. Specific gravity 2.7-2.8. Poor electrical and thermal conductivity. Fire resistance about 1500°. Dehydration temperature 800-1000°. t_{pl} 1530°. High acid and alkali resistance. Talc is easily processable and can be ground into a fine powder; chemically inert, capable of keeping certain active chemical substances on the surface of its particles; it is slippery, soft, greasy and adhesive, which is due to the properties of the crystal lattice. After heat treatment it is capable of becoming a dense and strong shell with a low thermal expansion, low thermal and electrical conductivity.

Talc is used: in the ceramics industry for the production of high-voltage insulators, radio components, ceramics for heating devices, technical dishware, ceramics for sanitary installations, lamp receptacles; in the production of refractories, i.e., of high-refractory periclaseforsterite kiln furniture, all-sawed products in the form of standard and intricately-shaped bricks; in the varnish and paint industry as a filler or white pigment in water paints; in the paper industry as a pulp filler; in the cable, rubber and roofing industry as a filler, for

powdering of products in order to prevent them from sticking together; in applied art and decorative sculpture as a finishing stone. The requirements put to talc differ depending on the character of its utilization.

References: Trebovaniya promyshlennosti k kachestvu mineral'nogo syr'ya [Industrial Requirements Put to the Quality of Mineral Ray Materials], Issue 1 - Chernosvitov, Yu.L. Tal'k i pirofillit [Talc and Pyrophillite], 2nd Edition, Moscow, 1961.

B.Ya. Merenkov

Manuscript Page No.

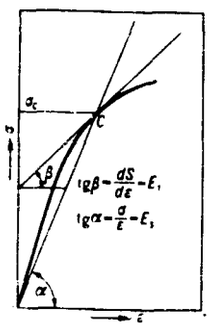
[Transliterated Symbols]

3987 пл = pl = plavleniye = melting

TANGENTIAL STRESS is the ratio of the force component lying in a given section to the area of this section. It is measured in kg/mm^2 or kg/cm^2. It determines the variation of the shape of the body (in contrast with the variation of the volume, which depends on the arithmetic average of the three normal stresses). The plastic deformation processes (yield, creep, pressure working) depend primarily on the tantential stress.

Ya.B. Fridman

TANGENT MODULUS is the index of intensity of strengthening in the elasto-plastic region. It is characterized by the tangent of the slope of the tangent to the considered point on the curve $|\sigma = \sigma(\varepsilon)|$ (figure). It is sometimes termed the strengthening coefficient. It is designated by the symbol E_T and has dimensions of a stress. The tangent modulus decreases with increase of the degree of plastic deformation.



S.I. Kishkina-Ratner

TANTALUM Ta – transition element of group V of Mendeleyev's periodic system; atomic number 73, atomic weight 180.948, structure of the external electron shell of the atom is $5p^6 5d^3 6s^2$. Naturally occuring isotopes are Ta^{180} and Ta^{181}. Tantalum is a refractory metal, gray colored with a bluish tinge. Discovered in 1802. As a metal first extracted in 1903, obtained on an industrial scale in 1922 (USA). The content of tantalum in the earth's crust is $2 \cdot 10^{-4}$ by weight. The ore deposits comprise about 10% of those of niobium. In nature Ta is almost always associated with niobium, which isomorphically replaces tantalum in minerals. The more important industrial minerals are: tantalite – columbate (iron and manganese tantaloniobate), loparite, microlite-pyrochlore. The ores are usually compound and are tantalum-poor. For methods of ore processing see in the article Niobium. Usually the following pure tantalum compounds are obtained from the ore concentrates: the pentoxide Ta_2O_5, potassium fluorotantalate K_2TaF_7, less frequently the chloride $TaCl_5$, from which the metal is reduced. The main industrial methods of tantalum powder production: electrolysis of the pentoxide dissolved in potassium fluoroniobate, reduction of the latter by sodium and carbothermal reduction of the pentoxide with hydration of the reduced tantalum, pulverization and dehydration of the powder, similar to niobium (see Carbothermal Niobium). Here substantial difficulties arise due to the high melting temperature of tantalum, the high chemical strength of the compounds and chemical activity upon heating. The tantalum powder is subsequently pressed into bars weighing 2.5-10 kg, with dimensions up to 32 x 64 (600-700) mm^3 in hydrelic presses with a capacity

of up to 3000 tons which are sintered in a high vacuum at temperature of up to 2600° by passing electric current through them (see Sintered Material), then are cold forged and after secondary sintering in vacuum are subjected to cold pressworking into sheets, foil, wire, etc., (see Tantalum Wire). To obtain tantalum blanks of different shape or of a higher weight, the sintered bars are subjected to vacuum arc and electron ray melting. Sometimes pure powdered tantalum is subjected to arc melting. Tantalum is used in electronics and electrical equipment ("hot fittings" of radio tubes, electrolitic capacitors with small overall dimensions and high capacitance for a wide temperature range), in chemical machine building (corrosion-resistant apparatus used, in particular, for chemical processing of nuclear fuel), in metallurgy (carbide of hard alloys, alloying of refractory and other alloys), in the medical industry (surgical instruments), etc. The great importance of tantalum for new equipment is due to the favorable combination of good plasticity, ease of cold pressworking, sufficient mechanical strength at normal and high temperatures, ability to weld together with Ta, Nb, Mo, W, Ni and other metals (see Welding of Refractory Metals), high corrosion resistance (see Corrosion of Tantalum) with refractoriness (t°_{pl} 2996°) and other valuable properties. Its crystal structure is: face-centered cube with a = 3.296 A. Interatomic distance 2.85 crystal structure measurement units; density at 20° = 16.6 g/cm^3; effective cross section for thermal neutron capture 20 barns/atom, t°_{kip} 5300°, vapor pressure (mm of Hg): $1 \cdot 10^{-3}$ (2820°), $1 \cdot 10^{-4}$ (2599°), $1 \cdot 10^{-5}$ (2407°), vaporization rate (g/cm^2-sec); $1.63 \cdot 10^{-2}$ (2000°K), $5.54 \cdot 10^{-8}$ (2600°K), heat (cal/g): of melting 37, of vaporization 1550, combustion 1379, temperature of transition to the superconductive state −268.8°, of transition to the brittle state - below −196°, α (0-100°) $6.5 \cdot 10^{-6} \cdot C^{-1}$, $\underline{c}$ (cal/g-°C): 0.03322 (0°), 0.03774 (1000°), λ (20-100°) 0.13 kcal/cm-

sec-°C, i.e., almost by a factor of higher than that for stainless steel, and by a factor of 40 higher than for glass. Coefficient of heat transfer between hydrochloric acid and water vapor in a tantalum heat exchanger exceeds 14,600 kcal/m^2-hour-°C, i.e., a cm^2 of tantalum is equivalent to 18 cm^2 of lead. $\rho \cdot 10^6$ (ohm/cm), 13.5 (20°), 17.2 (100°), 35 (500°), 103.9 (2527°), specific magnetic permeability $0.849 \cdot 10^6$ (18°), work function 4.12 ev, secondary emission coefficient 1.35, positive emission 10 ev, electron emission (amps/cm^2): $9.10 \cdot 10^{-6}$ (1600°K), $6.21 \cdot 10^{-3}$ (2000°K), 0.500 (2400°K), 2.25 (2600°K), 12.53 (2800°K), emissivity (w/cm^2): 7.36 (1600°K), 51.3 (2400°K), 105.5 (2800°K). Radiation coefficient 0.49 (20°, wavelength = 6500 A), 0.418 (1730°, wavelength = 6650 A).

Upon heating metallic tantalum intensely absorbs gases, thus being a good getter. Here its plasticity, mechanical strength, magnetic permeability and corrosion resistance are reduced; the crystal lattice period, hardness and electrical resistivity are increased. The solubility of H_2 at 1 atm comprises 294 (314°), 217 (400°), 110.5 (500°), 56.5 (600°), 51.2 (650°) millig/100 g.

To make it brittle, tantalum is hydrated, heated in a H_2 atmosphere at 500° and above. Tantalum is stable in air at room temperature, it starts to corrode at 280°. It interacts with oxygen at 400°, the limiting solubility at 1050° is 0.9% by weight (9.3 atomic %). It forms solid solutions with nitrogen at temperatures as low as 600°, but the solubility is very low. When the tantalum temperature is increased it forms with oxygen the oxide Ta_2O_5, with N_2 and NH_3 it forms nitrides (a higher nitride is TaN). Below 600° it absorbs CO, and at 1200-1400° it forms carbides with carbon-containing gases (the highest carbide being TaC).

Tantalum is refined from gases it absorbed by heating in a vacuum

not lower than $1 \cdot 10^{-4}$ mm of Hg. H_2 is rapidly separated from tantalum at 800-1200°. A perceptible removal of N_2 takes place above 1800-2000° by thermal decomposition of the nitride, the dissociation vapor pressure for which is 4.16 mm of Hg, the rate of decomposition of TaN reaches a maximum at 2400-2450°. Oxygen starts being generated in the form of Co (if the metal contains carbon) at 1350-1400°, it is generated rapidly at 1900°. It is also removed in the form of oxides of the admixture elements, and at high temperature in the form of a lower oxide of tantalum. Electron ray melting, vacuum arc melting and vacuum sintering are good methods for removing gas from tantalum. In conjunction with absorption of ordinary gases, all operations involving the heating of tantalum are performed in a high vacuum or in an atmosphere of purified inert gases (Ar, He). The ability to become brittle in a H_2 atmosphere is used in metallurgy for processing metallic tantalum wastes by hydration pulverization and (sometimes) dehydration, obtaining a powder for use or addition to basic tantalum powder.

The mechanical properties of tantalum depend to a great extent on the purity and state of the metal. The most pronounced effect on the properties is exerted by admixtures of O, N, H and C. When their content is increased, the hardness and strength of tantalum are increased, while plasticity is reduced. For example, when the O_2 content is increased, the HV hardness increases from 38 to 630 kg/mm^2 (4 atomic % of O_2), E increases from 18,100 to 19,640 kg/mm^2, δ is reduced from 39 to 4% (2 atomic % of O_2). The plasticity is reduced at a particularly high rate upon dissolution of hydrogen.

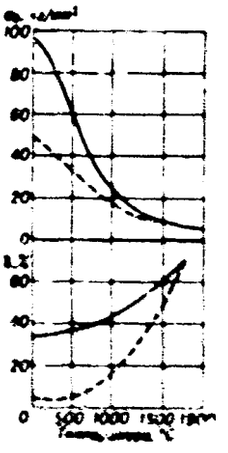
The mechanical properties of tantalum at 20°, which was smelted in an electric arc furnace and containing 0.003% O_2, 0.002% N_2 and 0.0008% H_2 in the hardened and crystallized states are presented in the table.

Unlike tungsten and molybdenum, tantalum is very plastic in the recrystallized state at room, as well as at subzero temperatures. The values of a_H, δ and ψ are not significantly reduced when the temperature is decreased to -196°. When tantalum is heated to above room temperature, the strength of the metal is reduced while the plasticity in-

Свойства	Состояние материала	
	Наклеп- ванное	Рекристал- лизо- ванное
HB (кг/мм²)	330	160
$\sigma_в$ (кг/мм²)	95—98	45—55
δ (%)	2—3	25—30
ψ (%)	5—7	75—80
$a_н$ (кгм/см²)		~12
E (кг/мм²)	18000	18000
μ	0,35	0,35

1) Properties; 2) state of the material; 3) hardened; 4) recrystallized; 5) kg/mm^2; 6) a_H (kg-m/cm^2).

creases. The change in mechanical properties of cast tantalum in an argon atmosphere as a function of the temperature is shown in the figure.



Mechanical properties of tantalum as a function of the temperature. Solid curve denotes recrystallized sheet; the dashed curve denotes cold worked sheet. 1) kg/mm^2; 2) temperature, °C.

The sheet thickness is 1.0 mm, working length 25 mm. Up to 1400-1500° the short-time strength of the hardened material is higher, while the plastic properties are lower than those for annealed material.

The short-time ultimate tensile strength of tantalum at 2000° is

~4.0 kg/mm^2.

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O.P. Kolchin, M.I. Gavrilyuk

Manuscript Page No.	[Transliterated Symbols]
3992	пл = pl = plavleniye = melting
3992	кип = kip = kipeniye = boiling

TANTALUM ALLOYS – tantalum-based alloys with an admixture of other alloying elements which are used in modern equipment. Tantalum-tungsten alloys have come into industrial use abroad. An alloy of tantalum with 10% W is the most extensively used. This alloy has good production process properties, retains a high strength up to very high temperatures, and is highly erosion resistant (up to 2200°). This alloy can be used for work in a wide range of temperatures from −130 to 2900°.

The mechanical and production process properties of a given alloy, as well as of tantalum, depends to a large extent on the metal's purity, particularly with respect to gas admixtures (N, O, H). As the content of these elements is increased, a sharp reduction in the metal's plasticity and a rise in its hardness and strength are observed. The mechanical properties of Ta + 10% W, smelted in an electric arc vacuum furnace and containing 0.01% O_2 and 0.008% H_2 are given in the table.

Mechanical Properties of an Alloy with Ta + 10% W at 20°

1 Свойства	Состояние материала 2	
	нагартованное 3	перекристаллизованное 4
HB (кг/мм²) 5	345	230
$\sigma_в$ (кг/мм²) 5	135	95–98
δ (%)	1–5	25–30

1) Properties; 2) state of the material; 3) hardened; 4) recrystallized; 5) kg/mm^2.

When Ta-W alloys are melted in an electron beam furnace the admixture content is sharply reduced. As a result, the plasticity of the me-

tal is increased while its strength is somewhat reduced. The Ta + 10% W alloy after melting in an electron beam furnace has the following characteristics: σ_b at 20° 102 kg/mm^2 in the hardened state and 56 kg/mm^2 after annealing; E = 21,000 kg/mm^2.

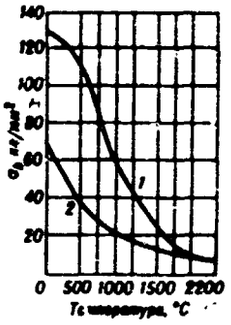
The dependence of the short-time strength of the Ta + 10% W alloy smelted in an electric arc vacuum furnace on the testing temperature is shown in the figure. The properties were determined on 1 mm thick and 25 mm long sheet in an argon medium. Up to 1500-1600° the hardened material has a higher strength than the annealed.

When heated in air at above 500-600° tantalum alloys are highly oxidized and at the same time absorb gases with the result that the plasticity is reduced, while the strength is increased. In conjunction with this, production process operations such as shaping, heat treatment, welding, soldering, etc., should be performed under a vacuum or in a neutral gas medium.

In the case when titanium alloys are used in an oxidizing medium, the metal surface should be coated by special protective coatings.

Ingots of the Ta + 10% W alloy are initially shaped in the heated state at 1100-1500°. Subsequent shaping of the metal by forging or rolling can be performed in the cold state without intermediate annealing with a degree of compression of up to 90-95%.

The Ta + 10% W alloy can be used for making sheets, strips, foil and tubes of various dimensions. This alloy is used abraod for solid fuel rocket engine nozzles and for jet engine components.



Dependence of the strength of the Ta + 10% alloy on the temperature. 1) Shaped sheet; 2) recrystallized sheet. A) kg/mm^2; B) temperature, °C.

References: Mastick, D.F., "Iron Age," Vol. 185, No. 14, page 98, 1960; "Chem. and Engng. News," Vol. 37, No. 42, pages 32-33, 1959.

M.I. Gavrilyuk

TANTALUM PIPES – see Tantalum Wire.

TANTALUM SHEET - see Tantalum Wire.

TANTALUM WIRE. Wire and round bars are produced from tantalum of types TN-3 and TCh. High-melting corrosion-resistant wire and tubing is used in the vacuum-tube industry and in the manufacture of chemical apparatus. Table 1 shows the impurity content and Table 2 certain of the characteristics of tantalum wire. The figure shows the σ_b and δ of type TN-3 wire (2.3% Nb, 0.056% Fe, 0.070% Ti, 0.010% Si, 0.019% Mo, and 0.067% W) after annealing at various temperatures in a vacuum of 10^{-4}-10^{-5} mm Hg. These are rough data, since the characteristics of cold-worked and annealed wire depend to a large extent on its content of impurities and gases: σ_b decreases and δ increases as the inpurity content is reduced.

TABLE 1

Chemical Composition of Tantalum Wire

1 Сплав	Nb (%)	Ta (%)	2 Примеси (%), не более Fe	Ti	Si	Mo	W
ТН-3 3	<3,5	остальное 5	0,1	0,1	0,1	0,1	0,1
ТЧ 4	<0,1	остальное	0,05	6 в сумме 0,1			

1) Alloy; 2) impurities (%), no more than; 3) TN-3; 4) TCh; 5) remainder; 6) total of.

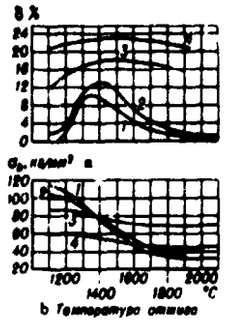
TABLE 2

Mechanical Characteristics of Tantalum Wire

1 Диаметр (мм)	14—3	2,8—1,6	1,5—0,3	0,28—0,05	0,10—0,01
2 Состояние поверхности	3 Ковяная, загрязненная маслами	4 Тянутая, покрытая пленкой графитовой смазки			5 Тянутая с чистой поверхностью
6 σ_b (кг/мм²)	—	—	90—115	120—150	155—180

1) Diameter (mm); 2) surface condition; 3) forged, smeared with oil;

4) drawn, coated with graphite-grease film; 5) drawn, with clean surface; 6) kg/mm^2.



Change in mechanical characteristics of type TN-3 tantalum wire with annealing temperature. Wire diameter (mm): 1) 0.05; 2) 0.01; 3) 0.5; 4) 1.0. a) kg/mm^2; b) annealing temperature.

In the electronics industry tantalum wire is used in the manufacture of generator-lamp circuits, direct-heating vacuum-tube cathod s, support and spring components, electrolytic capacitors and capacitor components, superconductive elements, etc.

Some wire is employed in the production of laminated sheets. Since tantalum does not irritate living tissues and retains constant characteristics on prolonged exposure to them, tantalum wire is used in surgery for suturing incised muscle tissue and blood vessels and for nerve-fiber and muscle-tissue prostheses.

Round tantalum tubing 0.5-50 mm in diameter is manufactured without seams, with welded seams, and by the cermet method. Such tubing is used principally in the electronics industry (for direct-heating cathodes) and in the chemical industry, in the production of bromine, hydrochloric, nitric, and sulfuric acids, and hydrogen peroxide, in petroleum cracking, etc.

References: Espe, V., Tekhnologiya elektrovakuumnykh materialov [Technology of Vacuum-Tube Materials], translated from German, Vol. 1, Moscow-Leningrad, 1962; Samsonov, G.V., Konstantinov, V.I., Tantal i

niobiy [Tantalum and Niobium], Moscow, 1959; Sokolov, Yu.A., Pikov, V.I , Avtorskoye svidetel'stvo [Author's Certificate], No. 109279, 1957.

Yu. A. Sokolov

TEARING RESISTANCE – one of the mechanical characteristics of rubber. In tearing the areas of maximum stress concentration are determined beforehand by making special cuts or by the shape of the specimen. The specimen is deformed by moving the holding devices of a tension apparatus at sufficiently high speed. According to GOST 262-53, the tearing resistance is the tearing load in kg for 1 cm of the initial thickness of the specimen. In addition, the tearing resistance is determined by the so-called characteristic energy T, which equals the work performed in forming a unit area of new surface. In practical terms, T equals the specific energy dissipated. The characteristic energy has not been fully defined in the physical sense.

G.M. Vartenev

TECHNICAL COPPER is copper which is used for the production of various mill products and as a charge material for smelting of the copper alloys. The chemical composition of technical copper is defined by GOST 859-41 (Table 1).

TABLE 1

Chemical Composition and Application of Technical Copper (GOST 859-41)*

Медь 1	2 Cu (%, не менее)	3 Содержание примесей (%, не более)											4 Применение	
		Bi	Sb	As	Fe	Ni	Pb	Sn	S	O	другие примеси 5	сумма примесей 6		
М0	99.95	0.002	0.002	0.002	0.005	0.002	0.005	0.002	0.005	0.02	0.0 Zn	0.05	Проводники тока, для сплавов высокой чистоты	7
М1	99.90	0.002	0.002	0.002	0.005	0.002	0.005	0.002	0.005	0.08	0.005 Zn	0.1	Проводники тока, для проката и высококачественных бронз, не содержащих олова	8
М2	99.70	0.002	0.005	0.01	0.05	0.2	0.01	0.05	0.01	0.1	—	0.3	высококачественные полуфабрикаты, для сплавов, обрабатываемых давлением	9
М3	99.5	0.003	0.05	0.05	0.05	0.2	0.05	0.05	0.01	0.1	—	0.5	Для проката обычного качества и литейных бронз	10
М4	99.0	0.005	0.2	0.2	0.1	—	0.3	—	0.02	0.15	—	1.0	Для литейных бронз и различных неответственных сплавов	11
М3С**	99.5	0.003	0.05	0.05	0.05	0.2	0.01	0.05	0.01	0.01	0.04 P	0.5	Трубы разных размеров для морского судостроения	12

*Methods of chemical analysis from GOST 635-52.
**Phosphorus content to 0.04% permitted.

1) Copper; 2) Cu (%, no less than); 3) impurity content (%, no more than); 4) application; 5) other impurities; 6) total impurities; 7) current conductors, for high purity alloys, 8) current conductors, for rolling high quality bronzes not containing tin; 9) high quality mill products, for bronzes which are pressure worked; 10) for rolling ordinary and casting quality bronzes: 11) for casting bronzes and various noncritical alloys; 12) piping of various diameters for ocean vessel construction.

Grade M0 technical copper is used for current conductors and for the production of high-purity alloys; M1 is used for current conductors,

various mill products produced by rolling, and for the production of high-quality, tin-free bronzes; M2 is used for high-quality mill products and for the production of bronzes which can be pressure worked; M3 is used for various mill products obtained by rolling, and for the production of ordinary-quality bronzes and other cast alloys; M4 is used for the production of cast bronzes and various noncritical alloys.

P, Sb, Bi, Si, As impurities markedly decrease the electro-conductivity of copper and in the M0 and M1 grades their content is limited to 0.002%. Bi, Sb and Pb impuirites reduce, in addition, the technological properties of copper, causing brittleness during hot pressure working. Ni, Ag, Zn and Sn impurities have no harmful effect on the mechanical and technological properties. Depending on the solidification conditions, the structure of cast pure copper may be equiaxed or transcrystalline. The dendritic structure is possible only in the contaminated grades of copper. Deformed and annealed copper has a polyhedral structure.

As a rule, current conductors are produced from the grades M0 and M1 technical copper, while electrical contacts in products for noncritical applications are also made from the copper grades M2 and M3. In the annealed condition copper has high plastic properties but relatively low strength. Cold deformation considerably improves all the strength characteristics of copper, but in this case there is some reduction of the electronconductivity and a marked reduction of the plasticity. Work hardening of hard copper can be relieved by annelaing (Table 2).

Annealing is performed in a weakly oxidizing medum to avoid "hydrogen disease", which can occur during heating of copper in a reducing atmosphere. Copper permits all forms fo pressure working, but in the soft condition these precesses proceed with difficulty, since the metal sticks to the cutting tool and poor separation of chips occurs. Machin-

TABLE 2

Technological Characteristics of Technical Copper

1 Свойства	Показатель 2 свойств
3 Темп-ра литья (°С)	1150—1200
4 Темп-ра горячей обработки (°С)	900—1050
5 Темп-ра отжига (°С)	500—700
6 Темп-ра начала рекристаллизации (°С)	200—300
7 Жидкотекучесть (см)	25
8 Линейная усадка (%)	2.1

1) Properties; 2) property indux; 3) casting temperature (°C); 4) hot working temperature (°C); 5) annealing temperature (°C); 6) temperature of beginning of recrystallization (°C); 7) fluidity (cm); 8) linear shrinkage (%).

ing is facilitated in the work hardened condition. Technical copper intended for grinding must be work hardened. Technical copper is easily pressure worked in the hot and cold conditions, welds well by any method and is amenable to soldering and brizing. In addition to current carrying components and electrical contacts, technical copper is used for the production of corrosion resistant oil and fuel lines, and also for sealing rings, washers, gaskets, etc. Technical copper has a high electrochemical potential, therefore, to avoid corrosion of parts made from other alloys which are in contact with parts made from copper or copper alloys the latter should be zinc coated. The mill products made from technical copper and their properties are presented in Table 3. For physical and mechanical properties of technical copper see also article on Copper.

O. Ye. Kestner

TABLE 3

Mill Products Produced from Technical Copper and their Properties

[1] Медь	[2] Вид полуфабриката	[3] Состояние	[4] Размер (мм)	σ_b (кг/мм²) [5]	δ (%)	ГОСТ или ТУ [6]
М1, М2, М3	Листы холоднокатаные [7]	Мягкие [8] (отожженные)	0,5—10,0	20	40	ГОСТ 495—50 [9]
		Твердые [10]	0,5—10,0	30	3	То же [11]
	Листы горячекатаные [12]	Без термич. обработки [13]	4—25	20	30	
М0, М1, М2	Лента [14]	Мягкая (отожженная) [15]	0,15—1,86	20	30	ГОСТ 9 [9] 1818—54
М1, М2, М3	Лента [14]	Мягкая [16]	>0,12—2,0	21	30	ГОСТ 9 [9] 1173—49
		Твердая [10]	0,5—2,0	30	3	То же [11]
М1	Полосы [17]	—	5—6	20	(не менее 40 кг/мм²)	ГОСТ 9 [9] 5369—52
М1, М2, М3	Плиты горячекатаные [18]	Без термич. обработки [13]	10—150	21	20	ЦМТУ 2974-48
М1, М2, М3, М3С [19]	Трубы тянутые [20]	Отожженные [21]	3—40 (по наружному диаметру) (толщина стенки 0,5—10,0) [22]	21	35	ГОСТ 617—53 [9]
		Твердые [10]	*	30	3,5	ЦМТУ 3451-53
М1, М2, М3	Прутки тянутые [23]	Мягкие [15] (отожженные)	5,0—40,0	20	30	ГОСТ 9 [9] 1535—48
		Твердые [10]	5,0—40,0	27	6	То же [11]
	Прутки прессованные [24]	Без термич. обработки [13]	14,0—120,0	20	8	*
	Прутки катаные [25]	*	35,0—100,0	20	8	*
М1	Проволока [26]	—	2,5—4,0	24	42	ГОСТ 9 [9] 6611—51
		—	1,0	32,5	1,2	То же [11]
		—	4,0	24	1,2	*
М1, М2	Проволока (наклеп 5—12%) для заклепок [27]	—	1,06—10,0	26	15	ЦГУ 18-54 [28]

1) Copper; 2) form of mill product; 3) condition; 4) size (mm); 5) σ_b (kg/mm^2); 6) GOST or TU; 7) cold rolled sheet; 8) soft (annealed); 9) GOST ; 10) hard; 11) same; 12) hot rolled sheet; 13) without heat treatment; 14) strip; 15)soft (annealed); 16) soft; 17) strip; 18) hot rolled plate; 19) M3S; 20) drawn tubing; 21) annealed; 22) (wall thickness); 23) drawn rods; 24) extruded rods; 25) rolled rods; 26) wire; 27) wire (work hardened 5-12%); 28) T_s TU.

TECHNICAL MAGNESIUM is refined electrolytic raw magnesium or resmelted refined magnesium obtained by a thermic process (carbothermic or silicothermic). Wide usage is made of the method of producing technical magnesium from raw magnesium by melting with fluxes (see Refining Magnesium Alloys).

Industry produces technical magnesium of 99.9% purity. The GOST provides that the producing plant guarantee an aluminum content in technical magnesium of no more than 0.02%. Technical magnesium of the Mg grade is used primarily for the production of special casting and deformable alloys based on magnesium and aluminum, pyrotechnic powders, and also in the chemical industry.

Chemical Composition of Technical Magnesium (GOST 804-62)

1 Марка	2 Mg (%, не менее)	3 Содержание примесей (%, не более)								4 сумма примесей
		Fe	Si	Mn	Na	K	Cu	Ni	Cl	
5 Мг	99.9	0.04	0.01	0.04	0.01	0.005	0.001	0.001	0.005	0.1

1) Grade; 2) Mg (%, not less than); 3) impurity content (%, not more than); 4) total impurities; 5) Mg.

A.A. Lebedev

TECHNICAL STRENGTH – a collective term used to designate the strength actually achievable with a material in contrast to its Theoretical strength, which is unrealizable or can be attained only with small specimens under special conditions (see Whiskers). Technical strength is generally evaluated from Ultimate strength on extension σ_b; for the plastic state σ_b corresponds to the resistance to substantial plastic deformation, while for the brittle state σ_b characterizes Rupture resistance. Until 1950 the highest technical strength was considered to be 200-220 kg/mm^2 (for quenched and low-tempered structural steel) and 300-350 kg/mm^2 for fine drawn steel wire. Techniques have recently been developed (thermomechanical processing, aging, etc.) that make it possible to raise ultimate strength to 300 kg/mm^2 or more and to pose the problem of further increasing technical strength. Strengths of up to 1000-2000 kg/mm^2 have already been achieved with individual specimens of very fine wire. For the majority of finished products with complex shapes static evaluation of technical strength from small smooth specimens is quite arbitrary, i.e., does not take into account notch sensitivity, surface condition, repeated loading, or the scale effect (see Structural strength, Theoretical strength, and Fatigue).

Ya.B. Fridman

TEFLON – see Fiber from Fluorine-Containing Polymers.

TEMPERATURE SENSITIVE PAINTS — paints whose films are capable of sharply changing their color upon reaching a certain temperature called the transition or critical temperature. Depending on whether the initial color of the paint is or is not restored when the temperature is reduced, the temperature sensitive paints are divided into reversible and irreversible. Inorganic, organic and organo-inorganic compounds are used as temperature sensitive paints. The transition temperature of temperature sensitive paints is substantially affected, in addition to temperature sensitive compounds, also by binders, fillers and additives which enter the composition of temperature sensitive paints. For the same temperature sensitive compound the transition temperature can be different depending on the binder used. Following are the shortcomings of temperature sensitive paints: they do not ensure automatic observation and recording, the transition temperature depends on the length of holding at the critical temperature and the rate at which the temperature reaches the critical value. Hence calibration is necessary whenever temperature sensitive paints are used under other temperature regime conditions than those specified in instructions. Temperature sensitive paints are used for rapid measuring of temperatures (with an accuracy of ±5-10°); for determining the temperature of current-conducting parts which are subjected to high voltages; for checking the heating of contacts and hot surfaces of boilers; for heat testing of electrical machinery; for study of the operational regimes of motors hidden from the observer's eye by jackets, in order to establish the shape of isotherms in various parts of the engine; in the heat treatment of metals,

i.e., quench hardening and tempering; rolling of shapes; bending of pipes; for studying the temperature of surface joined by oxy-acetylene and arc welding, etc. Temperature sensitive paints are also used in emergency repairs, repairs under field conditions and in many other cases. Temperature sensitive paints are made for measuring temperatures from 45 to 880° and above with intervals of 15-50°. The drying rate is 20-30 minutes, covering ability from 80 to 200 g/m^2, they are applied to solid body surfaces by a brush or atomizer. Sets of temperature sensitive crayons are produced alongside with temperature sensitive paints: No. 1 for instantaneous measuring of temperatures from 140° to 600° (11 crayons) and No. 2 for measuring temperatures with an interval of 10° from 230° to 360° and from 460° to 500° (12 crayons).

References: Belen'kiy, E F. and Riskin, I.V., Khimiya i tekhnologiya pigmentov [Chemistry and Technology of Pigments], 3rd Edition, Leningrad, 1960; Kiselev, V.S., Rassudova, N.S. and Laguzina, A.M., "Tr. Mosk. khim. tekhnol. in-ta im. D.I. Mendeleyeva" [Transaction of the Moscow Order of Lenin D.I. Mendeleyev Institute of Chemical Technology], Vol. 23, 1956; Rassudova, N.S., "Vestn. tekhn. i ekon. inform." [Herald of Technical and Economic Information], No. 3, page 59, 1961; "Instrum. and Control Systems," Vol. 33, No. 11, page 1826, 1960.

N.S. Rassudova

TEMPER BRITTLENESS OF STEEL – the decrease in the viscosity and resistance to brittle fracture of alloy steel during tempering within a certain temperature range or during slow post tempering or post annealing cooling over the range 650-450°. We can distinguish irreversible and reversible temper brittleness. Irreversible temper brittleness is manifested in a drop in viscosity during tempering at 250-400°. Chromium and manganese promote irreversible temper brittleness, while molybdenum, tungsten, and vanadium have no effect on this process. Silicon and to some extent chromium and other elements promote a shift in irreversible temper brittleness toward higher temperatures. A decrease in grain size leads to a reduction in irreversible temper brittleness, while comparatively moderate plastic deformation completely eliminates it. This type of brittleness is apparently associated with a change in the condition of the austenite-grain boundaries. Reversible temper brittleness is manifested in a drop in the impact strength of alloy steel during slow cooling over the range 650-450°, as well as during more or less prolonged holding within this temperature range during tempering. At the same time, when rapidly cooled after tempering at 650-450° steel with a tendency toward reversible temper brittleness acquires normal viscosity. Temper brittleness produced by slow cooling can be eliminated by reheating to a temperature above 650° and rapid cooling. Irreversible temper brittleness is produced not only by prolonged tempering at 650-450°, but also by slow post tempering cooling and by prolonged heating (at 550-450°) of annealed or normalized steel. Reversible temper brittleness is manifested in a sharp displacement of

the cold-shortness threshold toward higher temperatures. In the majority of alloy steels temper brittleness causes a decrease in impact strength and resistance to brittle fracture. Impact specimens exhibit intercrystalline rather than fibrous fracture. Mechanical characteristics (σ_b, δ, ψ) determined at room temperature are not affected by reversible temper brittleness, with the exception of a very slight rise in yield strength. A decrease in plasticity under tension occurs only when very severe reversible temper brittleness develops when notched specimens or low test temperatures are employed. Cold-working eliminates or prevents temper brittleness (when plastic deformation is carried out before the brittleness develops) in those cases where the steel is tested in the direction of plastic deformation (reversible temper brittleness may even be intensified in the direction perpendicularе to that of plastic deformation). Unnotched specimens tensile-tested at room temperature undergo considerable plastic deformation, so that reversible temper brittleness is eliminated near the fracture point and the mechanical characteristics (δ, ψ, σ_b) of such specimens are not affected by this type of brittleness. Reversible temper brittleness appears when the specimens are notched or the test temperature is reduced, both of which hamper plastic deformation. It has been established that reversible temper brittleness is manifested in a decrease in the brittle strength of the grain boundaries (of the austenite grains). Alloying with manganese, chromium, or nickel or an increase in phosphorus content promotes development of reversible temper brittleness. Addition of 0.3-0.5% Mo reduces such brittleness. Molybdenum is sometimes replaced by 1-1.2% tungsten for this same purpose, although the action of the latter is less effective. The method by which the steel is smelted has a strong influence on the development of reversible temper brittleness, so that different metallurgical melts

have a varying sensitivity to temper brittleness. Despite the enormous number of investigations which have been conducted and the interesting hypotheses which have been advanced, the physical nature of temper brittleness has still not been conclusively established. Special etching agents have made it possible to establish that steel damaged by temper brittleness undergoes a change in etchability at its grain boundaries. There is reason to suppose that temper brittleness and the thermal embrittlement of steel that occurs during prolonged operation at temperatures of 450-550° have the same origin.

References: Gulyayev, A.P., Termicheskaya obrabotka stali [Heat Treatment of Steel], 2nd Edition, Moscow, 1960; Mes'kin, V.S., Osnovy legirovaniya stali [Principles of the Alloying of Steel], Moscow, 1959; Zav'yalov, A.S., Senchenko, M.I., in book: Metallovedeniye [Metalworking], Collection 2, Leningrad, 1958; Zav'yalov, A.S., in book: Metallovedeniye [Metalworking], Collection 3, Leningrad, 1959.

Ya.M. Potak

TEMPERING OF STEEL – heating of quenched steel to a temperature below the lower critical point Ac_1 in order to reduce its hardness, increase its plasticity and viscosity, and relieve Internal stresses. During low tempering the martensite of quenched steel becomes impoverished in carbon, a process accompanied by a decrease in tetragonality and precipitation of iron carbides Fe_xC. In the initial stage of tempering the martensite contains a certain amount of carbon and the carbides Fe_xC remain coherent with it. When carbon steel is tempered at temperatures above 200° the residual austenite decomposes to form martensite and carbides of the Fe_xC type. As the tempering temperature is raised the carbon content of the martensite decreases, the carbide lattice separates from the martensite lattice, and the carbides become similar in composition to cementite; this reduces stresses of the 2nd and 3rd types. A further rise in tempering temperature leads to coagulation of the carbides. Carbide composition is altered during tempering

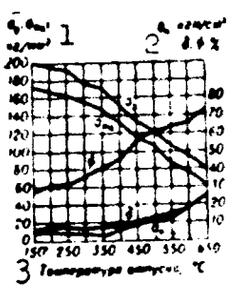


Fig. 1. Typical variation in the mechanical characteristics of quenched medium-carbon alloy structural steel during tempering. 1) kg/mm^2; 2) kg-m/cm^2; 3) tempering temperature, °C.

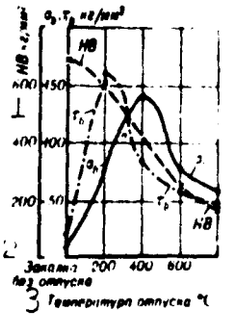


Fig. 2. Influence of tempering temperature on the variation in the hardness and strength of U7 steel during torsion and extension (S.I. Ratner). o – brittle fracture; · – plastic fracture.
1) kg/mm^2; 2) quenching without tempering; 3) tempering temperature, $^{\circ}$C.

of alloy steel. During high tempering of complex-alloy steels the carbides become enriched with chromium, molybdenum, vanadium, and tungsten. The composition of a steel has a considerable influence on the change in its characteristics during tempering and on its structure, particularly on the rate of carbide coagulation. Internal stresses of the 1st type are substantially reduced during tempering. Figure 1 shows the typical influence of tempering on the mechanical characteristics of alloy structural steel. Low tempering at 200-250° raises yield strength, somewhat reduces ultimate strength, and increases viscosity and plasticity. When the tempering temperature is further raised, the impact strength of the steel drops; it rises once more when the tempering temperature reaches 450°. Certain types of alloy steel exhibit two dips in impact strength, at 300-400° and 500-550°, which sometimes merge to form a single protracted drop (see Fig. 1). The rate of the decrease in strength during tempering depends on the alloying elements present in the steel. Such elements as silicon, cobalt, chromium, molybdenum,

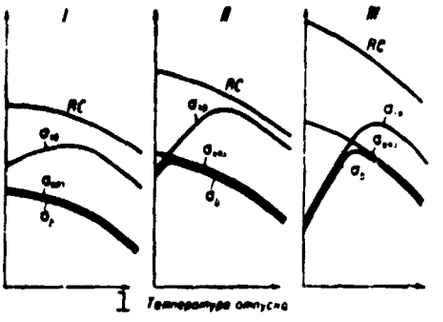


Fig. 3. Graphs showing the influence of tempering temperature on the variation in the hardness (RC), viscous strength (σ_{vyaz}), brittle strength (σ_{khr}), and ultimate strength (σ_b) of high-carbon (I), medium-carbon (II), and low-carbon (III) steel. 1) Tempering temperature.

tungsten, and vanadium retard the drop in hardness and strength. Some alloying elements (silicon and chromium) have a stronger influence during low and medium tempering, while others (vanadium) are most effective during high tempering. High-alloy steel containing considerable quantities of carbide-forming elements may retain its hardness and strength to the point of high tempering (500-550°). In some cases tempering at temperatures of approximately 500-600° causes an increase in hardness. The influence of tempering on the magnitude of internal stresses of the 1st type depends to a considerable extent on the point at which these stresses develop. Tempering causes a sharp decrease in internal stresses if they developed during quenching or before the steel was finally tempered (e.g., during straightening of untempered quenched steel). It causes a slight decrease in internal stresses in previously tempered components (e.g., tempered components subjected to straightening and then retempered to reduce internal stresses). In order for tempering to provide a maximal reduction of internal stresses after straightening the latter operation can be carried out with quenched steel or at least after tempering at a lower temperature than that used for the final tempering to relieve internal stresses. Blow

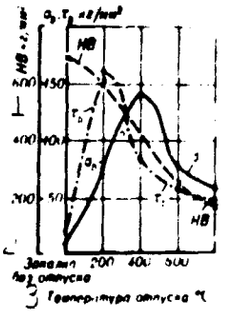
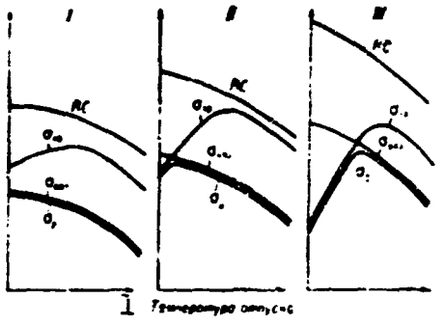


Fig. 2. Influence of tempering temperature on the variation in the hardness and strength of U7 steel during torsion and extension (S.I. Ratner). o – brittle fracture; · – plastic fracture.
1) kg/mm^2; 2) quenching without tempering; 3) tempering temperature, °C.

of alloy steel. During high tempering of complex-alloy steels the carbides become enriched with chromium, molybdenum, vanadium, and tungsten. The composition of a steel has a considerable influence on the change in its characteristics during tempering and on its structure, particularly on the rate of carbide coagulation. Internal stresses of the 1st type are substantially reduced during tempering. Figure 1 shows the typical influence of tempering on the mechanical characteristics of alloy structural steel. Low tempering at 200-250° raises yield strength, somewhat reduces ultimate strength, and increases viscosity and plasticity. When the tempering temperature is further raised, the impact strength of the steel drops; it rises once more when the tempering temperature reaches 450°. Certain types of alloy steel exhibit two dips in impact strength, at 300-400° and 500-550°, which sometimes merge to form a single protracted drop (see Fig. 1). The rate of the decrease in strength during tempering depends on the alloying elements present in the steel. Such elements as silicon, cobalt, chromium, molybdenum,



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tempering of quenched high-carbon steel leads to a decrease in hardness and an increase in strength, since the latter property of this steel is governed by its resistance to brittle fracture (rupture) (see Fig. 2). Figure 3 shows the influence of tempering temperature on the strength of high-carbon, medium-carbon, and low-carbon steel. The increase in brittle strength during low tempering is apparently associated with a decrease in martensite tetragonality. In order to give steel a bright surface after tempering it is subjected to "bright tempering," which is carried out in molten-alkali baths deoxidized with potassium ferrocyanide. Use of such tempering at temperatures above 550° is not recommended for especially critical components, since there is a danger of superficial nitrogen saturation, which causes an increased tendency toward brittle fracture.

References: Gulyayev, A.P., Termicheskaya obrabotka stali [Heat Treatment of Steel], 2nd Edition, Moscow, 1960; Mes'kin, V.S., Osnovy legirovaniya stali [Principles of the Alloying of Steel], Moscow, 1959; Bokshteyn, S.Z., Struktura i mekhanicheskiye svoystva legirovannoy stali [Structure and Mechanical Properties of Alloy Steel], Moscow, 1954; Potak, Ya.M., Khrupkiye razrusheniya stali i stal'nykh detaley [Brittle Fracture of Steel and Steel Components], Moscow, 1955.

Ya.M. Potak

TENASCO – high-strength cellulose hydrate fiber, obtained by spinning from viscose solutions into a settling bath with a reduced concentration of H_2SO_4 (80-110 g/liter) and an elevated content of zinc sulfate (60-120 g/liter) at 60-70°. The spun fiber is subjected to maximum stretching in water at 90° (by 90-100%). Tenasco is characteristic by almost complete structural uniformity over the cross section. When spinning by the continuous method a fiber is obtained with a rupture length of 29.7 km at an elongation of 16-17%. The wet strength is 20.7 km, elongation 23%, strength with a knot 18.9 km, elongation 10%. When using tenasco for cord production the fiber strength comprises 32.4-33.3 km, the elongation 9%. Specific tensile strength is about 50 kg/mm^2. At present tenasco-super 70, tenasco-super 105, tenasco-super 401, etc., fibers are produced with a strength in excess of 50 km. By its chemical resistance tenasco does not differ from other types of cellulose hydrate fibers. Tenasco is used for making cord fabric (low fiber numbers), ropes, knitted products used for technical purposes, i.e., conveyor belts, belts, etc.

References: Serkova, A.T., Konkin, A.A. and Kotomina, I.N., "KhV," No. 1, page 51, 1959; Moncruiff, R.W., "Khimicheskiye volokna" [Chemical Fibers], translated from English, Moscow, 1961.

L.S Gal'braykh

TENSILE STRENGTH – the mean tensile stress at the instant of tensile fracture. Although simultaneous fracture over the entire cross-section of a component corresponds to an infinite cracking rate and is consequently never achieved, tensile strength is a useful characteristic of structural materials. All other conditions being equal, the tendency to brittleness decreases and structural strength increases as tensile strength rises. In tension-brittle materials the tensile strength corresponds to the ordinary ultimate strength. Embrittling factors (a decrease in temperature, an increase in loading rate, introduction of notches or cracks, or a transition to biaxial extension) are necessary for evaluation of the tensile strength of tension-plastic materials. The tensile strength obtained in such cases is not always conclusive. Tensile strength usually increases rapidly as the structure of the material becomes finer. Many factors have different, sometimes opposite effects on tensile strength and resistance to plastic deformation; for example, raising the carbon content of low-temper steels reduces their tensile strength and increases their hardness (see Rupture, Tensile fracture).

Ya.B. Fridman

TENSILE TEST – is the determination of mechanical properties of metals in which the specimen (preponderantly of a round or square cross section) is loaded by two axial forces with opposite direction applied on the ends of the specimen. The wide use of the monoaxial stretching is caused by the fact that the determination of the most significant strength and plastic characteristics of the materials is relatively simple. The machines for tensile test (IM-4, IM-12, IM-30, R-5, etc., for example) are usually provided with self-recording devices which graph automatically the stretching curve in (Δl, p) (absolute elongation v.s. stress) coordinates. The conditional proportional limit, σ_{pts} and the yield limits σ_s or $\sigma_{0.2}$ (the physical or the conventional) are determined approximately on basis of the stretching curve (Figure); the tensile strength, σ_b, is determined with a sufficient exactness on basis of the graph dividing the maximum load by the initial area F_o of the specimens cross section. Gauges (mirror gauges, wire strain-gauges, etc.) must be used to determine exactly the conditional yield limit, proportional limit, elasticity limit and also the modulus E of elasticity and the Poisson's ratio μ. The relative elongation δ (in %) and the relative necking ψ (in %) in the moment of breaking are calculated on basis of the measurement of the working part of the specimen.

The methods of the tensile test, the requirements of the machines and devices, the dimensions and the technology of cutting and preparation of the specimens are standardized by GOST 1497-61.

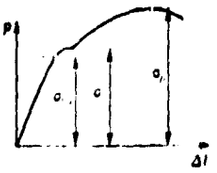

Fig. Stretching curve: Δl) Absolute elongation; p) force.

References: Shaposhnikov N.A. Mekhanicheskiye ispytaniya metallov [Mechanical Tests of Metals], 2nd edition, Moscow, Leningrad, 1954.

I.V. Kudryavtsev, D.M. Shur

TENSILE TEST WITH TWISTING – is the evaluation of the notching sensibility of materials; it makes apparent the tendency to brittle destructions and consists in the testing of a cylindrical specimen with a V-shaped notch displaced along the specimen to one of its ends under which a wedge plate is laid. Usually, plates with an angle of taper of 4°, 8°, or 12° are applied. The specimen is loaded with a stretching force, and the wedge plate generates additional bending stresses in it. The tensile test with twisting is carried out on universal or on breaking test machines. Bolts may be immediately subjected to the tensile test with twisting; the final turn under the nut which is screwed on the bolt, and under which the plate is laid, serves as a notch in this case. The notching sensitivity is evaluated in the tensile test with twisting by the relative decrease of the strength of the specimen or by the maximum load:

$$\eta = \frac{\sigma^{0}_{bH} - \sigma^{\alpha}_{bH}}{\sigma^{0}_{bH}} \quad \text{or} \quad \eta = \frac{P^{0} - P^{\alpha}}{P^{0}},$$

where σ^{0}_{bH} is the strength of the specimen, tested without twisting, and σ^{α}_{bH} is the strength of the specimen or the bolt tested with an angle of taper of $\alpha°$; P^{0} is the maximum load the bolt stood without twisting, and P^{α} is the load the specimen or bolt stood in the test with an angle of taper of $\alpha°$.

References: Shaposhnikov N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Tests of Metals], 2nd edition, Moscow-Leningrad, 1954.

N. V. Kadobnova

TERYLENE – synthetic heterochain fiber from polyethyleneterephalate (product of condensation polymerization of dimethyl ester of terephthalic acid and ethylene glycole). It is produced in England in the form of filament fiber of medium and high strength and in the form of staple fiber. The production of this fiber is assimilated in the USSR under the name of lavsan. For details on the properties and utilization of Terylene see Polyester Fiber.

E.M. Ayzenshteyn

TESTING OF SPRING STRIP – is the determination of the limit strength, the relative elongation (GOST 1497-61), the number of alternating bendings up to fracture (OST 1688), the Vickers hardness (GOST 2999-59) and of other mechanical properties.

The main mechanical characteristics of the spring strip are the modulus E of elasticity, the conditional proportional (elasticity) and yield limits. The magnitude of the elastic after-effect, the resistance to relaxation and the creeping are also important for strip materials destined for the production of elastic sensible elements of precision instruments (membranes, bellows, tube manometers, etc.).

The bending method is applied in the majority of the devices destined for the testing of strip materials, this fact is explained above all by the tendency to reproduce the stressed state occurring in the practical use of the elastic piece.

The static methods of testing spring strips are divided into 2 groups: 1) tests in which the force given to the specimen, and its deformation are measured (direct tests); 2) tests in which only the total and remaining deformation are measured (indirect tests); and the arising stresses are determined by the formula

$$\sigma = E\varepsilon_{obshch}$$

where E is the modulus of elasticity in kg/mm^2, ε_{obshch} is the total relative deformation.

The most perfect device for the tests of the first group is Gevondyan's device, in which the specimen is tested under conditions near to pure bending. The bending stress σ and the relative deformation ε aris-

ing during the test are determined by the formula

$$\sigma = \frac{2}{bh^2}\left(2M + \varphi\frac{dM}{d\varphi}\right) \quad \text{и} \quad \varepsilon = \frac{h\varphi}{2L},$$

where b, h, L are the width, thickness and length of the specimen, respectively, in mm; M is the bending moment in kgmm on the tested length; φ is the angle of bending in radians. The modulus of elasticity, the proportional limit σ_{pts} and the yield limit $\sigma_{0.2}$ are determined on basis of the drawn bending diagram (σ vs. ε).

From the second group of spring strips testing methods, the methods of Zubov, Tsobkallo, and Rakhshtadt are the most widely used. The Zubov method consists in the "forcing" of strip specimens by bending them around a ring or a drum. The stresses arising in this case are calculated by the formula

$$\sigma = E\frac{h}{2R},$$

where R is the fixed curvature radius along the neutral line in mm. Measuring the residual curvature radius ρ after the specimen has been set free, the magnitude of the relative residual deformation ε is calculated from the formula $\varepsilon_{ost} = \frac{h}{2\rho}$. The conditional elasticity limits $\sigma_{0.05}$, $\sigma_{0.01}$, etc. (at room temperature only) are determined from the (σ vs. ε_{ost}) function for a fixed allowance of the residual deformation.

In Tsobkallo's device, in which, as in Zubov's method, a pure bending is secured, the specimen is deformed by bending around the lateral face of a cylindrical mandrel. The flexure of the specimen, from which the residual deformation is calculated, is determined with a high exactness by a measuring microscope. The design of the device allows tests to be carried out both at room and at elevated temperatures.

Rakhshtadt's method is based on the measurement of the deformation by longitudinal bending (Fig.). The specimen with the length L obtains a longitudinal deformation Δx by means of an assembly set up on the

desk of the PMT-3 device, and the residual flexure f_{ost} after discharging of the specimen is measured by means of an optical device. Thereupon, the values of the fixed ε_{obshch} and residual ε_{ost} deformations are determined for the point B using the values of Δx and f_{ost} and formulae compiled to nomograms. The conditional elasticity limits are determined graphically on basis of the function (ε_{obshch} vs. ε_{ost}) in the same way as in Zubov's method. The simplicity of the test and the high reproducibility of the results are advantages of Rakhshtadt's method, but it can be carried out at room temperature only. The listed indirect methods permit tests for relaxation or elastic aftereffect. The elasticity limits determined by these methods are nominal, and their values exceeds the values of the true elasticity limits determined by direct methods, because the indirect methods use formulae valid in the elastic range.

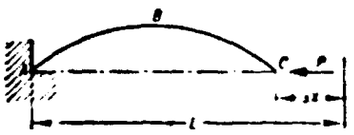

Fig. Scheme of the bending test of strip materials according to Rakhshtadt.

References: Gevondyan, T.A., Pruzhinnyye dvigatili [illegible] Driver, Moscow, 1956; Zubov V.Ya., "Zavodskaya laboratoriya," 1[illegible], Vol. 1[illegible], No. 12; Tsobkallo S.O., "Fizika metallov i metallovedeniye," 1[illegible], Vol. 2, No. 1; Rakhshtadt A.G., Shtremel' M.A., "Zavodskaya laboratoriya," 1960, No. 6.

I.B. Kalachev

TESTING OF WIRE – is an investigation in order to evaluate mechanical (tensile test, shearing test) or technological (winding, bending, torsion trials) properties of wires. The testing of wire for tension is carried out according to GOST 1497-42; the breaking strength (σ_b) and the elongation δ are usually determined, but rarely the proportional limit (σ_{pts}), the yield limits (σ_s, $\sigma_{0.2}$) and the modulus of elasticity E. "Snail" heads (Fig.) are used in order to avoid a pinching off of the wire in the clamps of the test machine. The shearing strength (τ_{sr}) is determined in the shearing test of wire (see Shearing Test). The ability of the wire to be deformed plastically is evaluated by torsion and bending trials. The torsion test of wire is carried out on machines and devices (GOST 1545-42) at a constant or alternating direction of the torsion. The plasticity of wire is evaluated by the number of repeated torsions causing the rupture of the wire. The look of the fracture and the surface of the twisted wire characterize the homogeneity of the material and the presence of defects in it (see Twisting Trial). The bending trial (GOST 1579-42) is the most important technological trial for wire: the sample, clamped in a cramp with rounded jaws, is broken by means of repeated bendings for 180°, or its surface shows damages (laminations or slight tears) as a result of the test. The degree of plasticity is determined by the number of bendings causing fracture or the appearance of damages on the surface (see Backward and Forward Bending Trial). The ability of the wire to undergo a fixed winding is determined by winding it in cold state on a mandrel with a fixed diameter or on a U-shaped clamped section of the wire itself (OST 1695).

I-4511

Device to hold
test wire.

The absence of laminations, exfoliations, cracks, slight tears and fractures proves that the wire has stood the trial.

N.V. Kadobnova

TEST OF SPRING WIRE – is a test for the determination of the strength, the number of bendings, and of the breaking torsions (GOST 1071-41, and GOST 9389-60), and also of other mechanical features. The elasticity limit in torsion, determined on the Siebel - Pomp apparatus, serves frequently as the basic characteristic of spring wire. The specimen with a working length of usually 100 mm obtains a torsional stress τ in kg/mm^2 by twisting, determinable by the formula: $\tau = \frac{\varphi d}{2l} G$, where φ is the torsion angle in radians; d and l are the diameter and the length of the specimen, respectively; G is the shearing modulus assumed for steel, for example, equal to 8000 kg/mm^2. Thereupon, the specimen is discharged, and the residual relative shearing angle γ_{ost} is determined by the formula: $\gamma_{ost} = \frac{\varphi_{ost} d}{2l}$, where φ_{ost} is the residual torsion angle. By means of successive tests, the function (τ, γ_{ost}) is obtained, which is used to determine the elasticity limit $\tau_{0.06}$ corresponding to a residual deformation $\gamma = 0.06\%$.

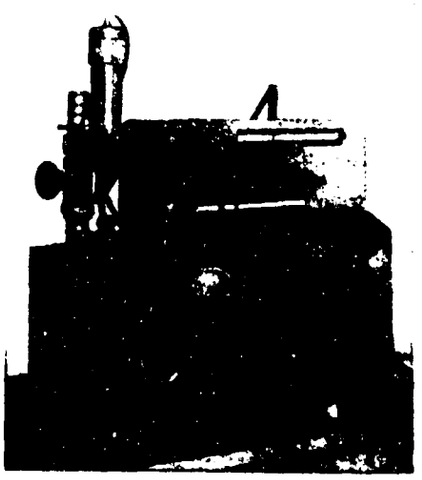

Fig. 1. Device for the test of spring wire (designed by the Ufa Aviation Institute).

A new device was developed (Fig. 1) because the Siebel-Pomp device is instable, has not a dynamometer, has a low efficiency, and the results are approximately owing to the approximately assumed shearing modulus; the new device is distinguished by a higher efficiency and has an electric dynamometer with a computer which determines automatically the elasticity limit and permits the drawing of

the whole torsion curve.

Wire materials used for power and sensible elastic elements must be frequently tested at raised and reduced temperatures. In this case, the characteristics obtained in long-time tests (elastic after-effect, relaxation, creep) become important in addition to the short-time characteristics (moduli of elasticity and shearing, proportional elasticity, and yield limits). In Fig. 2, a scheme of a device is shown for the determination of conditional elasticity limits and the measurement of the elastic after-effect at temperatures up to 800°. The specimen to be tested is fixed in clamps and obtains a fixed torsional deformation which results in a stress τ. The measurement of the residual deformation (after discharge) is carried out by means of a mirror and a tube. The elasticity limits which may be obtained with very small allowance (up to 0.001%) due to the high exactness of the measurement, are determined in the same way as in the Siebel-Pomp device. Characteristics of the elastic after-effect are also determinable by the new device on the basis of the obtained residual deformation as a function of the holding time at a given stress. The low efficiency is a disadvantage of this device.

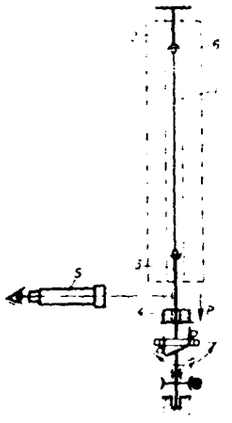

Fig. 2. Scheme of a device for the determination of the limits of elasticity and of the elastic after-effect of the wire: 1) Specimen; 2) and 3) clamps; 4) worm gear; 5) tube; 6) mirror.

The static torsional test of wire may be carried out by testing spring-specimens for compression. This method consists in a graphic-analytical drawing of the shift diagram according to the force characteristics of the spring, and a subsequent determination of the shearing modulus G, the proportional limit τ_{pts} and the yield limit $\tau_{0.}$ on basis of the diagram. The fact that the test is not carried out with pure tosion, is a disadvantage of this method; the high efficiency and the possibility to carry out the tests relatively easily at raised and reduced temperatures, are advantages of this method. A dynamic method is used to determine the relaxation of the wire during stretching; the method consists in the measurement of the natural frequencies of the stretched wire, and the subsequent determination of the value of the relaxation stress σ according to the formula $\sigma = 4\rho l^2 N^2$, where ρ is the density of the material in g/cm^3, l is the length of the specimen in mm; N is the natural frequency in cps. Torsional creep tests of wire may be carried out by testing spring specimens for compression. A fixed stress τ is given by a constant load P, determinable from the formula $P = \tau \frac{\pi d^3}{8D\cos\varphi}$ where d is the diameter of the wire in mm; D is the mean diameter of the spring in mm; φ is the angle of the coil pitch.

The test process gives the relative shear angle γ as a function of the holding time; γ is determined by the formula $\gamma = \lambda \frac{d}{\pi i D^2}$, where λ is the sagging of the spring in mm; i is the number of the working coils.

References: Tsobkallo S.O., "Fizika metallov i metallovedeniye," 1956, Vol. 2, No. 1; Kalachev I.B., Talakin N.I., "Zavodskaya laboratoriya," 1959, Vol. 25, No. 11; Davidenkov N. and Sakharov P. "Zhurnal tekhnicheskoy fiziki" [Journal of Technical Physics], 1934, Vol. 4, No. 2.

I.B. Kalachev

TESTS, MECHANICAL – see Mechanical Tests.

TESTS, MICROMECHANICAL – see Micromechanical Tests.

TEXTOLITE – laminated plastic material made by hot pressing of cotton impregnated by a thermosetting type resin. To impart specific

TABLE 1

Principal Characteristics of Sheet Textolite

1 Свойства	Текстолит листовой (ГОСТ 5–52)			Текстолит электротехнический (ГОСТ 2910–54)			
	2			3			
	4 Марки						
	5 ПТК	6 ПТ	ПТ-1	А	7 Б	8 ВЧ	Г
Удельный вес 10	1,3–1,4	1,3–1,4	1,3–1,4	не менее 11 1,3	1,3	1,3	1,3
Предел прочности (кг/см²) 12	не менее						
13 при изгибе	1600	1450	1200	900	1200	—	1200
при растяжении по основе 14	1000	850	650	600	650	500	650
то же по утку 15	—	—	—	450	550	400	450
при сжатии вдоль слоев 16	1500	1300	1200	—	—	—	—
Удельная ударная вязкость (кг·см/см²) 17	35	35	25	20	25	—	27
Теплостойкость по Мартенсу (°С)	125	125	120	125	125	125	125
18 Твердость по Бринеллю (кг/мм²) 19	—	—	—	30	30	30	30
Водопоглощение за 24 часа (г/дм²) 20	не более 21			0,6	0,6	не более 0,55	0,6
	0,35	0,36	0,65	при толщине 1 мм и более не менее 22			
Удельное объемное электрическое сопротивление (ом·см) 23	—	—	—	10^{12}* 10^{13}***	10^{12}* 10^{13}***	10^{12}* 10^{13}**	—
Удельное внутреннее электрич. сопротивление (ом) 24	—	—	—	10^{12}* 10^{13}***	10^{12}* 10^{13}***	—	10^{12}* 10^{13}***
Электрич. прочность при 90° (кв/мм) 25							
при толщине 0,8–1,9 мм 26	—	—	—	8*	4*	8*	4*
при толщине 2–3 мм 27	—	—	—	5*	2*	5*	2*
Электрическая прочность при 90° вдоль слоев, для листов толщиной 8 мм и более (кв/мм) 28	—	—	—	6,5*	4,5*	6,5*	4,5*
Тангенс угла диэлектрич. потерь при частоте 10^6 гц 29	—	—	—	—	—	не более 0,07	21
Диэлектрич. проницаемость при 10^6 гц 30	—	—	—	—	—	не более 8*	—

*After being held for 4 hours at 70° with subsequent holding at 20° and 65% relative humidity for not less than 6 hours.

**After being held in distilled water at 20° for 24 hours.

***After being held in a medium with 95% relative humidity at 20° for 24 hours.

1) Properties; 2) commercial grade textolite (GOST 5-52); 3) electrical equipment textolite (GOST 2910-54); 4) brands; 5) PTK; 6) PT; 7) B; 8) VCh; 9) G; 10) specific gravity; 11) not less than; 12) ultimate strength (kg/cm^2); 13) in flexure; 14) in tension along the warp; 15) same as above along the weft; 16) in compression along the layers; 17) specific impact ductility (kg-cm/cm^2); 18) Martens heat resistance (°C); 19) Brinell hardness (kg/mm^2); 20) water absorption for 24 hours; 21) not more than, 22) for a thickness in excess of 1 mm and more not less than; 23) specific volume electrical resistivity (ohm-cm);

24) specific internal electrical resistivity (ohms); 25) electric strength at 90° (kv/mm); 26) for a thickness of 0.8-1.0 mm; 27) for a thickness of 2-3 mm; 28) electric strength at 90° along layers for sheet thicknesses of 8 mm and more (kv/mm); 29) tangent of dielectric losses angle at a frequency of 10^6 cps; 30) dielectric permittivity at 10^6 cps.

properties to textolite, special additives, for example, graphite, are added to the composition. The fabric in textolite serves as the base (reinforcing filler), while the resin serves as a binder. Textolite is produced with phenol-, cresol- or xylenolformaldehyde resins; combined phenolaniline formaldehyde resins are also used. Coarse calico, calico, chiffon, gingham, nankeen, belting, etc., are used as the base. Nylon- and capron-based fabrics are also successfully used for the production of textolite. Textolite is subdivided by its external appearance into sheet and shaped, and by its intended service into building, commercial grade, electrical equipment and antifriction. Both these classifications are arbitrary to a substantial extent, since electrical equipment textolite frequently serves simultaneously as a building material (panels, traverse, etc.), building textolite is used as an antifriction material (bearing linings), etc.

Textolite is made in the form of sheets (plates) and in the form of shaped products (rods, tubes, sleeves, cylinders, gears, pressed bearing liners, rollers for control cables, L- and T-shaped components, etc.). For making pressed components by the consumer proper the industry produces a semifinished product in the form of resin-impregnated cotton fabric.

The compressive, tensile and static flexture strength of textolite in the temperature range from -60° to +150° decreases with an increase in temperature, having the highest indicators at -50°, -60°. The specific impact ductility of textolite is highest at a temperature

of 20° and is reduced as the latter changes in the direction of increasing above zero as well as subzero values.

Tables 1-5 percent the principal characteristics and fields of utilization of sheet and shaped textolite.

The physicomechanical and electrical insulation properties of textolite depend on the starting fabric (its structure, density, thickness, strength and presence of dressing), the nature of the resin, the percentage of the resin and fabric content in the finished material, as well as the process by which made. Changing the specific pressure within the limits of 75-150 kg/cm^2 does not perceptibly affect the physicomechanical properties of textolite. At a lower specific pressure (25-75 kg/cm^2) a certain tendency is observed toward an increase in certain indicators (specific gravity, flexuaral and compressive strength) and toward a reduction in the water absorption ability with an increase in the specific pressure; the changes thus observed are highly insignificant. Certain additional characteristics of sheet textolite of the PTK and PK brands are given in Table 2.

Textolite has a low friction coefficient and high wear resistance, which makes it into a good antifriction material. The wear resistance of textolite under the action of rubbing forces is higher than, for example, that of the copper-lead bearing alloy. This makes it possible to successfully use textolite as a material for bearing liners. Graphitized textolite has a lower friction coefficient and has an even higher wear resistance. The service life of bearings from textolite is by about a factor of 10-15 greater and of bearings from graphatized textolite is by a factor of 20-30 greater than that of copper-lead bearings.

Textolite has a relatively moderate hardness and substantial flexibility, for which reason rextolite bearings are deformed in the pro-

cess of operation by the pressure, taking on a shape which is most advantageous for rubbing. Water is used as the lubricant for textolite bearings which is practically impossible when metal bearings are used. Textolite absorbs the lubricant (water in amounts of up to 10% of its weight), with the result that the rubbing conditions differ substantially from those for metals which practically do not absorb the lubricant. Textolite is distinguished by a lower thermal conductivity (by a factor of 200-400 lower than that of bronze). The coefficient of linear thermal expansion of textolite is $3\text{-}4\cdot10^{-5}$ (it is $1.1\cdot10^{-5}$ for steel and pig iron and $1.9\cdot10^{-5}$ for brass), which also introduces its specifics in the design and operation of textolite bearings.

Textolite is sufficiently resistant to strong hydrochloric, acetic, phosphoric and weak sulfuric acids. Alkalis reduce the strength of textolite and destroy it. The high-temperature corrosion resistance of textolite is only by a factor of 5-7 higher than that of cellulose and is by approximately the same factor lower than that of phenolformaldehyde resin. This is due to the high flammability of the filler, i.e., the cotton fabric. Increasing the resin content and replacement of the organic filler by a mineral one greatly increases the high temperature corrosion resistance of the material.

Textolite does not resist mildew. The formation of mildew on it results in a large reduction in the electrical resistivity, both surface and volume. Hence textolite cannot be used under tropical conditions without special protection from enamels (PKE-19, Spd), which contain fungisides, which are poisonous to mildew fungi, or without being covered by the E-41-00 epoxy varnish, which creates a water-resistant film.

Radioactive radiation increases the brittleness and swelling capacity of textolite, reduces its tensile strength and the specific impact

ductility.

Textolite is machined on standard metal-cutting and woodworking lathes in the same manner as many metals and wood. The specific features of textolites must be taken into account when machining this material. Textolite does not have the rigidity of metal, it is flexible, for which reason the dimensional tolerances cannot be too small.

Textolite is used in a variety of mechanical, electrical and chemical products, starting with miniature bearing liners and insulators for rocket and guided missile body components. The high antifriction properties together with the fact that the weight of components from this material is by a factor of 5-6 lower than the weight of the same component from metal ensure textolite extensive use in making various friction components. Textolite is used extensively in machine building for the manufacture of gears. Such gears, when paired with metal gears,

TABLE 2

Certain Additional Characteristics of Sheet Textolite

1 Марки	2 Модуль упругости при растяжении 10^{-3} (кг/см²)	3 Относительное удлинение при разрыве (%)	4 Модуль сдвига 10^{-3} (кг/см²)	5 Предел выносливости при изгибе с симметричным циклом (кг/см²)	6 Коэффициент линейного расширения $\alpha \cdot 10^{-5}$ (1/°С)	7 Коэффициент теплопроводности (ккал/м·ч·°С)	8 Удельная теплоемкость (ккал/кг·°С)	9 При кручении: предел пропорциональности (кг/см²)	9 При кручении: модуль упругости (кг/см²)	10 Предел пропорциональности (кг/см²)
13 ПТК	100	1,0	25	200	3,3–4,1	0,20–0,29	0,35–0,36	495	22400	210
14 ПТ	95	1,0	24	200	3,3–4,1	0,20–0,29	0,35–0,36	–	–	–

1) Brands; 2) tensile modulus of elasticity (kg/cm^2); 3) relative elongation at break (%); 4) shear modulus 10^{-3} (kg/cm^2); 5) endurance limit in flexure with a symmetrical cycle (kg/cm^2); 6) coefficient of linear expansion $\alpha \cdot 10^{-5}$ (°C^{-1}); 7) thermal conductivity coefficient (kcal/m-hour-°C); 8) specific heat (kcal/kg-°C); 9) in torsion; 10) proportional limit (kg/cm^2); 11) ultimate strength (kg/cm^2); 12) modulus of elasticity (kg/cm^2); 13) PTK; 14) PT.

work noiselessly and wear out slower than metal gears. Textolite is also used for obtaining decorative facing material; it is applied one or

both sides of plywood or metal sheets. By facing one side of textolite with copper foil, the so-called foil-faced textolite for printing purposes is obtained.

TABLE 3

Fields of Application of Sheet Textolite

1 Вид изделия	2 Области применения
3 Текстолит подсечный (ГОСТ 5–52)	4 Листы и плиты толщиной от 0,5 до 70 мм
	5 Различные детали конструкционного назначения, к-рым не предъявляются требования электроизоляционного характера
6 Текстолит электротехнический (ГОСТ 2910–54)	7 Листы и плиты размером не менее 400 × 400 мм при толщине от 0,5 до 60 мм для марок А, Б и Г и от 0,5 до 8 мм для марки ВЧ
	8 Электроизоляционный материал в электротехнич. установках для работы при температуре окружающей среды от −60 до +70°, марки А и Б — для работы в трансформаторном масле и на воздухе, Г — для работы на воздухе, ВЧ — для работы в радиоаппаратуре на воздухе

1) Kind of products; 2) fields of application; 3) commercial grade textolite (GOST 5-52); 4) sheets and plates from 0.5 to 70 mm thick; 5) various building components to which no special electrical insulation requirements are presented; 6) electrical equipment textolite (GOST 2910-54); 7) sheets and plates with dimensions of not less than 400 x 400 mm with a thickness from 0.5 to 60 mm for brands A, B and G and from 0.5 to 8 mm for the VCh brand; 8) electrical insulation material in electrical engineering installations for operation at a surrounding medium temperature from −60° to +70°; brands A and B for work in transformer oil and in air, G for work in air and VCh for work in radio apparatus in air.

TABLE 4

Principal Characteristics of Shaped Textolite

1 Свойства	2 Виды изделий			
	3 стержни	4 цилиндры	5 трубки намотанные	6 трубки прессованные
8 Удельный вес	1,25–1,35	—	не менее 1,05	1,25
9 Предел прочности, (кг/см², не менее) при изгибе 10	1000	—	800	
при растяжении 11	В зависимости от диаметра от 440 до 650	—	450	1000
13 при сжатии в осевом направлении	—	—	450	1800
при разрыве в радиальном направлении 14	—	—	—	200
Водопоглощение за 24 часа (%, не более) 15	1,0	В зависимости от толщины стенки от 1,5 до 4,5 мм 16	5,0	9
17 Нагревостойкость в течение 24 часов (°С)	105	—	—	105
18 Масленостойкость в течение 4 часов (°С)	105	130	—	105
19 Теплостойкость по Мартенсу (°С, не менее)	—	—	—	150
20 Удельное поверхностное электрическое сопротивление (ом, не менее)	10^9	—	—	—
21 Удельное объемное электрическое сопротивление (ом × см, не менее)	10^8	—	—	—
22 Пробивное напряжение в масле (при расстоянии между электродами 1 мм (кв, не менее)	5	—	—	—

1) Properties; 2) kind of products; 3) bars; 4) cylinders; 5) wound tubes; 6) pressed tubes; 7) not less than; 8) specific gravity; 9) ultimate strength (kg/cm², not less than); 10) in flexure; 11) in tension; 12) depending onthe diameter from 440 to 650); 13) in compression in the axial direction; 14) in tension in the radial direction; 15) water

absorption for 24 hours (%, not more than); 16) depending on the wall thickness from 1.5 to 4.0%); 17) resistance to overheating for 24 hours (°C); 18) oil resistance for 4 hours (°C); 19) Martens heat resistance (°C, not less than); 20) specific surface electrical resistivity (ohms, not less than); 21) specific volume electrical resistivity (ohm-cm, not less than); 22) breakdown voltage along the layers for an interelectrode distance of 10 mm (kv, not less than).

TABLE 5

Fields of Application of Shaped Textolite

1 Вид изделий	2 Стержни длиной 200–500 мм, d = 8, 13, 18, 25, 40 и 60 мм	3 Цилиндры с внутренним d = 30–200 мм и толщиной стенки не менее 5–7 мм	4 Трубки с внутренним d = 10–25 мм и толщиной стенки 1–3 мм	5 Трубки размером 10 × 25, 10 × 28 мм
6 Области применения	7 Различные детали электрооборуд. и конструкц. назначения	8 Электроизоляц. детали для работы на воздухе и в трансформаторном масле	9 Защита проводов и тросов	10 Различные детали преимущественно монтажного назначения

1) Kind of product; 2) rods 200-500 mm long, d = 8, 13, 18, 25, 40 and 60 mm; 3) cylinders with an inside d = 30-200 mm and wall thickness not less than 5-7 mm; 4) tubes with an inside d = 10-25 mm and wall thickness 1-3 mm; 5) tubes with dimensions 10 × 25, 10 × 28 mm, 6) fields of application; 7) various electrical equipment and building components; 8) electrical insulation components for work in air and in transformer oil; 9) protection of wires and cables; 10) various components, primarily assembly.

References: Shugal, Ya.L. and Baranovskiy, V.V. Slоistyye plastiki [Laminated Plastics], Moscow-Leningrad, 1953; Avrasin, Ya.D. and Ivanov, N.V., Vliyaniye nekotorykh faktorov tekhnologicheskogo protsessa izgotovleniya tekstolita na yego fiziko-mekhanicheskiye svoystva [The Effect of Certain Factors of the Production Process Used in Making of Textolite on its Physicomechanical Properties], "KhP," No. 3, pages 21-24, 1954; Mashinostroyeniye. Entsiklopedicheskiy spravochnik [Machine Building. Encyclopedic Handbook], Vol. 4, Moscow, 1947; Spravochnik po elektrotekhnicheskim materialam [Handbook of Electrical Engineering Materials], Vol. I, Part 2, Moscow-Leningrad, 1959.

Ya.D. Avrasin and N.V. Ivanov

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[Transliterated Symbols]

4038 ГОСТ = GOST = Tosudarstvenny obshchesoyuznyy standart = All-Union State Standard

4038 ВЧ = VCh = vysokochastotnyy = high-frequency

TEXTOVINITES – see Leather Substitutes.

THEORETICAL STRENGTH – the resistance to deformation and fracture which a body should have according to calculations of the cohesive forces in solids. The theoretical strength of a material is of the order of 1/10 E, where E is Young's modulus. In some cases the strength of steel can be raised to 350 kg/mm^2, i.e., of the order of 1/60 E, by thermomechanical processing and magnetic quenching. The strength of drawn spring wire reaches 1/60 E, while that of very fine iron filaments (see Whiskers) is of the order of 1000 kg/mm^2, i.e., 1/20 E. It has thus been demonstrated that theoretical strength is experimentally achievable and that theoretical strength and Mechanical strength can be approximated. The number and distribution of defects and the surface condition of the material are enormously important in approaching theoretical strength. Elimination of surface defects (as by etching of glass or electrolytic polishing of metals) and creation of residual superficial compressive stresses (as by special heat treatment of glass or shot-blasting of metals) permit a considerable increase in strength; for example, that of glass can be raised from 10 kg/mm^2 to 80-100 kg/mm^2 or more.

References: Borisavskiy, I.A., Vitman, F.F., and Pukh, V.P., Povysheniye prochnosti tonkogo stekla [Raising the Strength of Thin Glass], DAN SSSR [Proceedings of the Academy of Sciences USSR], 1961, Vol. 138, No. 5, pages 1073-1076; Ivanova, V.S., Gordiyenko, L.K., Novyye puti povysheniya prochnosti metallov [New Techniques for Increasing the Strength of Metals], Moscow, 1964.

Ya.B. Fridman

THERMAL COEFFICIENT OF VOLUMETRIC EXPANSION β – a quantity characterizing the increase in a unit volume of a body when the temperature is raised 1°. It is calculated from the formula $\beta = 1/v \cdot \Delta v/\Delta T$, where v is the volume of the body at a selected temperature and Δv is the increase in this volume when the temperature is raised by ΔT. The coefficient β is approximately three times the thermal coefficient of linear expansion. In contrast to solids and liquids, β is roughly the same for all gases, equaling 1/273 degree^{-1}. The value of β usually increases with temperature. However, there are substances (water, pig iron, bismuth, quartz, etc.) in which β decreases on heating within a certain temperature range. A change in the aggregate state of a substance causes a sharp jump in its β.

G.M. Bartenev

THERMAL EFFECTS OF PHASE TRANSITIONS – absorption (generation) of heat at a constant temperature, which accompanies first-order phase transitions in a substance (melting, vaporication, sublimation, transition of solid bodies from one crystalline form to another, etc.). Thermal effects of phase transitions are assumed to be positive for absorption and negative for generation of heat. Phase transitions which take place without thermal effects of phase transitions (order phenomena in certain substitutional solutions, transition of superconductors from the normal to the superconducting state, etc.), are called second-order phase transitions. The thermal effects of phase transitions are, a rule, reduced with an increase in the phase transition temperature.

L.S. Priss

THERMAL EXPANSION – change in the dimensions of bodies upon heating. It is characterized by the bulk expansion coefficient β (see Bulk Thermal Expansion Coefficient), and for solid bodies it is also described by the linear thermal expansion coefficient α (see Linear Thermal Expansion Coefficient). The thermal expansion of monocrystal is anisotropic, while the thermal expansion of polycrystals, amorphous substances, liquids and gases is isotropic. In isotropic expansion $\beta = 3\alpha$.

The thermal expansion of substances is measured by various kinds of dilatometers.

References: Khvol'son, O., Kurs fiziki [A Course in Physics], Vol. 3, Leningrad, 1923; Roberts, D., Teplota is termodinamika [Heat and Thermodynamics]. Translated from English, Moscow-Leningrad, 1950; Strelkov, P.G., "Zhurnal neorganicheskoy khimii" [Journal of Inorganic Chemistry], Vol. 1, Issue 6, page 1350, 1956; Strelkov, P.G. [et al.], "ZhETF," Vol. 7, Issue 4, page 519, 1937; Bekkerdal, N., "J. Res. Nat. Bur. Standards," Vol. 43, No. 2, page 145; 1949.

G.M. Bartenev

THERMAL FATIGUE – process of changing the state and properties of a metal or alloy under the effect of multiple heating and cooling, which result in deformations and failure. The term thermal fatigue is used by analogy with the term mechanical fatigue, which arises in a metal upon application of varying loads. However, substantial differences exist between thermal and mechanical fatigue, which arises in a metal upon application of varying loads. However, substantial differences exist between thermal and mechanical fatigue.

Under thermal fatigue the stresses are produced not by external loads, but thwarted thermal displacements (expansion or compression) of the most highly heated or cooled elementary volumes of the metal in the nonhomogeneous temperature field of the component. In addition, under mechanical fatigue the averaged stresses (stresses of the 1st kind) correspond to moderate (macroscopic) deformations, which do not go past the elastic limit. Under thermal fatigue the deformations in the most highly heated zones go past the elastic limit and can produce stresses which exceed the yield point. As a result of this the thermal fatigue process is accompanied by an accumulation of residual deformations; here a substantial change in the shape and dimensions of the component is possible toward the instant of failure. In many cases, particularly at high temperature drops (δ = 0.5-0.6 T_{pl}), the cause of failure under thermal fatigue is found to be exhaustion of the material's plasticity.

In modern equipment thermal fatigue acquires a particular importance for materials which are used for making components of gas turbine

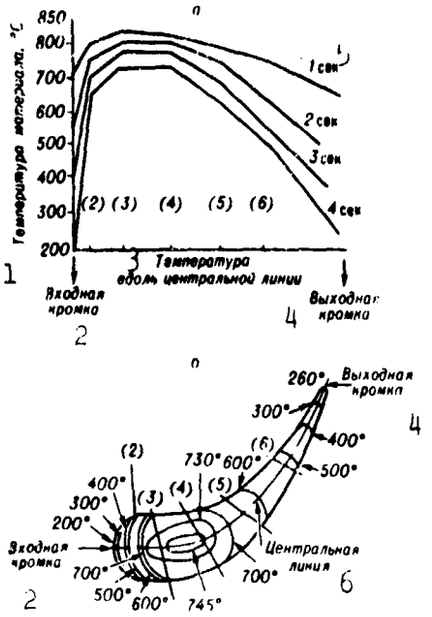

Fig. 1. Temperature distribution at the surface of a runner bucket (a) and the corresponding isotherms (b) after cooling for 4 seconds (gas heating – 1.5 min, compressed air cooling – 30 secs). 1) Material temperature, °C; 2) leading edge; 3) temperature along the center line; 4) trailing edge; 5) sec; 6) center line.

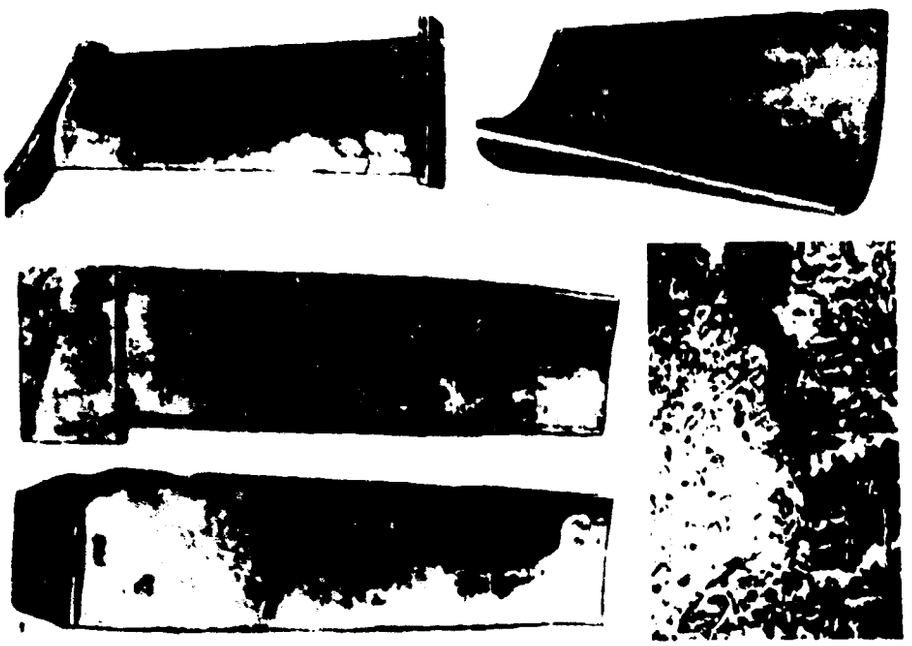

Fig. 2. Cracks in buckets from the ZhS3 alloy and the microstructure in the crack zone. 1, 2) Crack in the leading edge; 3) crack in the middle of the bucket. Magnification factor ×.

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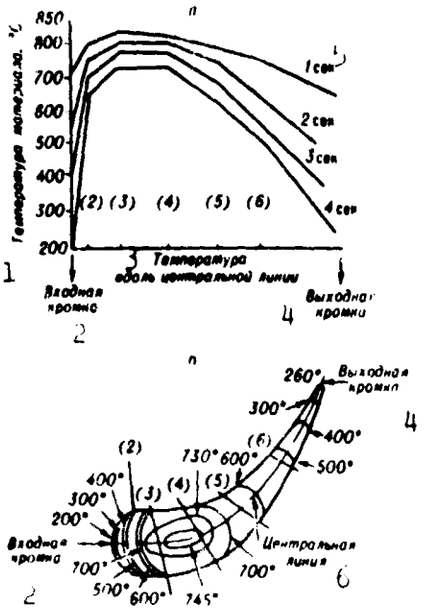

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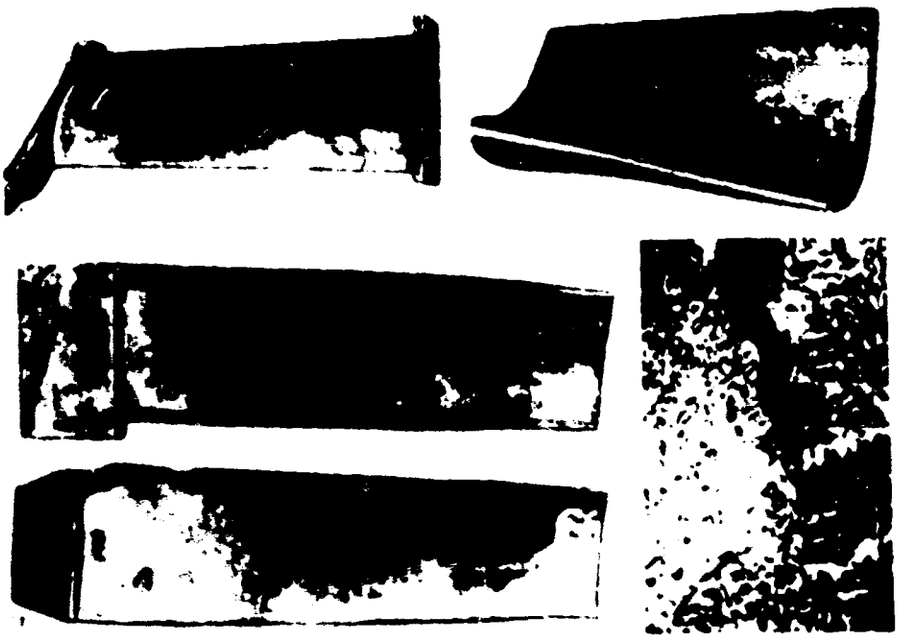

Fig. 2. Cracks in buckets from the ZhS6 alloy and the microstructure in the crack zone. 1, 3) Crack in the leading edge; 2) crack in the middle of the bucket. Magnification factor ×1.

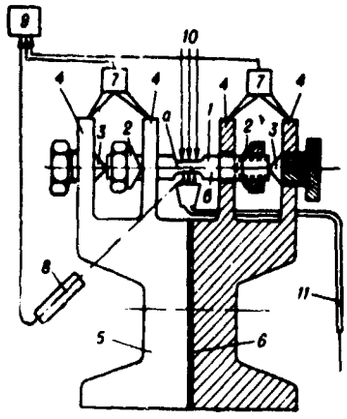

Fig. 3. Setup for thermal fatigue testing of bar stock. a) Test section of the specimen; b) points at which current is let in. 1) Specimen; 2, 3) inside and outside adjustable rests; 4) inside and outside adjustable supports; 5) bed; 6) insulating layer; 7) strain gages; 8) temperature pickups; 9) recording device; 10) heat supply; 11) surrounding medium supply.

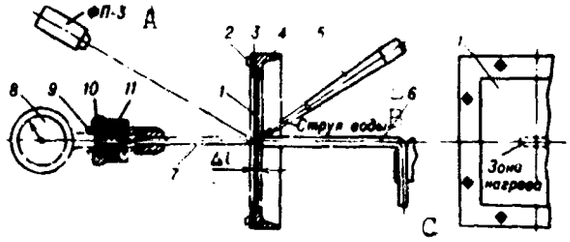

Fig. 4. Setup for thermal fatigue testing of sheet materials. 1) Specimen; 2) clamp fastening screw; 3) clamp; 4) frame for placing the specimen; 5) cooling water supply nozzle; 6) inductor; 7) quartz rod; 8) indicator; 9) adjusting screw; 10) lock nut; 11) bracket nut; δl is the space between the specimen and inductor; FP-3 is a photopyrometer. A) FP-3; B) water jet; C) heating zone.

engines, in atomic power generation, chemical machine building and other branches, where the working cycle is characteristic by a variable thermal regime at a high temperature level. Figure 1 shows the temperature distribution attendant to the heating and cooling of the running wheel buckets of a gas turbine typical for operation under thermal fatigue conditions, and the calculable isotherms. Figure 2 shows photographs of cracks which formed at the vanes of a gas turbine engine under thermal fatigue conditions.

The behavior of components under thermal fatigue is determined by

the characteristics of the material (α, λ, E, $\sigma_{0.2}$, δ, ψ), the shape and dimensions of components, medium and their heating condition; hence a complete estimation of resistance to thermal fatigue can be given

Fig. 5. Deformation (blowing up in the center of the test section) of a specimen from the KhN77TYuR alloy, which was tested when rigidly clamped in the setup shown in Fig. 3.

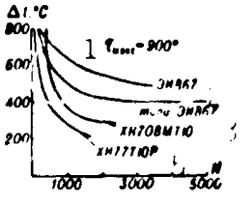

Fig. 6. The number of heating and cooling cycles as a function of the temperature drop for typical heat resistant alloys. 1) Maks; 2) E1867; 3) of the E1867 type; 4) KhN70VMTYu; 5) KhN77TYuR.

only for tests of full-scale specimens under conditions close to service conditions. Comparative estimation is performed by a simplified method on specimens in which the thermal stresses are produced by rigid, elastic or mixed clamping of specimens which are subjected to cyclical heating and cooling. Many methods of thermal fatigue testing are known. Figures 3 and 4 show the most extensively used setups for thermal fatigue testing of heat resisting alloys using bar and sheet stock specimens.

Thermal fatigue is usually evaluated by comparing the number of cycles at a given temperature drop and level or on the basis of the temperature drop for a given number of cyles at which partial or complete failure takes place. Usually the tests are continued either to complete failure or until a continuity disturbing source appears, which can be detected by observation instruments. In sheet specimens the evaluation is sometimes based on the magnitude of the specimen's deformation. Substantial deformation can precede the failure also of cylindrical specimens, particularly when made from plastic alloys and

rigidly clamped (Fig. 4). Figure 5 shows the resistance to thermal fatigue (the number of cycles to failure) as a function of the temperature drop δt for typical heat resistant alloys used for gas turbine engines; it can be seen from the graph that the test conditions can radically change the resistance of alloys to thermal fatigue, and alloys which are best at small δt turn out to be poorer at high δt. This is due to the fact that at small temperature drops the stresses in the more highly heat resistant alloys can basically remain within the limits of elasticity, while in less heat resistant alloys they exceed the elastic limit and result in a substantially higher rate of residual deformation accumulation. At large temperature drops substantial residual deformation can be produced in all alloys during a single cycle and the number of cylces will be determined by the large store of plasticity rather than by heat resistance, as in the first case.

Another difference between thermal and mechanical fatigue is the higher than under steady-state heat conditions nonuniformity of the progress of diffusion processes and also of reactions between the surface layers and the surrounding medium.

N.M. Sklyarov

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[Transliterated Symbols]

405. ФП = FP = fotopirometr = photopyrometer

4050 пл = pl = plavleniye = melting

4054 макс = max = maksimum = maximum

THERMAL FATIGUE TEST – see Thermal Fatigue.

THERMAL, HEAT, TEMPERATURE STRESS is the stress which occurs in bodies with variation of their thermal condition if free deformation of the body or parts of it is restricted. During heating or cooling thermal displacements take place in bodies. If the thermal displacements take place without restriction, there will be no thermal stresses, but free thermal displacements are not encountered in practice. Thermal displacement in a given volume is hindered by the thermal displacement of the neighboring elements if they have a different temperature or a different coefficient of thermal expansion. The difference between the theoretical free displacements and those actually present constitutes the "lost" displacement.

Thermal stresses occur in bodies with a nonuniform temperature field, in bodies with a coefficient of thermal expansion which is not constant throughout the body volume, and in details fabricated from materials having different coefficients of thermal expansion.

Thermal stresses which are within the elastic limits are calculated using the methods of elasticity theory by adding to the equations relating the stress and deformation the thermal displacement αt:

$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \sigma_z)] + \alpha t;$$
$$\varepsilon_y = \frac{1}{E}[\sigma_y - \mu(\sigma_x + \sigma_z)] + \alpha t;$$
$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)] + \alpha t.$$

In the simplest cases, for example, for bars of constant cross section, the thermal stresses may be calculated from the formulas:

a) with restraint of a uniformly heated bar $\sigma = -KE\Delta t$, where Δt is the temperature change, and K is the coefficient characterizing the

restraint stiffness;

b) with linear distribution of temperature across the section of a bar of rectangular section $\sigma_{max} = E\alpha\Delta t_{max}$ (compression stresses appear on the more highly heated side, and tensile stresses on the cooler side);

c) with rigid restraint of a uniformly heated plate $\sigma_{max} = -\frac{E\alpha\Delta t_{max}}{2(1-\mu)}$;

d) in a tube of infinite length with constant temperature of inner and outer surfaces

$$\sigma_{t_{max}} = \sigma_{x_{max}} = -\frac{E\alpha\Delta t_{max}}{2(1-\mu)},$$

where σ_{Tmaks} is the stress acting in the circumferential direction, σ_{xmaks} is the stress acting in the axial direction.

Thermal stresses may cause buckling and lead to failure. For brittle materials failure occurs when the thermal stresses calculated using the elastic methods exceed the material strength. For plastic materials the thermal stresses, as given by the deformation, can cause failure only under conditions of restricted deformation, for example, with high stress concentrations. As a rule, one-time occurrence of thermal stresses does not lead to failure of the plastic materials, this requires many repeated applications of the thermal stresses, as a result of which there may occur considerable residual deformation in the form of warping, change of dimensions, cracking and failure (see Thermal Fatigue). In the analysis of the long-term effect of thermal stresses it is necessary to consider that they, as given by the deformation will relax in time. Thermal stresses also include those which arise in connection with the change of volume of individual structural components during phase transformations, and also those resulting from change of metal specific volume during crystallization. These forms of thermal stresses must be taken into account in the analysis of hot cracks in castings and in weld seams, also quenching cracks, etc.

N.M. Sklyarov

THERMALLOY – see Thermomagnetic Alloys.

THERMAL RADIATION – is an electromagnetic radiation caused by the thermal motion of electric charges (electrons and ions) of the substance. Differing from other forms of electromagnetic radiation, the thermal radiation is in thermodynamical equilibrium with the emitting substance. Thermal radiation does not depend on the surrounding medium and is determined only by the temperature, chemical composition and physical properties of the emitting body. Solids and liquids have, as a rule, a continuous spectrum of thermal radiation. The spectrum of the thermal radiation of monoatomic gases consists of discrete lines (line spectrum), the spectrum of polyatomic gases shows characteristic bands. Volume radiation is specific for gaseous bodies. The surface layers with a thickness from some microns to 120-130 microns, depending on the density and compactness of the body, take part in the radiation of solids. This property of the thermal radiation is utilized in practice for changing the emissivity of bodies by covering their surface with thin coatings. The theory of the thermal radiation is most totally developed for the absolute blackbody, but the results of the theory are used with certain approximation to solve problems of the practice.

The emissivity E of a body is defined as the quantity of energy emitted in all directions by the unit area of the body surface in time unit. The spectral emissivity of the absolute blackbody into the hemisphere is determined by the equation

$$E_{0\lambda}(\lambda, T) = I_{0\lambda}(\lambda, T)\pi \left[\frac{W}{m^3}\right] \qquad (1)$$

where $I_{0\lambda}(\lambda, T)$ is the spectral intensity of the emission of the absolute blackbody; $d\lambda$ is an infinitesimal interval of wavelengths in m. The

Spectral intensity of the emission $I_{\lambda}(\lambda, T)$ is determined as a function of the wavelength by Planck's radiation law. According to this law

$$I_{\lambda}(\lambda, T) = C_1 \frac{1}{\lambda^5 \left| e^{\frac{C_2}{\lambda T}} - 1 \right|} \qquad (2)$$

where $C_1 = 3.17 \cdot 10^{-16}$ kcal·m^2/hr, $C_2 = 1.44 \cdot 10^{-2}$ m degree; γ is the wavelength in m; e is the basis of the natural logarithms. Approximate expressions may be obtained from Planck's formula:

a) The Rayleigh-Jeans formula for high temperatures or a great wavelength $(\lambda T > C_2)$

$$I_{\lambda}(\lambda, T) = C_3 \frac{T}{\lambda^4} \text{ [kcal/m}^3\text{·hr]} \qquad (2')$$

where $C_3 = C_1/C_2 = 2.2 \cdot 10^{-14}$ kcal·m/hr·degree; γ is the wavelength in m;

b) Wien's formula for low temperatures or short wavelength $(\lambda T < C_2)$

$$I_{\lambda}(\lambda, T) = C_1 \frac{\lambda^{-5}}{e^{\frac{C_2}{\lambda T}}} \text{ [kcal/m}^3\text{·hr]}. \qquad (2'')$$

Wien's formula is utilized practically in optical pyrometry and astrophysics. The spectral intensity of the radiation of the absolute blackbody as a function of the wavelength has a distinct maximum for each temperature, which shifts in the direction of shorter wavelengths at rising temperature. The connection between the wavelength, which corresponds to the maximum intensity of the radiation, and the absolute temperature is given by Wien's displacement law

$$\lambda_m T = \text{const [m·degree]}. \qquad (3)$$

At temperatures usual in technology, the maximum lies in the infrared range, at the surface temperature of stars (5000-10,000°K), it lies in the wavelength range of the visible light.

The maximum of the radiation intensity is given by the equation

$$I_{\lambda_m}(\lambda, T) = C_4 T^5 \text{ [kcal/m}^3\text{·hr]}, \qquad (4)$$

[illegible]

where [illegible]

The total emissivity of the absolute blackbody into the hemisphere over the whole range of wavelengths, the so-called energy luminocity, is determined by Stefan-Boltzmann's law

$$E_0(T) = \int_0^\infty E_{0\lambda}(\lambda, T)\, d\lambda = \sigma T^4 \ [\text{kcal/m}^2 \cdot \text{hr}], \qquad (5)$$

where σ is the Stefan-Boltzmann constant $\sigma = 4.96 \cdot 10^{-8}$ [kcal/m^2·hr·degree^4]. In technical calculations the Stefan-Boltzmann law is expressed in the form

$$E_0(T) = C_0 \left(\frac{T}{100}\right)^4 \ [\text{kcal/m}^2 \cdot \text{hr}], \qquad (6)$$

where C_0 is the radiation coefficient of the absolute blackbody ($C_0 = 4.96$ [kcal/m^2·hr·degree^4].

Emitting energy in the form of electromagnetic waves, all bodies are also able to absorb radiation energy which is incident on them. The processes of energy emission and absorption take place simultaneously and independently from each other.

The theory of the thermal radiation of real bodies is based on Kirchhoff's law which determines the universal quantitative connection between the emissivity and absorbing ability of bodies. According to Kirchhoff's law, the ratio of the emissivity of a body to its absorption coefficient does not depend on the nature of the body and is for all bodies equal to the emissivity of the absolute blackbody at a given temperature. For the spectral radiation is valid

$$\frac{E(\lambda, T)}{a(\lambda, T)} = E_0(\lambda, T), \qquad (7)$$

and for the total radiation

$$\frac{E(T)}{a(T)} = E_0(T) \qquad (8)$$

According to Kirchhoff's law, the emissivity of a nonblack (real) body cannot be greater than the emissivity of the blackbody at the same

temperature, ...

The state of the surface of the body influences essentially its emissivity. Metallic bodies with polished surfaces have a minimum thermal radiation due to the fact that they reflect well and absorb weakly the electromagnetic radiation. The intensity of the thermal radiation increases with increasing roughness of the surface. Nonmetallic substances (oxides, carbides, borides, silicides, etc.) show, as a rule, a higher emissivity than metals and, correspondingly, a higher absorption coefficient also.

It follows from Kirchhoff's law that the absorption coefficient is numerically equal to the degree of blackness for gray bodies at the same temperature. The Planck and the Stefan-Boltzmann laws may be used to calculate the emission of nonblack (real) bodies if their degree of blackness is known.

The spectral intensity of the radiation of real bodies can be calculated by means of the formula

$$I(\lambda, T) = \varepsilon(\lambda, T) I_0(\lambda, T) = \varepsilon(\lambda, T) C_1 \frac{\lambda^{-5}}{e^{\frac{C_2}{\lambda T}} - 1} \quad [\text{kcal/m}^3 \cdot \text{hr}], \qquad (9)$$

where $\varepsilon(\lambda, T)$ is the spectral degree of blackness. The total emissivity into the hemisphere is equal to

$$E(T) = \varepsilon(T) E_0(T) = \varepsilon(T) \sigma T^4 \quad [\text{kcal/m}^2 \cdot \text{hr}], \qquad (10)$$

where $\varepsilon(T)$ is the degree of blackness of the total radiation. The degree of blackness both of the spectral and the total radiation is an experimental value. The formula (10) for total energy radiation is strictly valid for gray bodies. For bodies whose spectral distribution of the thermal radiation differs from the spectrum of the absolute blackbody, the total radiation energy can be determined by the equation

$$E(T) = \int_0^\infty \varepsilon(\lambda, T) I_0(\lambda, T) \, d\lambda \qquad (11)$$

In practice, however, Eq. (10) is generally used for calculating the total radiation energy although the radiation of many real bodies is not proportional to the fourth power of the absolute temperature. In these cases, the blackness degree of the total radiation, contained in Eq. (10) and determined experimentally for each temperature and state of the body surface, is provided with a certain correction which permits one to apply the law of the fourth power of the absolute temperature to real bodies.

The distribution of the radiation energy as a function of the direction of propagation is determined by Lambert's cosine law, according to which the energy quantity emitted by a diffusely radiating surface in any direction is proportional to the cosine of the angle between the direction of the ray and the normal on the surface:

$$dQ_{\varphi}(T) = E_n(T)\,d\omega\cos\varphi\,dF \ \text{[kcal/hr]}, \qquad (12)$$

where $E_n(T)$ is the emissivity in the direction of the normal to the surface of the body

$$E_n(T) = \frac{\varepsilon(T)}{\pi} C_0 \left(\frac{T}{100}\right)^4 \text{[kcal/m}^2\text{·steradians hr]}, \qquad (13)$$

$d\omega$ is the solid angle in steradians; dF is the element of the radiating surface in m^2.

A surface emits the maximum of energy in the direction of the normal at $\varphi = 0$; the energy quantity decreases with increasing angle φ. It can be concluded from Eqs. (10 and 13) that the emissivity in direction of the normal to the surface, the so-called energy brightness, is π times smaller than the total emissivity of the body into the hemisphere.

Strictly speaking, Lambert's law is valid for the emission of the absolute blackbody and in general for bodies whose energy brightness does not depend on the direction of the radiation. For the diffuse radiation of rough surfaces, Lambert's law is valid up to an angle $\varphi \approx 70°$.

A considerable deviation from the cosine law is observable for polished metal surfaces at angles $\varphi > 40\text{-}50°$ where the radiation is strongly polarized which causes an increase in the radiation intensity.

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G.A. Zhorov

THERMAL SHOCK – the effect on a material of a rapid temperature increase (tens of hundreds or more degree per second) which results in deformation and failure. Only brittle materials: ceramics, glass, metal ceramics, etc., are destroyed by thermal shock. Usually the failure starts in the less heated zones in which tensile stresses arise; individual cases shearing stresses may produce failure sources even in the most heated zones.

Metallic alloys extremely infrequently fail by thermal shock, since due to their greater thermal conductivity, the temperature gradient is substantially lower than that of ceramic materials and cannot cause a tensile stress sufficient for failure in the less heated zones; on the other hand, the failure of metal in compression takes place attendant to deformations which substantially exceed the possible thermal displacement. Failure of metallic alloys on a rapid rise in temperature, which is usually ascribed to thermal shock, actually takes place not at the heating stage, but on cooling. The high heating rate is combined, on thermal shock, with the short time of duration, for which reason only a limited amount of heat is introduced into the metal, and due to its high thermal conductivity it is cooled at a rate which exceeds the rate of heating frequently by an entire order of magnitude. Tensile stresses which arise on rapid cooling result in failure.

Thermal shock is most dangerous for materials which have a high thermal coefficient of linear expansion and a low thermal conductivity, combined with low plasticity and high elastic modulus. The danger of thermal shock is increased if the product has cross sections with rapid

changes, holes, grooves, and other temperature stress raisers. The thermal shock is also used to denote the effect of several heat cycles with rapid heating and cooling, but these cases are more correctly considered as a particular manifestation of thermal fatigue.

N.M. Sklyarov

THERMAL SHRINKAGE. As the temperature of solid bodies changes, the mean distances between atoms and molecules change. As a result, thermal shrinkage takes place upon cooling. In addition to purely thermal shrinkage a material may sometimes undergo shrinkage at a specified temperature, for example, in heat treatment (annealing) in the process of which its structure changes. Shrinkage also takes place upon crystallization and cooling, in particular, of molten metals and alloys. In the process of metal casting blowholes, pores and voids are formed upon cooling. This is due to nonuniform solidification of the metal over the entire volume.

In another process for forming solid bodies – vitrification – when cooling below T_g, the vitrification temperature, the short range structure has not enough time to establish itself, and a structure corresponding to T_g is retained in the amorphous body. Thermal shrinkage in glass takes place only by changes in the average distances between the particles in the solid body, in liquids and melts, in addition, it also takes place by changing the short range structure with a change in temperature.

Thermal shrinkage of glass is of great significance in the glass quency hardening phenomenon. In the process of rapid cooling of soft glass the temperature and thermal shrinkage in various points in the specimen are different. Accordingly, the temperature deformations are also different, upon further cooling at T_g solidification does not take place uniformly over the glass volume, with the result that residual elastic stresses arise after temperature equalization. In the quench

hardened state the outside layers are under compression and the inside layers are under tension. In addition, the different cooling rate of the internal and outside layers results in a moderate difference in the structure which is retained: a less dense structure is retained in the outside parts of the specimen, while a more dense structure is retained in the inside parts. Since the factor responsible for quench hardening of glass is thermal shrinkage, then the degree of quench hardening is proportional to the thermal glass shrinkage coefficient (or its linear expansion coefficient).

Thermal expansion of plastic materials and rubbers upon heating and the thermal shrinkage upon cooling are of great applied importance, particularly in calculating the shrinkage of products produced by molding. The table presents values of linear thermal shrinkage coefficients of the more important materials. The highest thermal shrinkage is peculiar of rubbers (in comparison with metals it is by a factor of 10-20 greater). From this follows the necessity of calculating the shrinkage of rubber products in designing molds.

Thermal shrinkage is responsible for the loss of airtightness in rubber sealing subassemblies at low temperatures. The loss in the packing properties takes place as a result of hardening of the rubber at low temperatures and of a sharp difference in the thermal shrinkage coefficients of the metal and the rubber. The linear shrinkage coefficient for steel and rubber in the vitrified state differ by a factor of 6-7. As a result of this, the shrinkage of rubber takes place at a much higher rate than the shrinkage of metal, which is precisely responsible for the complete loss of airtightness. Thermal shrinkage and expansion are also used as a method for study of vitrification and determining the T_g of amorphous substances, in particular also of polymers.

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Linear Shrinkage Coefficients for Various Materials

Материал 1	Коэффициент линейной усадки $\alpha \cdot 10^4$ (1/°C) 2
Сталь 3	0,10
Железо 4	0,11
Алюминий	0,24
Кварцевое стекло 5 6	0,003—0,005
Стекла (неорганические)	0,03—0,09
Стекла (органические) 8 7	0,7—1,2
Резины 9	1,2—2,3

1) Material; 2) linear shrinkage coefficient $\alpha \cdot 10^4$ (1/°C); 3) steel; 4) iron; 5) aluminum; 6) quartz glass; 7) glass (inorganic); 8) glass (organic); 9) rubbers.

G.M. Bartenev.

THERMENOL – see High-Permeability Soft Magnetic Material.

THERMODIFFUSION COATINGS OF MOLYBDENUM – see Protective Coatings of Molybdenum.

THERMOELASTICITY – the field of the mathematical theory of elasticity which is concerned with the study of the origin, distribution and magnitude of temperature stresses in bodies governed by Hooke's law. In deriving the principal equations of thermoelasticity it is usually assumed that the elastic and heat characteristics are independent of the temperature. If the temperature of a body is constant or is a linear function of position, then no obstacles exist to thermal expansion and temperature stresses (in a homogeneous material) do not arise. In other cases the theory of thermoelasticity shows that thermelastic stresses arise which are the greater, the higher Young's modulus, the linear expansion coefficient and the temperature gradient. The latter usually increases with an increase in the wall thickness, which results in a rise in the thermoelastic stresses. Compressive stresses usually arise in those body zones which are heated rapidly while tensile stresses arise in those body zones which are rapidly cooled. The theory of thermoelasticity has studied stresses in beams, girders, plates, thin-walled pipes, rings, flexible plates, shells of revolution, etc. For local plastic deformation the thermelasticity equations must be supplemented by thermoplasticity equations. For this reason the values of stresses according to thermoelasticity turn out to be on the high side in comparison with actual stresses. However, even in these cases the theory of thermelasticity remains very important; it is used to determine the stresses from the start of the plastic deformation.

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Ya.B. Fridman

THERMOELECTRIC FLAW DETECTION METHOD – method based on measuring the thermoelectromotive force (temf) which arises at the point of contact of the product being tested and a heated electrode from a preselected material. Thermoelectric flaw detection is used for sorting of metals by brands, for determining the thickness of electrodeposited coatings, the carburized layer, depth of decarbonization, and also for determining the content of certain alloy elements.

The basic design of thermoelectric flaw detection instruments consists of a hot and cold (at room temperature) resistance-type temperature detectors with a galvanometer connected between them. The specified temperature of the hot detector is maintained by a special electric heater. When the cold and hot detectors come into contact with the product under test, a current is generated, the magnitude of which, all other conditions being equal, is determined by the temf, which depends on the chemical composition of the product being tested. The magnitude of the temf in steels is highly influenced by the Si and Al contents; Co, Cr and Mo exert a much lesser effect. Before the thermoelectric flaw detection method is used for sorting of steels or alloys by brands a study is made of the temf of a large number of components or semifinished products from various melts, of material subject to rejection, in order to establish the limits of possible values of this quantity for various brands under different deviations from the chemical composition permitted by technical specifications. Only those alloys can be sorted the scattering ranges of the temf of which do not overlap. The temperature of the hot detector is selected in a manner

such as to obtain the best resolution with respect to the values of temf of actual materials which are subjected to sorting under conditions prevailing at the given production unit. The hot detector can be made from one of the materials to be sorted which has a value of the temf which is average in comparison with the remaining materials. In this case in the testing of the given material the instrument's arrow will be near the zero position, and when testing other materials it will deflect through a substantially larger angle to the right or left.

In certain versions of thermelectric instruments for metal sorting by brands use is made of short-duration heating of the point of hot contact. In the given case a specimen with known chemical composition and heat treatment is clamped to the product under test and for a short period of time about 1000 amps of current is passed through the point of contact. Directly after the current is switched off the specimen and the product under test are connected to a measuring instrument (sensitive magnetoelectric galvanometer), the indications of which determine the group to which the product under test belongs. This version is most effective when the clamped specimen is made from one of the materials being sorted with average thermoelectric properties; here the inspector should take into account not so much the magnitude of the instrument arrow deflection as the sign of this deflection. The use of thermoelectric flaw detection to determine the thickness of surface layers is possible in those cases when the materials of the layer and the base materials are electrically conductive and differ substantially from one another by their thermoelectric properties.

The magnitude of the temf which is generated in the measuring circuit when the hot detector is placed on a coated product will depend not only on the temperature and thermoelectric characteristics of the

detector and material with which the detector is in contact, but also on the temperature at the boundary between the coating and the base material (in the region of the hot detector), a well as on the thermoelectric properties of the base material. The temperature at this boundary depends on the thermal conductivity coefficient of the coating material and on its thickness; hence, when the coating, base and hot detector materials as well as the hot detector temperature are stable, the temf which is generated in the circuit will be determined only by the coating thickness. Thermoelectric flaw detection is most effective for measuring the thickness of thin coatings (up to 20-30 microns), when the dependence of the temp is practically linear in character. When the thickness is increased, this relationship is no longer linear and the thickness sensitivity of the temf drops; at thicknesses higher than 0.1 mm the measuring accuracy becomes very low.

Thermoelectric flaw detection can be also used for determining the quality of adhesion of electrodeposited coatings to the base metal, and the binding of bimetal layers (when the upper layer thickness is not more than 0.5-1.0 mm). In this case the temf is measured 3-5 minutes after the hot detector has come into contact with the product under test, which is needed for establishing a steady thermal regime in the region of the section being tested.

The advantage of thermoelectric flaw detection over other methods consists in the practically complete insensitivity to the surface curvature of the section being tested and to the nearness of this section to the edge of the product. The possibility of using detectors of any shape and with small overall dimensions makes it possible to use this method for inspecting difficultly-accessible sections of products (fillet curve of gears, threading, holes, etc.).

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S.M. Rozhdestvennyy

THERMOMAGNETIC ALLOYS – alloys used for automatic adjustment of instrument errors which arise as a result of changes in the induction of magnets and in the electrical resistance of coils due to variations in the temperature of the surrounding medium. Thermomagnetic alloys are charterized by a low Curie point, their magnetic induction, as a function of climatic temperature changes, varies almost linearly and many-fold sharper than in permanent magnet materials. For thermomagnetic compensation the magnet of the instrument is shunted by a thermomagnetic alloy, with the result that on changes in the surrounding temperature the magnetic flux is redistributed between the magnet and the shunt. The dimensions of the shunt and the alloy properties are selected in a manner such that the aforementioned errors are compensated by changes in the magnet's flux. The following are used as thermomagnetic alloys: 1) Calmalloy (Ni and 30-40% Cu), which has a low induction; when the Cu content is 40% it is used in the temperature range from −50 to 10°, and when the Cu content is 30% it is used in the 20-80° range; 2) Thermalloy (Fe and 30% Ni), with an induction higher by a factor of 2-3, irreversible after cooling to −65° and very sensitive to variations in the content of Ni and admixtures; 3) compensator (Fe and 35% Ni, 7-12% Cr, 0.3% Si), little sensitive to composition variations and with an induction by a factor of 2 higher than Thermalloy, and by a factor of 4 higher than that of Calmalloy; it is used for compensation in the temperature range from −70 to 70°.

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B.G. Livshits, A.A Yudin

THERMOMECHANICAL PROCESSING OF METALS – ensemble of deformation, heating and cooling operations, as a result of which the formation of the structure of a metallic alloy takes place under conditions of increased density and corresponding distribution of structure imperfections which were produced by workhardening. Crystal structure imperfections affect the mechanism and kinetics of phase and structural transformations attendant to heat treatment. One of the main methods for creating structure imperfections is workhardening. Hence it is advantageous to assemble into a single production process the plastic deformations and phase (structural) transformations. Thermomechanical processing of metals can be used in all the cases when it is possible to have: polymorphic transformations, transformations in the solid solution which are related either to changes in the solubility of one component in another or by changes in correlation; structural changes attendant to plastic deformation (creation of a polygonized structure).

Thermomechanical processing of metals is one of the promising methods for obtaining high-strength metallic alloys with a sufficient plasticity store.

In thermomechanical processing of metals (or steel) which undergo polymorphic transformations according to the prevailing production process setups, it is customary to perform workhardening in the austenitic state with immediate quenching, in order for the martensitic transformation to take place in an alloy with an increased dislocation density. Since the directionality of elements of the fine structure of previously deformed austenite may affect the final structure after quenching,

it is necessary to specify the kind of deformation in the thermomechanical processing of metals.

The temperature at which austenite should be workhardened should be such that this phase be reliably stable at it and it should ensure the absence of recrystallization at a certain stage in its development (should exclude cumulative recrystallization).

In low-temperature thermomechanical processing of metals (NTMO) the workhardening of temperature for the starting austenite lies slightly above the martensitic point. Another production process setups, i.e., high-temperature thermomechanical processing of metals (VTMG) provides for workhardening of austenite at temperatures above the critical point.

The following should be noted in comparing the above two processes: a) high-temperature thermomechanical processing of metals is easier in terms of the capabilities of production processes, in addition, the heat of the forging or rolling heating can be used; low-temperature thermomechanical processing of metals provides for transfer of products to various furnaces, performance of isothermal holdings and achieving workhardening under conditions when the austenite has an elevated resistance to plastic deformation at intermediate range temperatures. b) Low-temperature thermomechanical processing of metals can be used only for steels with a high austenite stability, while such limitations practically do not exist in high-temperature thermomechanical processing of metals. c) Low-temperature thermomechanical processing of metals ensures the obtaining of a higher strength in connection with the absence of recrystallization at the deformation temperature; initial recrystallization stages apparently take place in a number of cases under high-temperature thermomechanical processing of metals, which results in obtaining lower strength values, but makes it possible to obtain a higher plasticity store, which in a number of cases of the

high-strength state (sudden overloads, complex stressed state, etc.), is of decisive importance.

A typical example of the change of properties of the 37KhN3A alloyed steel after high and low-temperature thermomechanical processing of metals is shown in the figure.

An important feature of thermomechanical processing of metals is the fact that an increase in the plasticity is obtained simultaneously with a substantial strength increase.

Thermomechanical processing of metals reduces the grain size of the starting austenite and increases the dispersion of martensitic crystals, retains a certain orientation in the location of carbides; as the degree of deformation increases the crystal lattice defect density is also increased.

The hardening produced by thermomechanical processing of metals is stable in character, under certain conditions it is retained after secondary heat treatment of the alloy by special regimes.

The properties of thermomechanically processes steels are reproduced after softening high tempering and subsequent quenching with short-duration heating periods. This "reversibility" of thermomechanical processing of metals expands the possibilities for its utilization and makes it possible to use this method for processing semifinished products at metallurgical plants. The subsequent shor duration tempering makes it possible to machine the metal, and quenching with rapid heating and the low tempering make it possible to obtain a high starting strength and elasticity in components. The main features of the structure of thermomechanically processed steel, which determine the retention of the hardening even in the case of subsequent $\alpha \rightarrow \beta$ and $\beta \rightarrow M$ transformation, are the following:

1. Retention of fine grained structure (if the temperature and

Mechanical properties of 37KhN3A steel after thermomechanical processing in accordance to various regimes. High-temperature thermomechanical processing regime (o) involves heating to 950-930°, deformation (rolling), oil quenching, tempering at 100° for 2 hours. The low-temperature thermomechanical processing of metals regime (▲) involves heating to 950-930°, cooling to 470°, deformation (rolling), quenching, tempering at 100° for 2 hours. 1) kg/mm^2; 2) ordinary heat treatment; 3) degree of deformation, %.

holding in subsequent heating exclude the development of cumulative crystallization).

2. The crystallographic deformation texture, which affects the orientation in subsequent heatings, particularly taking into account retention of the orientational correspondence on transformation.

3. Formation of a "dislocation texture" which is a nonuniform distribution of dislocation density between the possible crystallographic slip systems, which is determined by the arrangement of the stressed state. The retention of this "dislocation texture" in the alpha phase on heating to the critical point A_1 is due to the difficulty in recrystallization of two-phase structures, and in $\alpha \rightarrow \gamma$ and $\gamma \rightarrow M$ transformations it is due to the retention of the relative positions of closely lying atoms.

4. The "precipitation texture" is determined by the crystallographic texture (by means of the orientational correspondence) and the dislocation texture (due to the nucleating effect of packing defects). The retention of the "precipitation texture" in subsequent short duration heating is due to the localization and nonuniformity of decomposition within the limits of the martensitic crystals, as well as by retention

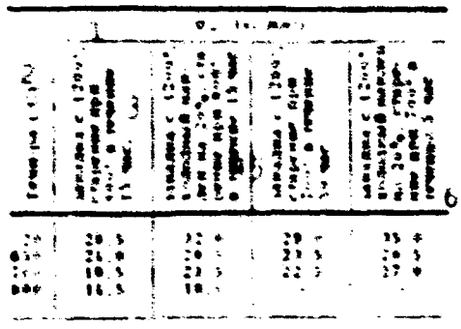
of the nonuniform distribution of carbon and alloying elements in the steel.

Thermomechanical processing of austenitic heat resistant alloys can be performed according to three production process schemes: heating to the quenching temperature → workhardening → quenching → aging; complete heat treatment cycle, i.e., (quenching + aging) → slow deformation (0.2-0.3%) at a temperature close to the aging temperature → holding at the deformation temperature for 20-50 hours; quenching → work hardening → aging.

The first scheme is easy to achieve, however, it involves the danger of intensive development of recrystallization (including cumulatie) due to the quite high deformation temperature. The second scheme substantially provides for polygonizing treatment. In conjunction with the comparative complexity of this scheme difficulties may arise in the processing of components.

The creation of a stable submicroscopic structural inhomogeneity after thermomechanical processing of metals according to the third scheme substantially increases the creep strength, strength in the complex stressed state and fatigue resistance of austenitic heat resisting steels (table). This hardening is retained even at elevated tempera-

The Fatigue Limit (σ_{-1}) of EI395 Steel at Different Temperatures



1) (kg/mm^2); 2) temperature (°C); 3) quenching from 1200° at 800° for 15 hours; 4) quenching from 1200°, cold workhardening by 20%, aging at

800° for 15 hours; 5) quenching from 1200°, aging at 700° for 50 hours; 6) quenching from 1200°, cold workhardening by 20%, aging at 700 for 5 hours.

tures, even slightly higher than the recrystallization temperature (under condition of formation of so-called "fine structures," which are responsible for the retention of submicroscopic inhomogeneity). In thermomechanical processing of metals according to the scheme quench hardening → workhardening → aging the recrystallization temperature is increased in conjunction with the development of poligonization. Retardation of recrystallization is due, in addition to poligonization, to the effect of the particles of the hardening phase. The higher the dispersion of particles and the degree of coherent bounding between them and the mother metal, the higher the effective retardation of recrystallization, which is very important for increasing the service stability of heat resisting steels.

Microstructure studies have shown that a more uniform distribution of the hardening phases, which are precipitated not only along grain boundaries, but also along slip and twinning lines, is observed as a result of thermomechanical processing of metals. Such a more uniform distribution of particles and the stable retention of sufficiently fine subgrains upon secondary heating of the deformed metal (in which a poligonization structure is produced) retards the coagulation of the hardening phases.

M.L. Bernshteyn

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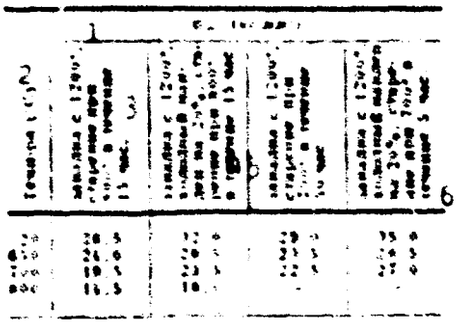

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M.L. Bernshteyn

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[Transliterated Symbols]

= NTMO = nizkotemperaturnaya termomekhanicheskaya obrabotka metallov = low-temperature thermomechanical processing of metals

= VTMO = vysokotemperaturnaya termomekhanicheskaya obrabotka metallov = high-temperature thermomechanical processing of metals

THERMOMECHANICAL TEST OF PLASTICS – is the determination of the effect of temperature and time on the deformation of plastics caused by a given load. The thermomechanical test of plastics is carried out by the following methods (see the Table on page 330).

The temperature at which a fixed deformation is reached, serves to characterize the heat resistance of plastics in methods 1, 2, 3, and 4. Thermomechanical curves, having in the case of thermoplasts the following shape (Fig. 1), are drawn by methods 5-8. The deformation ε is plotted on the ordinate, and the temperature on the abscissa. The deformation depends on the heating rate and the action time of the load: the smaller the heating rate at a continuously acting load or the longer the action time of the load the greater the deformation. Heated hard and brittle plastics passes from the vitreous state into the hyperelastic state in which the soft and elastic plastic is capable of great reversible deformations. The temperature at which this transition occurs is termed the vitrification temperature T_g or the softening point.

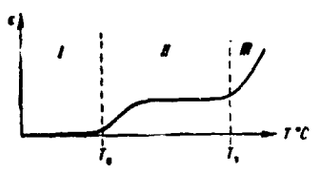

Fig. 1.

Irreversible deformations develop in the plastic beginning with the yield temperature T_t, when the temperature is raised further: the plastic passes into the viscousfluid state, in which flow occurs. It is especially important to know the value of T_t for the molding of objects. The thermomechanical curve of thermosetting plastics usually has the following shape (Fig. 2). The deformation changes insignificantly with rising temperature up to the

destruction temperature T_r at which point the destruction of the polymer sets in. The height of the curve changes depending on the degree of crosslinking, and this fact permits the evaluation of this degree.

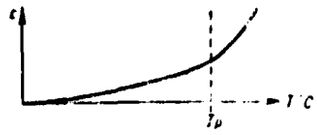

Fig. 2.

TABLE

A Метод испытания	B Вид деформации образца, величина прикладываемой нагрузки и тип нагружения	C Скорость повышения температуры (*град/час*)	D Фиксируемая деформация (*мм*)
1. Мартенса E	Изгиб консольный; F 50 *кг/см²*; непрерывное	50	6
2. ASTM Д--648 G	Изгиб двухопорной балки; 4,6 или 18,5 *кг/см²*; H непрерывное	120	0,25
3. Вика I	Вдавливание цилиндра площадью 1 *мм²*; 5 или 1 *кг*; непрерывное . . .	50	1
4. Журкова L	Вдавливание шарика с *d*=5 *мм*; 1 *кг*; дискретное . . . . . N	35	0,5
5. Каргина (динамометрические весы)	Сжатие; 0,07—1,5 *кг/см²*; O дискретное	P Выдерживается температурная площадка	Снимается кривая Q
6. Цетлина R	S Растяжение и сжатие; 0,002—0,2 *кг*; непрерывное	T Варьируется	U То же
V 7. Канавца W	Сдвиг; 0,1—0,4 и 10 *кг/см²*; дискретное и непрерывное	50	»
8. Лазуркина X	Вдавливание цилиндра площадью 1 *мм²*; 1 *кг*; Y дискретное	Выдерживается температурная площадка P	»

A) Testing method; B) kind of deformation of the specimen, magnitude of the applied load, and type of loading; C) rate of the temperature rise; D) fixed deformation (mm); E) Martens; F) cantilever bending; 50 kg/cm^2; continuous; G) D-648; H) bending of a beam resting on two supports; 4, 6, or 18.5 kg/cm^2; continuous; I) Vicat; K) impression of a cylinder with an area of 1 mm^2; 5 or 1 kg; continuous: L) Zhurkov; M) impression of a ball with d = 5 mm; 1 kg; discrete; N) Kargin (dynamometric balance); O) compression; 0.07-1.5 kg/cm^2; discrete; P) a temperature plateau is held; Q) a curve is plotted; R) Tsetlin; S) stretching and compression; 0.002-0.2 kg; continuous; T) varying; U) the same; V) Lazurkin; W) impression of a cylinder with an area of 1 mm^2; 1 kg; discrete.

References: Kargin V.A., Slonimskiy G.L., Kratkiye ocherki po fiziko-khimii polimerov [Short Essays on the Physical Chemistry of Polymers], Moscow, 1960.

Yu.M. Sivergin

THERMOPLASTICS – polymers and polymer-base materials, which are characterized by the fact that upon heating they melt, after which they solidify upon cooling, retaining the same properties as before heating. The heating and cooling process can be repeated again and again.

Thermoplastics have a linear or branched out molecular structure. The mechanical properties of thermoplastics are determined by their chemical composition and the physical structure.

A distinction is made between amorphous and crystalline thermoplastics. In the light of present-time conceptions about the polymer structure, the macromolecular structural unit of an amorphous polymer is the so-called packet, i.e., strictly directed location of molecular chains which can be short- and long-range. Long-range packets given a more dense packing of macromolecules and produce the crystalline state. When the location of side groups of the polymer in the packet is not strictly regular, a gascrystalline structure is formed. When the polymer is strictly stereoregular, maximum molecular packing density is obtained in the packets and the polymer attains a crystalline structure.

The following types of crystalline polymeric structures are in existence: microcrystalline (crystallization in packets), spherolites (combination of packets into more complex supramolecular structures, i.e., strips, planes, etc.) and single crystals (monocrystals).

Among the amorphous thermoplastics are polystyrene, polyacrylate, polyvinylchloride, among crystalline thermoplastics are polyethylene, polyamides and fluorine plastics. Amorphous polymers have a specific

limiting temperature, near which they gradually soften. Here the elasticity and shear moduli drop sharply. At temperatures higher than this the amorphous materials become plastic and are easily molded into products by pressure casting, injection molding and extrusion.

Crystalline polymers, which due to their ability to partially crystallize, melt in a narrow temperature range, are processed in the same manner as amorphous thermoplastics. The plasticity of thermoplastics is increased by adding plasticizers to the plastic material. Liquid and crystalline low-molecular compounds (derivatives of organic and phosphorous acids) are used as plasticizers. Plastification can be performed also by compolymerization or inoculation (addition of side groups, which improve the plasticity of the plastic material).

In designing machine components from thermoplastics, the dependence of their strength on the temperature must be thoroughly taken into account.

References: Kargin, V.A. and Slonimskiy, G.L. Kratkiye ocherki po fizikokhimii polimerov [Briefs Outlines of the Physical Chemistry of Polymers], Moscow, 1960; Kozlov, P.V., Metody issledovaniya plenochnykh materialov [Methods for Studying Film Materials], "PM," No. 10, page 4, 1961.

N.P. Gashnikova

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N.P. Gashnikova

THERMOSETTING PLASTICS ("REACTOPLASTICS") – polymers which become plastic upon initial heating and then become solid, infusible and insoluble. The solidification of thermosetting plastics is irreversible, i.e., upon secondary heating they do not become plastic, but remain solid up to the decomposition temperature. This is due to the fact that before heating the individual macromolecules of the polymer are not bound chemically to one another, while upon heating they combine, are cross-linked and form a reticular, space structure. Of great importance is the depth of solidification, i.e., the number of transverse bounds which is formed. The more transverse bounds, the more rigid the molecular lattice and the stronger the material which is obtained. However, very deep cross-linkage results in a complete loss of elasticity and in the appearance of brittleness; the depth of solidification also affects the aging processes in thermosetting plastics. New chemical counds may form by functional groups of the main molecular chain as well as by introducing special cross-linking substances. Thus, for example, phenolic resins are solidified by methylol groups of the main chain, while polyester resins are solidified by addition of cross linking substances such as styrene, methylmethacrylate, etc. The hardening process is exothermic, and the initial heating is only needed to start the reaction. Methods have been elaborated for solidying thermosetting resins without heating by using catalists.

Most extensive use in the production of thermosetting plastics is made of phenolformaldehyde, carbamide, polyester and epoxy resins, and also their modifications. These resins are obtained by condensation

polymerization. In the production of molding compounds the condensation polymerization process is not continued to the end, it ends in the die when molding the products. Resins combined with various polymers (rubber, polyvinylchloride, polyvinylacetals, etc.), retain their thermosetting nature and take on additional properties which are characteristic of the modifying polymer, i.e., elasticity, resilience, improved chemical resistance, etc. The combination takes place in the pr[illegible] of resin production and making the products.

Resins in the pure form are very infrequently used for obtaining thermosetting plastics, as a rule they are used for impregnating fillers such as powders (sawdust, ground quartz, mica), fibers (linters, asbestos, glass fiber, wood veneer), laminates (paper, cotton and glass fabrics). The fillers are used for increasing the strength, improving the heat resistance, chemical resistance and other properties. For example, asbestos fiber imparts to the materials increased heat resistance, high friction, dielectric and heat insulating properties. Thermosetting plastics which contain graphite are distinguished by good thermal and electrical conductivity and antifriction properties. Glass fiber filled thermosetting plastics have high mechanical strength. A great effect on the properties of thermosetting plastics is exerted not only by the kind of the filler, but also by its quantity, orientation and degree of dispersion.

Depending on the kind of binder (resins) and fillers, various kinds of thermosetting plastics are obtained.

Molding compounds, laminated plastics, glues and coatings primarily for technical use, with good physicomechanical and dielectric properties, which are easily molded into products are obtained by using phenolformaldehyde resins. These materials resist the effect of atmospheric factors, are capable of operation in any climatic zones, in-

cluding the topical and polar zones, and are one of the cheapest kinds of plastics. Their use in consumer products is limited, since they can be colored only in dark colors and are not suitable for food storage. Phenol and modified phenol resin based glues serve for cementing metals, rubber, fluorine plastics, capron and other nonmetallic materials.

Carbamide resins are used as bases in the production of molding compounds, fiber and decorative laminated plastics. The latter are easily colored into light shades, are harmless and are used extensively for consumer goods as well as for storing foods. In particular, urea-based molding compounds are less resistant to atmospheric effects and water than phenol plastics, while melamine-based molding compounds have a good resistance to water and, unlike phenolic molding compounds, have a good resistance to electric arc discharges. Urea resins, in addition, are used as glues and impregnating materials, while modifield resins are used as metal and wood varnishes.

Polyester resins are used for making cold and hot drying varnishes for wood and metal and for the production of reinforced plastics (glass plastics). Products with large overall dimensions (bodies of automotive vehicles, ship hulls, etc.) can be molded from polyester glass plastics by the contact method.

Epoxy resins, due to the presence of epoxy groups at the ends of the macromolecular chain and hydroxyl groups in the links, have excellent adhesion and good dielectric properties. They are strong, elastic, resistant to light, the solidification shrinkage of epoxy resins as varnishes, glues, as sealing and molding compounds, laminated plastics, metal stamping dies, etc.

Thermosetting plastics are made into products by direct molding, pressure casting, extrusion and contact molding. The latter method is used for making products with large overall dimensions from glass plas-

tics. Pipes and tubular products are made from these glass plastics by the winding method. Products from laminated plastics are produced by machining. Direct molding, which is achieved in special dies on hydraulic presses has come into the most extensive use in the production of thermosetting plastics. This process is determined by three parameters: molding temperature, specific pressure and the time the products are held in the die. The above parameters depend on the kind of the molding compound and the configuration of the product. To increase the molding productivity and improve the product quality, the molding compounds are preformed and heated by high-frequency currents, etc.

Pure and modified epoxy and phenolformaldehyde resins are used as bases for various glues (BF-2, BF-4, ED-6, VK-32-EM, EF-9, etc.), which ensure high strength and the glued joint

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M.S. Krol', S.M. Perlin

THERMOVYL — see Polyvinylchloride Fiber.

THEORY OF FRACTURE – physical, mechanical-mathematical, structural, and physicochemical explanations of the mechanism of mechanical Fracture. These explanations have not as yet been sufficiently interrelated and have often developed in isolation. It is necessary to distinguish the theory of the origin of fractures from that of their propagation. In 1920 Griffiths proposed a theory to explain the fracture of brittle (almost wholly elastic, of the glass type) bodies containing initial defects. According to this theory, propagation of a crack is accompanied by: 1) a rise in energy proportional to the increase in free surface; 2) a decrease in the elastic energy of the body. Griffiths' basic equation, $\sigma = \sqrt{\frac{2ET}{\pi c}}$, relates the strength of a brittle body to its surface tension T, the maximum length of the defect or crack 2c, and the modulus of elasticity E. This theory holds that a crack remains stable and does not propagate if σ is below its critical value. When σ reaches a certain ("critical") value the rate at which the elastic energy stored in the cracked specimen is liberated exceeds the rate at which energy is absorbed by formation of the new fracture surface. Cracking is then virtually instantaneous and propagation is unrestricted, leading to complete failure of the body. Although Griffiths' theory of fracture fails to take into account the kinetics of the fracture process and many other factors, it served as the basis for further study of brittle strength and was extended by Orowan and Irwin to the semibrittle fracture of metals by substituting the energy P expended in the plastic deformation of a thin layer near the surface for the surface tension T. The value of T ($\sim 10^6$ ergs/cm^2)

is three orders of magnitude (~1000 times) greater than that of T (~10^3 ergs/cm^2). Mott broadened Griffiths' theory, taking into account the role of kinetic energy, and demonstrated that the maximum fracture rate is a definite fraction (usually about 40-50%, but never more than 60%) of the speed of a longitudinal sound wave in the material (i.e., 0.6•5000 m/sec, or ~3000 m/sec, for iron and aluminum). Subsequent mathematical theories of fracture (Irwin and G.I. Barenblat for elastic bodies and L.M. Kashanov et al. for viscous-elastic bodies), just as many physical theories, consider the propagation rather than the formation of cracks. In contrast to hollows (which vary little in shape, even when there are considerable changes in loading), cracks can be greatly enlarged by even small changes in loading. The edges of a crack are assumed to converge smoothly (Fig.) and mathematical theories of fracture consider there to be adhesive forces near its "apexes" both within the body and over portions of the crack contour. Assumption of this crack shape produce a functional value for the stresses near the apex of a crack which conformed more closely to experimental results than the implausibly high, sometimes infinite stresses calculated for bodies containing cracks with pointed ends. The methods of elasticity theory have been used principally to study equilibrium cracks. A stress body containing such cracks is in equilibrium so long as the load does not exceed its critical ("fracture") value.

Shape of the end of an equilibrium crack.

It was shown in 1940 that crack propagation is initiated far earlier (with respect to time, loading, and total deformation) than complete failure. Thus, a body may not only retain its strength after

cracks have developed and begun to propagate, but may become even stronger for a certain time.

The theory of Dislocations has been used in working out physical theories of brittle, prolonged static, and fatigue fracture. It is assumed that cracks arise when dislocations are displaced as a result of interaction of the force fields surrounding them or of concentration of stresses in the dislocation zone. The stress required to cause cracking increases as grain size decreases. After a crack has developed its propagation is governed by the ratio of the energy supplied to the area near the apex of the crack (from the stressing system, e.g., the test machine, and from the regions of the body bordering the crack) to that absorbed in the propagation of the crack, in the formation of the new surfaces in the fracture and in adjacent cracks, in structural changes near the fracture, in dissipation of heat, etc.

All other conditions being equal, a crack selects the direction of greatest energy supply (for example, in fracture involving Tearing of surfaces perpendicular to the directions of greatest tension) and least energy absorption (for example, in brittle regions of the body). In some cases cracks propagate in the shortest directions (along geodesic lines, along spirals, cross sections, or genetrices in cylindrical specimens, along the arcs of great circles in spherical vessels, etc.). For theories of fracture which take account of the corrosive and adsorptive influence of the surrounding medium see Corrosion fatigue and Rebinder effect. Consideration of structural transformations should play a large role in theories of fracture, since the majority of materials (many alloys, plastics, etc.) undergo material structural alterations during fracture.

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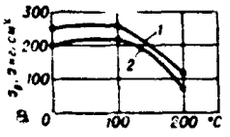
Ya.B. Fridman

THINNED GLASS TEXTOLITE – a laminated plastic obtained by pressing or forming fiberglass cloth impregnated with synthetic resins. Glass cloth with a standard weave, of the "false open-weave," curtain, or tricot types, is used in the manufacture of thinned glass textolite. Modified phenol-formaldehyde (VFT), modified silicoorganic (VPS-3), epoxy (EF32-301), and other resins are employed as binders. In some cases a frothing agent is added to the binder, so that the spaces between the glass filaments are completely or partially filled with the froth binder. It is possible to obtain textolites of this type with a density of 0.4–1.3, as well as with a variable density and various physicomechanical and electrical characteristics. Thinned glass textolite of varying



Ultimate strength of RST-T glass textolite (at 200°): 1) On extension; 2) on bending. a) kg/cm^2.

Плотность, г/см^3 1	2 Температура, 20°	
	σ	$tg\delta$
0.58	1.93	0.0103
0.72	2.26	0.0120
1.1	3.07	0.0178
1.65	4.08	0.0232

1) Density, g/cm^3; 2) temperature.

density is obtained by pressing glass cloth of varying coarseness at a constant pressure or by pressing glass cloth with a constant weave under varying pressure. These materials usually bear facing layers. In certain cases, these layers, which are virtually insensible to mechani-

cal loads and have no marked influence on the dielectric losses and dielectric permeability of the glass plastic, serve to increase the moisture and water resistance of the material. Textolites of this type are used as light fillers between high-strength facing layers. The mechanical characteristics of type RST-T glass textolite, which is based on a tricot glass cloth and VFT binder with a bulk weight of 0.3-0.4 g/cm^3, are shown in the figure. The table shows the dielectric characteristics of glass textolite based on EF32-301 binder as a function of density.

Thinned glass textolites are used for radio-engineering and structural products.

B.A. Kiselev

THIN PLASTIC COATINGS – coatings applied to metal sheets (surfaces) and components. They are elastic, sufficiently strong, and heat- and electrical-insulating, have high anticorrosion characteristics, and make it possible to produce components of varying configuration by deep drawing, bending, stamping, machining, and spot and seam welding; they can be used to obtain a ribbed (figured) surface. Polyamides and certain other types of films have good antifriction characteristics. Plastic films 0.2-0.5 mm thick are applied to steel, aluminum, and magnesium sheets (0.4-1.5 mm thick and 100-1700 mm wide). The coating thickness can vary, but should not exceed 0.2-0.3 mm for steel and aluminum 1 mm thick. Plastic coatings can be applied to one or both sides. When one side is coated the other is generally phosphated or plated with zinc (with copper, nickel, or chromium in some cases). Various patterns can be impressed on the coating when it has cooled. Polyvinyl chloride is the most common coating, polyethylene, polyamides, polyester resins, and cold- and hot-setting epoxy resins being employed less frequently. In some instances soot or dyes are added to the plastic. Epoxy coatings adhere very well to metals without special treatment. In most cases epoxy resins are applied by atomization, multilayer coatings being possible. Coatings of epoxy and polyester resins are most frequently used in the paint industry, in construction, and in electronics. Coating metals with a polyethylene film makes them resistant in aggressive media and gives them good electrical-insulating characteristics. Polyurethanes are employed for coating wood, metallic, and concrete surfaces (television and radio receivers and furniture), as well as computer and

automobile components. Plastic-coated rolled sheets are used in various branches of industry as a sheathing material and in the manufacture of wall panels, pipe, ventilators, machinery, machine components, radio and television cabinets, various containers, measuring instruments, tanks, refrigerators, milking machinery, luggage, and computer and automobile components. Plastics can be applied to these materials by various methods: a common procedure is application of a cold polyvinyl chloride film to a prepared heated metal surface coated with a binder underlayer. Plastic-lined metal pipes are used as substitutes for pipes of stainless steel and nonferrous metals and alloys; plastic lining increases the service life and reduces the cost of technological pipelines intended for transporting various aggressive media. Plastic coating is employed in the automobile, electronics, furniture, construction, and foodstuffs industries, various types of light industry, and the building of conveyor machinery.

Ya.D. Al'shits

THIOKOL – polysulfide rubber product obtained by condensing dihalogen derivatives of organic compounds with sodium polysulfides. Thiokol is produced on the industrial scale in the USSR, USA, England, Polish People's Republic in the form of solid and liquid rubber, latex materials and powders. The individual brands of thiokol produced in the USSR and abroad are denoted by letters and differ from one another by the starting composition, consistency and properties. Thiokol is produced in Japan under the commercial names of "tionite" and "ticatol"; in Belgium it is produced under the name "etanit."

Thiokol has a specific smell, which is due to the presence of low-molecular dithioles and cyclical compounds. Thiokol brands produced at present have a very weak smell. The specific gravity of Thiokol is 1.32-1.41. Thiokol does not readily dissolve in the majority of ordinary solvents, it has a better solubility in carbon sulfide and dichloroethane. Solid Thiokol is subjected to chemical plasticization on rolls in the presence of benzothiazolesulfide with a moderate amount of diphenylguanidine or other compounds which are used as vulcanization accelerators for ordinary rubbers, for example, Altax or Captax. Usually up to 10 parts by weight of zinc oxide is added as the vulcanizing agent, oxides and peroxides of metals and organic oxidizers (polynitrobenzols, benzoyl peroxide, etc.) can be used. Benzoic acid or sulfur serve as accelerators for the vulcanization of Thiokol. Liquid Thiokol is vulcanized by lead peroxide (5-10 parts by weight), which is usually introduced in the form of a paste in dibutylphthalate with a moderate amount of stearic acid. The duration of vulcanization

of the mixtures with lead peroxide at room temperature is 48 hours. Liquid Thiokol is usually subjected to cold vulcanization. Cumene hydroperoxide, pure or with an activating agent, usually diphenylguanidine, is also used.

Semia tive and gas blacks, as well as zinc oxide are used as fillers. To improve the filler distribution and prevent the sticking of the mixture to rolls, 0.5-1.0 parts by weight of stearic acid is added. The vulcanization time of typical mixtures at 141° is 40-50 minutes. No vulcanization shrinkage is observed in liquid Thiokol.

The most valuable properties of Thiokol rubbers is their extremely high resistance to solvents. The swelling of Thiokol rubbers which were held for a month in various solvents at room temperature is (% by volume): 0.6 in lubricating oil, 2.5 in acetone, 1.0 in gasoline, 3.0 in a gasoline-benzol mixture (50:20), 33.0 in benzol, 25.0 in kerosene, 1.3 in methul alcohol, 10.0 in carbon tetrachloride. Thiokol rubbers have a high gas impermeability, which exceeds the impermeability of butyl rubbers, a good aging and ozone resistance. Thiokol rubbers are not affected by water, alcohols and diluted acids. Concentrated acids and alkalis destroy Thiokol. Thiokol rubbers retain their elasticity at temperatures up to —50°- — °, and some new brands of Thiokol rubber are elastic up to —60°. The heat resistance of the majority of Thiokol rubber brands does not exceed 60-70°, individual recent Thiokol brands operate at temperatures up to 130°. The dielectric constant of Thiokol rubbers is 6.0-7.5, dielectric losses coefficient 0.015-0.05, specific electrical resistivity $1.0 \cdot 10^{13}$ ohm-cm. The mechanical properties of Thiokol rubber are comparatively moderate: the modulus in 300% elongation is 40-60 kg/cm², tensile strength 70-150 kg/cm², relative elongation 400-800%, residual elongation 10-20%, rebound elasticity 20-25%. A substantial shortcoming of Thiokol rub-

bers is the very low abrasion resistance (the abrasion of carbon black vulcanizers is 1000-1800 cm^3/kw-hour), and also moderate dynamic properties A substantial shortcoming of Thiokol for certain fields of application is its cold flowability. Due to the high resistance to light, oxygen and ozone aging Thiokol is used for making various ozone and light resistant products, for improving the production properties of divinylnitrile rubber mixtures. Cements and pastes from liquid Thiokol, which are used for hermetizing fuel compartments in aircraft, of prefabricated structural designs in plant and civil construction, are most extensively used. Liquid Thiokol is used for making products by pressure castings (flexible molds), cold-vulcanizing putties and coatings, which are used for protecting metals, including magnesium and aluminum, from corrosion. Thickol-base latex materials are used primarily for coating of underground gasoline stoarage facilities, concrete tankers and steel vessels which are used for storing raw petroleum. Powder Thiokol is used for storing raw petroleum. Powder Thiokol is used for gas flame coating of steel and bronze components of sea-going vessels, which eliminates corrosion produced by cavitation and electrolitic reaction between different metals. Gas flame Thiokol coatings are used for protecting sea water pipelines, and also the supports and plates of low-pressure condensers.

References: Sinteticheskiy kauchuk [Synthetic Rubber], edited by G.S. Withbie. Translated from English, Leningrad, 1957; Borodina, I.V. and Nikitin, A.K., Tekhnicheskiye svoystva sovetskikh sinteticheskikh kauchukov [Technical Properties of Soviet Synthetic Rubbers], Leningrad-Moscow, 1952.

I.V. Borodina

THREAD – a twisted filament obtained from comparatively short fibers by a spinning process. Thread can be uniform (cotton, wool, linen or silk) or mixed (semiwoolen, consisting of wool and cotton or of wool containing a staple fiber, wool with lavsan or caprone added, cotton and caprone, etc.). It can be produced from first-run fiber or from textile-production wastes (combings, refuse, bindings). Vicugna thread is produced from cotton waste with a small amount of wool waste added. We can distinguish thread for cloth manufacture, for tricot production, for sewing thread, for cord and rope, for fishnets, etc., which differ in appearance, physicomechanical characteristics, and processing method. The thread used for the warp in cloth production should be stronger and smoother than that used for the woof, which should be softer and more porous. The appearance and stiffness of thread depends to a substantial extent on the manner in which it is twisted; a more slanted twist is used for tricot production than for the warp threads in cloth manufacture. Threat for sewing-thread manufacture should have a high tensile strength and be highly uniform with respect to diameter. Threat can be single-filament or consist of several twisted filaments (twisted thread). The fineness of a thread is characterized by its metric number, the ratio of its length in meters to its weight in grams; the higher its metric number, the finer is the thread. Twisted thread of single filaments of the same number is designated by a faction whose numerator represents the metric number of the filaments and whose denominator represents the number of threads of this metric number. Thread No. 12/6 is produced from 6 twisted strans of thread No. 12.

The metric number of a twisted thread is approximately equal to that of a single stran divided by the number of strans, i.e., 2 in the illustration above. The metric number of cord produced from No. 37 cotton threat twisted in 5 and then 3 strans is $37:(5 \cdot 3) \approx 2.5$.

Depending on the spinning system, the following types of thread are produced: 1) equipment thread in comparatively low metric numbers from short fibers and commercial waste; 2) corded thread in low and medium metric numbers; 3) combed thread in high metric numbers from long fibers. Thread is produced in coarse and finished forms. The following types of cotton thread are manufactured: coarse, mercerized (cold-treated under tension with a concentrated alkali solution in order to give it a luster, increase its strength, and make it more elastic), uniformly dyed, and composite (spun from cotton strans dyed different colors or from a mixture of dyed and coarse cotton). Depending on its finish, wool thread can be classified as uniformly dyed or bleached. Linen thread is produced in coarse, boiled, bleached, and dyed forms. Silk thread can be boiled or uniformly dyed. Thread should exhibit the following characteristics, depending on its purpose: fineness, uniformity, strength, elasticity, and moisture content.

The basic characteristics of thread (strength, fineness, elongation) vary with its moisure content. Before testing thread is generally held under standard conditions (a relative humidity of 65 ± 5% and a temperature of 20 ± 5°) in order to give it a normal moisture content.

S.Ye. Strusevich

TIME FUNCTION OF STRENGTH – the relationship between time to fracture (service life) and the constant applied stress (usually tensile).

[1] Материал	lg A (сек) [2]	α (мм²/кг)[3]
[4] Полиметилметакрилат	10,5	3,4
[5] Алюминий	38,0	10,2
[6] Цинк	22,0	5,0
[7] Диацетат	17,0	3,7
[8] Нитроцеллюлоза (фотопленка)	14,5	2,3

1) Material; 2) sec; 3) mm^2/kg; 4) polymethylmethacrylate; 5) aluminum; 6) zinc; 7) diacetate; 8) nitrocellulose (photographic film).

The temporal strength function of solids is a special case of Fatigue of materials. This function is characteristic of all solids and is governed by the character of fracture, which is an activated process involving formation and propagation of microcracks under the action of thermal movement and stress. The time function of strength was first established for silicate glasses. For metals, plastics, inorganic glasses, and fibers not subject to surface-active or chemically active influences the temporal strength function is expressed by the equation:

$$\tau = Ae^{-\alpha\sigma}, \qquad (1)$$

where τ is the service life, σ is the tensile stress, and A and α are constants dependent on temperature. The table shows the values of the constants A and α for different materials at 20°.

Equation (1) is valid over a broad temperature range, while the coefficients A and α vary uniformly with temperature and the service-life curves, when plotted on semilogarithmic coordinates, form a family that radiates in the shape of a "V" from a single point (Fig. 1) corresponding to $\sigma = \sigma_{kr}$. The lower the temperature, the steeper is the slope of

the line and the less pronounced is the temporal strength function. At low temperatures (ordinary temperatures for high-melting metals and 200° or below for plastics) the loading time has virtually no influence on the fracture stress and fracture fails to occur at all $\sigma < \sigma_{kr}$ so long as the material is not stressed. This justifies introduction of the concept of ultimate strength σ_{kr} for certain materials. At higher temperatures the ultimate strength is the maximum technical strength realizable at maximum loading speeds. Under all other conditions strength testing of components or specimens is characterized by three constants: σ_{kr}, A and α. If the structure of the material is altered during testing simple linear relationships are no longer observed (Fig. 1). This results from a change in coefficients, especially the structure-sensitive constant α, with stress and time. The coefficient α depends to a large extent on the structure of the material; for example, α varies linearly with the square root of the grain size in polycrystalline specimens.

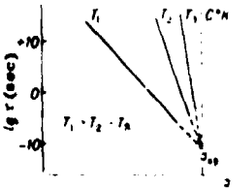


Fig. 1

Fig. 2

The time function of strength for soft rubbers does not follow the rule expressed in Eq. (1), but can be roughly represented by the formula:

$$\sigma = B\tau^{-n}, \qquad (2)$$

where σ is calculated for the true specimen cross-section; the constant B depends on the temperature, while n is independent of it. Caoutchouc-like polymers fall into a special category. As their intermolecular in-

teraction (cross-bonding, polarity, packing) increases their temporal function gradually approximates to the exponential relationship shown by Eq. (1), which is characteristic of solids. One of the reasons for the special form of the temporal strength function for caoutchouc-like polymers is their ability to undergo molecular orientation or extension, which leads to a change in the structure-sensiti e coefficient α. Eq. (1) is not valid for materials exposed to chemically active or surface-active agents. For example, silicate glasses in air (a humid atmosphere is a surface-active medium) are described by Holland and Turner's equation:

$$\tau = \tau_0 e^{-(\alpha - \beta \ln p)\sigma} \qquad (3)$$

Figure 2 shows the temporal strength function of silicate glass in air (1) and in a vacuum (2). As the stress σ increases the initial propagation rate of fracture-inducing cracks rises and the molecules of the active agent cannot follow the spreading cracks and influence fracture. As the stress increases there is a shift from the temperal strength function in the medium in question to that in a vacuum. At stresses close to the critical σ_{kr} the influence of the medium disappears.

References: Zhurkov, S.N., VAN SSSR [Herald of the Academy of Sciences USSR], 1957, No. 11; Bartenev, G.M., UKh [Advances in Chemistry], 1955, Vo. 24, No. 7; Bartenev, G.M., Gul', V Ye., Zh. Vses. khim. o-va [Journal of the All-Union Chemical Society], 1961, Vol. 6, No. 4.

G.M. Bartenev

TIME TO FAILURE of a loaded specimen is estimated by the time from the instant of stress application to the instant of complete breaking up of the specimen into parts (brittle failure) or its loss of the carrying capacity (for example, when subjected to a buckling load) or its loss of the carrying capacity (for example, when subjected to a buckling load); under repeated alternating loads it is estimated by the number of cycles to failure. The time to failure of a given material consists on the kind of stressed state, the surface finish, etc.; in certain cases, the time to failure determined under one test regime can be calculated for another test regime (see Creep Strength).

G.M. Bartenev

TIN BABBITT – a tin-based alloy for lining bearings. GOST 1320-55 describes two types of high-tin babbitts, B89 and B83, which are recommended for use in heavily loaded bearings (Table 1).

TABLE 1

Chemical Composition of Tin Babbitt (GOST 1320-55)

Сплав 1	2 Химический состав (%)								
	Sb*	Cu	Sn	Fe	As	Zn	Pb *	Bi	3 сумма примесей
				4 примеси, не более					
Б89 . 5 . .	7,25—8,25	2,5—3,5	Остальное	0,08	0,1	0,03	0,35	0,035	0,55
Б83 . . 6 . .	10—12	5,5—6,5	7	0,1	0,1	0,03	0,35	0,05	0,55

* The Pb content of B83 babbitt can be raised to 0.5% on request.

1) Alloy; 2) chemical composition (%); 3) total impurities; 4) impurities, no more than; 5) B89; 6) B83; 7) remainder.

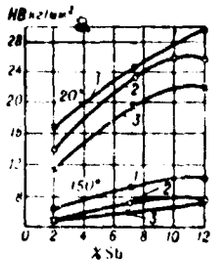


Fig. 1. Influence of antimony and copper content on the hardness of tin babbitts at normal and elevated temperatures: 1) 10% Cu; 2) 6% Cu; 3) 3% Cu. a) kg/mm^2.

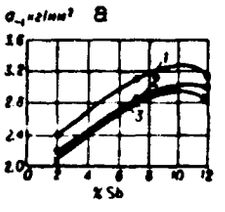


Fig. 2. Influence of antimony and copper content on the durability of tin babbitts (at $20 \cdot 10^6$ cycles): 1) 10% Cu; 2) 6% Cu; 3) 3% Cu. a) kg/mm^2.

TABLE 2

Mechanical Characteristics of Tin Babbitts

Сплав 1	Растяжение 2		Сжатие 4		5		6		
	$\sigma_в$ (кг/мм²) 3	δ(%)	$\sigma_{-0,2}$ (кг/мм²)	σ_- (кг/мм²)	Осадка (%)	НВ (кг/мм²)	$a_н$ (кгм/см²)	σ_{-1} (кг/мм²)	E (кг/мм²)
B89 7	8	9	5	10	40	25	0.8	2	4500
B83 8	9	6	7.2	11.5	38	30	0.6	2.5	4800

1) Alloy; 2) extension; 3) kg/mm^2; 4) compression; 5) shrinkage (%); 6) kg-m/cm^2; 7) B89; 8) B83.

TABLE 3

Physical Characteristics of Tin Babbitts

1 Сплав	2	Темпра затвердевания (°C) 3						
	γ (г/см³)	начало 4	конец 5	α (10⁻⁶ (1 °C)	λ (кал/см сек °C) 6	Коэффициент трения со смазкой 7	Износ баббита (мм³/см²·км) 8
9 B89	7.3	350	240	22.5	0.09	0.005	0.09
B83 10	7.3	370	240	23	0.09	0.005	0.1

1) Alloy; 2) g/cm^3; 3) solidification temperature; 4) initiation; 5) completion; 6) cal/cm·sec·°C); 7) coefficient of friction with lubrication; 8) wear (mg/cm^2·km); 9) B89; 10) B83.

TABLE 4

Technological Characteristics of Tin Babbitts

Сплав 1	Линейная усадка (%) 2	Жидкотекучесть (см) 3
B89 4	0.65	78
B83 5	0.55	70

1) Alloy; 2) linear shrinkage (%); 3) flowability (cm); 4) B89; 5) B83.

Antimony in concentrations of up to 7.5% dissolves in tin to form a solid solution. At higher antimony contents crystals of a β-solid solution with a cubic shape appear in the alloy. Tin dissolves only a small quantity of copper. A eutectic consisting of almost pure copper and a small amount of a copper-tin compound (Cu_6Sn_5) crystallizes at a Cu content of 1%. Both alloys, B89 and B83, have the same structure and consist of crystals of α- and β-solid solutions of antimony in tin and of copper-tin compounds, in the form of fine needles and eutectics, but they differ in their content of solid β and Cu_6Sn_5 crystals.

In B89 alloy, which has a lower antimony content, these crystals are smaller and the alloy has a lower hardness and a higher plasticity (Table 2). B83 alloy has a higher fatigue resistance. Increasing the antimony and copper contents of babbitt raises its hardness at both normal and elevated temperatures (Fig. 1) and increases its fatigue resistance (durability) (Fig. 2).

Tin babbitts differ little in their coefficient of friction and other physical characteristics (Table 3). Their wear resistance, however, rises with their copper content. Table 4 shows the technological characteristics of tin babbitts.

Tin babbitts are used for lining the bearings of steam engines, turbocompressors, turbopumps, compressors with powers of more than 500 hp, the diesel engines of locomotives and ships, marine and stationary steam engines with powers of more than 1200 hp, electric motors with powers of more than 750 kw, and generators with powers of more than 500 kw. Both alloys similar in composition to those employed in the USSR and alloys of different composition are used abroad. A distinctive feature of standard German alloys is the presence of lead in certain types containing more than 80% tin. In the USA and the German Federal Republic babbitts with high antimony and copper contents (up to 8.5-10%) are

used for power-turbine bearings and similar components.

References: Spravochnik mashinostroitelya [Machine-Builder's Handbook], 2nd Edition, Vol. 2, Moscow, 1956; Spravochnik metallista [Metalworker's Handbook], Vol. 3, Books 1-2, Moscow, 1959; Shpagin, A.I., Antifriktsionnyye splavy [Antifriction Alloys], Moscow, 1956.

O.Ye. Kestner

TIN BRONZE – an alloy of copper and tin, as well as more complex copper-tin alloys with phosphorus, lead, zinc, nickel, and other elements added. Tin bronzes have high strength and elasticity, good plasticity and corrosion resistance (Table 1), and high antifriction characteristics (wear resistance). The strength and hardness of these metals increases with their tin content, but their plasticity decreases (see Figure). Alloys containing up to 8% Sn or with other elements added are consequently used for pressure working (Table 2). Alloys with high tin contents (up to 20%) are used only in the cast state (Table 3). Tin bronzes exhibit liquid flow, readily fill the casting form, and have a low volumetric shrinkage, which makes it possible to obtain complex castings with sharp transitions from thin to thick cross-section. Tin bronzes are employed in shape and artistic casting (see Casting bronze) and are used in the form of a secondary metal (see Secondary bronze). These alloys are easily welded and soldered, are nonmagnetic, and do not spark when struck. Pressure-workable tin bronzes containing up to 5% tin have the structure of a homogeneous solid solution. Tin casting bronzes containing larger amounts of tin have a two-phase structure with inclusions of hard, brittle δ-phase crystals ($Cu_{31}Sn_8$). Tin bronzes with high tin contents (10-20%) are employed for especially critical components. The composition and characteristics of these alloys are specified by special TU; GOST 613-50 includes alloys containing an average of 4-5% Sn.

Addition of phosphorus to tin bronze reduces the region occupied by the solid solution of tin in copper and promotes an increase in the

TABLE 1

Mechanical Characteristics of Certain Tin Bronzes

Свойства 1	2 БрОФ 6,5 0,4			7 БрОЦС 4-4-4	
	3 литье в кокиль	4 деформированный		3 литье в кокиль	8 деформированный мягкий
		5 мягкий	6 твердый		
σ_b (кг/мм²) . 9 .	28	40	90	20	30
$\sigma_{0,2}$ (кг/мм²) . .	12	18	60	10	12
E (кг/мм²) . . .	9500	10500	11200	—	—
HB (кг/мм²) . .	82	80	180	68	62
δ (%)	20	60	0,5	10	40

1) Characteristic; 2) BrOF 6.5-0.4; 3) cast in chill molds; 4) deformed; 5) soft; 6) hard; 7) BrOTsS 4-4-4; 8) soft deformed; 9) Kg/mm^2.

TABLE 2

Chemical Composition of and Types of Semifinished Products Produced from Pressure-Workable Tin Bronzes

Сплав 1	2 Химический состав (%)				4 ГОСТ или ТУ	5 Виды полуфабрикатов
	Sn	P	3 другие элементы	Cu		
6 БрОФ 7-0,2	6—8	0,1—0,25	—	13 Остальное	14 ЦМТУ 669-41	Прутки 16
7 БрОФ 6,5-0,15	6—7	0,1—0,2	—	» 15	ГОСТ 5017—49	Прутки, полосы, ленты 17
8 БрОФ 6,5-0,4	6—7	0,3—0,4	—	»	ГОСТ 5017—49	Ленты, проволока 18
9 БрОЦ 4-0,25	3,5—4	0,2—0,3	—	»	ГОСТ 5017—49	Ленты, трубки 19
10 БрОЦ 4-3	3,5—4	—	2,7—3,3 Zn	»	ГОСТ 5017—49	Прутки, полосы, ленты, проволока
11 БрОЦС 4-4-2,5	3—5	—	3,5 Zn, 1,5—3,5 Pb	»	ГОСТ 5017—49	Полосы, ленты 20
12 БрОЦС 4-4-4	3—5	—	3—5 Zn, 3,5—4,5 Pb	»	ЦМТУ 512-41	Полосы, ленты 21

1) Alloy; 2) chemical composition (%); 3) other elements; 4) GOST or TU; 5) types of semifinished products; 6) BrOF7-0.2; 7) BrOF6.5-0.15; 8) BrOF6.5-0.4; 9) BrOTs4-0.25; 10) BrOTs4-3; 11) BrOTsS4-4-2.5; 12) BrOTsS4-4-4; 13) remainder; 14) TsMTU; 15) GOST; 16) bars; 17) bars, strips, bands; 18) bands, wires; 19) bands, tubes; 20) bars, strips, bands, wire; 21) bands, strips.

amount of δ-phase in its structure. A new phase, a phosphide (Cu_3P), appears when the phosphorus content exceeds 0.3%. Phosphorus gives tin bronze liquid flow and raises its strength, hardness, and antifriction characteristics. Pressure-workable bronzes contain no more than 0.4% P, while casting bronzes contain up to 1% P.

TABLE 3

Chemical Composition and Applications of Tin Casting Bronzes

Сплав 1	2 Химический состав (%) Sn	Zn	другие элементы 3	Cu	4 ГОСТ или ТУ	5 Области применения
БрОЦСН 3-7-5-1 6	2,5—4,5	6—9,5	3—6 Pb, 0,5—1,5 Ni	Остальное 17	ГОСТ 613—50 18 19	Арматура, работающая в условиях пресной и морской воды, а также в среде пара при давлении до 25 кг/см² 21 22
БрОЦС 3-12-5 7	2—4	8—15	3—6 Pb	»	То же	То же, но только в среде пресной воды
БрОЦС 5-5-5 8	4—6	4—6	4—6 Pb	»	»	Антифрикционные детали 23
БрОЦС 6-6-3 9	5—7	5—7	2—4 Pb	»	»	То же
БрОЦС 4-4-17 10	3,5—5,5	2—6	14—20 Pb	»	»	» 24
БрОЦС 3,5-6-5 11	3—4,5	5—7	4—6 Pb	»	Спец. ТУ 20	Детали тракторов
БрОФ 10-1 12	9—11	—	0,4—1 P	»	»	Ответственные детали
БрОС 10-10 13	9—10	—	6—11 Pb	»	»	То же 25
БрОЦ 10-2 14	9—11	1—3	—	»	»	»
БрОС 5-25 15	4—6	—	23—27 Pb	»	»	»
БрО 19 16	18—19,5	—	—	»	»	»

1) Alloy; 2) chemical composition (%); 3) other elements; 4) GOST or TU; 5) application; 6) BrOTsSN 3-7-5-1; 7) BrOTsS 3-12-5; 8) BrOTsS 5-5-5; 9) BrOTsS 6-6-3; 10) BrOTsS 4-4-17; 11) BrOTsS 3.5-6-5; 12) BrOF 10-1; 13) BrOS 10-10; 14) BrOTs 10-2; 15) BrOS 5-25; 16) BrO 19; 17) remainder; 18) GOST; 19) the same; 20) special TU; 21) fittings intended to function in fresh and salt water or in steam at pressures of up to 25 kg/cm^2; 22) the same, but only in fresh water; 23) antifriction components; 24) tractor components; 25) critical components.

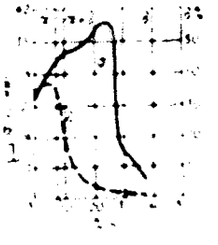


Figure. Influence of tin content on the mechanical characteristics of tin bronzes. 1) kg/mm^2.

Zinc added to tin bronze in a quantity of several % goes into solid solution in the copper and has no marked influence on the structure and mechanical characteristics of the alloy, although it improves its technological characteristics. Nickel present in a quantity of several

% also goes into solid solution, reducing the grain size of the bronze and increasing its corrosion resistance and mechanical characteristics. Lead, which is virtually insoluble in solid copper, is precipitated during solidification in the form of independent round inclusions rather uniformly distributed throughout the structure of the alloy. The presence of lead increases the density and cutability of castings, but reduces their mechanical characteristics. The principal purpose of addition of lead is to improve antifriction characteristics. Among the particularly detrimental impurities in tin bronzes are aluminum, magnesium, and silicon, which tend to oxidize and form films of high-melting oxides, which reduce casting strength and density. Bismuth, antimony, arsenic, and sulfur are also detrimental impurities in pressure-workable bronzes, making them brittle. The tin oxides (SnO_2) formed in these bronzes in the presence of oxygen, being very hard crystals, are extremely detrimental to components which must function under friction (especially in low-viscosity media), since they reduce the antifriction characteristics of the alloy. These crystals damage and erode the necks of shafts. As a result of their properties, tin bronzes are widely used in various areas of industry, including machine building, the chemical industry, artistic casting, etc., but their applications are being reduced as new alloys are developed in the USSR.

References: Bochvar, A.A., Metallovedeniye [Metalworking], 5th Edition, Moscow, 1956; Smiryagin, A.N. Promyshlennyye tsvetnyye metally i splavy [Commercial Nonferrous Metals and Alloys], 2nd Edition, Moscow, 1956; Zholobov, V.V., Zedin, N.I., Metallograficheskiy atlas po medi i mednym splavam, obrabatyvayemym davleniyem [Metallographic Atlas of Pressure-Worked Copper and Copper Alloys], Leningrad-Moscow, 1949; Mal'tsev, M.V., Barsukova, T.A., and Borin, F.A., Metallografiya tsvetnykh metallov i splavov [Metallography of Nonferrous Metals and Al-

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loys], Moscow, 1960.

O.Ye. Kestner

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TINNING OF THE TITANIUM ALLOYS is the plating of tin on the surface of the titanium alloys prior to brazing using soft brazes for the improvement of the drawing of wire and the stamping of sheets. Tinning of the titanium alloys is performed by immersion of details and blanks in molten tin at 650-700° for 20 minutes or in molten tin dichloride (or a mixture of tin dichloride with aluminum chloride in a 1:1 ratio) at 350-400°. The tin can also be plated by the electric arc of a welding unit with a current intensity of no more than 40-50 amps in an inert gas medium, then to obtain a smooth, thin layer of tin the details are heated to 300-500°. During tinning there is formed on the surface a layer of pure tin which is well bonded with the base metal by means of an intermediate nonbrittle diffusion layer of tin in titanium.

Reference: Titan i yego splavy [Titanium and Its Alloys], Vol. 1, L., 1960.

I.S. Anitov

TIN PLATE – is thin, cold-rolled strips or sheets produced from low-carbon rimming steel of the type 08kp (GOST 1050-60). Two grades of tin plate, differing in the use and in the surface quality, are obtainable: canning tin plate (ZhK), and tin plate for different purposes (ZhR). The surface of the tin plate is covered on both sides with a tin layer (by hot tinning); the requirements of the surface quality are described in standards (GOST 9488-60 and GOST 7530-61). The quality of the tin plating is determined by porosity tests according to GOST 326--46. Strip tin plate has a width from 120 to 512 mm and a thickness from 0.17 to 0.40 mm. Tin plate sheets are usually deliverable in the size 512 × 712 mm and in a thickness from 0.19-0.55 mm. The mechanical properties of tin plate are determined by the Erissen cupping test (depth of the crater 6-8 mm for canning tin-plate, and 5-7 mm for tin-plate for different purposes) and by the bending test around jaws with a diameter of 1.5-2 mm (depending on the thickness of the tin-plate). The specimens of the canning tin-plate must withstand an 8-fold bending, and those of the tin-plate for different purposes – a 6-fold bending.

M. L. Bernshteyn

TITANIUM Ti – chemical element of the IV group in Mendeleyev's periodic system, atomic number 22, atomic weight 47.90. Isotopes of titanium: 46 (7.95%), 47 (7.75%), 48 (73.45%), 49 (5.50%) and 50 (5.35%).

Titanium is a white-colored refractory metal which is similar to nickel. Despite its extensively prevalence (it occupies the ninth place with respect to its content in the earth's crust), titanium came into use as a material of construction only in the last decade, which is due to the great technical difficulties in obtaining it in the pure form. The creation of a large titanium industry has become possible only on the basis of the latest achievements of vacuum metallurgy.

Titanium exists in two allotropic forms – below the polymorphic transormation temperature (882°) in the form of the α-modification, which has a hexagonal, densely packed lattice with the periods a = = 2.9503 ± 0.004 A, c = 4.8831 ± 0.0004 A, and c/a = 1.5873 ± 0.0004 A; β-titanium with a cubic body-faced lattice with the period 3.283 ± ± 0.003 A at 20° (extrapolation) and 3.3282 A at 900 ± 5° exists at temperatures above 882°.

The specific gravity of α-titanium (at 20°) is 4.505, of β titanium (at 900°) it is 4.32 (calculated by the lattice periods). The normal elasticity modulus is 11,010 kg/mm^2, the shear modulus is 4110 kg/mm^2, the Poisson ratio is 0.32. Latent heat of transformation 478 cal/mole ± 10%, latent heat of melting 5 kcal/mole (hypothetically), latent heat of vaporization 110.5 ± 0.5 kcal/mole, t°_{pl} 1668 ± 5°, t°_{kip} ~ 3500°K (3227°C)

The linear expansion coefficient and the specific heat of titanium are given in Table 1, while the thermal conductivity is given in Table 2.

The electrical resistivity at 20° of titanium iodide is 0.42 ohm-mm^2/m, for commercial titanium it is 0.65 ohm-mm^2/m. Titanium is paramagnetic and has a magnetic permeability of $(3.2 \pm 0.4) \cdot 10^{-6}$ CGSM.

Titanium is a transition element and has an incomplete 3d layer in the electron shell. In the majority of chemical compounds with other elements the valence of titanium is four, less frequently it is three. Titanium with a valence of two yields unstable compounds (for example with halogens). The chemical activity of titanium increases with a rise in the temperature. In the presence of an activated surface titanium absorbs hydrogen at 20° and at 300° the rate of hydrogen absorption is quite high (see Hydrogen Embrittlement of Titanium Alloys). Perceptible interaction with oxygen starts at temperatures above 600°, with nitrogen it starts at above 700°. The solubility of hydrogen in titanium is reversible, which makes it possible to almost completely remove the hydrogen admixture by vacuum annealing. Oxygen, nitrogen, hydrogen and carbon admixtures, which form interstitial solid solutions with titanium, impair its mechanical properties. Titanium in the form of powder and shavings burns in a nitrogen atmosphere, and in an oxygen atmosphere massive pieces of titanium may also burst into flames (see Inflammation of Titanium). Only very fine titanium shavings burn in air upon intensive local heating (for example, when cut by a blunted tool). In the molten state titanium reacts strongly with all refractories used in equipment, reducing them, and it forms a carbide with carbon (~20% C).

Major chemical compounds of titanium. Titanium dioxide in the pure form is a white powder, t°_{pl} 1830-1850°; is used for making white

TABLE

[illegible]
of Titanium

[illegible] 1	[illegible]
[illegible] 2	[illegible]

1) Temperature (°C); 2) [illegible] (cal/cm-sec-°C).

TABLE 2

Thermal Conductivity of Titanium

Temperature (°C) 1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
λ [illegible] 2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1) Temperature (°C); λ(cal/cm-sec-°C).

mineral pigments, sometimes for obtaining metallic titanium. Titanium tetrachloride ($TiCl_4$) is a transparent liquid with t°_{kip} 136°, which fumes in air due to hydrolitic reaction with the air moisture. It is an intermediate product in obtaining titanium by magnesium or sodium reduction. It is used for the production of smoke pots. Gaseous compounds of titanium with iodine (TiI_2 and TiI_4) are used for obtaining highly pure metallic titanium by thermal dissociation. Titanium hydride ($\sim TiH_2$) is a gray-colored substance which decomposes on heating. It is obtained for obtaining very fine titanium powder, as well as of highly pure hydrogen. Titanium carbide TiC(~20% Ti) is refractory (t°_{pl} [illegible]°), hard and is contained in a number of solid alloys. With nitrogen titanium forms a refractory (2950°) nitride (TiN).

Titanium has high corrosion resistance due to the formation of a strong oxide film (see Oxidation of Titanium Alloys). It is resistant to sea water and the atmosphere, has a good resistance to hydraulic cavitation. Resists the effect of nitric acid in all concentrations with the exception of red fuming nitric acid which gives rise to corr-

sion cracking; here the corrosion products have explosive properties. The resistance to diluted sulfuric acid is satisfactory. Hydrochloric acid reacts with titanium, particularly at elevated temperatures. Hydrofluoric acid reacts intensely with titanium. In addition, titanium is rapidly corroded by hot organic acids: oxalic, trichloracetic and formic acids. Boiling solutions of acetic, lactic, citric and stearic acids of all concentrations, carbon tetrachloride, trichloroethylene, formaldehyde, chloroform practically do not affect titanium. At 20° titanium resists the effect of ammonium hydroxide and diluted solutions of sodium hydroxide and potassium hydroxide, as well as of a hot solution of a moderate concentration of sodium hydroxide. Of great importance for the industrial application of titanium is its high resistance to moist chlorine, chlorine water, hot and cold solutions of chlorates of all concentrations, with the exception of the boiling solution containing more than 25% of aluminum chloride.

An important property of titanium is its ability to form solid solutions with atmospheric gases and hydrogen. Hence when titanium is heated in air an oxygen saturated solid (alpha-phase) layer, whose thickness depends on the temperature and heating duration is formed at its surface, in addition to the scale. This layer consists of an α-titanium-based solid solution, which is stabilized by the oxygen and has a higher transformation temperature than the base metal. The formation of the α-phase layer on the surface of components and semifinished products is undesirable, since it can give rise to brittle failure. To remove this layer components are etched in acids and in salt and alkaline solutions; here in certain cases it is necessary to follow this by vacuum annealing (to remove hydrogen absorbed during etching). The formation of the α-phase layer can be reduced or entirely prevented by heating the components in an argon atmosphere or by using special

protective lubricants.

Obtaining of metallic titanium. The starting raw material are simple or compound rutile- and ilmenite-type oxide ores. Due to the strength of the titanium oxide (TiO_2) it is necessary to use very strong reducing agents. Titanium can be obtained by several methods using vacuum or a neutral gas atmosphere.

Molten calcium method – reduction of titanium dioxide by metallic calcium yields a metal highly contaminated with oxygen and other admixtures (purity not higher than 98-98.5%), which is unsuitable for construction purposes. Has not come into practical use.

Calcium hydride method – reduction of titanium dioxide by calcium hydride yields a mixture of titanium hydride with calcium oxide, which is then leached in weak hydrochloric acid (see Sintered Titanium Alloy).

The iodide method – decomposing gaseous titanium iodides by the application of heat – is more correctly regarded as a refining method, since the starting material is impure metallic titanium obtained, for example, by the molten calcium method. The iodide method does not have independent industrial significance, and is used primarily for laboratory purposes and when very high purity metal is heeded. Titanium obtained by the iodide method is supplied in the form of coarse-crystalline bars up to 40 mm in diameter and up to one meter long.

Molten sodium method – reduction of titanium tetrachloride by molten sodium is one of the most extensively used industrial methods for obtaining metallic titanium. First titanium tetrachloride is obtained by chlorinating titanium dioxide in the presence of carbon, and then the tetrachloride is reduced, obtaining sodium chloride and fine-granular titanium. The products of reaction are separated by leaching. Due to the fact that the titanium tetrachloride used for

reducing does not contain oxygen, it is possible to obtain titanium with a moderate contaminant content, which is a good base for high-strength and heat resistant titanium alloys. A certain disadvantage of the molten sodium method is the need to produce highly pure metallic sodium in large quantities.

Molten magnesium method – reduction of titanium tetrachloride by magnesium. At present it is the basic method for industrial production of titanium in our country and abroad. The tetrachloride is reduced by molten magnesium in an argon atmosphere according to the reaction:

$$TiCl_4 + 2Mg = Ti + 2MgCl_2 + 1545 \text{ cal/kg.}$$

The product of reaction is a mixture of spongy titanium with magnesium chloride and metallic magnesium (residue of the reducing agent) Then the mixture is vacuum distilled after which spongy titanium is obtained. The molten magnesium method has the following advantages: yields a high quality metal (since the starting product, i.e., titanium tetrachloride, does not contain oxygen, is easy to purify from contaminants by fractional distillation, filtering and passing through absorbers, and the reduction reaction goes to the end). The reducing agent – metallic magnesium – is produced in sufficient quantities; here unlike calcium and sodium, magnesium has its own significance as a valuable metal of construction. Hence the capital investments for expanding the production of magnesium will be justified even if the method of obtaining of titanium is changed; the byproducts – magnesium chloride and the metallic magnesium residue – can be reused at the initial stage of the process, which makes it possible to create a closed cycle and reduce production costs. Ten brands of spongy titanium (according to technical specifications of 1964) are produced in the USSR (Table 3).

Titanium semifinished products are produced primarily from brand

TG-110 to brand TG-140 sponge. The TG-100 and TG-105 brands are produced in limited quantities as experimental metals for study purposes and for special fields of application alongside with titanium obtained from iodides. The TG-ChM brand is used in ferrous metallurgy for deoxidizing and alloying of steel.

TABLE 3

Chemical Composition of Spongy Titanium

Марка 1	НВ (кг/мм²) 2	3 Примеси (%), не более					
		Fe	Si	C	Cl	N	O
4 ТГ-100оп	100 и менее 5	0,07	0,05	0,03	0,08	0,02	0,05
ТГ-105оп	101—105	0,08	0,05	0,03	0,08	0,025	0,05
6 ТГ-110	106—110	0,09	0,05	0,03	0,08	0,03	0,05
ТГ-120	111—120	0,11	0,05	0,04	0,08	0,03	0,065
ТГ-130	121—130	0,13	0,05	0,04	0,10	0,03	0,08
ТГ-140	131—140	0,15	0,05	0,05	0,10	0,03	0,09
ТГ-155	141—155	0,20	0,08	0,06	0,10	0,05	0,10
ТГ-170	156—170 8	0,23	0,08	0,06	0,12	0,05	—
ТГ-190	171—190	0,30	0,10	0,06	0,12	0,06	—
7 ТГ-ЧМ	191 и выше	—	—	—	—	—	—

1) Brand; 2) kg/mm^2); 3) admixtures (%), not more than; 4) TG...op; 5) and less; 6) TG; 7) TG-ChM; 8) and above.

The <u>electrolytic method</u> for obtaining metallic titanium from its compounds has not as yet come into use due to difficulties, but it will be used successfully for refining titanium wastes and scrap.

The high strength (the ultimate strength of titanium alloys can exceed 150 kg/mm^2), lightness and excellent corrosion resistance, which in a number of cases exceeds the corrosion resistance of stainless steel, make titanium a particularly promising material for the aircraft, chemical and shipbuilding industries. In the majority of cases titanium is used in the form of alloys with aluminum, molybdenum, vanadium, manganese and other metals (see <u>Titanium Alloys</u>). A property of titanium alloys which is of particular importance to modern aircraft construction is the high heat resistance as compared with aluminum and magnesium alloys.

<u>Mechanical properties</u>. <u>Particularly pure</u> (iodide) titanium has the following properties: HV 83.4, σ_b = 25.6 kg/mm^2, $\sigma_{0.2}$ = 0.6 kg/mm^2,

δ = 72% (on a length of 13 mm), ψ = 86.2%. The admixture content: 0.01% O, 0.001% N, 0.03% C, 0.02% Fe and 0.03% Si; the remaining admixtures, as a rule, are in the trace form. Commercial titanium, obtained by magnesium or sodium reduction of titanium tetrachloride, differs from the particularly pure titanium by an increased admixture content, particularly of oxygen.

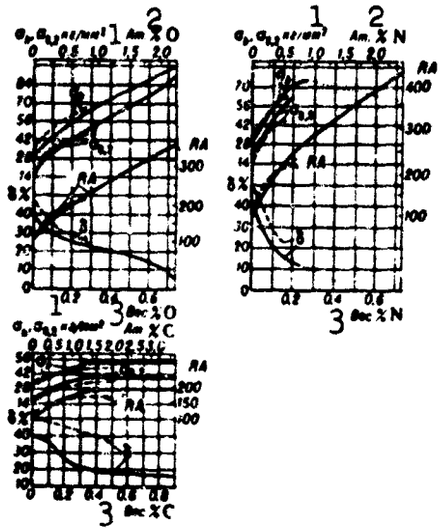


Fig. 1. Effect of oxygen, nitrogen and carbon on the mechanical properties of titanium (at 20°), according to Jaffe, Ogden and Maycalf (solid curves) and Finley and Snyder (dashed curves). 1) Kg/mm^2; 2) atomic; 3) by weight.

Figure 1 shows curves of the mechanical properties of titanium as a function of the admixture content. The greatest strength increase is produced by nitrogen, the lowest by carbon. When the nitrogen content is 0.3%, titanium becomes so brittle that it cannot be tested in tension. Carbon has a perceptible effect on the strength and hardness only when the solid solution concentration is up to the critical magnitude (0.3-0.4%), after which the carbide precipitation starts; the plasticity continues to drop even after the carbide has precipitated. Hydrogen almost does not affect the strength and plasticity of statistically loaded titanium, but it significantly amplifies its sensitivity to the prolonged application of steady loads. Hydrogen produces slow embrit-

tlement in titanium alloys as a result of diffusion precipitation of the hydride.

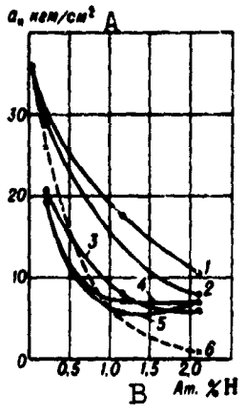


Fig. 2. Effect of hydrogen on the impact ductility of titanium, according to Lenning, Craighead and Jaffe. 1) Quenching from 400°; 2-5) aging (after quenching; 2) one day; 3) one week; 4) one month; 5) six months; 6) slow cooling from 400°. A) kgm/cm^2; B) atmomic.

Figure 2 shows the impact ductility of commercial titanium as a function of the hydrogen content after heat treatment according to various regimes and after natural aging for up to one half a year. The greatest embrittlement is observed after slow cooling from 400° (curve 6). The metal quenched from this temperature ages slowly; here the impact ductility is reduced most perceptibly during the first week (curve 3), whereupon the process slows down (see Titanium Alloys).

References: Yeremenko, V.N., Titan i yego splavy [Titanium and its Alloys], 2nd Edition, Kiev, 1960; MacQuillen, A.D. and MacQuillen, M.K., Titan [Titanium], translated from English, Moscow, 1958; Titan i yego splavy [Titanium and its Alloys], edited by L.S. Moroz, Vol. 1, Leningrad, 1960; Glazunov, S.G., in the book Spravochnik po mashinostroitel'nym materialam [Handbook of Machine-Building Materials], Vol. 2, Chapter 6, pages 356-82, Moscow, 1959; Titan v promyshlennosti [Titanium in the Industry], Collection of articles under the editorship of S.G. Glazunov, pages 5-30, 41-78, 142-59, 216-226, 232-65, Moscow,

1961; Glazunov, S.G , Sovremennyye titanovyye splavy, "Metallovedeniye i termicheskaya obrabotka metallov" [Modern Titanium Alloys, "Metal Science and Heat Treatment of Metals"], No. 2, 1963; Molchanova, Ye.K., Atlas diagramm sostoyaniya titanovykh splavov [Atlas of Phase Diagrams of Titanium Alloys], Moscow, 1964.

S.G. Glazunov

Manuscript Page No.	[Transliterated Symbols]
4125	пл = pl = plavleniye = melting
4125	кип = kip = kipeniye = boiling

TITANIUM ALLOYS – titanium-base alloys (50% Ti). Among the more important alloying elements are Al, Mo, V, Mn, Cr, Sn, Fe, Zr and Nb. The greatest strength increase is produced by iron, and the lowest by vanadium (Fig. 1).

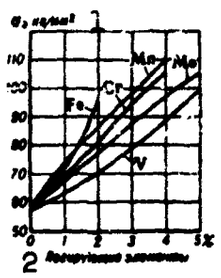


Fig. 1. Effect of alloying elements on the strength of titanium (according to Craighead, Simmons and Eastwood). 1) kg/mm^2; 2) alloying elements.

Titanium forms alloys with practically all metals (with the exception of alkaline and alkaline-earth), and also with silicon, boron, hydrogen, nitrogen and oxygen.

In comparison with other materials of construction titanium has a better combination of high mechanical properties, corrosion resistance and low specific gravity (4.5-4.8). Depending on the alloying and heat treatment, it is possible to obtain titanium alloys with σ_b from 50 to 140 kg/mm^2, which corresponds to a specific strength (σ_b/γ) of from 10 to 32 km. This distinctive feature of titanium alloys is retained over a wide temperature range (from –253° to +500°). Certain other properties of titanium alloys, such as the low linear expan ·n coefficient which makes it possible to reduce the thermal expansion gaps in engines and reduce the thermal stresses due to the heating of aircraft

skin; the fact that titanium alloys are nonmagnetic, which eliminates the harmful effect of the metallic structure on navigation instruments, and also reduces the danger of exploding on magnetic mines, are also valuable. The absence of cold shortness in nonalloyed titanium and in a number of titanium alloys makes them for a promising material for cryogenic equipment. The ability of titanium and its alloys to absorb nitrogen and oxygen at high temperatures makes it possible to use them in electron vacuum engineering as getters. Titanium and its alloys are prone to inflammation in an oxygen medium under pressure (see Inflammation of Titanium), which somewhat limits their application in designs operating in oxygen-containing media.

A great influence on the properties of titanium alloys is exerted by the character of the solid solutions they form, which depends on the relationship between the atomic diameters of the alloying elements; elements with small atoms (H, O, N and C) form interstitial solutions; elements whose atoms are close in size to that of titanium atoms (Zr, V, Al, etc.) form substitutional solid solutions. The alloying elements exert a varying effect on the allotropic transformation temperature of titanium; elements which increase this temperature (Al, O, N) are called α stabilizers, elements which reduce it (the majority of metals, for example, Mo, Mn) are called β stabilizers. Elements which have little effect on the transformation temperature are called neutral or two-phase hardening agents; the most typical representative of the latter group is thorium, which has the same allotropic transformation temperature as titanium and which does not form intermetallic phases; on the double phase diagram for Ti-Th the α- and β-regions are divided by a horizontal straight line; Sn, Hf and Zr also belong to this group; α stabilizers primarily increase the strength of α titanium, while β stabilizers due the for β titanium, the neutral stabili-

zers exert approximately the same strengthening effect on α and β titanium. Figure 2 shows a composite phase diagram for titanium with three typical alloying elements: Al, Mo and Sn.

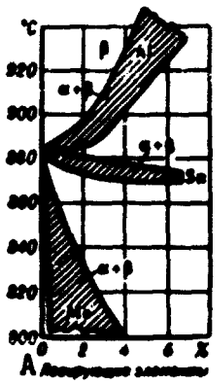


Fig. 2. Composite phase diagram of an alloy of titanium with Al, Mo and Sn. A) Alloying elements.

The rate of the allotropic transformation of the β-α forms is of significant importance; in the majority of titanium alloys with β stabilizers it is possible to retain by quenching a certain quantity of the β phase, which depends on the alloys concentration and the quenching temperature; however, the allotropic transformation in certain titanium alloys with β stabilizers, for example, Ti-Si, takes place at such a high rate, that the β phase cannot be retained by quenching.

The effect of alloying elements on titanium with respect to the character of the solid solution, their influence on the temperature and rate of allotropic transformations can be illustrated by a schematic (Fig. 3). Elements which form solid interstitial solutions are impurities, while those forming substitutional solid solutions are used as alloying elements in obtaining titanium alloys. In nonalloyed titanium and its alloys with α stabilizers the β phase is not retained by quenching, but undergoes a martensitic transformation, forming the acicular α' phase. Martensitic α' and α" phases can also form in low-alloyed and medium alloyed titanium alloys with β stabilizers (2-6%)

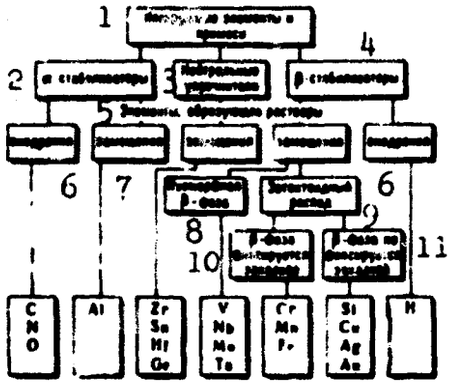


Fig. 3. Classification of alloying elements and impurities by their effect on titanium. 1) Alloying elements and impurities; 2) α stabilizers; 3) neutral hardening agents; 4) β stabilizers; 5) solution-forming elements; 6) interstitial; 7) substitutional; 8) isomorphous β phase; 9) eutectoid decomposition; 10) β phase is retained by quenching; 11) β phase is not retained by quenching.

when they are quenched from the β region.

By their structure titanium alloys are divided into 4 groups: 1) alloys with an α structure, which include titanium and its alloys primarily on the basis of the Ti-Al system, and also alloys of the Ti-Sn and Ti-Zr systems. These alloys do not contain β stabilizers or contain them in amounts such that they are completely soluble in α titanium; they can also contain elements from the neutral hardening agents group (Sn, Zr, etc.); they weld well by fusion welding, retain high plasticity at low temperatures and are not sensitive to heat treatment hardening. Among shortcomings of α alloys are reduced production process plasticity, particularly in alloys with a high aluminum content; 2) binary alloys α + β with a predominance of the α structure, containing up to 2% of β stabilizers. These alloys have a higher plasticity than α alloys and at the same time retain their good weldability; they are practically insensitive to heat treatment; 3) binary α + β alloys containing more than 2% of β stabilizers. They have a good plasticity after annealing or quenching and high strength after quenching and

aging; weld poorer than alloys of the first two groups, heat treatment for improving the plasticity of the welded joint is needed after welding; 4) alloys with a predominance of the β structure (β alloys). Due to a cubic crystal lattice they are highly plastic at room temperature. Their strength can be increased by heat treatment to a level which exceeds the strength of alloys of the preceding group; the welded seam is very plastic after welding but brittle after hardening heat treatment. These alloys oxidize upon heating in air to a greater depth and faster than alloys of the preceding groups, and are hydrogenated at a higher rate when etched in acid solutions; hence they should be carefully protected during heat treatment from gas contamination. The nomenclature of serially produced and several experimental titanium alloys used in the Soviet Union is presented in Table 1.

TABLE 1

Chemical Composition of Titanium Alloys

Марка или система сплава 1	Номинальный химический состав (%, Ti — остальное) 2
3 α-сплавы	
4ВТ1-00	5 Технический титан
ВТ1-0	10 пс 6
ВТ1-1	" 6
ВТ1-2	"
Ti–2Al	2,5 Al
Ti–3Al	3,5 Al
7ВТ5	5 Al
ВТ5-1	5 Al, 1,0 Sn
ВТ5-1	5 Al, 2,5 Sn
Ti–Al–Zr	3 Al, 2,5 Zr
ВТ1-00*	5 Al, 2,5 Sn, 1 Cu
8 α + β-сплавы (содержащие β-стабилизаторов до 2%)	
ОТ4-1	2 Al, 1,5 Mn
ОТ4	3 Al, 1,5 Mn
ВТ6	6 Al, 1,5 Mn
АТ-3	3 Al, 1,5 (Fe + Cr + Si + B)
АТ-4	4 Al, 1,5 (Fe + Cr + Si + B)
ОТ4-2*	6 Al, 1,5 Mn
ВТ12*	6 Al, 1 Mo, 3 Ni, 2 Zr
9 α + β-сплавы (содержащие β-стабилизаторов свыше 2%)	
ВТ16 10	2,5 Al, 2,5 V
ВТ6	6 Al, 4 V
ВТ6	6,5 Al, 1,5 Mo, 0,25 Si
ВТ8*	6,5 Al, 3,5 Mo, 0,25 Si, 2 Zr
ВТ3	5,5 Al, 2,5 Cr
ВТ3-1	5,5 Al, 2 Mo, 2 Cr, 1 Fe
ВТ14	4 Al, 3 Mo, 1 V
ВТ16	2,5 Al, 2,5 Mo
11 β-сплавы	
ВТ15*	3 Al, 8 Mo, 11 Cr

*Experimental alloys.

1) Alloy brand or system; 2) nominal chemical composition (%, the balance being Ti); 3) α alloys; 4) VT; 5) commercial titanium; 6) same as above; 7) VTL; 8) α + β alloys (containing up to 2% of β stabilizers); 9) α + β alloys (containing more than 2% of β stabilizers); 10) VT6S; 11) β alloys.

TABLE 2

Classification of Titanium Alloys by the Strength Level

Группа сплавов 1	σ_b (кг/мм²) 2	Сплавы 3
Сплавы невысокой прочности свариваемые 4	30–70	ВТ1-00, ВТ1-0, ВТ1-1, ВТ1-2, Ti–2Al, Ti–3Al, Ti–Al–Zr ОТ4-1 5
Сплавы средней прочности 6	70–100	ВТ3, ВТ3-1, ВТ4, ОТ4, ВТ5, ВТ5-1, ВТ6, ВТ6С, ВТ8, ВТ9, ВТ12, ВТ14, ВТ15, ВТ16 (после отжига) 7 8
Сплавы высокопрочные 9	Более 100 10	ВТ6, ВТ14, ВТ15, ВТ16 (после закалки и старения) 11

1) Alloy group; 2) (kg/mm^2); 3) alloys; 4) moderate strength weldable alloys; 5) VT; 6) medium strength alloys; 7) VT6S; 8) VT16 (after annealing); 9) high strength alloys; 10) more than 100; 11) VT16 (after quench hardening and aging).

By the strength level at room temperature titanium alloys are divided into moderate, medium and high strength alloys (Table 2).

At cryogenic temperatures moderate strength α alloys and commercial titanium become high-strength material. For example, at the temperature of liquid hydrogen σ_b of commercial titanium exceeds 100 kg/mm^2. A particular effect on the properties at low temperatures is exerted by the content of interstitial elements (oxygen and nitrogen) and also of iron. For titanium alloys used at low temperatures their content should be at minimum. The VT3, VT3-1, VT5, VT5-1, VT8 and VT9 alloys are used as heat resisting alloys. These alloys are supplied only in the form of forgings and stampings (except for VT5-1); all the others are also supplied in the form of sheets, pipes and shapes. The VTL1 alloy is used only for casting of intricately shaped products; the commercial alloy which is widely used for casting of intricate shapes is VT5. Welding wire is made from the VT1-0 commercial alloy and from

an alloy with 2% of Al.

At present the limiting operating temperature for titanium alloys in prolonged service is 500-550°, for short-duration operations it is up to 800°. The interval of changes in heat resistance properties for commercial titanium alloys with respect to 100 hour creep strength at 500° comprises from 20 (VT5) to 65 kg/mm^2 (VT9); with respect to 100 hour creep resistance at 500° it comprises from 5 (FT3-1) to 30 kg/mm^2 (VT9). The fatigue strength of titanium alloys depends to a substantial extent on the surface finish and can be improved by various production process operations. Usually the fatigue strength under 10^7 cycles comprises 45-50% of the ultimate strength of the alloy. A serious obstacle to the use of titanium alloys above 500° consists in the low oxidation resistance and an increase in the capacity for interaction with oxygen and hydrogen with an increase in temperature. Heat resistant titanium alloys should also have a high temperature resistance over the entire range of operational temperatures.

The production process features of titanium alloys are determined by the physicochemical properties of the titanium proper. Titanium alloys should be smelted in a vacuum or in an argon medium (the latter is used when the alloy contains volatile components, for example Cr), in copper water cooled crucibles (which usually also serve as ingot molds) or in graphite crucibles with titanium lining to reduce carburization. The heat source is a direct current arc which is produced between the cruicible bottom and a consumable electrode, which is made by cold pressureworking of sponge titanium with an addition of alloying elements. For casting of intricate shapes from titanium alloys it is best to use metal or graphite molds. When titanium alloy sheets are etched in acid etching agents for scale removal, hydrogenation of the metal is observed which is the more intensive, the more β phase is

contained in the alloy, the longer the etching time and the higher the solution's temperature. To protect the sheets from hydrogenation they are clad by unalloyed titanium, while vacuum annealing is used for removing hydrogen from the metal. When heating semifinished products for production process operations it is necessary to avoid extremely high temperatures and extended holding times in order to prevent deep oxidation with attendant formation of a solid and brittle layer at the product surfaces.

The expedience of using titanium alloys for aircraft and aviation engines is determined primarily by the combination of a low specific gravity with a high strength, while the use in chemical machine building and in shipbuilding is determined by the corrosion resistance in sea water and aggressive media (see Corrosion of titanium alloys).

In hydrometallurgical production of cobalt and nickel use is made of sulfate-chloride solutions, which highly corrode apparatus from stainless steel, in particular pumps, the service life of which usually does not exceed 3 months. Apparatus made from titanium alloys was found to resist corrosion during several years of service. The use of titanium coils instead of lead coils in the production of paints and plastics increases the service life of apparatus from 2 to 10 and more years. The resistance of titanium alloys to organic and fatty acids makes them a very promising material for the food and winemaking industries. The use of titanium and its alloys in the chemical industry not only gives large savings, but also makes it possible in a number of cases to increase the rate of production processes by increasing the temperature, pressure and concentration of the reagents. Titanium alloys can be used in the power producing industry for making motors and blades for stationary steam and gas turbines and also for high-capacity compressors which are installed on long pipelines. In medical equip-

ment titanium and its alloys are successfully tested for the making of surgical instruments, autoclaves, distillation vats, as well as for prosthesis; here use is made of the low specific gravity of titanium and of the fact that it is inert to living tissue. Good prospects for the use of titanium alloys exist in the petroleum industry, in particular, for making light and strong pipes which are used in drilling extremely deep wells and for facing of steel scaffold bridges over areas constantly wetted under sea oil extraction conditions. The shipbuilding industry uses titanium and its alloys for making seagoing fittings, pumps, various apparatus which works in brine and fish slime, and also for sheathing the hulls and stabilizer fins of sea and river vessels.

References: MacQuillen, A.D. and MacQuillen, M.K., Titan [Titanium]. Translated from English, Moscow, 1958; Titan i yego splavy [Titanium and Its Alloys], under the editorship of L.S. Moroz, Vol. 1, Leningrad, 1960; Kornilov, I.I. and Budberg, P.B., Diagramy sostoyaniya dvoyunykh i troynykh sistem titana [Phase Diagrams for Binary and Tertiary Titanium Systems], Moscow, 1961; Yeremenko, V.N., Titan i yego splavy [Titanium and Its Alloys], 2nd Edition, Kiev, 1960; Spravochnik po mashinostroitel'nym materialam [Handbook of Machine-Building Materials], Vol. 2, Chapter 6, Moscow, 1959; Molchanova, Ye.K., Atlas diagrams sostoyaniya titanovykh splavov [Atlas of Phase Diagrams for Titanium Alloys], Moscow, 1964; Titan v promyshlennosti [Titanium in Industry]. Collection of articles under the editorship of S.G. Glazunov, Moscow, 1961.

S.G. Glazunov

TITANIUM ALPHA-STABILIZERS – elements that raise the temperature of the allotropic transformation of titanium. The solubility of titanium alpha-stabilizers in α-titanium is higher than that in β-titanium. Introduction of such elements into titanium broadens the region of existence of the α-phase with the hexagonal close-packed atomic lattice. The titanium alpha-stabilizers include Al, O, C and N. Aluminum forms a substitutional solid solution with titanium; oxygen, nitrogen and carbon, on the other hand, form interstitial solid solutions. Oxygen, nitrogen and carbon must be categorized as harmful impurities, since their presence in the alloys in quantities exceeding the permissible level lowers plasticity and thermal stability and is detrimental to weldability and other valuable properties.

References: Makkvillen, A.D. and Makkvillen, M.K., Titan [Titanium], translation from the English, Moscow, 1958.

Ye.A. Borisova

TITANIUM BARS – semifinished products manufactured from almost all titanium alloys. These bars can be distinguished as round or square according to cross section and as pressed or rolled according to fabrication method.

TABLE 1

Types and Sizes of Titanium Bars

1 Вид прутков	2 Диаметр, сторона квадрата (мм) прутка	3 Длина (м)
Прессованные, 4 круглые и квадратные	15–20 25–30 35–50 55–200	6 До 5 До 4 До 3 До 2
5 Катаные	10–14 16–35 40–60	До 2–5

1) Type of bar; 2) diameter or side of square (mm); 3) length (m); 4) pressed, round and square; 5) rolled; 6) up to.

TABLE 2

Mechanical Characteristics of Titanium Bars at 20°*

1 Сплав	2 Состояние образцов	3 σ_b (кг/мм²)	δ (%)	ψ (%)	4 (кг·м/см²)
5 ВТ1-1	Отожженное 16	45–60	20	45	7
6 ВТ1-2	То же 17	55–75	15	40	5
7 ВТ3-1	»	100–120	10	25	3
8 ОТ4	»	70–90	10	30	3.5
9 ОТ4-1	»	65–75	15	35	4.5
10 ВТ4	»	85–105	10	30	3.5
11 ВТ5	»	75–95	10	25	3
12 ВТ5-1	»	80–100	10	25	4
13 ВТ6	»	95–110	10	30	3
14 ВТ8	»	105–125	8	10	3
15 ВТ14	»	90–110	10	35	5
ВТ14	Закаленное 18 состаренное	Не менее 110	6	20	2.5

*A slight reduction in δ and ψ is permissible for large-diameter bars.

1) Alloy; 2) condition of specimens; 3) kg/mm²; 4) kg-m/cm²; 5) VT1-1; 6) VT1-2; 7) VT3-1; 8) OT4; 9) OT4-1; 10) VT4; 11) VT5; 12) VT5-1; 13) VT6; 14) VT8; 15) VT14; 16) annealed; 17) the same; 18) quenched and aged; 19) no less than.

TABLE 3

Mechanical Characteristics of Titanium Bars at High Temperatures

1 Сплав	2 Состояние образцов	3 Темп-ра испытания (°С)	σ_b	σ_{100}
			4 (кг/мм²)	
5 ВТ3-1	10 Отожженное	450	60	55
6 ВТ5	11 То же	350	43	40
7 ВТ6	»	400	65	60
8 ВТ14	12 »	300	70	—
9 ВТ14	Закаленное и состаренное	300	90	—

1) Alloy; 2) condition of specimens; 3) test temperature (°C); 4) kg/ /mm^2; 5) VT3-1; 6) VT5; 7) VT6; 8) VT14; 9) VT14; 10) annealed; 11) the same; 12) quenched and aged.

Table 1 shows the sizes of the bars most frequently employed commercially.

The technical specifications for manufacture of titanium bars set their tolerances with respect to size, surface quality, macrostructure (absence of defects and permissible draininess), mechanical characteristics at room and elevated temperatures, and chemical composition.

Tables 2 and 3 show the mechanical characteristics of titanium bars up to 100 mm in diameter at room and elevated temperatures.

In producing titanium bars it is necessary to ensure a sufficient degree of deformation in the α-phase (for single-phase alloys) or α + + β-phase (for two-phase alloys) region. In the major'ty of cases deformation at higher temperatures (in the β-region) leads to severe deterioration of macrostructure and microstructure and a decrease in plasticity.

N.F. Anoshkin

TITANIUM BETA-STABILIZERS – elements which reduce the allotropic-transformation temperature of titanium, have a higher solubility in β-titanium than in α-titanium, and expand the region in which the β-phase, with its cubic body-centered lattice, exists. Depending on the character of the solid solutions which they form with titanium, these β-stabilizers can be classified as elements which form detrimental solutions (H) and those which form protective solutions. These groups are in turn divided into isomorphic (V, Mo, Nb, and Ta) and eutectoid-forming (Cr, Fe, Mn, Si, Cu, and Ag) β-stabilizers. The latter group can be still further divided into β-stabilizers with a slow eutectoid breakdown (Mn, Cr, Fe), which makes it possible to fix the β-phase by quenching, and β-stabilizers with a rapid eutectoid breakdown (Ni, Cu, Si), where the β-phase is not fixed and only martensitic transformation is observed. Tin, zirconium, germanium, hapnium, and thorium occupy a special place among the elements used for alloying titanium. These elements have a high solubility in both α- and β-titanium and have only a very slight influence on the allotropic-conversion temperature of titanium and on alloy structure. They are consequently referred to as "neutral."

A two-phase region is formed when titanium is alloyed with β-stabilizers, expanding as the alloying-element concentration increases. When the β-stabilizer content is above a certain critical level, e.g., 15–16% for V and 12–13% for Mo, almost pure β-phase can be fixed at room temperature by quenching the alloy from temperatures at which the high-temperature β-modification exists. Alloys with a wide range of mechanical and technological properties can be produced by varying the

relative quantities of the α- and β-phases. Addition of β-stabilizers to titanium leads to an increase in hot strength at temperatures of up to 350-400° and an increase in technological characteristics, especially susceptibility to hot deformation, since the alloy now contains the β-phase, which is plastic at the temperatures used for pressure working.

References: See article entitled Al'fa-stabilizatory titana [Titanium Alpha-Stabilizers].

Ye.A. Borisova

TITANIUM CASTING ALLOYS – alloys which serve for making components by casting of intricate shapes. The VTl-1 and VT5 single-phase α alloys and the VTL-1 special casting alloy (for the chemical composition see Titanium alloys) are most extensively used for these purposes. The advantage of these alloys consists in excellent weldability, high thermal stability after being held for prolonged periods of time at elevated (up to 500°) temperatures, and also by their high plasticity in the cast state. Almost all the titanium shaping alloys can be used as casting alloys, since they have good casting properties and retain a sufficiently high level of plasticity in the cast state.

The mechanical properties of the VTl-1, VT5 and VTL-1 alloys are presented in the following table:

Mechanical Properties of As-Cast Alloys

Сплав 1	E	σ_b	$\sigma_{ползуч}$	δ	ψ	a_H 2	3 Температура испытания	
	(кг/мм²)			(%)			$\sigma_{ползуч}$	$\sigma_{длит}$
							4 (кг/мм²)	
ВТ1-1 5	11000	45–60	–	15–23	30–50	5	–	–
ВТ5	11400	70–90	63	7–12	15–25	3.5	30–40	27–29
6 ВТЛ-1	11500	100–110	93–103	5–10	11–20	1.5	63	44

1) Alloy; 2) a_H (kgm/cm^2); 3) temperature 400°; 4) (kg/mm^2); 5) VTl-1; 6) VTL-1.

These excellent casting properties are due to the narrow crystallization interval of all the titanium alloys. The castability is approximately the same and, when determined on spiral specimens 0.56 mm thick (cast in a steel mold with graphite liners) at a metal temperature of 1850° comprises 410-460 mm; the linear shrinkage is 1%, the volume shrinkage is up to 3.0%.

Metal for casting intricate shapes is smelted in vacuum arc lined furnaces with a graphite crucible. The presence of the lining prevents the molten metal from coming into contact with the graphite with the result that no carbon saturation takes place in a normal process. The metal is poured and the molds cooled either in an inert gases atmosphere or in a vacuum. The molds are made from graphite, ceramic materials or metals which do not interact with molten titanium casting alloys. Pouring into molds can be either gravity or by the centrifugal method.

Titanium casting alloys are used for making rings, tubular blanks, components of intricate configuration; they can also be successfully used for art castings. See Weldable titanium shaping alloys.

References: Titan v promyshlennosti [Titanium in Industry]. Collection of articles under the editorship of S.G. Glazunov, Moscow, 1961; Gulyayev, B.B., Magnitskiy, O.N. and Demidova, A.A., Lit'ye z tugoplavkikh metalloy [Castings from Refractory Metals], Moscow-Leningrad, 1964.

Ye.A. Borisova

TITANIUM FORGINGS – see Titanium Stampings.

TITANIUM PIPES – are produced as hot rolled or cold shaped from commercial titanium of various groups and from the OT4-1, OT4, etc., titanium alloys. Hot-shaped pipes as well as blanks for cold-shaped pipes are in a number of cases made by extrusion; depending on the dimensions and on the metal properties they are obtained directly from the cast metal or after pre-shaping of the billets. Hot-shaped pipes are made with diameters 50 to 325 mm and with a wall thickness from 3-6 mm to 13-35 mm, respectively, as well as with other dimensions; hot-rolled pipes are made with diameters of 75 and more mm.

Cold-rolled and cold-drawn pipes are supplied with diameters of 10-130 mm. Pipes 10-60 mm in diameter have a wall thickness from 0.15-0.16 mm to 2-7 mm. The wall thickness of large diameter pipes is within the limits from 2.5-4 mm to 9.0 mm, depending on the diameter; pipes with a diameter less than 10 can also be made. Hot-rolled pipes are supplied in nonstandard lengths from 1.5 to 8 m, and in standard length from 2 to 8 m, depending on the diameter and wall thickness. Cold-shaped pipes are supplied in nonstandard lengths from 4 to 7 m, depending on the wall thickness, and in standard lengths of not more than 6 m.

Titanium pipes are supplied in the heat-treated state, in the etched state; hot-rolled pipes can be machined to a finish of ∇3-∇4. By the state of the outside and inside surfaces, cold-shaped pipes are supplied of standard and high quality. The suppliers guarantee absence of a gas-saturated layer on the pipe surfaces.

Welded titanium pipes are used extensively. The assortment of

these pipes with respect to dimensions and alloys is determined by the pipe welding machines, the weldability characteristics of the alloys and the feasibility of making ribbon, needed for pipe welding, from these alloys. For the use of titanium pipes see Titanium Alloys, Weldable Titanium Shaping Alloys.

N.F. Anoshkin

TITANIUM PLATES - see Titanium sheets.

TITANIUM FOIL — is prepared in the same manner as the strip from iodide-titanium or commercial titanium of diverse grades.

The assortment of the titanium foils and strips is quoted in the Table.

Assortment of Titanium Foils and Strips*

Толщина (мм) 1	2 Допуск по толщине (мм)	Ширина (мм) 3
0,05	−0,01	20–150
0,08	−0,015	20–200
0,10	−0,02	20–200
0,12	−0,02	20–200
0,15	−0,03	20–200
0,20	−0,03	20–200
0,25	−0,03	20–200
0,30	−0,04	20–200
0,40	−0,04	20–200
		4 и более
0,50	−0,05	20–200
		4 и более

*The tolerance in width is -1.0 mm for all dimensions.

1) Thickness (mm); 2) tolerance in thickness (mm); 3) width (mm); 4) and more.

The titanium foil and strip are prepared from the flat blank by alternating operations of cold rolling and annealing in a vacuum or in a neutral atmosphere. The strip is, ordinarily, pickled or degassed before the annealing. Titanium foil and strip are available both in annealed and in cold hardened state. The final annealing is carried on in a vacuum in order to remove the hydrogen from the metal. Titanium foil and strip are rolled on four-high or six-high strip-rolling mills; the diminishing of the thickness of the finished strip and foil is carried out by means of special multiple-roll boxes or on hard multiple-roll mills. The latter allow the production of foils with a thickness of

0.01 mm and less.

Titanium foil and strip are delivered in tightly rolled rolls or in the form of strips of the required length according to special TU, arranged between the client and the supplier, which concern the quality of the surface, the degree of warping, the weight of the rolls and other requirements. For information on the application of titanium foil and strip see Titanium alloys.

N.F. Anoshkin

TITANIUM STAMPINGS. Titanium alloys possess a limited technological plasticity in a cold state and a high one in a hot state. Therefore, the treatment by pressure is carried out mainly in the hot state. Sheet-metal stamping is also carried out in a hot state heating both the blanks and the tool. Titanium alloys have a high technological plasticity in a previously deformed (forged) state, and a considerably lower one in a cast state. Hence, the hot deformation of cast blanks, especially by rapidly acting hammers, is carried out carefully (to avoid the destruction and crushing of the coarse cast structure). The deformation of the cast metal must begin at temperatures not lower than 1000°. The permissible degree of deformation, especially in a cast state, drops rapidly when lowering the temperature, and the resistance to deformation increases at the same time. It is more expedient to carry out the forging or stamping on presses at temperatures higher than 1000° due to the better technological plasticity and the minimum of resistance to deformation. High deformation temperatures, however, deteriorate the structure and reduce the mechanical properties, especially the plasticity (ψ). Only deformation at lower temperatures (920-960°) in the range of the $\alpha + \beta$ phases provides the manufacture of semi-products with a good structure and with the best mechanical properties.

Of great importance are not only the deformation temperature, but also the degree of deformation per one heating, especially during the last heating, and also the preliminary treatment of the metal before the final forging and stamping, and the cooling conditions after the

hot deformation. The mechanical properties of the hot deformed semiproducts increase with an increasing deformation degree. A supplementary increase of the mechanical properties of the products is achievable by a quick quenching in water after the hot deformation instead of the usual cooling in air.

TABLE 1

Temperature Intervals of the Drop Forging of Titanium Alloys

Сплав	Температурный интервал штамповки на молотах (°С) заготовок весом:							
	менее 1 кг (лопатки и др.)		1–5 кг (лопатки и др.)		5–25 кг (лопатки и др.)		более 25 кг (диски и др.)	
	начало не выше	конец не ниже	начало не выше	конец не ниже	начало не выше	конец не ниже	начало не выше	конец не ниже
ВТ1	850	700	900	700	950	700	1000	700
ВТ3, ВТ3-1	980	850	1000	850	1020	850	1030	850
ВТ4	980	800	1000	800	1020	850	1030	850
ОТ4	950	800	980	800	1000	800	1020	800
ВТ5	1000	900	1030	900	1070	900	1100	850
ВТ5-1	1000	880	1020	880	1050	880	1080	880
ВТ6	930	800	950	800	980	800	980	800
ВТ8, ВТ9	980	850	1000	850	1020	850	1040	850
ВТ9-1	980	850	1000	850	1040	850	1070	850
ВТ10	980	850	1000	850	1020	850	1050	850
ВТ14	900	800	920	800	940	800	950	800

1) Alloy; 2) temperature interval for drop forging of blanks with a weight of; 3) less than 1 kg (blades, etc.); 4) 1-5 kg (blades, etc.); 5) 5-25 kg (blades, etc.); 6) more than 25 kg (discs, etc.); 7) beginning, not higher than; 8) end, not lower than; 9) VT..; 10) OT.. .

TABLE 2

Temperature Intervals for Stamping of Titanium Alloys on Presses

Сплав	Температурный интервал штамповки на прессах (°С) заготовок весом					
	менее 5 кг		от 5 до 25 кг		более 25 кг	
	начало не выше	конец не ниже	начало не выше	конец не ниже	начало не выше	конец не ниже
ВТ1	850	700	900	700	950	700
ВТ3, ВТ3-1	950	850	970	850	980	850
ВТ4	950	800	980	800	1000	800
ОТ4	900	800	930	800	950	800
ВТ5	1000	850	1050	850	1100	850
ВТ5-1	980	850	1020	850	1050	850
ВТ6	920	800	940	800	960	800
ВТ8, ВТ9, ВТ9-1	970	850	980	850	1000	850
ВТ10	970	850	1000	850	1020	850
ВТ14	900	800	920	800	940	800

1) Alloy; 2) temperature interval (°C) for the stamping on presses of blanks with a weight of; 3) less than 5 kg; 4) between 5 and 25 kg; 5) more than 25 kg; 6) VT; 7) OT.

The conditions of heating the castings and blanks (Tables 1 and 2) before forging or stamping must be strongly observed in order to provide a high quality of the objects manufactured by means of hot forging and stamping.

References: Korneyev, N.I. and Skugarev, I.G., Osnovy fizikokhimich. teorii obrabotki metallov davleniyem [Principles of the Physicochemical Theory of the Treatment of Metals by Pressure], Moscow, 1960.

V.Ya. Kleymenov

TITANIUM SHEET is produced from the VT1 (two groups), OT4-1, OT4, VT5-1, VT4, VT6S, VT14 (VT14M and VT14T) and certain other alloys. The sizes of titanium sheet most often used in industry are shown in Table 1.

TABLE 1

Titanium Sheet Sizes

Сплав 1	2 Ширина листа (мм)			
	600	700	800	1000
	3 Толщина листа (мм)			
ВТ1-1 и ВТ1-2 4	0.2—10	0.8—10	0.8—10	1.5—10
ОТ4-1	0.5—10	0.8—10	0.8—10	1.5—10
ОТ4	0.5—10	1—10	1—10	1.5—10
ВТ5-1 5	0.8—10	1.2—10	1.5—10	2—10
ВТ6С 6	2—10	2—10	3—10	3—10
ВТ14М и ВТ14Т 7	1.5—10	2—10	2—10	2—10

1) Alloy; 2) sheet width (mm); 3) sheet thickness (mm); 4) VT1-1 and VT1-2; 5) VT5-1; 6) VT6S; 7) VT14M and VT14T.

The sheets are usually produced in lengths to 2 meters. Titanium sheet of larger size and less thickness is produced in accordance with special Specifications.

The technological process for the production of titanium sheet consists of the following basic operations: stamping or forging of slabs from round titanium billets, milling (or planing) of the slab surfaces, hot rolling of the slabs into strips, etching of the hot-rolled strip after breaking up the scale by rolling or removal of the scale by other methods, then "warm" (at 750-650°) or cold rolling with intermediate heating or annealing, and the final finishing operations consisting of various combinations of straightening or "warm" rolling on rolling mills to achieve the required flatness, and subsequent annealing and etching.

The mechanical properties of the titanium sheet (Table 2) for all the alloys are characterized by a reduction of the relative elongation

TABLE 2

Mechanical Properties of Titanium Sheet

Толщина листа (мм) 1	$\sigma_в$ (кг/мм²) 2					
	ВТ1-1 3	ВТ1-2 4	ОТ4-1	ОТ4	ВТ5-1 5	ВТ6С 6
0,3—0,4	55—60	65—70	60—75	70—90	75—95	85—100
0,5—0,7	45—60	55—70	60—75	70—90	75—95	85—100
0,8—1	45—60	55—70	60—75	70—90	75—95	85—100
1,2—1,8	45—60	55—70	60—75	70—90	75—95	85—100
2—6	45—60	55—70	60—75	70—90	75—95	85—100
6,5—10	45—60	55—70	60—75	70—90	75—95	85—100

Продолжение

Толщина листа (мм) 1	$\sigma_в$ (кг/мм²) 2		δ (%, не менее)							
	ВТ14М * 9	ВТ14Т * (не менее) 10	ВТ1-1 3	ВТ1-2 4	ОТ4-1	ОТ4	ВТ5-1 5	ВТ6С 6	ВТ14М 7	ВТ14Т 11
0,3—0,4	90—110	115	25	—	—	—	—	10	10	15
0,5—0,7	90—110	115	30	25	25	20	—	10	10	15
0,8—1	90—110	115	30	25	20	20	15	10	10	15
1,2—1,8	90—110	115	30	25	20	15	12	10	10	15
2—6	90—110	115	25	20	15	12	10	10	10	15
6,5—10	90—110	115	20	15	13	12	8	10	10	15

* VT14M is an alloy used in the annealed condition; VT14T is an alloy used in the thermally strengthened condition.

1) Thickness of sheet (mm); 2) (kg/mm^2); 3) VT1-1; 4) VT1-2; 5) VT5-1; 6) VT6S; 7) continued; 8) (%, not more than); 9) VT14M*; 10) (not less than); VT14T.

with an increase of the sheet thickness. The higher values of the elongation on the thinner sheets are achieved as a result of the greater degree of deformation during "warm" rolling (at temperatures significantly below the temperatures of the $\beta \rightarrow \alpha + \beta$ transformations), and also the use of cold rolling.

With increase of the sheet thickness there is a reduction of the value of the bend angle (Table 3) determined with mandrel thickness equal to one (for VT1) or one-and-a-half (for the remaining alloys) thicknesses of the sheet with specimen width of 15 mm.

Cold rolling of sheets of commercial titanium and the medium-alloyed alloys in combination with intermediate annealing in vacuum or in an inert atmosphere ensure obtaining sheets with shiny surface which do

not require etching.

The most typical defects of the titanium sheet are surface cracks, whose formation is associated with the formation and subsequent destruction of the surficial brittle gas-saturated layer, unfavorable thermomechanical conditions during hot rolling, and also high degrees

TABLE 3
Bend Angle of Titanium Sheet

Толщина листа (мм) 1	3 Угол загиба (°, не менее) 2				
	ВТ1-1	ВТ1-2	ОТ4-1	ОТ4	ВТ5-1
0.3–0.5	140	130	100	80	—
0.6	140	130	100	80	—
0.7	130	120	100	80	—
0.8	120	110	80	70	60
1	110	100	80	70	60
1.2	100	90	70	60	60
1.5	90	80	70	60	50
1.8	80	70	70	60	50
2–6	80	70	60	50	40
6.5–10	80	70	60	50	40

1) Sheet thickness (mm); 2) bend angle (°, not less than; 3) VT.

of reduction (between anneals) during the cold rolling. Prevention of the formation of a sizable gas-saturated layer or its timely removal, as well as proper arrangement of the fabrication technological process, provide for the absence of cracks on the sheet surface.

The sheets are delivered annealed and etched, flat, with trimmed edges. The nature of the acceptable warping and the surface quality are defined by the current specifications and in particular cases by special specifications.

Fabrication of bimetallic titanium-aluminum, titanium-iron, titanium-nickel sheet expands the field of application of titanium sheet in electronics, chemical industry and other branches of mechanical engineering as a result of the lower cost (iron-titanium, for example) or the production of sheet with the required physico-mechanical properties (titanium-copper, titanium-nickel, titanium-aluminum) in comparison

with sheets made from pure titanium or its alloys. The most promising method for producing bimetallic sheet is the method involving preliminary welding of a packet of the metals by high-temperature heating in a vacuum and subsequent hot rolling (iron-titanium, titanium-nickel, titanium-copper) or by cold rolling the packet with large degrees of reduction (titanium-aluminum). The intermediate annealing of the bimetallic sheets must be performed at the lowest possible temperature which will provide relieve of the strain-hardening but does not lead to the growth of diffusion and the formation of a brittle intermediate layer. In individual cases the weldability of the packets during vacuum annealing or deformation is provided by the introduction of a lamina of some other metal or alloy.

N.F. Anoshkin

TITANIUM STRIP, see Titanium Foil.

TITANIUM WIRE. This wire is manufactured from VT1 and other titanium alloys and is employed principally as welding wire. Titanium wire is produced in diameters of from 1.2 to 7 mm, although it can also be manufactured in smaller diameters for special purposes. Wire 1.2-4.0 mm in diameter is delivered in coils, while wire more than 4 mm in diameter is delivered in coils or bundles. Titanium wire is subjected to tensile and bending tests. The production process for this wire consists of hot rolling of forged blanks and subsequent cold drawing. The wire is delivered in the annealed state with its surface pickled. Titanium wire intended for welding is subjected to vacuum annealing. The principal TU for titanium wire is ANTU 449-59.

N.F. Anoshkin

TOMBAC – copper-zinc alloys containing from 88 to 97% of copper. Depending on the copper content, the color of tombac varies from red (97% Cu) to yellow (88% Cu). Tombac includes shaping brasses (GOST 1019-47) of the L96 (96% Cu and 4% Zn) and L90 (90% Cu and 10% Zn) brands.

Tombac has a slightly higher strength and hardness than copper and a good hot and cold plasticity. Depending on the copper content and the state of the material, the ultimate strength of tombac comprises from 22 to 60 kg/mm^2 and the relative elongation is from 3 to 60%.

Tombac is a highly corrosion-resistant metal, has no tendency to corrosion cracking even in a humid atmosphere containing ammonia and sulfur dioxide admixtures. In comparison with other tombac brands, L96 has the highest thermal conductivity, for which reason it is used for making radiator and condenser tubes. L90 brand tombac welds well with steel, in conjunction with which it is used for making the steel-brass bimetal. Due to its goldish color, L90 tombac is used for art articles, rewards for excellence and accessories. For the properties of tombac, see in the article Shaping Brass.

Ye.S. Shpichinetskiy

TOOL SHAPING BRONZE – a bronze intended for the manufacture of instrument and apparatus components. Any type of tin, aluminum, or other shaping bronze can be used when high strength is required (see Structural shaping bronze). Strips, bands, and wire of tin, beryllium, alum-

TABLE 1

Mechanical Properties of Tool Shaping Bronzes

Сплав 1	2 Хим. сост. (содержание легирующих элементов)	3 Состояние материала	E (кг/мм²) 4	σ_b (кг/мм²) 4	δ (%)	HB (кг/мм²)
5 МКд	0.9–1.2% Cd	7 Мягкое	—	40	20	65
		8 Твердое	12500	70	2	115
ТМ	0.12–0.18% Cd 0.12–0.16% Sn 0.3–0.4% Mg	Мягкое	—	30	40	—
		Твердое	—	75	2	—
6 Тоб	0.25–0.35% Cd 0.45–0.55% Sn 0.35–0.45% Mg	Мягкое	—	32	40	—
		Твердое	—	65	2	—

1) Alloy; 2) chemical composition (content of alloying elements); 3) condition of material; 4) kg/mm^2; 5) MKd; 6) Tob; 7) soft; 8) hard.

TABLE 2

Physical and Technological Properties of Tool Shaping Bronzes

Сплав 1	γ (г/см³) 2	α·10⁶ (1 °C)	ρ (ом мм² м) 3	Темп-ра горячей обработки (°C) 4	Темп-ра отжига (°C) 5	Температурный коэфф. электросопротивления 6	Электропроводность (% от электропроводности чистой меди)
8 МКд	8.9	17.0	0.0257	780–800	500–700	0.0039	85
ТМ	8.9	17.0	0.0298	790–810	500–700	0.00152	33.6
9 Тоб	8.9	17.1	0.0425	790–810	500–700	0.00152	23.5

1) Alloy; 2) g/cm^3; 3) ohm·mm^2/m; 4) hot-working temperature; 5) annealing temperature (°C); 6) temperature coefficient of electrical resistance; 7) electrical conductivity (% of conductivity of pure copper); 8) MKd; 9) Tob.

inum, and other bronzes are used in the production of elastic elements, such as flat and helical springs (see Spring shaping bronze, Beryllium bronze).

TABLE 3

Corrosion Resistance of Aluminum Bronzes

Сплав 1	Потеря в весе за сутки (г/м²) 2	
	в морской воде 3	в 10%-ном растворе H_2SO_4 4
БрАЖ 9-4 5	0.25	—
БрАМц 9-2 6	0.25	—
БрАЖМц 10-3-1,5 7	0.20—0.25	0,7
БрАЖН 10-4-4 8	0.18	0.58

1) Alloy; 2) loss in weight over 24 hr (g/m^2); 3) in salt water; 4) in 10% H_2SO_4; 5) BrAZh 9-4; 6) BrAMts 9-2; 7) BrAZhMts 10-3-1.5; 8) BrAZhN 10-4-4.

TABLE 4

Acid Resistance of BrKMts3-1 Bronze at Different Temperatures

Концентрация кислоты (%) 1	Уксусная 2	Соляная 3		Серная 4	
	20°	20°	70°	20°	70°
	потеря веса (г) 5				
3	—	0.099	0.780	0.069	0.178
10	0.005	0.091	0.584	0.058	0.066
20	—	0.079	1.019	—	—
25	0.041	—	—	0.036	0.094
35	—	0.526	6.863	—	—
50	0.051	—	—	—	—
70	—	—	—	0.018	0.020
75	0.102	—	—	—	—
99.5	0.325	—	—	—	—

1) Acid concentration; 2) acetic; 3) hydrochloric; 4) sulfuric; 5) loss in weight (g).

Corrosion resistance under atmospheric conditions is important for a substantial majority of instruments, while resistance to various aggressive media is important in chemical-apparatus building. The components of many instruments must have high electrical conductivity and be readily cuttable. Tin-phosphorus, tin-zinc, and tin-zinc-lead bronzes, which are produced in bars and bands, are rather strong, corrosion-resistant, and quite cuttable. Aluminum, beryllium, and silicon-manganese (BrKMts3-1) bronzes have high corrosion resistance. Cadmium bronze and

TM and Tob telephone-wire bronzes are used in the manufacture of current-carrying components. Tables 1 and 2 show the typical mechanical and physical properties of certain alloys, while Tables 3 and 4 show their corrosion resistance.

TOOL STEEL – is a steel with a high carbon content, destined for the production of diverse tools, mostly of their working parts only. The high carbon content depends on the required hardness of the tool. All high-carbon steels are termed tool steels although they may be utilized not only for the production of tools. Tool steel contents, as a rule, more than 0.6-0.7% C; tool steels destined for the production of certain tools, for example, of dies for drop forging of metals, holing punches, snap hammers, etc., which contain only 0.3-0.6% C, are an exception.

Tool steels are divided into three main groups: carbon steels, alloy steels, and high-speed (high-alloy) steels.

Carbon tool steels. The composition of the mostly widespread carbon tool steels is given in Table 1.

TABLE 1

Content of Elements in Carbon Tool Steels (%)*

1 Сталь	C	Mn	Si	S	P
2 У7	0.6–0.74	3 менъше 0.4	3 менъше 0.35	3 менъше 0.03	3 менъше 0.04
У8	0.75–0.84	» 0.4	» 0.3	» 0.03	» 0.04
У10	0.95–1.09	» 0.3	» 0.3	» 0.03	» 0.04
У12	1.1–1.25	» 0.3	» 0.3	» 0.03	» 0.04

* The number behind the character U denotes the mean carbon content in tenths of percent.

1) Steel; 2) U; 3) less than.

Carbon tool steels differ from any other by their carbon content, the content in other elements is low and is cuased either by the necessity to add them for deoxidation of the steel (manganese, silicon) or by the impossibility to remove them (sulfur, phosphorus). The character A (U7A, u*A, etc.) is added to the grade symbol of the steel if the

sulfur content is lower than 0.03% and the phosphorus content is lower than 0.04%. A peculiarity of the heat treatment of carbon tool steels is the fact that, after the hardening heating at the temperatures used in practice (780-800° for U7; 770-790° for U8; 760-780° for U10-U12, the cooling must be carried out in water because of the high critical hardening of these steels. This causes a tempering of the carbon tool steels in a small depth only. The necessity to use water for the hardening of tools from carbon steels involves the risk of formation of quenching cracks, especially in the case of heating above the mentioned temperatures and also in that of an excessively rapid quenching. Therefore, large tools or tools with abrupt changes in the cross section must not be produced from carbon but from alloy tool steel, which permits one to apply oil as a quenching medium. The steels listed in Table 1 have a hardness of 62-64 RC in a hardened state. A higher tempering (150-350°), causing a reduction of the hardness to 58-50 RC, is applied when the toughness of the hardened carbon tool steel must be boosted, for example, in the production of nibs or of locksmith's tools.

Diverse cutting toos, especially small tools for manual labor, as taps, drills, chisels, broaches, files, etc., locksmith's and joiner's tools as locksmith's chisels, cutting edges for planes, wood saws, punches, screw drivers, axes, and marking irons, measuring tools as gages, checking devices, micrometers, etc., surgical instruments, simple shaped dies for drop forging and cold pressing, etc., are produced from carbon tool steels. The carbon tool steels with lower carbon content (U7, U8), characterized by a higher impact strength, are used if the tool is exposed to impact loads during working (chisels, marking irons, etc.). Steel with higher carbon content (U12), which possesses an elevated wearing resistance due to the higher content in iron carbides, is used if keenness is required (files).

Carbon steel with a high carbon content and high hardness in a hardened and tempered state is used not for the production of tools only: the U8 and U10 carbon steels are used for the production of wires, springs, membranes, vehicle springs and other parts requiring a high elasticity; U6 and U8 are used for the production of side-arms; the composition of the U6 and U7 steels is near to that of rail steel from which rails are produced.

Alloy tool steels. The composition of the mostly widespread Soviet alloy tool steels is given in Table 2. The content of sulfur and phosphorus in alloy tool steels must not be greater than 0.03%. The alloy tool steels listed in Table 2 are widely used for diverse purposes. The Kh and 9KhS steels are used for cutting and measuring tools of both compact and complicated shape because they are well hardenable in oil, and formation of cracks occurs more rarely than in carbon tool steels. The KhG and KhVG steels, so-called low-malleable steels, are characterized by a high hardness, and the shape of objects prepared from them changes only insignificantly during hardening, a fact which is important in the production of gages and a number of other tools, and also of parts of precision tools. KhV5 steel, the so-called diamond or cutting steel, possesses and extraordinarily high hardness in the hardened state (up to 67-68 RC) and is used for cutting thin chips from hard materials as refined cast iron, rock, glass, etc. Gages (with a small deformation in hardening), running rollers, cutting tools, chisels and other tools for metal machining at conditions intermediate between those for tools from carbon and alloy steel on the one hand, and for tools from high-speed steel on the other, are made from Kh12F1 or Kh12M steel; the same steels are used for cold pressing dies. The steels Kh6VF, Kh12F1, Kh12M, 7Kh3, 4KhS, 3KhV8, 5KhNM are termed die steels. They are used for relatively heavy die stamping work, whereas for light

working the carbon steels U7 and U8 are used. 7Kh3 steel is destined preponderantly for dies machining the metal in cold pressing, and also for stamping. 4KhS steel, characterized by a high toughness caused by a lower carbon content compared with that of other tool steels, is used for impact pressing tools and chisels of pneumatic drills. Tools for highly responsible purposes dies for die casting of metals, for example, are made from 3KhV8 steel. 5KhNM steel and the steels 5KhNS and 5KhnV, which are not listed in Table 2, and also other similar steels containing about 0.5% C, 1% Cr, and 1.5% Ni, are used for making forging dies of mean and large sizes.

TABLE 2

Content of Elements in Alloy Tool Steels (in %)*

1 Grade	C	Cr	Mn	Si	V	W
X 2	0.95—1.1	1.3—1.6	up to 0.4	up to 0.35	—	—
9X 3	0.85—0.95	0.95—1.25	0.3—0.6	1.2—1.6	—	—
Xr 4	1.3—1.5	1.3—1.6	0.45—0.70	up to 0.35	—	—
XW 5	0.9—1.05	0.9—1.2	0.8—1.1	0.15—0.35	—	1.2—1.6
XB5 6	1.25—1.5	0.6—0.5	up to 0.3	up to 0.3	—	4.5—5.5
X6BΦ 7	1.2—1.15	5.5—7.0	" 0.45	" 0.85	0.5—0.7	1.1—1.5
X12Φ1 8	1.25—1.5	11—12.5	" 0.35	" 0.4	0.7—0.9	—
X12M 9	1.45—1.7	11—12.5	"	"	0.15—0.30	—
6XC 10	0.35—0.45	1.3—1.6	up to 0.4	1.2—1.6	—	—
7X3 11	0.6—0.75	3.2—3.8	0.2—0.4	up to 0.35	—	—
4X2B8 12	0.3—0.4	2.2—2.7	0.2—0.4	" 0.35	0.2—0.5	7.5—9
4X5B2Φ 13	0.35—0.45	5—5.5	up to 0.35	" 0.5	0.8—1.2	1.6—2.4
5XHM 14	0.5—0.6	0.5—0.8	0.5—0.8	" 0.35	1.4—1.8 Ni	0.15—0.30 Mo

* The characters in the mark stand for: Kh = chromium; S = silicon; G = manganese; V = tungsten; F = vanadium; the figure behind the characters signifies the average content of the given element.

1) Steel; 2) Kh; 3) 9KhS; 4) KhG; 5) KhVG; 6) KhV5; 7) Kh6VF; 8) Kh12F1; 9) Kh12M; 10) 4KhS; 11) 7Kh3; 12) 4Kh2V8; 13) 4Kh5V2FS; 14) 5KhNM; 15) less than.

The conditions of the heat treatment of alloy tool steels are given in Table 3. Alloy tool steels are founded in electric steel-melting furnaces. Those which have a low carbon content and do not contain tungsten, may be melted at certain technological conditions in Martin furnaces also.

High-speed tool steels differ from the other tool steels in the fact that tools made from them may operate at relatively high cutting

speeds. This is based on the red-hardness of the high-speed steels, i.e., on their property to maintain the hardness obtained in hardening

TABLE 3

Conditions for the Heat Treatment of Alloy Tool Steels

1 Марка	2 Темп-ра закалки (°С)	3 Темп-ра закалки (°С)	4 Охлаждающая среда при закалке	5 Твердость после закалки (RC)	6 Темп-ра отпуска (°С)	7 Твердость после отпуска** (RC)
Х 8	770–790	780–800	14 масло	62–64	150–200	60–62
9ХС 9	780–810	790–820	15 то же	62–64	150–200	60–62
ХВГ 10	770–790	820–850		62–64	160–220	59–61
ХВ5 11	800–820	800–820	1 масло 14	65–67	120–150	61–63
Х12Ф1 12	800–820	1040–1070		62–63	150–200	58–62
5ХНМ 13	700–750	1150–1170	15 то же	62–66	520 *	60–62
		820–860			500–520	510–600 ***

* Cold treatment is carried out before the tempering.

** The lower values of hardness correspond to the tempering at the higher temperature given in the foregoing column, the higher ones – to the tempering at the lower temperature.

*** According to Brinell.

1) Steel; 2) hardening temperature (°C); 3) quenching temperature (°C); 4) cooling medium for hardening; 5) hardness after quenching (RC); 6) tempering temperature (°C); 7) hardness after tempering** (RC); 8) Kh; 9) 9KhS; 10) KhVG; 11) KhV5; 12) Kh12F1; 13) 5KhNV; 14) oil; 15) the same; 16) water.

also after heating up to red heat (600-650°) (see High-speed Steel). The permissible heating temperature (without softening) of carbon and alloyed tool steels does not exceed 200-250° (for special hard alloys this temperature reaches 900-1000°).

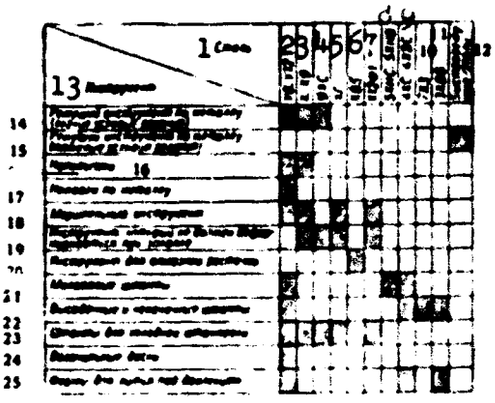
Alloy steels do not have beeter cutting properties than carbon steels. The steel of the Kh12 grade (i.e., containing 11-12% Cr), submitted to heat treatment for the so-called secondary hardness, i.e., hardening, cold treatment, and tempering at high temperature (see Table 3, Kh12F1 steel), has an intermediate position between the alloy and high-speed steels. An approximate scheme for the suitable selection of tool steels for diverse tools is given in Table 4.

A gradually decrease in the consumption of carbon tool steels and also high-speed steels is observable, the latter being replaced by hard

alloys. The demand for cermets does rise.

Many of tool steels are used for the production of diverse machine parts which are exposed to high stresses. When tool steels are used for these purposes, it must be taken into account that the hardness de-

TABLE 4



1) Steel; 2) U8, U12; 3) Kh, Kh9; 4) 9KhS; 5) KhG; 6) KhV5; 7) Kh12F1, 8) 5KhNS, 5KhNV; 9) 4KhS, 4KhVS; 10) 7Kh3; 11) 3KhV8; 12) high-speed steels; 13) tools; 14) metal cutting tools (light cutting conditions); 15) metal cutting tools (heavy cutting conditions); 16) files; 17) metal saws; 18) measuring tools; 19) tools which shall not deformate at hardening; 20) tool for diamond boring; 21) knurling dies; 22) upsetting and embossing dies; 23) dies for cold pressing; 24) draw plates; 25) dies for die casting.

creases and the tensile strength increases when the inferior tempering temperature is raised.

Kh steel and its diverse modifications are used as ball-bearing steel. Practically, the composition of the tool of the Kh grade and that of the mostly widespread ball-bearing steel ShKh15 are identical, a difference exists only in the fact that the latter must answer high requirements with regard to nonmetallic inclusions. Steels for impact tools (grades 4KhS, 5KhNM, 4 KhSV2FS, etc.) have a high strength (σ_b = 200 kg/mm^2) and a sufficient toughness (a_H = 2-4 kgm/cm^2). Many modifications of die steels for impact tools are used as high-strength steel. Parts of equipments (parts of heating equipments, for example) are made from tool steels when high resistance to wear, maintaining of the size and absence of impacts are required; the insufficient tough-

ness and plasticity of these steels does not hinder their application.

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A.P. Gulyayev

TOPAZ – mineral of the silicate group. Its color varies depending on the mechanical admixtures; colorless (water transparent), yellow, blue, violet, green and pink topaz is encountered. After prolonged effect of sunlight the color fades. Mohs hardness 8, specific gravity 3.52-3.57. Specific heat at 50° 0.83 joules/g.

When heated in the range of 300-1400 it loses water and fluorine. When roasted to 1000° it retains its properties; at 1100-1500 it is transformed into mullite. Thermal expansion at 1200° is 1.210. Decomposition of topaz produces a pure mullite roasting product which is used in the production of refractories. The difficulty in roasting of topaz consists in the aggressive effect of fluorine which is thus liberated. Topaz is used in the production of cast mullite high-alumina refractories, similar to sillimanite. The use of topaz is particularly effective in glass production, electric steel smelting furnaces, in the production of electrical porcelain and other refractory and ceramic materials. Due to its high hardness topaz is used as an abrasive (particularly fine-grained topaz stone). Transparent, beautifully colored topaz crystals or pebbles have been long used as precious stones. Requirements to topaz have not been elaborated in detail.

References: Stuckey, J.L. and Amero, J.J., Physical Properties of Massive Topaz, "J. Amer. Ceram. Soc.," Vol. 24, No. 3, 1941; Burgess, B.C., Topaz – a New Industrial Mineral, "Engng. and Mining J.," Vol. 142, 1941; by the same author, Topaz Development as a Source of Alumina, "Bull. Amer. Ceram. Soc.," Vol. 21, No. 1, 1942.

P.P. Smolin

TORSION TEST – is a statistical test of materials in which the specimen (as a rule, with a round cross section) is loaded with two opposite couples applied on the ends of the specimen and acting in planes perpendicular to its longitudinal axis ("pure shearing" stress). The torsion test is applied to determine the strength and plasticity of materials used for the production of machine parts operating under torsion stress (of shafts for diverse purposes, for example) and also to evaluate the plasticity of brittle and high-strength materials (of low-tempered alloyed steels, for example), which is difficult or impossible to determine in tensile or bending tests. The machines for the torsion test (K-20, K-50, for example) are usually provided with diagram recorders automatically recording the torsion curve of the specimen in "twist v.s. torsional moment" coordinates during the test. The proportional limit τ_{pts}, the conditional yield strength $\tau_{0.3}$, the conditional torsion strength τ_b, the ultimate elasticity τ_{up}, and the modulus of torsion G are determined using the formulae for the calculation of tangential stresses at elastic torsion (GOST 3565-58). The true torsion strength t_k is calculated by the formula utilizing the torsion curve. The torsional plasticity is evaluated from the limit torsion angle of the working part of the specimen or on basis of the magnitude of the relative shift.

References: Shaposhnikov N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Tests of Metals], 2nd edition, Moscow-Leningrad, 1954; Fridman Ya.B., Mekhanicheskiye svoystva metallov [Mechanical Properties of Metals], 2nd edition, Moscow, 1952.

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TORSION TESTING – determination of the ability of metal wire to undergo plastic deformation on repeated twisting in the same or alternate directions. Torsion tests are conducted in devices or machines (GOST 1545-63). The calculated specimen length ℓ_0 = 100 d (where d is the wire diameter), but should be no less than 50 mm and no more than 500 mm. The specimen is held under tension (equal to 2% of the tensile strength of the wire to be tested) in clamps, one of which can only be displaced longitudinally, while the other can only rotate about the specimen axis. The specimen is given successive twists in the same direction (at a speed of approximately 60 rpm for wire less than 3 mm in diameter and approximately 30 rpm for wire 3 mm or more in diameter) until it fractures; the test is invalid when fracture occurs near the clamps (less than 3 mm away) or when the test is interrupted. The measure of plasticity in this type of testing is the number of twists to fracture. One twist is assumed to be one complete revolution (360° of the rotating end of the specimen, regardless of the torsion direction. When this direction alternates the number of alternate twists is noted. The type of fracture and the surface condition of the twisted wire permit detection of nonuniformities and defects such as separation, cracking, etc. in the material (see Technological testing).

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N.V. Kadotnova

TOTAL FATIGUE PROBABILITY DIAGRAM – graphical relationship between the endurance and the maximum stress of the cycle and the probability of specimen failure. The total failure probability diagram is constructed on the basis of results of fatigue tests on 15-20 specimens for each of the three-four stress levels. After the distribution function is substantiated and the parameters of this function determined, the results of fatigue tests can be represented in the form of any of three total fatigue probability diagram, depicted in three quadrant (Fig. 1). The coordinates in the first quadrant are (σ_{maks}, N), while

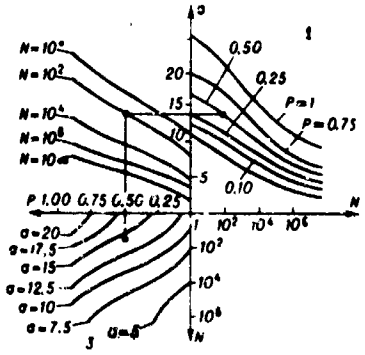

Fig. 1. Three forms of total fatigue probability diagrams and their interrelationship.

the failure probability P serves as the parameter. These curves are also called endurance curves for different failure probabilities. The coordinates in the second quadrant are (σ_{maks}, P) and N is the parameter. Curves in the second quadrant are the distribution of the fatigue limits for various bases. Curves in the third quadrant are constructed in the (P, N) coordinates with σ_{maks} as the parameter and are endurance distribution curves for the specified stress levels. Any of the three endurance diagrams can be used as a basis for constructing the other

two. Total fatigue probability curves depicted in the first and third quadrants have come into the more extensive practical use. Figure 2 shows endurance distribution curves for specimens 6.74 mm in diameter

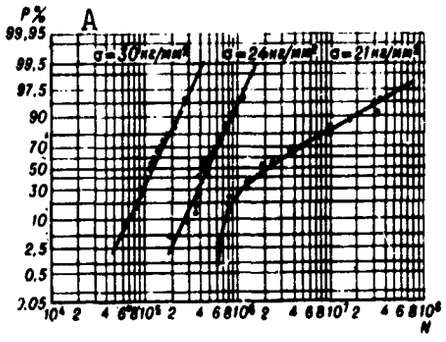

Fig. 2. Endurance distribution curves for specimens from the V95 aluminum alloy at three stress levels. A) Kg/mm^2.

made from the V95 aluminum alloy, rigidly supported at one end and tested for flexure with rotation at three stress levels.

References: Serensen, S.V. [et al.], Issledovaniye rasseyaniya kharakteristik vynoslivosti konstruktsionnykh alyuminiyevykh splavov v svyazi s tekhnologiyey ikh proizvodstva [Study of the Scattering of Endurance Characteristics of Structural Aluminum Alloys in Conjunction with the Production Processes Used in Their Fabrication], "Tr. Mosk. aviats. tekhnol. in-ta" [Transactions of the Moscow Institute of Aviation Technology], Issue 35, 1958.

M.N. Stepnov.

Manuscript Page No.

[Transliterated Symbols]

4180 макс = maks = maksimum = maximum

TOURMALINE - mineral of the boron-containing aluminosilicate group. Specific gravity 2.90-3.25, Mohs hardness 7-7.5. The hardness in the direction perpendicular to the c-axis is higher than in the direction parallel to it. The color of tourmaline depends on its chemical composition. Magnesium varieties of tourmaline are called dravite, iron varieties are called schorl, lithium varieties are called albaite, while alumina-rich varieties have no name. Varieties which do not contain iron or which are iron-poor, are colored in various shades of the green, pink, and red colors. Iron varieties are intensely colored in the colors: red (schorl), dark green (verdelite), dark blue (indigolite); dark red tourmaline is called rubellite. Tourmaline crystals are characteristic by their piro- and piezoelectric properties, they are electrified by heating, rubbing, pressure; here one end of the crystal is charged positively while the other negatively. Tourmaline is frequently encountered in association with other minerals in pegmatites, not infrequently it is observed in hydrothermal ore deposits. Large tourmaline crystals are used in radio equipment.

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V.P. Butuzov

TRACER ATOM METHOD in the study of metals. Tracer atoms, i.e., atoms artificially introduced or created in the specimen being studied, differ from the other atoms of the same element in composition of the nucleus (isomers). As tracer atoms, use is made primarily of the radioactive isotopes or isomers which are convenient for recording because of their radiation, sometimes use is also made of the stable isotopes which can be detected by mass spectrographic analysis. In comparison with the chemical and spectroscopic methods of study, the tracer atom method, dependin g on the half-life of the radioactive isotope being u used, is more sensitive by millions and or billions of times. The existence of radioactive isotopes of nearly all the elements (about 1100 artificially radioactive isotopes and 250 stable isotopes are known) makes the tracer atom method very universal. Among the methods for recording the radioactive radiation of the tracer atoms, wide use is made of the photographic and electrical methods. Among the photographic methods the widest use has been made of the autoradiographic and trace-counting methods. They are both based on the fact that the radioactive radiation, similar to visible light, acts on the photographic emulsion and causes it to darken. In the electrical methods a recording is made of the electrical current or the charge which arise with interaction of radiation with matter (ionization, photoeffect, etc.).

The tracer atom method is used with success for the study of the metals, particularly the internal structure of the metallic alloys and the processes which take place in them (distribution of the elements in the alloys, diffusion and interatomic interaction, phase analysis),

metal friction and wear processes, and also in the study of the metallurgical processes, technological operations, etc.

Study of the distribution of the elements in alloys. Real metals and alloys are nonhomogeneous in structure, and the processes leading to structure variation are of a local nature. An effective and direct means for studying nonuniformities of the metallic alloys is the autoradiography method. In the specimen of an alloy containing a radioactive additive, after exposition and development there arises a picture of the additive distribution in the alloy (autoradiogram). To obtain results, i.e., a sharp image with adequately high resolving power, it is necessary during autoradiography to provide for tight and uniform contact between the specimen being studied and the photo emulsion, irradiate thin specimens, eliminate the possibility of chemical interaction of the photo emulsion and the metallic specimen, use photo emulsions which are sensitive to radioactive radiation and suitable for radiography. Usually the emulsion layers used are markde by small thickness (3-10 microns), high concentration of silver halide (more than 80%) and small grain size (0.1-0.5 microns). To improve the contact between the specimen and the photo emulsion, use is made of the method of pouring liquid emulsion over the specimen, strippable emulsions, and the like. The most perfect contact provides for a resolving power of about 1 micron.

The chemical nonhomogeneity of an alloy may be evaluated quantitatively. In quantitative autoradiography use is made of either the trace-counting method, when the content of the radioactive substance in the alloys is determined from the number of traces left in the emulsion by the radiation, or the method of contrast autoradiography, when the content of the element is determined by measuring the darkening density, i.e., by photometric analysis of the radioautographs.

Alloys with radioactive isotopes may be prepared by various means. Most widely used is introduction of the radioisotope into the molten metal. With use of β-radiators, in many cases the alloy becomes sufficiently active with the introduction of 1 microcurie of isotope per 1 kg of alloy. An alloy may be made active with the aid of electrodeposition of a radioactive element, by saturation from a gaseous phase, by evaporation of the radioisotope in a vacuum and precipitation on the specimen being studied, by preparation of a mixutre of metallic powders containing the radioavtive isotopes. Irradiation of the prepared specimen in a nuclear reactor may be performed, which makes possible the use of finished products and radioisotopes with very short half-life. The chemical nonhomogeneity in various alloys (iron, nickel, aluminum, magnesium, titanium, etc.) has been established on the basis of the a autoradiography method. The tracer atom method has been used to study the processes of crystallization and redistribution of elements during thermal treatment, plastic deformation of an alloy, during certain technological processes (casting, welding) and so on. Results of the study of metal structure by the autoradiographic method are in good agreement with the results of metallographic analysis.

The autoradiographic method has outstandingly high sensitivity. Thus, for example, in the study of the lead-antimony alloy the enrichment of the grain boundaries by the additive (polonium) is detected even with a content of one one-hundred-millionth of a percent of the latter. The presence of any component simultaneously in several phases but in different concentrations shows up clearly and may be evaluated quantitatively.

The tracer atom method detects chemical nonhomogeneity of a metal within the limits of a single phase, individual elements of the structure (differentiating the concentrations of the alloying elements with-

Fig. 1. Distribution of tungsten in nickel (autoradiogram). Enlarged 10 times.

in the crystal and along its boundaries, along the contour of the grain boundaries, within individual crystals). Thus, tungsten introduced into nickel in the amount of 0.1-6% is arranged primarily in the dendrite axes (Fig. 1) (solubility of tungsten in nickel up to 40%). Elimination of this nonhomogeneity is very difficult as a result of the very low diffusional mobility of tungsten in nickel alloys (established with the aid of a radioactive isotope of tungsten). Very-long-term annealing at 1200° does not eliminate the nonuniform distribution of tungsten, and only after annealing at 1250° for 200 hours is it possible, as shown by the autoradiographic study, to obtain a quite homogeneous alloy. The nonuniform distribution is detected with a very low concentration of the element. For example, with a content of 0.007% Nb in nickel (limiting solubility of niobium in nickel is 6%) enrichment of the grain boundaries by the niobium is clearly seen (Fig. 2).

Fig. 2. Niobium distribution in nickel alloy (autoradiogram). Enlarged 30 times.

Study by the tracer atom method of constructional chromium steel (0.4% C, 2.45% Cr) has shown that the chromium is concentrated primarily along the grain boundaries. Elimination of chromuum liquation takes place only after diffusional annealing at 1300° for 2 hours. An optimal regime for homogenization of chrome steel was selected on the basis of the study. It is characteristic that the processes of equalizing the chemical nonuniformity in the cast alloys take place considerably more slowly than in the wrought alloys.

The autoradiographical studies have shown that the additives are

Fig. 3. Sulfur distribution in nickel alloy (autoradiogram). Enlarged 50 times.

concentrated primarily along the grain boundaries and in the interdendritic regions. For example, sulfur, phosphorus, tin, lead, antimony enrich the grain boundaries of the nickel and iron alloys (Fig. 3). However in the case of a sulfur content less than the limiting solubility, there is observed a uniform distribution of the sulfur in the nickel. This confirms that up to 0.006% sulfur does not increase the brittleness of nickel. Moreover, analysis of the autoradiograms has shown that adter cold plastic defo mation (rolling) and subsequent diffusional annealing (700-1200°) the sulfur is distributed nonuniformly within the individual nickel crystals, which is explained by the nonuniform diffusion taking place preferentially in the strongly deformed (compressed) grains. In place of increasing the homogeneity, diffusional annealing leads in certain cases to increase of the heterogeneity of the alloy. Thus, with long-term annealing of the nickel alloy (1000° for 100 hours) there was observed gradual formation of a phosphide grid along the grain boundaries, which is explained by grain enlargement during annealing and corresponding reduction of the extent of the grain boundaries. This fact explains why after homogenizing annealing there is sometimes noted deterioration of the mechanical properties of the high temperature alloys.

Very small quantities of boron (less than 0.01%) have a very strong effect on the properties of the iron and nickel alloys. Establishing the nature of the distribution of negligibly small quantities of boron in the alloys by the conventional method of autoradiography is impossible as a result of the fact that the radioactive isotope of boron has a very short half-life (0.012 sec). The problem is resolved by use of a nuclear reaction based on the interaction of slow neutrons with the

boron nuclei. During irradiation of an alloy containing boron by boron neutrons the floowing reaction takes place:

$$_5B^{10} + _0n^1 \rightarrow _3Li^7 + _2He^4.$$

The α-particles formed as a result of the interaction with the photo emulsion show the boron distribution in the alloy. On the basis of the autoradiograms the conclusion is drawn that small quantities of boron (about 0.01%) are distributed in the steel primarily along the grain boundaries.

Study using the autoradiographic method of the effect of plastic deformation has shown that this process increases the homogeneity of the alloy, in this case the processes of equalization of the composition proceed more rapidly than in the cast alloys. In studying the nickel alloys it was found that the dendritic structure may be retained after considerable plastic deformation (50%), which could not be disclosed by conventional methods. Of great practical importance is the use of radioactive isotopes to study technological processes, particularly welding.

Study of diffusion in metals. Diffusional migration of atoms is the process which is the basis of many structural changes observed in metals. The rate of phase transformations fueing heat treatment, the nonequilibrium states in which the alloys used in practice are found, and the stability of the nonequilibrium states depend on the diffusional mobility. Behavior of alloys under loading and at high temperatures depends on the atomic mobility.

The use of the tracer atom method has expanded considerably the study of the diffusion processes, making possible direct determination of the self-diffusion parameters, i.e., the movement of the atoms of elements in their own crystalline lattice without change of the concentration. This method has been used to determine the self-diffusion

of lead, tin, silver, gold, copper, iron, cobalt, nickel, chromium, molybdenum, tantalum, tungsten and other elements. The methods of determing the diffusional characteristics based on the use of tracer atoms may be divided into two groups. The fission method is used to study the change of distribution of radioactive substances in a specimen as a result of diffusional annealing. The absorbtion method is used to determine the reduction of the radiation caused by penetration of radioactive substances into the depth of the specimen. An important characteristic of the self-diffusion process is the activation energy of this process, which in the pure metals characterizes to a certain degree the strength of the interatomic bond in the crystal lattice. Usually it is assumed that the greater the activation energy of the self-diffusion and diffusion processes, the higher the high-temperature strength of the metal. For example, the self-diffusion activation energy of the refractory metals, as shown by study using radioactive isotopes, is quite high. For tantalum, molybdenum and tungsten it is equal respectively to 110,000, 115,000 and 135,000 cal/gram-atom, for iron it is 74,000 cal/gram-atom. At 1000° the self-diffusion coefficient (D) of tantalum is three orders smaller than the self-diffusion coefficient of iron (10^{-13} and 10^{-10} cm^2/sec). At this same temperature D for molybdenum is eight orders less than D for nickel. In the final analysis, all this determines the higher level of the high-temperature strength of the refractory metals. In comparing the pure metals – nickel and molybdenum – the same stress (10 kg/mm^2 for 100 hours) is sustained by the first at 600° and by the second at 1000°.

The alloy composition has a considerable effect on the diffusion parameters. Studies using the tracer atom method have shown that the diffusional mobility depends on the alloy structure as well as the composition. Using radioactive isotopes it has been established that the

diffusional mobility on the interfaces between grains is significantly greater than in the grain body. Thus, for example, the activation energies of the self-diffusion process of silver on the crystal surface, along the grain boundaries, and within the crystal are equal to 10,300, 20,00 and 45,950 cal/gram-atom respectively, i.e., considerably less than on the interfaces.

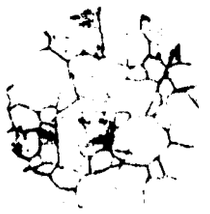

Fig. 4. Self-diffusion of nickel at 700° (autoradiogram). Enlarged 50 times.

Tin, zinc, iron, nickel, chromium move predominantly along the grain boundaries during self-diffusion (Fig. 4). This influence of the boundaries is retained up to very high temperatures: for self-diffusion of iron to 1200°, chromium to 1350°. The energy of the self-diffusion process along the grain boundaries is considerably less than within the grains. On the basis of autoradiographic studies, these quantities are respectively: 30,600 and 67,000 cal/gram-atom for iron, 46,000 and 76,000 cal/gram-atom for chromium. The application of stresses to the specimen during self-diffusional annealing has an effect on the rate of the process. Thus, tensile stresses and plastic deformations reduce the activation energy and increase the mobility of iron during self-diffusion and also during the heterodiffusional process (Fig. 5). Mechanical working (grinding, sand blasting) increase the diffusional mobility in the surface layers of the metal ten-fold (Fig. 6).

Study of interatomic interaction. The tracer atom method can be used to measure the rate of evaporation and, consequently, to determine the vapor pressure, including the partial pressure of the components over the solution. The temperature dependence of the vapor pressure permits determining the bond energy in crystals of solid solutions and other thermodynamic characteristics. This method is a development

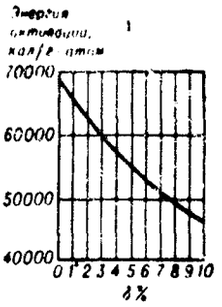

Fig. 5. Effect of plastic deformation on activation energy of self-diffusion in iron. 1) Activation energy, cal/gram-atom.

of the methods of Langmuir and Knudsen in which the measured quantities are the vacuum evaporation rate (in the first case) and the flux of vapor passing through a small opening located above the evaporation surface. Determination of the quantity of matter condensing on the target using radioactive isotopes is simpler and more accurate than making this determination on the basis of chemical analysis as is done in the methods of Langmuir and Knudsen.

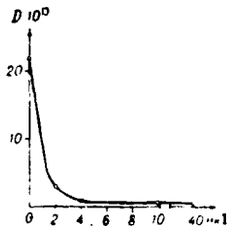

Fig. 6. Variation of diffusion coefficient with depth of ground specimen of the nickel alloy EI437. 1) Microns.

Another method is based on the measurement of the rate of exchange between two lamina of solid solid solutions of the same composition, one of which contains a radioactive isotope of the component and the other consists of a stable isotope. The rate of change of activity of the laminas depends on the vapor pressure and on the diffusion coefficient in the solid solution.

Study of phase composition. The tracer atom method may be used for rapid and precise study of the composition of phases separated from an alloy. Since the radioactive isotope is chemically identical to the stable isotope of the element being studied, by following the behavior of the former we can draw conclusions on the behavior of an alloying element. For an alloy containing the radioactive

isotope A the following relation is valid

$$\frac{C_{\phi}^{A}}{C_{spl}^{A}} = \frac{i_{\phi}}{i_{spl}}$$

where C_{ϕ}^{A} is the concentration of element A in the particular phase, C_{spl}^{A} is the concentration of element A in the alloy, i_{ϕ} is the specific activity of the particular phase, i_{spl} is the specific activity of the alloy. Thus, to calculate, for example, the content of an alloying element in the carbide phase it is necessary to know three quantities: the content of the alloying element in the steel, the intensity of the radiation of the carbide precipitate, and the intensity of the radiation of the same batch of steel. The tracer atom method may also be of use for simultaneous analysis of two radioactive elements. The tracer atom method using radioactive chromium has been used to study the kinetics of the process of redistribution of an alloying element between ferrite and carbide during tempering of chrome steel (0.7% C, 2.94% Cr). In this case the relative error was 5-6%.

Study of metal wear. The essence of the various tracer atom methods for studying wear amounts to the following. A radioactive isotope is introduced into the material of the part (material is activated) by means of irradiation in a reactor, electrolysis, introduction of the radioactive substance into the molten metal, diffusion, the radioactive monitor-insert method, etc. The activity of the wear products is recorded, which is particularly convenient for circulating lubrication systems when the wear products are carried away with the oil and a counter is installed in the oil line or close to it. The advantages of the tracer atom method in wear studies lie in the speed, high sensitivity (0.0001 mg), possibility of continuous recording of the wear (counter connected with a recorder), and ability to study wear under any conditions and with any operational regimes. In contrast, in conven-

tional testing of an engine, for example, the parts are measured before testing and after testing, which requires disassembly of the engine and the use of considerable fuel and lubricant during testing.

When using the tracer atom method of investigation, recording of the pulses by an automatic recorder with the aid of an autoelectronic potentiometer permits continuous recording of the wear at various operating conditions of the engien under road test conditions. This method was used to discover the phenomenon of delay in the transition from the high wear regime to the low wear regime – the "run-in" period (30-90 minutes).

In studying wear of a surface covered with a protective metallic film, the cover coating is activated by adding the corresponding isotope to the electrolytic bath. For example, in studying the wear of chromed piston rings the amount of chromium transferred from the rings to the cylinder walls was determined autoradiographically. The high sensitivity of the method permits studying the initial stages of wear, which is important to the mechanism of this phenomenon. The tracer atom method is used to study refractory wear in blast furnaces. During construction of the blast furnace ampoules containing a gemma-radiator which is recorded by counters mounted externally are installed at various depths. Destruction of the lining is judged by the disappearance of the radiation. Radioactive isotopes are used to study not only the wear of parts and mechanisms, but also to study numerous other processes which are required to evaluate the operation of machines, for example the rate of formation of carbon deposits in an engine (in the combustion chamber).

Study of metallurgical processes. In the production of steel, important characteristics are the coefficients of the distribution of the various elements between the metallic phase and the slag and the kinet-

ics of the transition of elements from one phase of another. The radioactive isotopes of phosphorus, sulfur, calcium may be used to determine the distribution of these elements between the alloys and slag, to determine the temperature dependence of the distribution, the kinetics of the dephosphorization processes, establish the depth of desulfurization (to 0.0001%) with the use of definite forms of slags, which is of critical importance for improving ghe quality of the metal.

The radioactive isotopes are used to detect contamination by nonmetallic inclusions, for example, inclusions of calcium (in ball bearing steel) which severely reduce the service life of ball bearings. To do this the Ca tracer is introduced sequentially into the "suspected" sources of contamination (slag, crucible lining, spout, ladle lining). It was found that the principal "source" of nonmetallic inclusions was the ladle lining. The tracer atom method is also used to study the kinetics of the redistribution of the alloying element between phases during isothermal decomposition of supercooled austenite of chrome and tungsten steels. The radioactive isotopes Cr^{51} and W^{185} are used for this.

Radioactive isotopes are used to tag various grades of steel. To do this some amount of radioactive isotope is added to the steel during melting. The steel grade may be determined in a few minutes with the aid of a γ-counter. This method is particularly important in use of alloys under conditions of severely aggressive media, high temperature, in atomic reactors, when careful control of all the products is required. See also Gamma-Defectoscopy.

S.Z. Bokshteyn

TRANSFORMER STEEL - see Electrical Equipment Sheet Steel.

TRANSLATIONAL SLIP – one of the most important mechanisms of Plastic deformation, consisting in displacement (translation) of one part of a crystal relative to another. This process usually occurs along the most tightly packed crystallographic planes (the planes which are farthest apart) and, within these planes, along the most tightly packed directions (the directions in which the translational-slip "pitch" is least). At moderately low temperatures the number of translational-slip planes and directions is considerably greater in cubic face-centered Al, Cu, Ni, γ-Fe) and body centered (α-Fe, Mo, W, Cr) lattices than in hexagonal (Mg, Zn, Cd) lattices. Metals of the latter group consequently have low plasticity at temperatures of 20° or less. When the temperature is raised translational slip may occur along other crystallographic planes, which consequently increases the plasticity of the metal. For other mechanisms of plastic deformation see the articles entitled Diffusion plasticity and Twinning.

Ya.B. Fridman

TRIACETATE FIBER – artificial fiber (staple or filament) obtained from solutions of celluslose-triacetate in glacial acetic acid or in methlene chloride by wet or dry spinning. Triacetate fibers have a higher melting temperature than fibers from regenerated cellulose acetate (acetate fiber), lower moisture absorption, high resistance to prolonged effect of heat. The starting raw material in obtain cellulose triacetate used for producing the fiber is cotton down or special grades or purified wood pulp. Triacetate fibers are produced under the names: Arnel (USA), Courpleta and Tricel (England), Trialben (France).

Physicomechanical properties of triacetate fiber: specific weight 1.28-1.32, moisture content (at 20° and relative air humidity of 65%) 4.5%, $t°_{pl}$ 300°, softening temperature 180° before the fiber is heat treated and 240-250° after heat treatment, heat resistance up to 250°. After being heated for 20 hours at 130° triacetate fiber (Arnel) loses 30% of its initial strength, cotton loses 65% and nylon 80%. Triacetate fibers are characterized by high resistance to the effect of light; when irradiated in a Fadeometer for 200 hours it loses 15% of its initial strength. When held in sunlight under glass for 200 hours, Arnel loses about 6% of its initial strength (just like Orlon), while fiber from regenerated acetate and cotton lose 48% and nylon loses 94% of the initial strength. Triacetate fiber has a high electric resistivity, being inferior in this respect only to Terylene (lavsan), polyethylene, Teflon and glass fiber. To prevent the accumulation of static electricity charges in spinning, the triacetate fibers are treated by antistatic preparations. Triacetate fiber resists diluted alkalis at stand-

ard temperature and is saponified by them upon heating, it is resistant to the effect of diluted acids, is destroyed by strong concentrated acids, is soluble in methylene chloride, glacial acetic acid, concentrated formic acid, swells in acetone and dichloroethane. It is dyed by dispersion dyes and also by pigments (dyeing in the mass). The rupture length of triacetate fiber in the dry state is 10.4-15.0 km, and the strength loss in the wet state is 20-25%. Ultimate tensile strength 13.3-14.5 kg/mm^2. Elongation 20-23% in the dry and 35-40% in the wet state. Initial modulus of elasticity about 460 kg/mm^2. Lately a process has been developed for producing the Arnel-60 fiber with a dry rupture length of about 19 km and an elongation of 25%. The wet rupture length is 13.5 km and the elongation 36%. Triacetate fibers have a considerable tendency to crystallization. The degree of crystallization can be increased by heating at 170-200° or at 110-130° with simultaneous steaming. After heat treatment triacetate fiber acquires a substantial wrinkle resistance which, combined with the low moisture absorption makes it possible to use it in fabrics for creating creases which are retained in multiple washings and dryings (pleated articles, fabrics with an engraved design, etc.) Triacetate fiber is used as an electric insulation material. The major field of use are consumer goods. Triacetate fiber is used in the pure form and mixed with other fibers (cotton, wool); mixtures containing 50% of triacetate fibers are used for making fabrics with a high wrinkle resistance, mixtures containing 70% of triacetate fibers are used for making wrinkle-proof drapery fabrics and outerwear fabrics.

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L.S. Gal'braykh

TRIBOELECTRIC METHOD OF FLAW DETECTION – method based on measuring the magnitude of triboelectric charges which are generated by rubbing of different materials. The magnitude of the triboelectric potentials is determined, other conditions being equal, by the chemical composition of the rubbing bodies, for which reason the triboelectric method of flaw detection is used primarily for sorting semifinished products (less frequently of components) with respect to material brands. To increase the reliability of materials sorting many modern devices are equipped with both thermoelectric and triboelectric pickups with a single measuring system. The advantage of the triboelectric (as well as the thermoelectric) method over other flaw detection methods consists in the fact that the test results are not affected by the dimensions and shape of the components and materials being tested.

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S.M. Rozhdestvennyy

TRICEL – triacetate filament fiber produced in England (see Triacetate Fiber).

TRIPOLI - loose or dense rock containing up to 90% silica; consis sists primarily of round globules 1-2 microns (less frequently 10-12 microns) in diameter of a silica hydrate (opal) composition, usually contains a moderate admixture of argilaceous and sandy material. It differs from diatomite, to which it is close by composition and utilization, by the absence of presence in insignificant amounts of silica shells and organisms and by lesser degree of hydration of the silica. The color is yellowish, light-gray, gray. The compression strength of dense varieties is tens of kg/cm^2. Specific gravity 2.20-2.501, specific weight 0.50-1.27 (for pieces), up to 0.80 for powders. The porosity is 60.2-64.0%. Mohs hardness 1-3 (can be cut by a knife). Thermal conductivity at 50°: 0.075 kcal/m-hour-°C for the powder and 0.12 kcal/m-hour-°C in finished products. The adsorption power is lower than that for diatomite. The uses of tripoli and the requirements put to it are the same as for diatomite.

P.P. Smolin

TROOSTITE – structural component of steel, which is a mixture of ferrite and cementite. It differs from pearlite and sorbite, which are also a mixture of ferrite and cementite, by the very high degree of dispersion of these components; individual particles of ferrite and cementite in troostite can be detected only when analyzing the structure under an electron microscope, i.e., using a magnification of several thousand. Steel with a troostite structure has an elevated hardness and strength and a moderate plasticity and ductility.

M. L. Bernshteyn

TROPICAL RESISTANCE – ability of a material to withstand the specific effects characteristic of the atmosphere, biological and other conditions of low geographical latitudes. The most general effects are: 1) high total solar radiation intensity; 2) high (up to 95-97%) and very low (3-8%) relative air humidity, depending on the tropical region; 3) presence of specific insects (termites) and microorganisms (mildew, etc.) which destroy various materials. The presence of heated dust, salt-saturated atmosphere, etc., is also characteristic of the tropics. The high solar radiation intensity heats the soil to 50-70° and above, while dark-color objects, for example, automotive vehicle tires are heated to 90-100°. Despite the fact that the ozone concentration near the ground is lower in tropical zones than in higher latitudes, the combined effect of ozone and light in the tropics is more intense. In humid tropical regions the atmosphere contains an elevated quantity of hydrogen peroxide.

Various materials, including polymers (PM) have quite different tropical resistances. Thus, polyethylene is fully resistant to the effect of microorganisms, while natural and synthetic rubbers are destroyed by them. Polyamide fibers are more tropically resistant than viscose or capron fibers. Cotton fibers, which are rapidly destroyed by mildew are the least resistant to tropical effects. However, cellulose protected by natural fungicides, is highly resistant to tropical effects. Polymers, which are subjected to frequent deformation, as, for example, the rubber fabric frame of automotive vehicle tires, is not acted upon by microorganisms, while the latter destroy unprotected

tires which are stored in a warehouse. The usual means for increasing the resistance of polymers to the light-ozone thermal aging are not always effective under tropical conditions. Thus, the protection of rubbers requires the use of additional antioxidants, for example, cyclohexylaminodiphenilamine and sulfur-containing compounds. Rubber-fabric products are reliably protected by hydroxydiphenyl and albichtols (a product of shale refining). The tropical resistance of polyethylene is increased by introducing certain blacks, primarily of gas duct black. A number of polymers is effectively protected by salicylanilide. Certain microorganisms are capable of dissolving and using for their activity chalk, magnesium oxide, etc., which serve as fillers, and adding them to polymers reduces, rather than increases the tropical resistance.

Protective films which are used for increasing the tropical resistance of materials should not be subjected to the action of microorganisms. Certain plastics (teflon, stabilized polyethylene, etc.) have a good tropical resistance. As far as possible, the surface of the material should not be hygroscopic. The mechanical strength of the coating should also be elevated. It should be taken into account that many microorganisms are capable of destroying organic substances in the total absence of water and oxygen. In conjunction with this antiseptics and fungicides should be carefully selected for each type of material which has to be imparted desirable tropical resistance.

N.N. Lezhnev

TROPIC-RESISTANT LACQUER AND PAINT COATINGS are coatings which are resistant to the conditions of the tropical climate. The severe climatic conditions of the tropics pose the following special requirements on the coatings and their application technology: careful preparation of the surface to be painted, use of primers having high anticorrosion properties and good adhesion to the metal, use of external coatings with high atmospheric and moisture resistance, introduction of fungicides for prevention of fungus growth on the coatings. The tropic-resistant coatings are divided into two groups: 1) for protection and decorative finishing of articles subjected to direct solar radiation; 2) for articles used under conditions of high humidity and temperature but not subjected to the action of solar radiation (indoors, shaded). In both cases use is made of both cold and hot drying coatings; the first for large-scale articles for which hot drying is difficult; the second for articles or parts which can be dried at 150-200°. The cold drying coatings have adequate atmospheric resistance, good resistance to fungi, but low mechanical strength. The hot drying coatings have high atmospheric resistance, high mechanical strength and better external appearance.

For articles subjected to solar radiation, as cold-drying tropic-resistant coatings use is made of: the perchlorvinyl enamels (PKhV-715 of various colors, PKhV-512 with a protective color, KhV-16 matte black, KhV-75 black and PKhV-714 aluminum). The enamels are applied in 3-4 coats by a paint sprayer on a surface pre-primed using FL-OZK (for the ferrous metals), FL-OZZh and AO- [illegible] or all forms of metals); the ena-

mels are dried at 15-25° for 2-2.5 hours, are thinned using R-5 or R-4 to the working consistency of 12-14 seconds measured on the VZ-4. The hot-drying enamels are auto enamels of various colors made on an alkyd-melamine base: the epoxy-nitrocellusosic enamel EP-51 applied in two coats, drying temperature 70°; the epoxy enamels: EP-74T is gray and is applied in two coats, the OEP-4171 is green and is applied in two coats, each coat is dried for 2 hours at 120°, while the EP-74T is dried for 1 hour at 150°.

As primers for the epoxy enamels on the ferrous and nonferrous metals use is made of AG-10s, FL-OZZh, FL-OZK (only for the ferrous metals), EP-09T is used for the OEP-4171 and EP-74T enamels. For articles which are not subject to direct solar radiation, as the cold-drying coatings use is made of the type KhV and PKhV perchlorvinyl enamels, the KhS-77 matte black enamel; the AP nitroenamels are used for the second coat. These enamels are applied on the primers indicated for the cold-drying enamels subjected to the action of solar radiation. For protection from the action of chemical reagents (acids, alkalis and others), use is made of the KhSE GOST 7313-55) and VKhE-4023 and VKhE-4001 enamels (see Chemically Resistant Lacquer and Paint Coatings); the hot drying enamels - the glyptal auto enamels; the pentaphthalic enamels of various colors, AS-81 white; for instruments, the black enamels (PF-28) are used with a drying temperature of 200°; FL-76 with drying temperature of 180°; moire enamel 250 with drying temperature of 200°; the gasoline- and oil-resistant FL-75 and 60T enamels; the AL-701 and AL-70 enamels which are resistant to high temperatures. Under the conditions of the tropical climate the quality of the preparation of the surface prior to painting is of particularly great importance; it determines the service life of the tropic-resistant coatings. The articles or parts are carefully cleaned of the corrosion products, scale and contamination and are degreased. After cleaning, the details or

parts made from the ferrous metals are phosphatized while the nonferrous metal parts are oxidized. In those cases when the phosphatization cannot be performed, phosphatizing primers (VL-02 or VL-08) are used.

I.I. Denker

TRUE DEFORMATION (natural, effective, cumulative, additive) – the sum of infinitesimal relative deformations for a continuously changing initial size; can be expressed, for example, in terms of the true elongation $\underline{e}$, or maximum shear g_{maks}. The concept of true deformation is introduced in the study of deformation process beyond the elastic limit. The magnitudes of true deformation are related to values of conventional deformation (see Conventional Deformation) and to one another. In tension: $e = \ln(1+\delta) = \ln\frac{1}{1-\psi}$ where δ is the conventional elongation, ψ is the reduction in the cross-sectional area; $g_{maks} = 1.5\ e$. In torsion $g_{maks} = \ln\left(1+\frac{\gamma^2}{2}+\gamma\sqrt{1+\frac{\gamma^2}{4}}\right)$ where γ is the maximum conventional shear.

N. V. Kadobnova

TRUE STRESS is the ratio of the force to the actual cross section at a given moment. It is measured in kg/mm^2 or kg/cm^2. With small deformations the change of section is small and the true stress nearly coincides with the nominal stress. With large deformations (for the plastic metals of the type of copper, aluminum, and others) the true stress exceeds the nominal stress in tension (section is reduced sharply) and is less than the nominal stress in compression (section increases sharply). The true stress is widely used for the study of large deformation of metals, rubbers and other materials.

Ya.B. Fridman

TShM-2 RUBBER HARDNESS. Hardness determination by the TShM-2 instrument (GOST 253-53) consists in measuring the depth of penetration (h, mm) of a steel ball 5 mm in diameter (d) into a rubber specimen at least 6 mm thick under a load p = 1 kg for 30 secs. The hardness is calculated in kg/cm^2 by the formula $HB = \frac{25000 - 10 \cdot (57 - RC)^2}{100 - RC}$.

The TShM-2 hardness tester makes it possible to determine hardness from 3.18 to 636.94 kg/cm^2 when the ball penetrates the rubber specimen to a depth from 0.01 to 2 mm.

V.V. Ovchinnikov

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[Transliterated Symbols]

4211 ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = All-Union State Standard

TUNGSTEN W – chemical element of group VI of Mendeleyev's periodic system, atomic number 74, atomic weight 183.92. Natural tungsten consists of a mixture of five stable isotopes with the mass numbers: 180 (0.135%), 182 (26.41%), 183 (14.4%), 184 (30.64%) and 186 (28.41%). Tungsten is a silvery gray metal with a density of 19.3 g/cm^3, $t°_{pl}$ 3410±10°, $t°_{kip}$ 5930°. Use is also made of artificial isotopes W^{181}, W^{185} and W^{187}. The most widely occuring tungsten-containing minerals are: wolframite $(FeMn)WO_4$ and scheelite $CaOWO_3$.

Compact tungsten can be obtained from metal powder by the following methods: 1) sintering of tungsten powder in a hydrogen flow (see Sintered Tungsten); 2) melting in arc or electron-ray vacuum furnaces (see Tungsten Alloys); 3) spraying of powder or wire by a plasma burner (see Plasma Spraying of Tungsten); 4) precipitation from the gas phase. The first method is the one most widely used. Sintered tungsten is produced by the industry in the form of bars, rods (see Tungsten Rods), sheets and strips (see Tungsten Sheets), wire (see Tungsten Wire).

Spraying by a plasma burner is used to produce from tungsten moderate-size compact products, primarily in the form of finished articles. This method is also used for applying more or less thin layers of tungsten to other metals (see Tungsten Coatings).

The crystal lattice of tungsten is a body-centered cubic with a lattice period of 3.1649 A. The atomic radius is 1.41 A. Vapor pressure (mm of Hg): $1.93 \cdot 10^{-15}$ (1530°); $1.0 \cdot 10^{-11}$ (1730°); $7.9 \cdot 10^{-9}$ (2130°); $1.3 \cdot 10^{-7}$ (2230°); $6.55 \cdot 10^{-5}$ (2730°); $1.2 \cdot 10^{-3}$ (3030°); 1.0 (3990°); 10 (4507°); 760 (5927°). Heat of fusion 44 cal/g. Heat of sublimation (at

the fusion temperature) 1050 cal/g. Heat of vaporization (at the boiling temperature) 1183 cal/g. Rate of vaporization ($g/cm^2 \cdot sec$): $3.7 \cdot 10^{-13}$ (1730°); 2.03×10^{-9} (2230°); $9.69 \cdot 10^{-7}$ (2730°); $1.60 \cdot 10^{-5}$ (3030°). $\underline{c}$ ($cal/g \cdot °C$): 0.032 (20°); 0.033 (100°); 0.034 (500°); 0.036 (1000°); 0.041 (2000°); $\alpha \cdot 10^6$ ($1/°C$): 4.2 (−100°); 4.4 (27°); 4.5 (100°); 4.6 (500°); 5.2 (1000°); 6.2 (2000°); 7.2 (2300°); λ ($cal/cm \cdot sec \cdot °C$): 0.46 (−183°); 0.40 (0°); 0.40(20°); 0.39(100°); ~0.29(500°); ~0.28(1000°); ~0.30(2000°); ~0.36(3000°). ρ (micro·ohm·cm): 0.61 (−196°); 5.5 (20°); 7.2 (100°); 19 (500°); 34 (1000°); 66 (2000°); 100 (3000°). The temperature coefficient of electric resistivity (from 0 to 100°) 0.0046. Specific susceptibility $0.28 \cdot 10^{-6}$. The absorption cross section for thermal electrons 19.2±1.0 barns. The work function of an electron 4.50 ev. Enthalpy (25°) cal/g.

Tungsten is highly resistant to corrosion in acids, alkalis, and certain molten metals (see Corrosion of Tungsten). At 20° it has high chemical resistance to water and air. When heated to above 400-500° it is intensely oxidized, forming a loose oxide film which does not protect the metal from further oxidation. Tungsten does not interact with hydrogen even at very high temperatures. Interaction with nitrogen is observed at temperatures above 2000°. To avoid intensive oxidation of tungsten, it should be heat treated, welded (see Welding of Refractory Metals), soldered and also heated before shaping in vacuum or in an inert gas medium. Tungsten is shaped only in the hot state. The shaping deformation temperature of cast tungsten lies between the limits of 1650-1200°. It is preferable to perform it in vacuum or in an inert gas medium. Tungsten is machined with difficulty at room temperature. Hence products from tungsten are heated to 400-500°.

In engineering tungsten is used in the pure form and in the form of alloys (see Tungsten Alloys). Metallic tungsten is used extensively

in the electric lamp, radio engineering and electric vacuum industry. Filaments, heating elements and grids of high-temperature vacuum ovens, emitters, electric contacts, x-ray tube cathods, etc., are made from tungsten. Tungsten is widely used in the metallurgical industry in the production of alloyed steels and hard alloys and in the chemical industry for the production of dyes and catalizers. Tungsten may have use in the future in rockets and jet technology for products operating at high temperatures (up to 2500-2700°), and also in the atomic industry (crucibles for storing radioactive materials, and other products).

When using tungsten for work in an oxidizing medium it must be protected by special coatings (see Protective Coatings of Tungsten).

The mechanical properties of tungsten depend on the degree of its purity, the state of the metal and the test conditions. The most unfavorable effect on the properties of tungsten is exerted by admixtures of O_2, N_2, C, Fe, P, Si and other elements. These admixtures are present in commercial-grade tungsten in amounts from hundredths to hundred thousands of percent by weight. The maximum purity of commercial-grade domestically produced [in the USSR] tungsten is 99.95%. Tungsten with commercial-grade purity is very brittle at 20°. The temperature at which tungsten passes from the brittle to the plastic state depends on the degree of purity of the metal, test conditions and the state of the metal (hardened, recrystallized). The temperature threshold of cold shortness of hardened, commercial-grade purity tungsten (in tension tests) lies at about 300-400°, and that of recrystallized is about 500°. Very high purity tungsten which is obtained by multiple zone purification by electronic rays is plastic at 20° (the relative elongation is 12-15%). The recrystallization temperature of commercially pure tungsten comprises 1450°. Typical mechanical properties of 99.95% pure tungsten in the hardened and recrystallized states, obtained by testing

round specimens of the metal with ϕ 5 mm and working length of 25 mm are presented in Table 1.

TABLE 1

Mechanical Properties of Tungsten at 20° and 400°

Свойства 1	20°	400°
HB (кг/мм²) 2		
деформированного 3	415	—
рекристаллизованного 4	320	—
σ_b (кг/мм²) 5		
деформированного	~90	72—78
рекристаллизованного	~50	~30
δ_5 (%)		
деформированного	0	12—15
рекристаллизованного	0	0— 5
ψ (%)		
деформированного	0	40—60
рекристаллизованного	0	0— 5
E (кг/мм²) 6	40 000	—
μ	0,29	—
Коэффициент сжимаемости 7	$0,293 \cdot 10^{-6}$	—

1) Properties; 2) HB (kg/mm²); 3) of deformation hardened; 4) recrystallized; 5) E (kg/mm²); 6) E (kg/mm²); 7) compressibility coefficient.

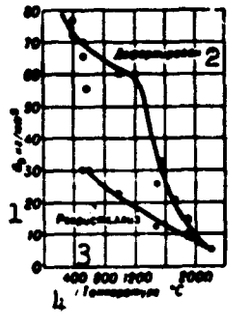

Fig. 1. The temperature dependence of the strength of tungsten. 1) kg/mm²; 2) deformation hardened; 3) recrystallized; 4) temperature, °C.

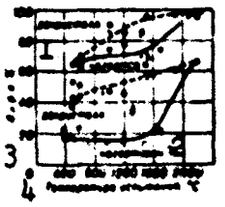

Fig. 2. Change in the plasticity of tungsten as a function of the temperature. 1) Recrystallized; 2) deformation hardened; 3) δ and ψ in %; 4) test temperature, °C.

Tungsten exceeds all the metals by its high-temperature strength. Changes in the momentary strength of tungsten as a function of the tem-

perature are shown in Fig. 1, and changes of the plastic properties are given in Fig. 2. They were determined by testing specimens of the cast

TABLE 2

Ultimate Strengths of Tungsten at Temperatures 2250-2800°

Темп-ра испытания (°С) 1	2 Предел прочности (кг/мм²)			
	за 10 мин. 3	за 50 мин. 4	за 100 мин. 5	за 200 мин. 6
2250	4.2	3.2	2.8	—
2500	2.2	1.7	1.5	1.3
2700	1.7	1.4	1.2	1.0
2800	1.5	1.2	1.0	0.9

1) Test temperature (°C); 2) ultimate strength (kg/mm^2); 3) after 10 minutes; 4) after 50 minutes; 5) after 100 minutes; 6) after 200 minutes.

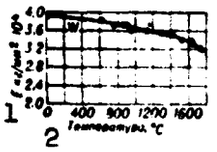

Fig. 3. Change in the modulus of elasticity of tungsten as a function of the temperature. 1) E, kg/mm$^2 \cdot 10^4$; 2) temperature, °C.

metal (ϕ = 5 mm and working length 25 mm) in an argon medium. Up to temperatures of the order of 1500-1600° the momentary strength of deformation hardened metal is lower than that of recrystallized metal. The yield strength of tungsten at 2000° is 8 kg/mm^2, at 2200° it is 6 kg/mm^2 and at 2500° it is 3 kg/mm^2. The creep strength of tungsten at these temperatures varies with time as shown in Table 2. The plasticity of cast tungsten increases continuously as the test temperature is increased (for the sintered metal it drops at temperatures above 1400°).

The ultimate creep strength of tungsten after 100 hours at 1370° is 7 kg/mm^2 and at 1500° it is 6 kg/mm^2. It was determined by testing sintered tungsten specimens (ϕ = 6.35 mm and the working length 19 mm) in a helium atmosphere.

References: Smitells, K.G., Tungsten, translated from English, Moscow, 1958; Slavinskiy, M.P. Fiziko-khimicheyskiye svoystva elementov [Physicochemical Properties of the Elements]. Moscow, 1952; Nuclear Reactors, translated from English, Vol. 3, Moscow, 1956 (Materials of the Atomic Energy Commission of the USA); Abashin, G.I. and Pogosyan, G.M., Tekhnologiya polucheniya vol'frama i molibdena [Technology of Obtaining Tungsten and Molybdenum]. Moscow, 1960; Gavrilyuk, M.I. and German, Ye.N., in the book: Sbornik nauchnykh dokladov po teorii zharoprochnosti [Collection of Scientific Reports on the Theory of Heat Resistance]. Page 224, Moscow, 1961; Austin, W.W., "Metal Progress," Vol. 76, No. 6, pages 71-75, 1959; Green, W.V., "Trans. Metallurg. Soc. AIME," Vol. 215, pages 1057-60, 1959.

M.I. Gavrilyuk

TUNGSTEN ALLOYS – tungsten-based alloys with addition of other alloying elements.

The most extensively used tungsten alloys in the USSR as well as abroad are those of tungsten with rhenium. Addition of 25-35% of rhenium reduces the temperature at which tungsten passes to the brittle state, sharply increases the plasticity at 20° and also improves its production process properties, particularly, it makes it possible to obtain welded seams which are plastic at room temperature. The alloys are produced by methods of powder metallurgy and by melting in electric arc vacuum furnaces. Unlike sintered tungsten, the cast metal has a very coarse-grained structure and hence it is pressure worked and machined poorly, but under certain conditions it may have a lower temperature of transition to the brittle state (see Tungsten).

The workability of the cast metal can be improved by reducing the grain size by adding modifiers in the melt. The cast metal is used primarily for making linings for the throat sections of rocket nozzles using solid fuel.

Vacuum smelting in electric arc or in electron-beam furnaces can be used for obtaining ingots for further remaking into semifinished products or for direct production of simply shaped products. When producing intricately shaped castings from tungsten alloys the metal is melted in lined furnaces and centrifugal castings in graphite ingot molds is used. This method is used for obtaining blanks of rocket nozzles made from an alloy of 50% tungsten and 50% molybdenum weighing up to 28 kg and rings up to 250 mm in diameter and weighing about 100 kg.

The ingot diameters can vary within wide limits, from 80 to 250 mm.

Tungsten ingots are usually plastically shaped by pressing at temperatures 1650-2300°. Blanks obtained in this manner can be forged and rolled at lower temperatures.

Mechanical Properties of W-Re Alloys*

Состав сплава 1	Состояние материала 2	Температура испытания (°С) 3	$\sigma_в$ (кг/мм²) 4	δ (%)
30% Re	Литой рекристаллизованный 5	21	137.0	5.0
		1093	105.5	7.0
		1315	95.0	8.0
		1650	35.0	13.0
30% Re	Литой не рекристаллизованный 6	21	218.0	0.0
		1095	119.5	7.0
		1315	56.0	8.0
		1650	21.0	9.0
		1800	14.0	5.0
25% Re	Литой не рекристаллизованный 6	21	271	—
		1500	30	6.7
		1800	16	9.0

* The properties were determined in vacuum.

1) Alloy composition; 2) state of material; 3) test temperature (°C); 4) kg/mm²; 5) cast recrystallized; 6) cast not recrystallized.

Among the other alloys particular attention is paid abroad to tungsten alloys with molybdenum. According to data of the "Climax Molybdenum" Company, an alloy consisting of 85% W and 15% Mo is suitable for work at 3038°. High strength properties are also exhibited by an alloy with 25% Mo, 0.11% Zr and 0.05% C. This alloy has an ultimate strength at 980° of 69.1 kg/mm² and at 1316° its ultimate strength is 51.6 kg/mm².

When heated in air to above 400° all tungsten alloys are highly oxidized for which reason the service and performance of production process operations (hot forming, welding, soldering, heat treatment, etc.) should be performed in a vacuum or in an inert gas medium. In the

case when tungsten alloys are to be used in an oxidizing medium, the products should be coated by special protective coatings (see Protective Coatings for Tungsten).

W-Re alloys are used for the making of thermocouples and electric contacts, and W-Mo alloys are used for rocket engine nozzles.

References: Savitskiy, Ye.M., Tylkina, M.A. and Shishkina, L.L., "IAN. OTN. Metallurgiya i toplivo" [Bull. Acad. Sci. USSR, Tech. Sciences Section, Metallurgy and Fuel]. No. 3, 1959; "Missiles and Rockets," Vol. 5, No. 48, page 68, 1959; Lement, B.S., and Perlmuter, J., "J. Less-Common Metals," Vol. 2, Nos. 2-4, pages 253-71, 1960.

M.I. Gavrilyuk, O.Z. Budzinskiy

TUNGSTEN BARS – round and square semifinished products used as electrodes for arc welding, in the manufacture of various components by machining, and in the manufacture of strips by rolling. Bars up to 1 m in length and 50 × 50 mm in cross section are now produced in the USSR (see Tungsten wire).

TUNGSTEN COATINGS – tungsten layers of various thickness applied on the surfaces of components made from metal graphite, ceramics and other materials. Tungsten can be applied to component surfaces by precipitation from the gas phase and spraying by a plasma burner (see Plasma Spraying of Tungsten) and by electrolysis from molten salts.

Precipitation from the gas phase is performed by pyrolitic decomposition of tungsten carbonides [$W(CO)_6$] and reduction of tungsten hexafluoride (WF_6) or tungsten hexachloride (WCl_6) by hydrogen.

The most promising method for obtaining tungsten is its extraction from WF_6. Tungsten forms with fluoride only one compound, which is WF_6, which is gaseous at room temperature. The production process involved in precipitating tungsten from WF_6 consists in passing a mixture of gaseous H_2 and WF_6 (in a 1:3 ratio) over the surface of the product which is heated to 650-700°. When the gas mixture comes in contact with the product's surface the tungsten is deposited and they hydrogen fluoride (HF) which is formed in the reduction reaction is adsorbed by an entrainment separator.

Tungsten is precipitated from WF_6 at the rate of 1.6 mm per hour; here it is deposited in the greatest amounts at the first instant of gas supply. It is possible to obtain a uniform rate of tungsten deposition with respect to time by designing the installation in such a manner as to supply gas uniformly to the component's surface.

Tungsten precipitated from the gas phase is highly pure and of high density (19.3 g/cm_3). Its density is higher that that of tungsten obtained by plasma spraying. The hardness of precipitated tungsten is

475 HV. This method can be used to obtain both thin tungsten coatings on various components and entire components of simple shape, for example, sleeves, tubes, etc. In the latter case tungsten is deposited on special metal frames which can be removed by chemical diluting.

Tungsten coatings can find various uses in the industry: 1) or components operating at very high temperatures and reducing and neutral media, for example, nozzles of rockets and guided missiles. The basic materials for such components can be successfully made from metals with a lower melting temperature and a smaller specific weight, such as iron or nickel base alloys, and also graphite, ceramics, etc., 2) For casting molds for casting under pressure, which are made from molybdenum and coated by tungsten, which are used for obtaining rods of highly radioactive metals. 3) For applying a thin layer of tungsten on molybdenum with subsequent siliconizing. In this case it can be useful as a reinforcing element for the silicon coating (see Protective Coatings for Molybdenum). 4) For components subjected to friction, taking into account the high wear resistance of the tungsten coating.

References: Schultze, H.W., "Metal Progr.," Vol. 76, No. 3, pages 74-80, 1959; "Nat. Bur. Standards. Technical news bulletin," Vol. 44, No. 2, pages 32-33, 1960; "Missiles and Rockets," Vol. 7, No. 11, pages 23-24, 1960.

Ye.N. Novikova

TUNGSTEN SHEET is produced by forging and subsequent rolling. For the production of sheet, strip and foil from tungsten, use is made primarily of the metal obtained by the powder metallurgy method. Blanks of sintered tungsten are first forged into strip at 1500° and are then rolled at 1400°. In the course of the reduction of the strip thickness the rolling temperature is gradually reduced to 1000-800°. Since tungsten becomes quite brittle on recrystallization, all the operations in the production of tungsten sheet must be carried out below the recrystallization temperature. Heating of the metal for rolling is performed in a hydrogen atmosphere. The oxidized surface layer is removed by immersion of the tungsten sheet in molten caustic soda. As a rule, the sheets are not subjected to annealing after rolling. In case of necessity, a low-temperature anneal of the sheets is performed at 1000-1200° to relive the stresses. The dimensions of the tungsten sheets are determined by the size of the initial blanks and may vary over wide limits. In view of the brittleness of tungsten at room temperature, bending and stamping of tungsten sheet must be performed in the hot condition. Depending on the sheet thickness, the working temperature may vary in the limits from 100 to 600°. Tungsten sheet can be bent and stamped with strict observance of the temperature regime. Cutting of the sheets is done best by use of an emery stone. The tungsten sheet can be welded by spot contact welding with the use of a tantalum foil gasket. Tungsten sheet and strip find wide application as heaters and screens for high-temperature vacuum thermal furnaces, for details of electron tubes and other instruments.

M.I. Gavrilyuk

TUNGSTEN STRIP see Tungsten Sheet.

TUNGSTEN WIRE. This wire is produced from scintered tungsten by powder-metallurgical pressure working, pressing the powdered tungsten into square moldings in steel press forms under a pressure of 2-3 t/$/cm^2$.

TABLE 1

Characteristics of Tungsten Wire

1 Свойства	2 Проволока первых переходов (3—2 мм)	3 Тонкая проволока (20—15 мк)
σ_b (кг/мм²) [4]	75—100	425—470
E (кг/мм²)	12000—15000	35000—38000
δ (%)	0,5—1,0	0,8—1,2
$\alpha \cdot 10^6$ (20—1000°) (1 °C)	4,5—6,3	4,5—6,3
λ (20—1000°) (кал/см·сек·°C) [5]	0,38—0,29	—

1) Characteristic; 2) initial-conversion wire (3-2 mm); 3) thin wire (20-15 μ); 4) kg/mm^2; 5) cal/cm•sec•°C.

TABLE 2

Vapor Tension of Tungsten

1 Температура (°C)	2 Упругость пара (мм рт. ст.)
1530	1,93·10⁻¹⁵
2130	7,9·10⁻⁹
2730	6,55·10⁻⁵
3130	4,68·10⁻³
3990	1,0·10⁻²

1) Temperature (°C);
2) vapor tension (mm Hg).

TABLE 3

Electronic Emission of Tungsten

1 Температура (°С)	2 Электронная эмиссия (а/см²)
830	$1,5 \cdot 10^{-10}$
1630	$2,3 \cdot 10^{-1}$
1730	1,0
2230	298

1) Temperature (°C);
2) electromic emission (amp/cm^2).

The pressed moldings are subjected to preliminary scintering at 1150-1300° in a hydrogen atmosphere and then to high-temperature treatment by passing a current through them in special welding equipment; the heating obtained reaches 90-95% of the melting temperature of the moldings. Such treatment, referred to as "welding," ensures production of almost completely compact metal and permits further pressure-working. Moldings subjected to "welding" are forged into round bars in rotary forging machines and converted to wire by drawing.

Tungsten wire is manufactured in diameters of from 3 mm to 2-3 μ. A continuous increase in the strength of the tungsten occurs as processing continues and the diamter of the wire is reduced.

When necessary, the hot strength of tungsten wire can be raised by adding oxides (ThO_2, SiO_2, Al_2O_3, etc.) to the raw materials. This makes it possible to obtain nonsagging wire, which is very important in applications such as vacuum tubes, where tungsten filaments are used. Table 1 shows certain characteristics of tungsten wire.

In connection with the fact that tungsten wire is employed principally in tubes which incandesce at high temperatures, the vapor tension of tungsten at various temperatures is a very important index (Table 2).

Incandescent tungsten wire emits surface radiation with an energy

that increases with temperature; for example, the power of the radiant energy emitted is 0.9 watts/cm^2 at 800° and 245 watts/cm^2 at 3030°. Table 3 shows the electronic-emission characteristics of tungsten.

The specific resistivity of tungsten wire is $5.5 \cdot 10^{-6}$ ohm·cm at 20° and $66 \cdot 10^{6}$ ohm·cm at 2000°.

Tungsten wire is widely used in enginerring (principally for various types of vacuum tubes), in instruments, and as incandescent elements in electric furnaces.

References: Meyerson, G.A. and Zelikman, A.N., Metallurgiya redkikh metallov [Metallurgy of Rare Metals], Moscow, 1955; Smittels, K.J., Vol'fram [Tungsten], translated from English, Moscow, 1958

V.S. Rakovskiy

TURBINE AND BOILER BUILDING STEEL - steel for making the principal components of steam and gas turbines and also of steam boilers. It is

TABLE 1

Chemical Composition of Steel for Welded Boiler Components

1 Сталь	2 Содержание элементов (%)								
	C	Si	Mn	Cr	Ni	Mo	S	P	4 другие элементы
							3 не более		
20K	0,16–0,24	0,15–0,30	0,35–0,65	≤0,30	≤0,30	–	0,045	0,040	≤0,30 Cu
22K	0,18–0,25	0,17–0,37	0,7–0,9	≤0,30	≤0,30	–	0,045	0,045	≤0,1 Ti
5 16ГНМ	0,12–0,20	0,17–0,37	0,7–0,9	≤0,30	1,0–1,5	0,40–0,55	0,040	0,035	–
6 12Х1МФ	0,08–0,15	0,17–0,37	0,4–0,7	0,9–1,2	≤0,25	0,25–0,35	0,025	0,035	0,15–0,30 V; ≤0,20 Cu; ≤0,25Ni
7 15Х1М1Ф	0,10–0,16	0,15–0,35	0,4–0,7	1,1–1,4	≤0,30	0,9–1,1	0,025	0,030	0,20–0,35V
8 Х18Н12Т	≤0,12	≤0,80	1,0–2,0	17,0–19,0	11,0–13,0	–	0,020	0,035	Ti=(5 C–0,02) b≤ ≤0,70.
9 1Х14Н18В2БР (ЭИ695Р)	0,07–0,12	≤0,6	1,0–2,0	13,0–15,0	18,0–20,0	–	0,020	0,035	2,0–2,75 W; 0,9–1,3 Nb; 0,005 B; 0,020 Ce
10 Х16Н14В2БР (ЭП17)	0,07–0,12	≤0,6	1,0–2,0	15–17	13–15	–	0,020	0,03	2,0–2,75 W; 0,9–1,3 Nb; 0,005 B; 0,02 Ce

1) Steel; 2) element content (%); 3) not more than; 4) other elements; 5) 16GNM; 6) 12Kh1MF; 7) 15Kh1M1F; 8) Kh18N12T; 9) 1Kh14N18V2BR (EI695-R); 10) Kh16N14V2BR (EP17).

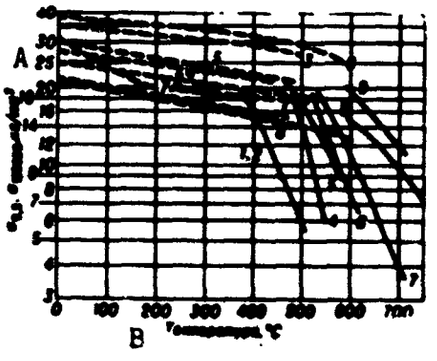

Fig. 1. Yield strength (dashed line) and the ultimate creep strength after 100,000 hours (solid line) of boiler component steel as a function of the temperature. 1) 20K; 2) 22K; 3) 16GNM; 4) 12MKh; 5) 12Kh1M-F; 6) 15Kh1M1F; 7) Kh18N12T; 8) 1Kh14N18V2BR; 9) 1Kh16N16MV2BR. A) kg/mm^2. B) temperature °C.

TABLE 2

Mechanical Properties of Steel for Welded Boiler Components

1 Сталь	2 Режим термич. обработки	3 Механич. свойства (по ТУ)				
		$\sigma_{0,2}$	σ_b	δ	ψ	5 $a_н$ (кгм/см²)
		4 (кг/мм²)		(%)		
20К	Нормализация с 880—920°, охлаждение на воздухе, отжиг 6при 880—900°, отпуск при 620—680°	25	41—50	19—22	—	5—7
22К	7 То же	—	>44	20	—	7.0
16ГНМ 8	Нормализация с 920—930°, охлаждение на воздухе, отпуск при 660—680°	27	51	16	—	7
10 12Х1МФ	Нормализация с 950—980°, охлаждение на воздухе, отпуск при 720—760°	26	48—65	21	55	5—7
12 15Х1М1Ф	Нормализация с 1020—1050°, охлаждение на воздухе, отпуск при 730—760° 13	>35	58	16	45—50	4—5
14 Х18Н12Т	Нормализация с 1050—1100°, охлаждение на воздухе или в воде, отпуск при 800° в течение 10 час. или при 700° в течение 20 час. 15	24	54	35	55	—
16 Х14Н18В2БР (ЭИ695Р)	Аустенитизация с 1100—1150°, охлаждение на воздухе или в воде 17	22	55	35	50	—
18 Х16Н14В2БР (ЭП17)	Аустенитизация с 1050—1100° (перегревательные трубы), с 1100—1150° (паропроводные трубы), охлаждение в воде	22	55	35	50	15

1) Steel; 2) heat treatment regime; 3) mechanical properties (according to TU); 4) (kg/mm^2); 5) a_H (kgm/cm^2); 6) normalization from 880-920°, air cooling, annealing at 880-900°, tempering at 620-680°; 7) same as above; 8) 16GNM; 9) normalization from 920-930°, air cooling, tempering at 660-680°; 10) 12Kh1MF; 11) normalization from 950-980°, air cooling, tempering at 720-760°; 12) 15Kh1M1F; 13) normalization from 1020-1050°, air cooling, tempering at 730-760°; 14) Kh18N12T; 15) normalization from 1050-1100°, air or water cooling, tempering at 800° for 10 hours or at 700° for 20 hours; 16) 1Kh14N18V2BR (EI695R); 17) austenitizing from 1100-1150°, air or water cooling; 18) Kh16N14V2BR (EP17); 19) austenitizing from 1050-1100° (superheater tubes), from 1100-1150° (steam line pipes), water cooling.

supplied in the form of bar stock, forgings, plates and castings. All kinds of welding are permitted when making components from the aforementioned semifinished products. Steel for boiler shells, pipeline pipes, superheater tubes and its properties are described in Tables 1 and 2.

Carbon steel boiler plate is supplied in the normalized, annealed or high-tempered states.

TsL-20M electrodes are used for welding pipes from 12Kh1MF steel, while TsL-34 electrodes are used for welding 15Kh1M1F steel. After welding, the 12Kh1MF steel is tempered at 720-740°, while the 15Kh1M1F

TABLE 3

Mechanical Properties of Pearlitic and Martensitic-Ferritic Class Steel for Turbine Components

1 Сталь	2 Режим термич. обработки	3 Механич. свойства (по ТУ)				
		$\sigma_в$	$\sigma_т$	δ	ψ	5 $a_н$
		4 (кг/мм²)		(%)		(кгм/см²)
6 25Х1МФ (ЭИ10)	Закалка с 930–950° в масле, отпуск при 620–660° 7	75	90	14	50	6
8 25Х2М1Ф (ЭИ723)	Нормализация с 1030–1060°, нормализация с 950–970°, отпуск при 680–720° 9	75	90	10	40	4
10 25Х1М1Ф (Р2)	Нормализация с 970–990°, нормализация с 930–950°, отпуск при 680–700° 11	68	85	13–16	35–40	4–5
12 20Х3МВФ (ЭИ415)	Отжиг при 950–960°, нормализация с 1050–1100°, закалка с 980–1020° в масле, отпуск при 660–680° 13	85–75	90	12–13	35–45	6.0–7.0
14 20Х1М1Ф1ТР (ЭП182)	Закалка с 980–1000° в масле, отпуск при 680–720° 15	75	85	15	45	6.0
16 20Х1М1Ф1БР (ЭП44)	Нормализация с 1030°, отпуск при 700–725° 17	70–80	90	14	50	6.0
18 1Х13	Закалка с 1030–1050° на воздухе или в масле, отпуск при 730–750° 19	60–65	80–85	17–20	65–60	7–9
20 2Х13	Закалка с 1000–1020° на воздухе или в масле, отпуск при 720–750° 21	65–50	70	16–18	50–60	7–8
22 1Х11МФ (15Х11МФ)	Нормализация с 1050–1100°, отпуск при 720–740° 23	50	70	16	55	6
24 1Х12ВНМФ (ЭИ802, ЭИ952, 15Х12ВМФ)	Закалка с 1050° в масле, отпуск при 660–700° 25	65–75	80–90	15–17	35–45	3–4
26 2Х12ВМБФР (ЭИ993)	Закалка с 1050° в масле, отпуск при 650–700° 27	50	75	12	45	4
28 18Х11МФБ	Нормализация с 1100–1130°, нормализация с 1080–1110°, отпуск при 730–750° 29	50–65	70	16	60	5

1) Steel; 2) heat treatment regime; 3) mechanical properties (according to TU); 4) (kg/mm^2); 5) a_H (kgm/cm^2); 6) 25Kh1MF (EI10); 7) quenching from 930-950° in oil, tempering at 620-660°; 8) 25Kh2M1F (EI723); 9) normalizing from 1030-1060°, normalizing from 950-970°, tempering at 680-700°; 12) 20Kh3MVF (EI415); 13) annealing at 950-960°, normalizing from 1050-1100°, oil quenching from 980-1020°, tempering at 660-680°; 14) 20Kh1M1F1TR (EP182); 15) oil quenching from 980-1000°, tempering at 680-720°; 16) 20Kh1M1F1BR (EP44); 17) normalizing from 1030°, tempering at 700-725°; 18) 1Kh13; 19) quenching from 1030-1050° in air or oil, tempering at 730-750°; 20) 2Kh13; 21) quenching from 1000-1020° in air or oil, tempering at 720-750°; 22) 1Kh11MF (15Kh11MF); 23) normalizing from 1050-1100°, tempering at 720-740°; 24) 1Kh12VNMF (EI802, EI952, 15Kh12VMF); 25) oil quenching from 1050°, tempering at 660-700°; 26) 2Kh12VMBFR (EI993); 27) oil quenching from 1050°, tempering at 650-700°; 28) 18Kh11MFB; 29) normalizing from 1100-1130°, normalizing from 1080-1110°, tempering at 730-750°.

steel is tempered at 750°. Pipes from the Kh18N12T austenitic steel are not prone to intercrystalline corrosion. The TsT-15 electrode is used for welding the Kh18N12T steel. The AZh-13-18 electrode is used for welding pipe joints from 1Kh14N18V2BR steel with subsequent austenizing at 1100°. Figure 1 shows the change in the ultimate yield and creep strengths of steel for boiler component as a function of the tempera-

TABLE 4

Chemical Composition of Pearlitic and Martensitic-Ferritic Class Steel for Turbine Components

1 Сталь	2 Содержание элементов (%)											4 Другие элементы
	C	Si	Mn	Cr	Mo	W	V	Nb	Ni	S	P	
5 25Kh1MF (EI10)	0,22—0,29	0,17—0,37	0,40—0,70	1,5—1,8	0,25—0,35	—	0,15—0,30	—	0,24	0,025	0,025	—
6 25Kh2M1F (EI723)	0,22—0,29	0,17—0,37	0,40—0,80	2,1—2,5	0,6—1,1	—	0,15—0,30	—	—	0,020	0,030	—
7 25Kh1M1F (R2)	0,22—0,29	0,24—0,56	<0,70	1,4—1,8	0,6—0,8	—	0,20—0,30	—	0,30	0,025	0,030	0,8—1,0 Mo from P2M
9 20Kh3MVF (EI415)	0,16—0,24	0,17—0,37	0,25—0,50	2,8—3,3	0,35—0,55	0,10—0,50	0,60—0,85	—	0,5	0,025	0,030	—
10 20Kh1M1F1TR (EI182)	0,16—0,28	<0,35	<0,5	0,9—1,4	0,8—1,1	—	0,7—1,0	—	0,5	0,030	0,030	0,15—0,35 Ti; 0,005 B
11 20Kh1M1F1BR (EI44)	0,16—0,23	<0,37	0,50—0,80	1,0—1,3	0,8—1,1	—	0,7—1,0	0,10—0,15	0,65	0,030	0,030	0,005 B
12 1Kh13	0,09—0,15	<0,60	<0,60	12,0—14,0	—	—	—	—	0,60	0,025	0,030	—
13 2Kh13	0,16—0,24	<0,60	<0,60	12,0—14,0	—	—	—	—	0,60	0,025	0,030	—
14 1Kh11MF (15Kh11MF)	0,12—0,19	<0,50	<0,70	10,0—11,5	0,6—0,8	—	0,25—0,40	—	0,60	0,025	0,030	—
15 1Kh12V-MF (EI802; EI952; 15Kh12VMF)	0,12—0,18	0,40	0,5—0,9	11,0—13,0	0,5—0,7	0,7—1,1	0,15—0,30	—	0,6—0,9	0,025	0,030	—
16 2Kh12VMBFR (EI993)	0,15—0,22	<0,50	0,50	11,0—13,0	0,5—0,8	0,6—0,7	0,15—0,30	0,2—0,4	—	0,025	0,030	0,003 B
17 2Kh11MFB (EP291)	0,18—0,21	<0,60	0,6—1,0	10,0—11,5	0,8—1,1	—	0,20—0,40	0,20—0,45	0,5—1,0	0,030	0,035	—

1) Steel; 2) element content (%); 3) not more than; 4) other elements; 5) 25Kh1MF (EI10); 6) 25Kh2M1F (EI723); 7) 25Kh1M1F (R2); 8) 0.8-1.0 Mo in R2M steel; 9) 20Kh3MVF (EI415); 10) 20Kh1M1F1TR (EI182); 11) 20Kh1M-1F1BR (EI44); 12) 1Kh13; 13) 2Kh13; 14) 1Kh11MF (15Kh11MF); 15) 1Kh12V-MF (EI802; EI952; 15Kh12VMF); 16) 2Kh12VMBFR (EI993); 17) 2Kh11MFB (E-P291).

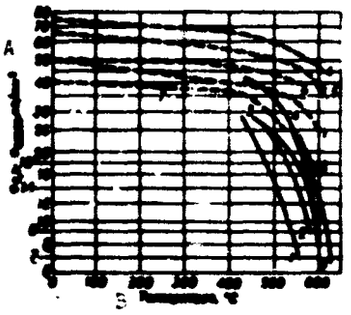

Fig. 2. Ultimate yield (dashed line) and creep strengths after 100,000 hours (solid line) of turbine component steel as a function of the temperature. 1) 34KhM; 2) 25Kh1M1F; 3) 20Kh3MVF ($\sigma_{0.2}$ = 65 kg/mm^2); 4) 20-Kh3MVF ($\sigma_{0.2}$ = 75 kg/mm^2); 5) 1Kh12VMF; 6) 2Kh12VMBFR; 7) 1Kh13. A) kg/mm^2; B) temperature, °C.

ture.

Pipes from the 12Kh1MF steel retain their properties and structure in extended operation at 550°. The workhardening reduces the creep plasticity of Kh18N12T steel which is reflected in the pipe properties.

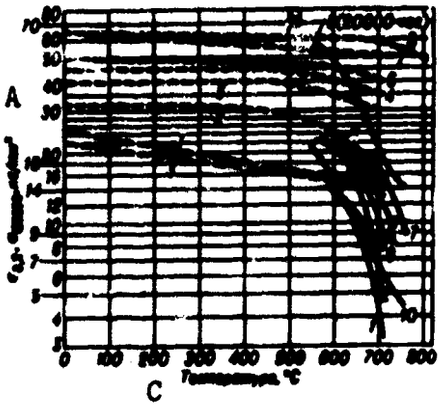

Fig. 3. Ultimate yield (dashed line) and 100,000 hour creep strengths (solid line) of steel and austenitic class alloys for turbine components as a function of the temperature. 1) Kh16N13M2B; 2) 3Kh19N9MVBT; 3) 1Kh14N18V2BR1; 4) KhN35VT; 5) EI612K; 6) EI607A; 7) EI869; 8) EI765; 9) EI402M-L; 10) LA-1. A) kg/mm^2; B) hours; C) temperature, °C.

TABLE 5

Chemical Composition of Steel and Alloys of the Austenitic Class for Turbine Components

1 Стали	2 Содержание элементов (%)									4 Другие элементы
	C	Si	Mn	Cr	Ni	W	Ti	S	P	
								3 не более		
5 Х16Н13М2Б (ЭИ405)	≤0.12	0.80—1.1	≤0.80	16.0—17.0	12.0—14.5	—	—	0.030	0.030	1.5—2.0 Mo; 0.8—1.2 Nb
6 3Х19Н9МВБТ (ЭИ572)	0.30—0.35	≤0.80	0.80—1.50	18.0—20.0	8.0—10.0	1.0—1.5	0.20—0.50	0.020	0.035	1.0—1.5 Mo; 0.2—0.5 Nb
7 1Х14Н18В2БР1 (ЭИ726)	0.07—0.12	≤0.6	1.0—2.0	13.0—15.0	17.0—20.0	2.0—2.75	—	0.020	0.035	0.8—1.3 Nb; ≤0.025 B
8 ХН35ВТ (ЭИ612)	≤0.12	≤0.60	1.0—2.0	14.0—16.0	34.0—36.0	2.6—3.5	1.1—1.5	0.020	0.030	≤0.020 Co
9 ЭИ612К	≤0.10	≤0.50	1.0—2.0	14.0—16.0	34.0—36.0	2.8—3.5	1.2—1.6	0.020	0.020	3.5—4.5 Co; 0.005 B
10 ЭИ607А	≤0.08	≤0.8	≤1.0	13.0—17.0	остальное	—	1.6—1.8	0.020	0.020	1.0—1.5 Nb; 0.5—1.0 Al; ≤3.0 Fe
12 ЭИ869	≤0.08	≤0.8	≤1.0	14.0—17.0	остальное 11	—	1.5—1.9	0.020	0.020	1.0—1.5 Nb; 1.1—1.4 Al; 0.005 B; 0.003 Zr; ≤3.0 Fe
13 ХН70ВМЮТ (ЭИ765)	0.10—0.16	≤0.6	≤0.5	14.0—16.0	остальное	4.0—5.0	1.0—1.4	0.020	0.020	3.0—5.0 Mo
14 ХН35ВТР (ЭИ725)	≤0.10	≤0.6	≤1.0	14.0—16.0	33.0—36.0	4.0—5.0	1.1—1.5	0.020	0.030	≤0.008 B; ≤0.025 Co

1) Steel; 2) element content (%); 3) not more than; 4) other elements; 5) Kh16N13M2B (EI405); 6) 3Kh19N9MVBT (EI572) 7) 1Kh14N18V2BR1 (EI-726); 8) KhN35VT (EI612); 9) EI612K; 10) EI607A; 11) residue; 12) EL-869; 13) KhN70VMYuT (EI765); 14) KhN35VTR (EI725).

Operations involving cold shaping (flexure) must be followed by austenitizing. The following high-temperature oxidation resistance has been established: 0.07 mm/year at 585° and 0.12 mm/year at 600° for the 12-Kh1MF steel; 0.09 mm/year at 570° and 0.17 mm/year at 610° for the 15-

TABLE 6

Mechanical Properties of Austenitic Class Steel and Alloys for Turbine Components

1 Сталь	2 Режим термич. обработки	3 Механич. свойства (по ТУ)				
		$\sigma_{c,s}$	σ_b	δ	ψ	5 a_H (кгм/см²)
		4 (кг/мм²)		(%)		
6 Х16Н13М2В (ЭИ405)	Аустенитизация с 1050—1100°, старение при 750° в течение 10 час.	24	55	30—40	35—50	3,0—8,0
9 Х19Н9МВБТ (ЭИ572)	Аустенитизация с 1150—1180° в воде, старение при 700—800° в течение 15—50 час.	30	60	30	40	4,0—6,0
10 1Х14Н18В2БР1 (ЭИ726)	Аустенитизация с 1120—1140° на воздухе или в воде, старение при 750° в течение 25 час.	22	52	30	44	5,0—12,0
12 ХН35ВТ (ЭИ612)	Аустенитизация с 1080—1100° в воде, старение при 850—900° в течение 10 час., старение при 700° в течение 25—50 час.	40	75	25	25—35	5,0—8,0
14 ЭИ612К	Аустенитизация с 1080—1100° в воде, старение при 850—900° в течение 10 час., старение при 700° в течение 50 час.	35	65	15	35	6,0
16 ЭИ607А	Аустенитизация с 1100°, выдержка 5 час., охлаждение в воде, старение при 1000° в течение 2 час., охлаждение до 800° в течение 2 час., старение при 750° в течение 20 час., старение при 700° в течение 48 час.	45	85	26	30	7
18 ЭИ869	Аустенитизация с 1080—1100° в течение 6 час., старение при 1000° в течение 2 час., охлаждение до 800° в течение 2 час., старение при 750° в течение 20 час.	55	95	24	28	10
20 ХН70ВМЮТ (ЭИ765)	Аустенитизация с 1150°, выдержка 3 час., охлаждение в масле, старение при 800° в течение 20 час.	60	105	20	25	8
22 ХН35ВТР (ЭИ725)	Аустенитизация с 1130—1150°, охлаждение на воздухе, старение при 750° в течение 24 час.	45	80	20	35	10

1) Steel; 2) heat treatment regime; 3) mechanical properties (according to TU); 4) (kg/mm^2); 5) a_H (kgm/cm^2); 6) Kh16N13M2B (EI405); 7) austenizing from 1050-1100°, aging at 750° for 10 hours; 8) 3Kh19N9MVBT (EI-572); 9) austenizing from 1150-1180° in water, aging at 700-800° for 15-50 hours; 10) 1Kh14N18V2BR1 (EI726); 11) austenizing from 1120-1140° in air or water, aging at 750° for 25 hours; 12) KhN35VT (EI612); 13) austenizing from 1080-1100° in water, aging at 850-900° for 10 hours, aging at 700° for 25-50 hours; 14) EI612K; 15) austenizing from 1080-1100° in water, aging at 850-900° for 10 hours, aging at 700° for 50 hours; 16) EI607A; 17) austenizing from 1100°, holding for 5 hours, water cooling, aging at 1000° for 2 hours, cooling to 800° during 2 hours, aging at 750° for 20 hours, aging at 700° for 48 hours; 18) EI-869; 19) austenizing from 1080-1100° for 6 hours, aging at 1000° for 2 hours, cooling to 800° during 2 hours, aging at 750° for 20 hours; 20) KhN70VMYuT (EI765); 21) austenizing from 1150°, holding for 3 hours, oil cooling, aging at 800° for 20 hours; 22) KhN35VTR (EI725); 23) austenizing from 1130-1150°, air cooling, aging at 750° for 24 hours.

Kh1M1F steel, and 0.015-0.070 mm/year at 700° for the 1Kh16N14V2BR steel.

The chemical composition and mechanical properties of turbine com-

TABLE 7

Chemical Composition of Steel for Cast Turbine Components

1 Сталь	2 Содержание элементов (%)									
	C	Si	Mn	Cr	Ni	W	Mo	S	P	3 Другие элементы
								не более		
5 20ХМ-Л	0,15–0,25	0,20–0,45	0,50–0,80	0,40–0,70	до 0,30	—	0,40–0,60	0,040	0,040	—
6 20ХМФ-Л	0,18–0,25	0,20–0,35	0,40–0,60	0,90–1,20	до 0,30	—	0,50–0,70	0,030	0,030	0,2–0,3 V
7 15Х1М1Ф-Л	0,14–0,20	0,17–0,37	0,40–0,70	1,20–1,70	0,65	—	0,90–1,20	0,030	0,030	0,25–0,40 V
8 15Х11МВФ-Л (Х11ЛБ)	0,14–0,18	0,20–0,55	0,50–1,00	10,5–12,5	0,50–0,80	0,80–1,10	0,50–0,75	0,025	0,030	0,15–0,30 V
9 15Х11МФБ-Л (Х11ЛА)	0,13–0,20	до 0,55	0,60–1,00	10,0–12,0	0,50–0,90	—	0,80–1,05	0,025	0,025	0,20–0,30 V, 0,10–0,25 Nb
10 12Х11В2НМФ-Л (ТЖ5)	0,10–0,15	0,17–0,40	0,60–0,80	10,5–12,5	0,8–1,1	1,7–2,2	0,60–0,80	0,030	0,030	0,20–0,35 V
11 ЛА-1	до 0,16	0,55	0,7	15,0–16,0	15,0–16,0	0,8–1,2	1,8–2,2	0,020	0,035	0,15–0,35 Ti, 2,8–3,2 Cu
12 ЭИ402М-Л	≤0,12	≤0,60	3,5–4,5	16,0–18,0	9,5–11,0	—	0,9–1,2	0,025	0,025	0,7–1,1 Nb

1) Steel; 2) element content (%); 3) not more than; 4) other elements; 5) 20KhM-1; 6) 20KhMF-1; 7) 15Kh1M1F-1; 8) 15Kh11MVF-L (Kh11LB); 9) 15KhMFB-1 (Kh11LA); 10) 12Kh11V2NMF-L (TsZh5); 11) LA-1; 12) EI402M-L.

TABLE 8

Mechanical Properties of Steel for Cast Turbine Components

1 Сталь	2 Режим термич. обработки	3 Механич. свойства (по ТУ)				
		$\sigma_{0,2}$	σ_b	δ	ψ	5 $a_н$ (кгм/см²)
		4 (кг/мм²)		(%)		
6 20ХМ-Л	Отжиг при 850–900°, нормализация с 890–910°, отпуск при 640–660° 7	25	47	18	30	3
8 20ХМФ-Л	Нормализация с 940–950°, нормализация с 920–940°, отпуск при 690–710° 9	32	50	20	35	3,5
10 15Х1М1Ф-Л	Отжиг при 1050°, нормализация с 980–1000°, отпуск при 710–740° 11	35–55	>50	14	50	3,0
12 15Х11МВФ-Л (Х11ЛБ)	Нормализация с 1100°, нормализация с 1050°, отпуск при 680–700°	50	60	15	50	5,0
14 15Х11МФБ-Л (Х11ЛА)	Отжиг при 880–900°, нормализация с 1130–1150°, нормализация с 1040–1060°, отпуск при 750–770° 15	50	60	15	50	5,0
16 12Х11В2НМФ-Л (ТЖ5)	Отжиг при 1100°, нормализация с 1050°, отпуск при 680° 17	50	60	15	50	5,0
18 ЛА-1	Аустенитизация с 1150–1170°, выдержка 2–4 часа, старение при 750–800° в течение 5–10 час 19	20	40	15	—	3,5
20 ЭИ402М Л	Аустенитизация с 1160–1180°, выдержка 8 час. и охлаждение на воздухе, старение при 750° в течение 16 час. 21	20	40	15	25	1,0

1) Steel; 2) heat treatment regime; 3) mechanical properties (according to TU); 4) (kg/mm²); 5) a_H (kgm/cm²); 6) 20KhM-L; 7) annealing at 880-900°, normalizing from 890-910°, tempering at 640-660°; 8) 20KhMF-1; 9) normalizing from 940-950°, normalizing from 920-940°, tempering at 690-710°; 10) 15Kh1M1F-L; 11) annealing at 1050°, normalizing from 980-1000°, tempering at 710-740°; 12) 15Kh11MVF-L (Kh11LB); 13) normalizing from 1100°, normalizing from 1050°, tempering at 680-700°; 14) 15Kh11MFB-L (Kh11LA); 15) annealing at 880-900°, normalizing from 1130-1150°, normalizing from 1040-1060°, tempering at 750-770°; 16) 12Kh11V2NMF-L (TsZh5); 17) annealing at 1100°, normalizing from 1050°, tempering at 680°; 18) LA-1; 19) austenizing from 1150-1170°, holding for 2-4 hours,

aging at 750-800° for 5-10 hours; 20) EI402M-L; 21) austenizing from 1160-1180°, holding for 8 hours and air cooling, aging at 750° for 16 hours.

TABLE 9

Uses of Turbine and Boiler Building Steel

1 Основные детали	2 Сталь и предельная рабочая темп-ра
3 Барабаны котлов	20К, 22К, 16ГНМ 4
5 Трубы паропроводов и перегревателей котлов	12Х1МФ (560°), 15Х1М1Ф (580°), Х18Н12Т (600°), 1Х14Н18В2БР, 1Х16Н14В2БР (650—680°) 6
7 Цилиндры, сопловые коробки, арматура и др. отливки	20ХМ-Л (540°), 20ХМФ-Л (560°), 15Х1М1Ф-Л (580°), 15Х11МВФ-Л, 15Х11МФБ-Л, 12Х11В2НМФ-Л (580—600°), 8 ЛА-1, ЭИ402М-Л (600—650°)
9 Роторы и диски турбин и др. поковки	25Х1М1Ф (Р2) (540°), 20Х3МВФ (560°), 1Х12ВНМФ (560—580°), Х16Н13М2Б, 3Х19Н9МВБТ (600°), 1Х14Н18В2БР1, 10 ХН35ВТ (650°), ЭИ612К (700°)
11 Рабочие и направляющие лопатки турбин	1Х13, 2Х13 (500°), 1Х11МФ, 18Х11МФБ (550°), 1Х12ВНМФ (580°), Х16Н13М2Б (600°), ХН35ВТ (650°), ЭИ612К, 12 ЭИ607А (700°), ЭИ869, ЭИ765 (750°)
13 Крепежные детали (болты, шпильки)	25Х1МФ (510—530°), 25Х2М1Ф (550°); 20Х1М1Ф1ГР, 20Х1М1Ф1БР (580°), 2Х12ВМБФР, 1Х12ВНМФ (550—565°), 14 ХН35ВТ (650°)
15 Камеры сгорания (листы)	ХН35ВТР (750°) 16

1) Major components; 2) steel and limiting operating temperatures; 3) boiler shells; 4) 16GNM; 5) steam line pipes and boiler superheater tubes; 6) 12Kh1MF (560°), 15Kh1M1F (580°), Kh18N12T (600°), 1Kh14N18V2-BR, 1Kh16N14V2BR (650-680°); 7) cylinders, nozzle boxes, fittings and other castings; 8) 20KhM-L (540°), 20KhMF-L (560°), 15Kh1M1F-1 (580°), 15Kh11MVF-L, 15Kh11MFB-L, 12Kh11V2NMF-L (580-600°), LA-1, EI402M-L (600-650°); 9) turbine disks and rotors and other forgings; 10) 25Kh1M-F (R2) (540°), 20KhMF-L (560°), 15Kh1M1F-1 (580°), 15Kh11MVF-L, 15Kh11-V2NMF-L (580-600°), LA-1, EI402M-L (600-650°); 11) moving blades and guide vanes of turbines; 12) 1Kh13, 2Kh13 (500°), 1Kh11MF, 18Kh11MFB (550°), 1Kh12VNMF (580°), Kh16N13M2B (600°), KhN35VT (650°), EI612K, EI607A (700°), EI 869, EI765 (750°); 13) fasteners (bolts, pins); 14) 25Kh1MF (510-530°), 25Kh2M1F (550°), 20Kh1M1F1TR, 20Kh1M1F1BR (580°), 2Kh12VMBFR, 1Kh12VNMF (550-565°), KhN35VT (650°); 15) combustion chambers (plates); 16) KhN35VTR (750°).

ponent (rotors, disks, buckets, bolts) steel are presented in Tables 3-6.

The temperature dependence of the mechanical properties of steel and alloys for turbine components is given in Figs. 2 and 3.

Rotor forgings for up to 100 megawatt capacity steam turbines are made from the 34KhM steel, forgings for high-pressure stage rotors of higher-capacity turbines (150-300 megawatt) are made from the 25Kh1M1F (R2) and 20Kh3MVF steels. Disk forgings from the 20Kh3MVF steel are

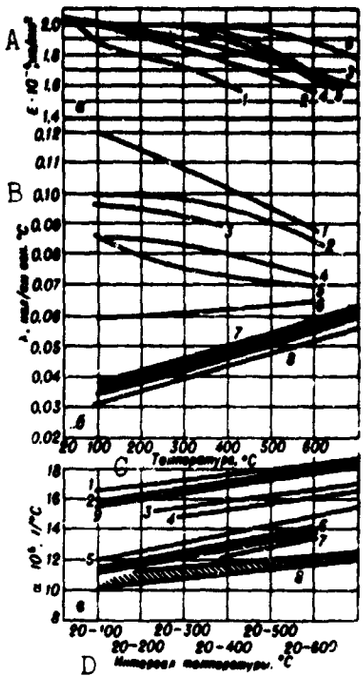

Fig. 4. Physical properties of turbine and boiler building steels. a) Modulus of elasticity (1) 20K, 22K; 2) Kh16N13M2B; 3) 3Kh19N9MVBT, Kh-35VT; 4) 25Kh1MF, 20Kh3MVF; 5) 1Kh13, 1Kh12VNMF; 6) EI607A, EI765); b) thermal conductivity (1) 20K, 22K; 2) 15Kh1M1F; 3) 34KhM; 4) 12Kh1MF; 5) 20Kh3MVF; 6) 1Kh12VNMF, 2Kh12VMBFR; 7) Kh18N12T, 1Kh14N18V2BR, Kh16-N13M2B, 3Kh19N9MVBT, EI607A, EI869, EI765; 8) KhN35VT, EI612K); c) mean liner expansion coefficient (1) Kh18N12T; 2) 1Kh14N18V2BR, 1Kh14N18V2B-R1; 3) 3Kh19N9MVBT, KhN35VT; 4) EI612K; 5) EI607A, EI869, EI765, 34KhM; 6) 20K, 22K, 15Kh1M1F, 25Kh1M1F, 12Kh1MF; 7) 20Kh3MVF; 8) 1Kh13, 1Kh12-VNMF, 2Kh12VMBFR; 9) EI402M-L).

are supplied with higher mechanical properties ($\sigma_{0.2}$ = 75 kg/mm^2) than rotor forgings ($\sigma_{0.2}$ = 65 kg/mm^2). In the 3Kh19N9MVBT steel after 10,000-20,000 hours at 600° and after 6000-10,000 hours at 650° an intermetalloid σ-phase which embrittles it at 20° is precipitated, which limits the service life of components from this steel. The Kh16N13M2B, 1Kh14N18V2BR1 and 3Kh19N9MVBT steels have low yield strength at operating temperatures and a high creep plasticity (plasticity store). The KhN35VT and EI612K steels have a high yield strength. The EI612K has a higher creep plasticity than the KhN35VT steel. The 1Kh12VNMF stainless chromium steel, which has the necessary heat resistance and high creep plasticity is a promising material for steam turbine rotors and gas

turbine disks operating at temperatures up to 600°. The 1Kh11MF, 1Kh12-VNMF and 2Kh11MFB stainless steels are used extensively for the moving blades of turbines of 150-300 megawatt capacity. Heat-resistant austenitic steel and nickel-chromium alloys are used primarily for the guide vanes and moving blades of gas turbines (KhN35VT, EI612K, EI607A, EI-869, EI765, etc.) at temperatures of 650-750°. Austenitic steels are also used for gas turbine disks (1Kh14N18V2BR1, 3Kh19N9MVBT, KhN35VT, EI612K). Austenitic steels are welded by using the KTI-5, KT-7, etc., electrodes.

Fasteners (bolts, pins) are made extensively from the 25Kh2MFA and 25Kh2M1F steels. The 20Kh1M1F1TR and 20Kh1M1F1BR steels are most relaxation resistant. Bolts and pins operating at 650-680° are made from the KhN35VT steel, while nickel-chromium alloys (EI765 etc.) are used for higher temperatures. The fasteners of cast turbine casings from stainless chromium steels are made from the 2Kh12VMBFR and 1Kh12VNMF steels.

The chemical composition and mechanical properties of steel for cast turbine components are presented in Tables 7 and 8. The 20KhM-L, 20KhMF-1 and 15Kh1M1F-1 steels have come into the most extensive use for castings.

The TsL-14, TsL-20M electrodes are used for welding the castings. The 15Kh11MVF-L and 15Kh11MFB-L, which have a good weldability, are promising for castings, nozzle boxes, valves and other components of large turbines. Castings from austenitic steels are used for working temperatures above 600°.

The physical properties of turbine and boiler building steels are presented in Fig. 4, and the uses are given in Table 9.

References: Liberman, L.Ya. and Peysikhis, M.I., Spravochnik po svoystvan staley, primenyayemykh v kotloturbostroyenii [Handbook on Properties of Steels Used in Boiler and Turbine Building], 2nd edition,

Moscow-Leningrad, 1958; Mikhaylov-Mikheyev, P.B., Spravochnik po metallicheskim materialam turbino- i motorostroyeniya [Handbook on Turbine and Engine Building Metallic Materials], Moscow-Leningrad, 1961; Sichikov, M.F., Metally v turbostroyenii [Metals in Turbine Building], Moscow, 1954; Liberman, L.Ya., Materialy, primenyayemyye v energomashinostrcyenii [Materials Used in Power Generating Machinery Building], Moscow, 1961; [Larichev, V.A.], Metall dlya ustanovok vysokogo davleniya [Metals for High-Pressure Installations], Moscow-Leningrad, 1948.

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[Transliterated Symbols]

4230 TY = TU = tekhnicheskiye usloviya = technical specifications

TWINNING – a form of plastic deformation in which a portion of a crystal reorients itself in a jump into a position parallel to the twinning plane, but in the opposite direction. Twinning can take place in the growth of crystal as well as on their formation. In the latter case twinning is sometimes (for example, in the case of iron and many kinds of steel) accompanied by audible snapping. The temperature dependences of the stress at which twinning starts and of resistance to brittle failure are frequently very close to one another, which points to the interrelationship between the processes of twinning and brittle failure; cracks, which then result in complete failure, are produced by twinning.

References: Schmid, E. and Boas, W, Plastichnost' kristallov, v osobennosti metallicheskikh [Plasticity of Crystals, in Particular of Metallic Ones]. Translated from German, Moscow-Leningrad, 1938; Fracture. Proceedings of an internation conference on the atomic mechanisms of fracture, held in Swampscott, Massachusets, April 12-16, 1959, ed. B.L. Averbach [a.o.], New York-London (1959).

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TWINNING SLIP – See Twinning.

TYPES OF ALUMINUM – classification of industrial varieties of aluminum in accordance with their content of impurities of iron, silicon, and copper. The types of aluminum shown in the table are standard (GOST 3549-55).

Types A000–A3 are ordinary-purity aluminum obtained directly from alumina by electrolysis of cryolite-alumina melts. Types AV0000–AV0 are

Chemical Composition of Aluminum (in %)

Марка	Al	2 Примеси (не более)				
		Fe	Si	Fe+Si	Cu	Всего
АВ0000 4.	99.996	0.0015	0.0015	—	0.0010	0.004
АВ000	99.99	0.0030	0.0025	—	0.0050	0.010
АВ00	99.97	0.015	0.015	—	0.0050	0.03
АВ0	99.93	0.04	0.04	—	0.01	0.07
А000	99.80	0.12	0.10	0.18	0.01	0.20
А00	99.7	0.16	0.16	0.26	0.01	0.30
А0	99.6	0.25	0.20	0.36	0.01	0.40
А1	99.5	0.30	0.30	0.45	0.015	0.50
А2	99.0	0.50	0.50	0.90	0.02	1.0
А3	98.0	1.1	1.0	1.80	0.05	2.0

1) Type; 2) impurities (no more than); 3) total; 4) AV.

high-purity aluminum obtained from ordinary-purity metal by electrolytic refining. High purity aluminum (designated by the letter "V") is employed principally for the production of chemical apparatus and electrical capacitors and for research work. Aluminum of types A000, A00, and A0 is used in the manufacture of foil, for protecting (plating) sheets, for cables and current carriers, in the chemical industry, and for production of high-purity alloys. Aluminum of type A1 is widely employed in the electrical industry (for the manufacture of cables, busbars, etc.), in machine building, in the manufacture of aluminum alloys, and in the fabrication of containers. Aluminum of type A2 is used pri-

marily for the production of alloys, cables, current carriers, and ligatures. Aluminum of type A3 is used when less rigorous requirements are to be met: in the production of alloys, the manufacture of ligatures, and aluminothermy. In setting up plants for casting aluminum and aluminum-alloy ingots by the continuous method aluminum of types A000, A00, A0, A1, A2 and A3 with a silicon-iron ratio of no more than one should be used to improve casting properties. In addition to iron, silicon, and copper, aluminum may contain small (of the order of 0.0001-0.008% by weight) impurities of zinc, titanium, sodium, manganese, arsenic, antimony, aluminum oxides, and certain other compounds and elements. The content of these unstandardized impurities must be taken into account in each individual case. For example, a sodium content of more than 0.005% reduces the properties of Al-Mg alloys. Impurities of titanium or manganese have a detrimental influence on the conductivity of aluminum, etc.

Aluminum is produced in smooth and necked ingots, wire billets, flat and round billets, and aluminum plate.

References: Al'tman, M.B., et al., Plavka i lit'ye legkikh splavov [Melting and Casting of Light Alloys], Moscow, 1956; Belyayev, A.I., Metallurgiya legkikh metallov [Metallurgy of Light Metals], 4th Edition Moscow, 1954.

TYPES OF FRACTURE – the classification of the various kinds and cases of fracture. Types of fracture are often differentiated by the ratio of Tearing to Shear, which can be evaluated both statistically (from the frequency curve for small sections) and from the ratio of the tear to the shear areas were of the crystalline to the fibrous regions (see Fractography). Other differences among the types of fracture reduce to the proportions of fatigue and instantaneous fracture, of fatigue and prolonged static fracture, of mechanical and corrosive factors, etc.

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ULTIMATE DURABILITY – a characteristic of the durability of a material with a horizontal segment in its Fatigue curve. In tests with a constant coefficient of cycle asymmetry the ultimate durability is defined as the greatest maximum (with respect to amplitude) cyclic stress at which the specimen withstands fatigue fracture for an arbitrary number of cycles. In tests with a constant mean cyclic stress the ultimate durability is defined as the greatest cyclic-stress amplitude at which the specimen withstands fatigue fracture for an arbitrary number of cycles. Ultimate durability is expressed as a nominal stress and is designated as σ_μ and τ_μ, where μ is the coefficient of cycle asymmetry.

G.T. Ivanov

ULTIMATE STRENGTH – the stress corresponding to the maximum load that the specimen can withstand during testing to fracture. We can distinguish the following types of ultimate strength, in accordance with the type of testing: tensile (short-term resistance) σ_b, compressive σ_{-b}, warping σ_{bsm}, bending σ_{bizg}, tortional τ_b, and shear (shear resistance) τ_{sr}. In all types of testing other than tensile testing the maximum load equals the load necessary to cause fracture or appearance of the initial crack. In these cases the ultimate strength characterizes the fracture resistance; in tensile testing this is true of those structural materials that do not neck. In the majority of instances the fracture of structural materials during tensile testing is preceded by necking, i.e., local plastic deformation arising in many materials when the uniform reducti in area reaches 5-15%. In this case the fracture load may be considerably lower than the maximum load corresponding to initiation of necking (see the figure in the article on Physical yield strength) and the ultimate strength characterizes the resistance to plastic deformation. Engineering generally utilizes arbitrary ultimate strengths, which are determined without taking into account the actual cross-sectional stress distribution and the change in specimen size during deformation; the term "arbitrary" is usually omitted. The arbitrary ultimate strength is designated by the symbol σ_b or τ_b, sometimes with an additional subscript indicating the type of test.

The tensile (σ_b), compressive (σ_{-b}) and single-shear (τ_{sr}) ultimate strength are calculated by dividing the maximum load (in kg) by the initial cross-sectional area of the specimen F_0 (in mm^2 or cm^2);

in double shear the maximum load is divided by twice the cross-sectional area of the specimen (see Shear testing). It is possible to determine σ_{-b} only when the specimen fractures under a gradually increasing load. Highly plastic materials (copper, aluminum, etc.) generally do not fracture and σ_{-b} is replaced by the stress at which cracking occurs on the lateral surface of the test specimen. For the majority of structural alloys the arbitrary compresive ultimate strength exceeds the tensile ultimate strength by a factor of 1.5-2.5; for brittle materials (tool steel, cast iron, glass) σ_{-b} generally exceeds σ_b by a factor of 3-7 (Table). In nonuniform composite materials, such as Glass textolite, the ultimate compressive strength may be considerably lower than the ultimate tensile strength in the sheet plane; this is due to the loss of stability on the part of individual elements of the complex material during compressive testing. The ultimate shear strength of metals and alloys usually amounts to 0.6-0.75 of their ultimate tensile strength, provided that they exhibit viscous fracture (see Viscous strength); in brittle materials (e.g., cast iron) τ_{sr} may exceed the ultimate tensile strength (see Table). During torsion and bending the stresses are distributed nonuniformly over the cross section of the specimen and the ultimate strength characterizes the stress on the marginal, most heavily loaded fibers at the instant of fracture. The arbitrary ultimate bending and torsional strengths are calculated on the basis of an assumed linear (elastic) stress distribution over the specimen cross section, using the formulas for the resistance of materials:

$$\sigma_{b.изг}=M_{изг}/W \text{ и } \tau_b=M_{кр}/W,$$

where M_{izg} and M_{kr} are the bending and torsional moments required for fracture in kg-cm or kg-mm and W is the moment of cross-sectional resistance in cm^3 or mm^3, depending on the cross-sectional size and shape

of the specimen. In evaluating the characteristics of structural materials rectangular specimens are most often used for bending tests and round specimens for torsional tests. The ultimate bending and torsional strengths are calculated from the formulas:

$$\sigma_{b\,изг} = 6M_{изг}/bh^2 \text{ и } \tau_b = 16M_{кр}/\pi d^3,$$

where d is the diameter, b the width, and h the height of the specimen in mm or cm.

Ultimate Tensile, Compressive, Bending, Shear, and Torsional Strengths of Certain Structural Materials

1 Материал	2 Состояние материала	3 Пределы прочности (кг/мм²) при: 4 растяжении ($\sigma_в$)	5 сжатии ($\sigma_{-в}$)	6 срезе ($\tau_{ср}$)	7 кручении ($\tau_в$)	8 изгибе ($\sigma_{в\,изг}$)
9 Алюминиевые сплавы: Д1	Закаленный и естественно состаренный 29	41	100	27	38	—
10 Д16		52	90	30	39	—
11 Магниевые сплавы: МА5	Закаленный 30	32	46	18	21	—
12 ВМ65-1	Закаленный и искусственно состаренный 31	33	47	16	23.5	—
13 МЛ2	Литой 32	10	16	7	—	—
14 МЛ5	Закаленный и искусственно состаренный 31	25	34	14	17	—
15 Бронза БрАЖН10-4-4	Литой в кокиль 33	65	130	45	—	—
16 Углеродистая сталь У7	Закаленный и отпущенный при 200° 34	75	350	—	170	—
17 Чугун магниевый МН40-10	Отожженный 35	55	180	—	—	—
18 Чугун антифрикционный ЧМ1,8	Отожженный	33	115	—	—	60
19 Чугун жаростойкий ЧЯ	Литой	25	210	36	35	—
20 Чугун для поршневых колец ПЧ	Состаренный 36	28	140	30	33	—
21 Стекловолокнит марки В	—	2.5	6	—	—	9
22 Волокнит	—	3.5	13.5	—	—	8
23 Стеклотекстолиты:						
24 ВПС-1	—	37	16	1.3	—	17
25 ВФТС	—	40	17	—	—	11
26 Стекло органическое: СОЛ	—	7	14	7.5	9.7	9.9
27 СТ-1	—	8	17	8	—	12
28 Ситалл	—	—	10—30	—	—	3—6

1) Material; 2) state of material; 3) ultimate strength (kg/mm^2) on; 4) extension ($\sigma_в$); 5) compression ($\sigma_{-в}$); 6) shear (τ_{sr}); 7) torsion (τ_b); 8) bending (σ_{bizg}); 9) aluminum alloys: D1; 10) D16; 11) magnesium alloys: MA5; 12) VM65-1; 13) ML2; 14) ML5; 15) BrAZhN10-4-4 bronze; 16) U7 carbon steel; 17) MN40-10 magnesium cast iron; 18) ChM1,8 antifriction cast iron; 19) ChYa high-hot-strength cast iron; 20) PCh piston-ring cast iron; 21) type V steklovoloknit; 22) voloknit; 23) glass textolites; 24) VPF-1; 25) VFTS; 26) organic glass: SOL; 27) ST-1; 28) Sitall; 29) quenched and naturally aged; 30) quenched; 31) quenched and artificially aged; 32) cast; 33) cast in chill molds; 34) quenched and tempered at 200°; 35) annealed; 36) aged.

Bending tests are especially important in determining the ultimate strength of low-plasticity or brittle materials, since reliable determination of this quantity by tensile testing is hampered by the fact that the load may be eccentrically applied (this can be eliminated by use of special complex axial alignment devices). The ultimate bending strength of cast iron and glass is generally 2-5 times greater than their ultimate tensile strength (see Table), both because of uncompensated eccentricity and as a result of the appearance of a sort of scale effect: when specimens of the same size are used those subjected to bending are loaded over a comparatively small cross-sectional area lying near the loaded layers, while the entire cross section is loaded during extension. The ultimate bending strength of nonuniform composite materials is often lower than their ultimate tensile strength; this results from disruption of the adhesion between the binder and the filler. Smooth specimens of plastic structural materials do not as a rule fracture during bending tests and their ultimate bending strength consequently cannot be determined. During warping the stresses are distributed nonuniformly over the aperture and the ultimate warping strength (σ_{bsm}) is calculated by dividing the fracture load by the projected warping area (see Warping tests). The ultimate warping strength is infrequently determined; according to the available data, it exceeds the ultimate tensile strength by a factor of 1.6-1.7 for aluminum and titanium alloys and by a factor of 1.4-1.5 for magnesium alloys.

True ultimate strengths are often employed in studying the general mechanisms of formation and investigating the relationship between strength indices on extension and under other types of stress (see True stress). The true ultimate tensile strength F_b characterizes the ratio of the maximum load to the actual cross-sectional area of the specimen F_b at the instant that P_{maks} is reached; it is calculated

from the formula $S_b = \sigma_b/(1 - \psi_b)$, where ψ_b is the uniform transverse reduction in specimen area. In medium-strength structural steels and aluminum and magnesium alloys S_b is generally 8-12% higher than σ_b; in high-strength steels the former is 2-4% greater, while in plastic brasses and certain types of stainless steel it is 20-30% higher. The true ultimate compressive strength S_{-b} is determined by dividing the fracture load by the cross-sectional area of the specimen at the instant of fracture. S_{-b} is always less than σ_{-b}, the magnitude of this difference increasing with the plasticity of the material. The true ultimate bending strength of a rectangular specimen of width b and height h and the ultimate torsional strength of a round rod of radius r are calculated from the formulas

$$S_{b\text{изг}} = \frac{2}{bh^2}\left(2M_{\text{изг}} + v\frac{dM}{dv}\right)$$

and

$$t_b = \frac{1}{2\pi r^2}\left(3M_{\text{кр}} + \theta\frac{dM}{d\theta}\right),$$

where v is the angle of inclination of the tangent to the specimen axis in the boundary section ($v = \delta l/h$, where l is the computed length and δ is the elongation of an extended fiber at fracture) and θ is the twist angle (in radians) per unit specimen length at fracture.

S.I. Kishkin-Ratner

ULTRAHARD BRONZE – bronze which has been pressure-worked to a high degree of deformation. Ultrahard bronzes in this condition have a high elastic limit, ultimate strength, and hardness coupled with low plasticity (δ = 1-2%). Ultrahard bands and strips are produced from BrKMts3-1 silicon-manganese bronze, BrOF6.5-0.15 tin-phosphorus bronze, and BrOTs4-3 tin-zinc bronze, while bars with a hardness of 180-230 kg/mm^2 are fabricated from BrOF7-0.2 bronze. Ultrahard bronzes are used for flat and helical springs, the grids of calibration screws, balance beams, and supports.

O.Ye. Kestner

ULTRA-HIGH-STRENGTH STEEL – steel with an ultimate strength of 240-300 kg/mm^2 or more. Its relative elongation, relative reduction in area, and impact strength have values characteristic of high-strength structural steel with an ultimate strength of 160-220 kg/mm^2. The high strength of this steel is achieved by methods which conjoin exposure to mechanical and thermal factors. These methods include: 1) cold working during the drawing of steel wire, whose σ_b may reach 450 kg/mm^2 as a result of mechanical hardening at high degrees of plastic deformation (95% or more) and special heat treatment. 2) Thermal-mechanical processing of strips, sheets, rolled shapes, stampings, forgings, and other semifinished products and components, which can be given their basic size and shape by pressure working at a sufficiently high (50% or more) degree of deformation. In this case σ_b may reach 280-320 kg/mm^2.

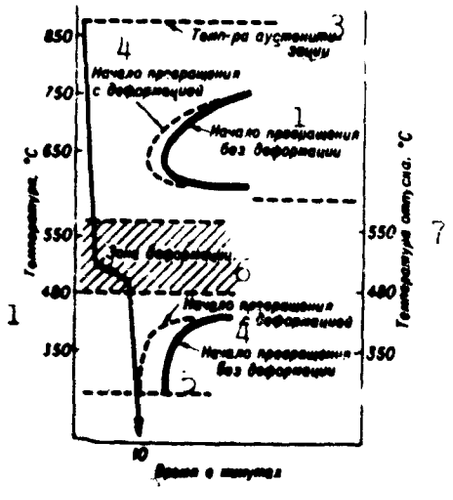

Fig. 1. Diagram of thermal-mechanical treatment of steel (ausforming). 1) Temperature, °C; 2) time in minutes; 3) austenitization temperature; 4) beginning of transformation with deformation; 5) beginning of transformation without deformation; 6) deformation zone; 7) tempering tem-

perature, °C.

Thermal-mechanical processing of ultra-high-strength steel combines quenching and pressure working, which makes it possible to raise the strength and plasticity of the martensite formed by quenching. The fact that it is possible to obtain steel in which high viscosity is conjoined with high strength and hardness by a combination of heat treatment and pressure working was known long ago to armorers, who employed quenching as the final operation in forging. Scientific attention was first called to this practical procedure by the noted Russian metallurgist P.P. Anosov, who developed a quite advanced technique for the production of Damascus steel during the middle of the 19th century. At present, thermal-mechanical processing essentially consists in cold working of austenite at a temperature below its recrystallization point and subsequent transformation to martensite. Cold working can also be conducted at a temperature above the recrystallization point of austenite, but the deformation time must be limited.

Thermal-mechanical processing of ultra-high-strength steel is carried out in the following manner. A blank fabricated from steel whose alloying permits execution of the scheme shown in Fig. 1 is heated to a temperature 100-200° above the critical point Ac_3 to permit formation of a homogeneous γ-solid solution (austenitization stage). It is then cooled to a temperature below the recrystallization point of austenite (500°), at which deformation (rolling, stamping, pressing, etc.) is carried out. The minimum degree of deformation (reduction in area) required to produce noticeable hardening of the steel depends on its carbon content, amounting to 50% for 0.4% C; optimum hardening is observed at deformations of 90% or more. In order to keep its temperature from dropping to the level at which loss of austenite stability begins, the

blank being deformed cannot be cooled by the tool (roller, punch, etc.). For this purpose the blank is placed in a container of high-plasticity steel or machined with a heated tool. It is also necessary to take into account the fact that the stability of the austenite depends on the degree of deformation, decreasing as the latter increases (as shown by the dash lines in Fig. 1). After deformation the blank is subjected to final cooling in air or in water, depending on the alloying of the steel.

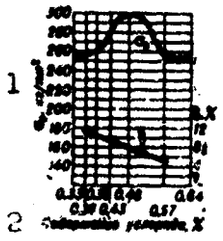

Fig. 2. Influence of carbon content on the mechanical characteristics of type VL-1 steel after thermal-mechanical processing (Si ≈ 1%, Mn ≈ 1.2%, Cr ≈ 1.75%, Ni ≈ 2.25%, W ≈ 1%, and Mo = 0.45%). 1) kg/mm^2; 2) carbon content, %.

Fig. 3. Influence of degree of deformation on the mechanical characteristics of steels with different carbon contents. Tempering at 100°. 1) kg/mm^2; 2) deformation (reduction in area), %.

The strength of ultra-high-strength steel is governed by: 1) its carbon content – as this factor increases the strength of the steel rises at first, reaches a maximum, and then decreases (Fig. 2); 2) its degree of deformation – as this factor increases the strength of the steel rises (Fig. 3); 3) the austenitization temperature – as this factor increases the strength of the steel rises, the increase in strength halting at the temperature of intensive grain growth and the strength of the steel beginning to decrease; 4) the deformation temperature – the in-

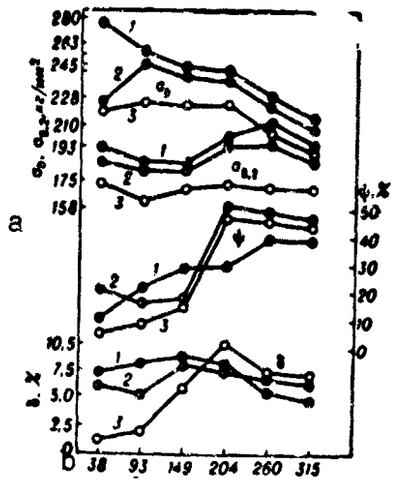

Fig. 4. Influence of tempering temperature (holding time – 1 hr) on the mechanical characteristics of steel (0.40% C, 4.75% Ni, 1.45% Cr, and 1.55% Si): 1) Degree of deformation on 75% extension; 2) degree of deformation on 25% extension; 3) without deformation. a) kg/mm^2; b) tempering temperature, °C.

crease in this factor as the austenite recrystallizes causes a drop in the strength of the steel; 5) the tempering temperature – as this factor increases the strength of ultra-high-strength steel decreases more sharply than is the case for ordinary high-strength steel (Fig. 4); 6) the metallurgical quality of the metal – purification with respect to sulfur, phosphorous, and nonmetallic inclusions, vacuum smelting, and elimination of crystallization and liquation defects in the ingot by use of crystallizers during electric-slag and electric-arc remelting increase the strength and plasticity of the steel more markedly at low tempering temperatures and especially when tempering is not employed. It should be noted that a slight additional increase in the strength of ultra-high-strength steel can be obtained by application of a strong magnetic field during the martensitic transformation.

The strength of steels which retain austenitic stability on cooling to 20°, in which the austenite decomposes on plastic deformation, and which are subject to further age hardening (steels bounding the

transition class) can be increased by mechanical cold working to high degrees of deformation (up to 90%) and subsequent aging. True ultra-high-strength steels can also be obtained by plastic deformation of austenitic and transition steels at low temperatures (–70° or less). The fact that all these technological procedures require plastic deformation to an extent that greatly alters the size and shape of the component, the virtual impossibility of conducting operations such as forming, bending, etc., after hardening, and the fact that welding is made extremely difficult by the substantial softening (by a factor of more than 2) of the welded joint greatly restrict the use of ultra-high-strength steel as a structural material. Wide utilization of ultra-high-strength steel is also hampered by its sensitivity to stress concentrations, which greatly reduce its structural strength, and the difficulties presented by machining, which can be conducted only by special methods (e.g., electric-erosion and electric-discharge polishing); the latter method requires that great care be taken to avoid burning. Figure 5 shows the brittle strength of VL1 steel after quenching and thermal-mechanical processing. Essentially, this steel can be used only for the fabrication of components that are given their final shape and quality by stamping or rolling to considerable degrees of deformation (30–90%) and which require minimal machining. It must be taken into account that steels whose austenitic stability corresponds to that shown in Fig. 1 can be given the strength of ultra-high-strength steel only in light components, since it is difficult to provide the cooling rate necessary for retention of stable austenite when dealing with a large mass of metal. Ultra-high-strength steel is most easily produced in the form of strips, rolled plates, and small tubing and stampings.

Thermal-mechanical processing is somewhat more widely employed with an inverted hardening scheme, mechanical hardening following rather

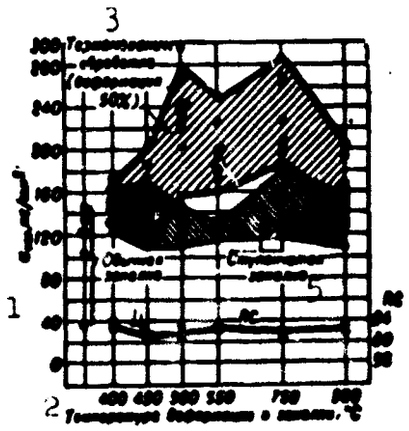

Fig. 5. Brittle strength of type VL1 steel (C = 0.63%) after ordinary and stepwise quenching and thermal-mechanical processing. 1) kg/mm^2; 2) deformation and quenching temperature, °C; 3) thermal-mechanical processing (50% deformation); 4) ordinary quenching; 5) stepwise quenching.

than preceding heat treatment and the decomposition products of the solid solution (martensite or bainite) being subjected to deformation.

In this case the degree of deformation required to achieve high strength can be substantially reduced (to 10-25%); when this scheme is used in conjunction with aging the degree of deformation can be reduced to 5% or less.

The inverted scheme makes it possible to obtain a σ_b = 240-280 kg/mm^2, a lower sensitivity to stress concentrators, and a higher lability than the direct method (e.g., austenitic + martensitic transformation).

N.M. Sklyarov

ULTRASONIC FLAW DETECTION – flaw detection, which combines nondestructive testing methods based on the use of elastic vibrations in the ultrasonic (above 20 kcps) and sonic frequency range. Ultrasonic flaw detection methods which use primary sonic frequencies are usually called acoustic methods (see Acoustic Flaw Detection). Ultrasonic flaw detection is used for detecting internal and surface flaws in shaped semifinished products, castings and finished products with simple configurations, which are made from metallic and nonmetallic materials. It is also used for thickness measurements when the product is accessible from one side. Ultrasonic flaw detection methods are based on the effect the flaw has on the conditions of propagation and reflection of elastic waves or on the vibrational regime of the product. Elastic waves are capable to propagate in materials over large distances. Longitudinal, transverse (shear), surface, normal (free, Lamb), rod and other waves can exist in a solid body. Only longitudinal waves can be propagated in liquids and gases.

The rate of propagation of elastic waves depends on their type and on the properties of the medium material (elastic constants and density). The velocity c_t of transverse waves for the majority of materials comprises 0.325-0.68 of the velocity c_l of longitudinal waves in an unbounded medium; the velocity of surface waves is about 0.9 of the velocity of transverse waves. The propagation rates of normal and rod waves depend on the frequency, product thickness and the vibrational mode. Incidence at the interface of two media results in reflection, refraction and wave transformation. For example, when the longitudinal

wave L (Fig. 1) is incident on the interface of two solid media, the longitudinal wave L' and the transverse wave T' which was produced by transformation is reflected into the first medium. The longitudinal L" and transverse T" waves are propagated through the second medium. The angles of reflection and refraction are defined by the relationship:

$$\frac{\sin\alpha}{c_{l_I}}=\frac{\sin\beta}{c_{t_I}}=\frac{\sin\alpha'}{c_{l_{II}}}=\frac{\sin\beta'}{c_{t_{II}}},$$

where c_{l_1} and c_{l_2} are the rates of propagation of the longitudinal waves in media I and II, respectively; c_{t_I} and $c_{t_{II}}$ are the rates of propagation of transverse waves in media I and II.

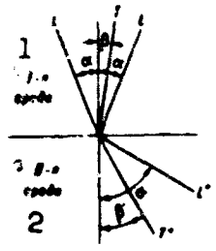

Fig. 1. Reflection and refraction of elastic waves at the interface between two media. 1) Medium I; 2) medium II.

Selecting an angle of incidence α of the longitudinal wave and using the complete internal reflection phenomenon, it is possible to obtain only a transverse or only a surface wave in medium II, which is practically used in ultrasonic flaw detection to excite these waves in an article. A measure of the reflection at the interface between two media is the reflection factor R, which is defined as the ratio of the intensity of the reflected to the intensity of the incident wave. In the case of normal incidence at the interface between two media, which are sufficiently extended in the direction of wave propagation, $R = (W_I - W_{II})^2/(W_I + W_{II})^2$, where W_I and W_{II} are the specific wave resistances of media I and II. (W, the specific wave resistance, is defined as the product of the density ρ of a medium and the rate of prop-

agation c of an elastic wave of a given type in it.) Table 1 presents the values of specific wave resistances and rates of propagation of longitudinal and transverse waves for certain materials.

TABLE 1

Rates of Propagation of Elastic Waves and Specific Wave Resistance of Certain Materials

1 Материал	2 Скорость распространения продольных упругих волн в безграничной среде (м/сек)	3 Скорость распространения поперечных упругих волн (м/сек)	4 Уд. волновое сопротивление для продольных волн $\left(\frac{г}{см^2 \cdot сек}\right)$	5 Уд. волновое сопротивление для поперечных волн $\left(\frac{г}{см^2 \cdot сек}\right)$
Алюминий 6	6260	3080	$1{,}69 \cdot 10^6$	$0{,}83 \cdot 10^6$
Железо 7	5850	3230	$4{,}56 \cdot 10^6$	$2{,}52 \cdot 10^6$
Латунь 8	4430	2123	$3{,}61 \cdot 10^6$	$1{,}73 \cdot 10^6$
Органич. стекло 9	2670	1121	$0{,}315 \cdot 10^6$	$0{,}132 \cdot 10^6$
Вода 10	1500	—	$0{,}15 \cdot 10^6$	—
Масло трансформаторное 11	1425	—	$0{,}128 \cdot 10^6$	—
Воздух 12	331	—	43	—

1) Material 2) rate of propagation of longitudinal elastic waves in a boundless medium (m/sec); 3) rate of propagation of elastic transverse waves (m/sec); 4) specific wave resistance for longitudinal waves (g/cm^2-sec); 5) specific wave resistance of transverse waves (g/cm^2-sec); 6) aluminum; 7) iron; 8) brass; 9) organic glass; 10) water; 11) transformer oil; 12) air.

Upon incidence of an ultrasonic (UZ) wave on a plane interface, the dimensions of which are substantially larger than the wavelength, a mirror reflection takes place; here the angle of incidence is equal to the angle of reflection. Obstacles with a rough surface give diffracted reflection.

The propagation of elastic vibrations in materials is accompanied by irreversible energy losses, a measure of which is the damping coefficient δ, which is defined as $\delta = \frac{1}{x - x_0} \ln \frac{A_0}{A}$, where A_0 and A are the vibrational amplitudes in cross sections with coordinates x_0 and x, respectively (it is assumed that reference is had to a plane wave). The

damping coefficient , usually expressed in terms of nepers per centimeter (np/cm), depends highly on the material's properties and on the frequency of elastic vibrations. For the majority of liquids the coefficient δ is proportional to the square of the frequency, for solid bodies the increase in δ with an increase in the frequency is governed by a more complex law. The lowest losses for materials used in machine building are characteristic of homogeneous metals and alloys with a finely-grained structure (pressureworked semifinished products from light alloys, highly deformed steels, etc.). High values of δ are characteristic of weakly deformed forgings, products from complex heterogeneous alloys, ingots from light and heat-resistant alloys, cast iron and multiphase materials and materials with a coarsely-grained structure. The greatest losses are characteristic of nonmetallic materials, i.e., rubber, plastics, laminated plastics, etc. As δ increases, the distance over which the elastic waves propagate is reduced. Hence when inspecting materials with high losses use is made of lower frequencies. If the length of the elastic wave is eommesurable with the dimensions of the metal's grains, then a perceptible energy energy reflection takes place at the boundaries of these grains. As a result, interferences arise which make inspection difficult and which usually must be eliminated also by reducing the vibration frequencies. In principle, the sensitivity of ultrasonic flaw detection methods is limited by the diffraction of the elastic waves. Nonhomogeneities in materials which extend over less than half of a wavelength are usually not detected. As the frequency is reduced, the size of the flaws which are detected is increased.

Ultrasonic waves are usually radiated and received by piezoelectric (quartz, barium titanate, lithium sulfate, etc.), transducers. The transducers are mounted in search heads which serve for seeking the

flaw in the product being inspected. Separate and combined type search heads are used in ultrasonic flaw detectors. In separate heads the functions of the emitter and receiver are performed by different piezo-elements, while in combined heads both functions are performed by the same element. The emission and reception of ultrasonic waves is directed and the directionality is the more high, the greater the ratio of the transducer diameter to the wavelength. For the majority of heads used the angles within the limits of which the emission and reception of elastic vibrations takes place are from 5 to 60°. Elastic waves are transmitted from the search head to the article being inspected and back by the contact, immersion or contactless methods. In the first case the ultrasonic waves pass through a layer of fluid (couplant) with a thickness smaller than the ultrasonic wavelength. The couplant (oil, water, etc.) is applied to the product surface before inspection. In acoustic flaw detection methods, which use primarily sonic frequencies, use is made of the dry contact between the product and the head. In the immersion method the acoustic contact is created by using a thick layer of fluid, for which purpose the inspected product is immersed in a bath, or special heads with a fluid-filled gap are used. In the contactless method the ultrasonic vibrations are emitted and received through an air layer.

The utilization of a large number of wave types in a wide frequency range with pulsating or continuous emission, of various methods for introducing the vibrations and the use of several physical principles, makes ultrasonic flaw detection one of the most universal methods of nondestructive testing.

A distinction is made between five principal methods of ultrasonic flaw detection: reflection method, shae (or through-sounding method), resonance, impedance methods and the method of free vibrations. The

last two methods belong to acoustic flaw detection. Table 2 presents certain data which show the variety of variable parameters which are used in different supersonic flaw detection methods.

The ultrasonic reflection method is based on the sending into the product being inspected of elastic vibrations in short pulses and on the receiving of the reflected signals. It is one of the more universal flaw detection methods. It is used extensively for detecting internal and surface flaws in metal semifinished products and in products with a simple shape (from thin sheets and wire to forgings with large overall

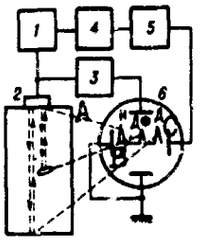

Fig. 2. Block diagram of an ultrasonic reflection flaw detector. A) N; B) D_f; C) D.

dimensions), and less frequently for flaw detection of products from nometals (for example, porcelain, insulators, etc.). All the aforementioned types of elastic waves are used. It is used in the contact, immersion and contactless versions.

The ultrasonic contact reflection flaw detector (Fig. 2) operates as follows: electric pulses generator 1 excites the piezoelectric inducer of the search head 2, which radiates pulses of elastic vibrations into the product being inspected. The elastic pulse is propagated through the product in the form of a directed beam, reaches the opposite face (bottom), is reflected from it and returns to search head. The piezoelectric element of head 2 transforms a part of the received ultrasonic energy and the electric voltage pulse. The latter is amplified by receiver 3 and is fed to the plates of the cathode ray tube 6,

TABLE 2

Methods of Ultrasonic Flaw Detection

Метод 1		Измеряемые параметры 2	Вид применяемых упругих колебаний 3	Излучение 4	Способ ввода колебаний 5	Диапазон используемых частот 6
Эхо-метод 7		Время прихода, амплитуда и фаза отраженных сигналов 8	Продольные, поперечные, поверхностные, нормальные, стержневые 9	Импульсное 10	Контактный со смазкой, иммерсионный, струйный, бесконтактный 11	0.2–25 *Мгц* 12
Теневой 13	Обычный вариант 14	Изменение интенсивности поля после прохождения УЗ волн через изделие 15	Продольные, нормальные 16	Непрерывное, импульсное 17	Иммерсионный, контактный со смазкой 18	50 кгц–5 *Мгц* 19
	Зеркальный вариант 20	Изменение интенсивности поля после двойного прохождения УЗ волн через изделие 21	То же 22	Импульсное 10	То же 22	0,5–10 *Мгц* 12
Резонансный 23		Резонансные частоты изделия, острота резонанса 24	Продольные 25	Непрерывное 26	Контактный со смазкой, иммерсионный 27	0,5–20 *Мгц* 12
Импедансный * 28		Механический импеданс (полное механич. сопротивление) 29	Изгибные	То же 22	Сухой контакт 31	1–8 кгц 19
Метод свободных колебаний * 32		Изменение спектрального состава, амплитуды и декремента затухания ударно возбужденных колебаний 33	То же 22	Импульсное (удар по изделию) 34	То же 22	50 гц–25 кгц 35 19

*See Acoustic Flaw Detection.

1) Method; 2) parameters being measured; 3) kind of elastic vibrations being used; 4) radiation; 5) method by which the vibrations are introduced; 6) range of frequencies used; 7) reflection method; 8) time of arrival, amplitude and phase of the reflected signals; 9) longitudinal, transverse, surface, normal, rod; 10) pulsating; 11) contact with couplant, immersion, jet contactless; 12) megacps; 13) shade; 14) standard version; 15) change in the field intensity after passing of ultrasonic waves through the product; 16) longitudinal, normal; 17) continuous, pulsating; 18) immersion, contact method with couplant; 19) kilocps; 20) mirror version; 21) change in the field intensity after double passing of ultrasonic waves through the product; 22) same as above; 23) resonance; 24) resonance frequencies of the product, sharpness of resonance; 25) longitudinal; 26) continuous; 27) contact with couplant, immersion; 28) impedance*; 29) mechanical impedance (total mechanical resistance); 30) deflected; 31) dry contact; 32) method of free vibrations*; 33) change in the spectral composition, amplitude and damping decrement of shock-excited vibrations; 34) impulse (hitting the product).

deflecting the beam along the vertical. Simultaneously with the electric pulses generator, the timer 4 starts up scanner 5, which reflects the electron beam in the horizontal direction. The entire cycle is repeated periodically many times per second. The initial signal (N) in

the left side of the tube's screen corresponds to the instant when the pulse is sent into the product. The bottom reflected signal (D) is shifted relative to the initial signal (N) through the time needed for the passing of the elastic waves to the bottom face and back. If a flaw is present, the signal reflected from it (Df) reaches the head earlier and is visible on the screen between the initial and the bottom pulse. When the immersion version of the reflection method is used additional reflected signals, which are due to the reflection of ultrasonic pulses from the liquid-product interface (Fig. 3) are observed on the flaw detector screen. The distance h between the head and the product is selected in a manner such that the signal II, produced by the second reflection of the pulse in the fluid-filled interval should take place after the bottom signal.

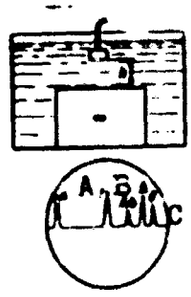

Fig. 3. Position of the head and the product and the image on the flaw detector screen when inspecting by the immersion version of the ultrasonic reflection method. A) N; B) D; C) Df.

Longitudinal signals are introduced normal or at moderate angles to the product surface, transverse, surface, normal and rod waves are usually excited by transforming longitudinal waves which impinge at an angle at the head-product interface (contact version) or fluid-product interface (immersion version). A dead zone (MZ) is peculiar to the reflection method. The dead zone is a section in the product, flaws in which cannot be detected. When inspecting by longitudinal ultrasonic waves the dead zone embraces material layers which adjoin the surface

at which the ultrasonic waves are introduced and to the bottom surface opposite it. The presence of the dead zone is due to the fact that the signals reflected from flaws situated near the aforementioned surfaces of the product combine with the initial or bottom signals. The dead zone is reduced in size with a decrease in the pulse duration. When separate heads are used, the dead zone adjoining the surface where waves are introduced is due to the directionality in sending and receiving the ultrasonic waves. Transverse, surface, normal and rod waves are usually capable of detecting flaws in layers adjoining the surface. Products with a complex shape have dead zones which are produced by the geometry of the given products. As the complexity of shape is increased, the volume of the dead zone is usually increased.

The greatest sensitivity of the reflection method is achieved when inspecting products from homogeneous materials with fine-grained structure. Inspection of coarse-grained materials (for example, castings) is made difficult by interfering reflection from boundaries of individual crystallites and high scattering of the ultrasonic waves. As the frequency of ultrasonic vibrations is reduced (the wavelength λ increased), the interference level is reduced and conditions for wave propagation are improved However, this also increases the dimensions of the minimum flaw that can be exposed, which are approximately equal to $\lambda/2$.

The contact version of the reflection method is used primarily for inspecting unique and serially produced semifinished and finished products (see Flaw Detection in Forgings and Stampings, Flaw Detection in Rolled Plates). The method consists in displacing the flaw detector head along a previously lubricated (usually with oil) product surface, simultaneously following the image on the instrument's screen (or the signals of an automatic flaw signaling device). As the surface finish is improved, the sensitivity is increased, for which reason surfaces

are frequently finished to V5-V7 before ultrasonic inspection. The type of elastic waves to be used is selected depending on the inspection conditions. Flaws in products more than 15-20 mm thick oriented at moderate angles to the wave introduction surface are detected by longitudinal ultrasonic waves. Combined type heads which emit perpendicular to the ultrasonic wave introduction surface are usually used for inspection. Here the dead zone which adjoins this surface comprises 4-8 mm for frequencies of 2.5-5.0 megacps and 10-15 mm for frequencies of 1.5-1.8 megacps. The use of separate heads makes it possible to reduce the dead zone to 1-1.5 mm. The dead zone adjoining the bottom surface for products less than 200-250 mm thick comprises 4-5 mm for frequencies of 2.5-5.0 megacps and 6-8 mm for for frequencies of 1.5-1.8 megacps. As the product thickness increases, the dead zone becomes larger; however, this can be prevented by using special means (retarding the flaw detector scanning, establishing the position of the bottom signal by a depth gage mark, etc.).

Flaws in products more than 5-7 mm thick oriented at an appreciable angle to the surface of ultrasonic wave introduction (radial cracks in disks, flaws in weldded butt joints, etc.) are detected by transverse waves. Surface waves are used for detecting surface and subsurface flaws. Flaw detection of sheets and shells (particularly of think, 0.1-5 mm thick) is performed by normal ultrasonic waves, which are excited by longitudinal waves impinging at angle to the product boundary.

General-purpose ultrasonic reflection contact flaw detectors have several operating frequencies, from a fraction of megacps to several megacps. The higher frequencies are used for inspecting products and materials with a fine-grained structure, while the lower frequencies are used for coarse-grained structures. These devices are frequently supplied with supplementary subassemblies; depth gage for determining

the distance from flaws and determining the thickness in case of one-sided access, retarding the scanning to increase the resolving power, automatic flaw signaling, etc. Special flaw detectors are produced for solving of particular problems (inspection of rails, turbine buckets, etc.).

The immersion version of the reflection method is used for high-productivity automated inspection of metal blanks of simple shape (rolled plates, pressed shapes, forgings, stampings, etc.) produced in large series or by mass production. The sounding-through results are usually recorded by an automatic recording device. The advantage of the immersion version over the contact method consists in the fact that it is possible to inspect products with a rougher surface, in a more stable acoustic contact between the head and the product, in facilitating inspection of products with curvilinear (particularly concave) surfaces, in eliminating wear of heads, in facilitating automation of the inspection process, in a higher productivity and in a smaller dead zone. A disadvantage of the immersion version of the reflection method is the complexity and high cost of the apparatus.

The contactless version of the reflection method is used for inspecting bar stock, wire and other long products from ferromagnetic materials. The ultrasonic waves (usually rod) are excited and received by making use of the magnetostriction effect of the material of the product proper.

The ultrasonic shade method is based on the attenuation of the intensity of ultrasonic waves which pass through the product by a flaw located in the path of the ultrasonic beam. It is used for detecting flaws in metallic and nonmetallic products with moderate and average thickness: sheets, plates, pipes, bimetallic liners of sliding bearings, rubber tires, plastic products, etc. (see Flaw Detection in

Sheets, Flaw Detection in Sliding Bearings, Flaw Detection in Rubber Products, Flaw Detection in Plastic Products). The ultrasonic waves are transmitted by the immersion or contact methods. The shade method is used in the standard and mirror versions. In the standard version (Fig. 4) the radiating head 1 excited by generator 2, sends ultrasonic waves into product 3. The receiving head 4 converts the ultrasonic waves which have passed through the product into electrical signals, which are amplified by the amplifier 5. The level of the received signals is evaluated according to the output indicator 6. In the absence of flaws the ultrasonic waves pass freely through the product being inspected. A flaw reflects a part of the energy of the ultrasonic beam and reduces

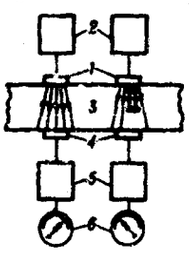

Fig. 4. Block diagram of an ultrasonic shade flaw detector.

the intensity of the wave field at the receiving head 4 which is recorded by a reduction in the readings of the output indicator 6. The usual version of the shae method requires two-sided access to the product being inspected and uses pulsating or continuous emission.

In the mirror version one of the heads is replaced by a reflector. The ultrasonic waves, which are generated in short pulses, pass through the product being inspected, reach the reflector, are reflected from it and return to the search head. The flaw attenuates the intensity of the reflected signal received from the reflector. Special reflecting surfaces as well as elements of the installations (for example, the immersion bath bottom) or surfaces of the product being inspected proper are used as reflectors. For the mirror version of the shade method it is

sufficient to have one-sided access to the product being controlled. The standard version of this method is used more frequently than the mirror method. The shade method uses primarily longitudinal and normal waves.

Industrial ultrasonic shade flaw detectors are high-productivity mechanized installations usually equipped with a system for signaling or recording the inspection results. To increase the productivity, several pairs of heads are frequently used. In inspecting by longitudinal waves using the standard version the heads of one pair are placed at different sides of the product, when using normal waves it is possible also to place the heads to one side of the product. The moving of heads relative to the product being inspected is mechanized in the majority of shade flaw detectors.

Plastic materials, rubber and other nonmetallic materials are inspected by using lower frequencies than those used for metals. The dimensions of the flaws are evaluated on the basis of recordings (when an automatic recording device is provided), relative change in the signal level and the length of the zone in which signal attenuation is observed.

The ultrasonic resonance method is based on observing the natural resonant vibrations when elastic vibrations are excited in the product. It is used for measuring the wall thickness in hollow metallic and certain nonmetallic products (pipes, tanks, etc.) with one-sided access, and less frequently for detecting cleavages, zones effected by corrosion, flaws in soldered and cemented joints, etc. This method uses longitudinal waves in the frequency range from 0.5 to 20 megacps. The ultrasonic vibrations are introduced into the product by the contact method. The limits within which thicknesses can be measured in steels and aluminum alloys are from tenths to several tens of millimeters. The

error is 1-3% of the thickness measured. The product goes into resonance when an integral number of half waves fits its thickness b. The resonant frequencies are determined from the expression f = nc/2b, wher where n is an integral and c is the rate of propagation of ultrasonic waves. The lowest resonant frequency f_1 (n = 1) is called the fundamental or first harmonic, while the others are called higher harmonics. When c = const the first harmonic uniquely determines the product thickness. The difference between the frequency of any two successive harmonics is equal to the first harmonic.

The elastic waves are excited in the product being inspected by a piezoelectric head, which is fed by an adjustable-frequency self-controlling vacuum tube oscillator. When the emitted frequency coincides with the natural frequency of the product, the vacuum-tube oscillator regime changes (the anode current of the tube increases) which is recorded by the instrument's indicator. The vacuum-tube oscillator frequency can be varied manually or automatically. Resonance thickness measuring devices with manual frequency adjustment are more portable. They are used under field conditions and for inspecting objects the

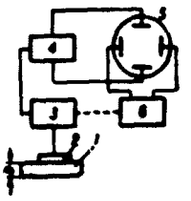

Fig. 5. Block diagram of an ultrasonic resonance thickness measuring device.

access to which is difficult. An arrow device or receiver serves as the indicator. Thickness measuring devices with an automatic frequency adjustment, constructed according to the block diagram of Fig. 5 are most frequently used.

The piezoelectric transducer 2, excited by the vacuum-tube self-

controlling oscillator 3, emits ultrasonic vibrations with a continuously varying frequency into product 1 being inspected. At instants when the emitted frequencies coincide with the emitted frequencies the anode current of the vacuum-tube oscillator changes. Pulses which are

Fig. 6. Image on the screen of the V4-8R resonance thickness measuring device.

received are amplified by the vacuum-tube amplifier 4 and are supplied to vertical deflection plates of the electron-beam tube 5. The scanning generator 6 is made so that a known frequency of emitted vibrations corresponds to each point on the scanning line. At instances of resonance peaks, situated at points corresponding to the natural frequencies of the product, are observed on the tube's screen (Fig. 6). The thickness is determined by the position of these peaks. Resonance thickness measuring devices make use of various systems for reckoning the thickness on the basis of the location of peaks on the device's screen. Direct reckoning systems, which are based on the comparison of the natural frequencies of the product being inspected with the resonance frequency of standard calibrated measuring device are most convenient and accurate. Adjusting the measuring device the operator obtains a coincidence of one (or several) of its frequencies with the resonant frequencies of the product being inspected. An equality of the frequencies is noted by the coincidence of the resonance peaks of the product and the measuring device on the instrument's screen. The measurement is made on a scale graduated in millimeters.

The ultrasonic resonance method is the basic means of checking the thickness (particularly less than 4-5 mm) of the walls of extended hollow products. It is used for measuring the thickness of walls of chemical apparatus, power equipment, ship hulls and bulkheads, etc. Measurements can be performed directly in the process of machining the products.

Inspection by the resonance method is possible provided that the product thickness in the zone of contact with the head is constant or changes smoothly. A sharp change in thickness (slope of more than 1:50) and also unevenness in the internal surface (for example, due to corrosion effects) make measurement difficult.

Cleavages are detected by a sharp reduction in the number of resonance peaks on the instrument's screen. Flaws which are oriented at substantial angles to the product surface cause the resonance peaks to vanish. By its sensitivity to flaws the resonance method is inferior to other ultrasonic methods (the shade and reflection methods).

References: Defektoskopiya metallov [Flaw Detection in Metals]. Collection of articles edited by D.S. Shrayber, Moscow, 1959; Nondestructive Testing Handbook, Vol. 2, New York, 1959; Krautkrämer, J. and Krautkrämer, H., Werkstoffprüfung mit Ultraschall, Berlin, 1961.

Yu.V. Lange.

Manuscript Page No. [Transliterated Symbols]

4260 УЗ = UZ = ul'trazvukovaya = ultrasonic

4263 Н = N = nachal'naya = initial

4263 Д = D = donny = bottom

4263 ДФ = Df = defekt = flaw

4265 МЗ = MZ = mertvaya zone = dead zone

ULTRASONIC FLAW DETECTOR – instrument for detecting flaws (primarily continuity disturbances) in blanks or products by one of the methods of ultrasonic flaw detection (see Ultrasonic Flaw Detection). Depending on the inspection method and the means by which the elastic vibrations are transmitted to and from the product, a distinction is made between several types of ultrasonic flaw detectors, for example, the ultrasonic shade flaw detector (contact or immersion), resonance, etc. Certain ultrasonic flaw detectors are used for inspection by 2 methods (for example, by the shade and reflection method) in the contact as well as in the immersion versions. A distinction is made between general purpose ultrasonic flaw detectors which serve to solve a wide range of flaw detection problems, and special detectors which are used for inspecting specific products (railroad rails, rubber tires, turbine buckets, etc.).

References: see at the end of article Ultrasonic Flaw Detection.

Yu.V. Lange.

UNDECAN - synthetic heterochain fiber from a product of condensation polymerization of aminoundecane acid. The production technology is being assimilated in the USSR; in France Undecan type fiber is produced under the name "Rylsan."

References: Demina, N.V. [et al.], "KhV", No. 5, 1960.

E.M. Ayzenshteyn.

UNDERSTRESSING – accumulation of changes in a metal by clical deformation which increase its fatigue resistance. These changes are due to the hardening effect of workhardening and to the formation of residual stresses in individual crystal groups. Understressing, or hardening, corresponds to the initial stages of the fatigue process and is reflected in the shape of the probable damage curve (see Damageability), which at this stage is situated in the region of negative damage values, i.e., in the hardening region. Understressing affects not only an increase in the number of cycles to failure, but also increases the fatigue limit, which is determined on specimens which have first undergone understressing. The understressing effect depends on its regime, i.e., the level and number of preloading cycles and on the presence of stress raisers. The optimum understressing regimes for different metallic alloys can differ substantially. The understressing effect is parparticularly intensely expressed upon a gradual increase in the amplitude of variable stresses, when the increasing changes produced by plastic deformation add up. Here the increase of the fatigue limit of plastic steels can be as high as 20-30%.

S.V. Serensen

UNIDIRECTIONAL STRESS CYCLE – a cycle in which maximum and minimum have the same sign. See Fatigue.

G.T. Ivanov

UNIFORM NECKING – the relative decrease in specimen cross-sec ional area at the instant when the greatest tensile load (final uniform deformation) is reached. It is expressed as a ratio or percentage: $\psi_b = (F_0-F_b)/F_0 \cdot 100\%$, where F_0 is the cross-sectional area of the specimen before testing and F_b is its cross-sectional area over the region of uniform deformation (determined from its diameter d_b, which is measured when the greatest stress is reached during testing or at a distance $\lambda \geq 3d_0$ from the cracture, where d_0 is the pretest specimen diameter). For materials that do not neck the uniform necking is approximately equal to the final reduction in area ψ_k and the elongation δ. For the majority of plastic materials the uniform necking is substantially less than the concentrated necking (see Concentrated necking). On nominal deformation graphs showing "nominal stress versus reduction in area," the uniform necking is the abscissa corresponding to the ultimate strength σ_b.

N.V. Kadobnova

UPSILON-ALLOY (Y-alloy; U-alloy) is a heatproof aluminum-base alloy, castable or malleable, hardenable by heat treatment, containing 4% Cu, 2% Ni, and 1.5% Mg. In some countries, the malleable variation of this alloy contains about 0.6% magnesium. The mechanical properties at room temperature are: for the castable alloy σ_b up to 30 kg/mm^2, $\sigma_{0.2}$ up to 27 kg/mm^2, δ = 0.5%; for the malleable alloy: σ_b = 37-42 kg/mm^2, $\sigma_{0.2}$ = 24-36 kg/mm^2, δ = 5-13%. It is used for the production of engine pistons. Alloys of a similar type are known in USSR under the grade marks AL1 and AK2 (see Aluminum Alloys for Casting; Forgeable, Maleable Aluminum Alloys.).

O.S. Bochvar, K.S. Pokhodayev

UREA-FORMALDEHYDE MOLDING COMPOSITIONS are molding compositions based on urea-formaldehyde resin and cellulose sulfite, having the form of a fine powder which may be colored in soft light tones either in the process of mixing the components (wet method), or during grinding of the dry mass (dry method). Two grades are produced: A (for transparent articles) and B (for nontransparent articles). Volatile content is 2.8-3%; Rasching yield is 60-160 mm. It is recommended that the powder be tableted to obtain higher quality articles during pressing. The tablete molding composition is transformed into articles by hot pressing at 143 $\pm$ 5° with a specific pressure of 105-420 kg/cm^2; press hold time is 1 min/mm. The properties of the urea-formaldehyde molding compositions are: specific weight 1.4-1.5; specific impact strength is 5-6 kg-cm/cm^2; ultimate strength (kg/cm^2): in compression 1000-2900, in tension 370-500, in bending 600-800; tensile elongation 0.2-0.5% tensile modulus of elasticity 75,000-100,000 kg/cm^2; Brinell hardness 35-55 kg/mm^2; water absorption 0.45-0.65% coefficient of thermal conductivity is 0.108-0.2 dcal/m-hr-deg; Martens thermal stability 100°; surface resistivity $10^{10} - 10^{11}$ ohms; volume resistivity 10^{11} ohm-cm; electric strength 14-16 kg/mm.

The urea-formaldehyde molding compositions have good light transmittance, are resistant to the action of weak acids and alkalis. The finished articles do not require maching other than to remove flashing. When required, machining (drilling, etc.) is performed using tools made from the hard alloys. Threads and inscriptions are formed in the molding process. Articles made from the urea-formaldehyde mold-

ing compounds can operate in the temperature range from -30 to +50°. The urea-formaldehyde molding compositions are not resistant to tropical conditions. They are used primarily for the production of technical articles for noncritical application (meter cases, radio housings, certain forms of electrical equipment (sockets, plugs) and so on) which are not subject to alternating action of moisture, high temperatures or climatic factors which reduce the mechanical, physical and dielectrical properties of the urea-formaldehyde molding compositions during long-term service, and also articles for household use — toys, dishware for dry foods, furniture components, etc.

V.N. Gorbunov, V.Z. Mayevskaya

URETHANE RUBBER (polyester rubber, polyisocyanate rubber) - is the product of the condensation of a dibasic acid with glycol and a subsequent reaction of the obtained ester with di-isocyanate. Urethane rubbers are delivered in the trade marks SKU (USSR), Vulcollan (German Federal Republic), Vulcaprene (Great Britain), Chemigum, Adiprene, and Gentane (U.S.). Urethane rubbers are characterized by high physicomechanical indices: tensile strength, elasticity, resistance to alternating deformations and a high tear resistance, an excellent resistance to abrasion which considerably surpasses that of other industrial rubber types. Urethane rubbers are stable to oxidation and to thermal aging. The mechanical properties vary in a considerably wide range depending on the type of the initial polyesters and di-isocyanates, also on the composition: tensile strength 300-420 kg/cm^2; relative elongation 400-650%; residual elongation 5-35%; modulus at 300% elongation 50-250 kg/cm^2; rebound elasticity at 20° 50-70%; TM-2 hardness 50-95; tear resistance 50-175 kg/cm; abrasion factor 20-40% (with respect to a standard natural rubber filled with carbon black). Urethane rubbers are characterized by a high resistance to the action of oils, they have almost no swelling in them, and also a high resistance to gasoline, kerosene, benzene, and other aliphatic and aromatic hydrocarbons. The stability of urethane rubbers at high and low temperatures depends on the type of the initial polymers (esters or ethers). Urethane rubbers on polyester basis are practicable in the temperature range from -30, and -40 to +130, +140°. Urethane rubbers on ether basis are frostproof up to -70, -75°. Urethane rubbers are insufficiently resistant to hot

water, steam, alkalis and acids. The high shock-absorption power and the good gas-tightness being 0.1-0.2 only of that of natural rubbers, are valuable properties of the urethane rubbers. Urethane rubbers of the Vulcollan type on basis of esters are obtained in the form of vulcanized products; the specific gravity is 1.26; they are insoluble in usual solvents, they maintain their elasticity in the temperature range from -30° to +130°; they are not workable on the usual equipment of rubber plants (rollers, mixers, calanders, extruders); they are not miscible with other rubbers and also with fillers, softeners and other ingredients of rubber stocks. Products of urethane rubbers are produced by means of lathes, millers, polishing and other metal-working machines, and also by the most modern technology of direct molding. This simplifies the process of production of monolithic products with a homogeneous structure. In contrast to the urethane rubbers on ester basis, the urethane rubbers on ether basis of the Adiprene type are obtainable in the form of a nonvulcanized rubber; they have a specific gravity of 1.07; they are soluble in tetrahydrofuran, methyl ethyl ketone, dimethylformamide, and they swell in chlorinated solvents and petroleum hydrocarbons; they are worked on the usual equipments of rubber plants; they are compatible with the ingredients of rubber compounds; their vulcanization is carried out by means of di-isocyanates; the most modern types of these rubbers are vulcanized by means of sulfur and organic peroxides, especially by di-isopropyl benzene peroxide. Raw compounds of urethane rubbers, vulcanizable by di-isocyanates, show an increased tendency to scorching and cannot be stored for a long time. Compounds vulcanizable by peroxides and sulfur are sufficiently stable and do not tend to scorch. Nonfilled rubbers on Adiprene basis, especially those which are vulcanizable by sulfur and peroxides, have a tensile strength in the range of 100-200 kg/cm^2. Fillers, such as carbon black, resins,

especially coumarone indene resins, silica, kaolin, chalk, etc., are used in order to increase the strength and to improve the other physicomechanical properties. The tensile strength of rubbers containing active carbon black reaches to 380 kg/cm^2. Besides the solid urethane rubbers, liquid urethane rubbers are obtainable which are vulcanizable by the action of polyamines, polyglycols, or water, forming solid elastic rubbers with high mechanical characteristics. Addition of fillers to liquid urethane rubbers increases the modulus and the hardness of the rubbers. Liquid urethane rubbers are well compatible with epoxy-resins. Such compounds possess after curing a low brittleness point (-61°), a high strength (140-700 kg/cm^2), and a high resistance to ozone, oxygen, petroleum fuels, lubricating oils, and certain solvents.

The instability to the action of water is one of the main disadvantages of liquid urethane rubbers; they must, therefore, be stored hermetically sealed. Compounds of liquid urethane rubbers can be used for the production of objects by the molding method. The linear shrinkage is 1-2.5%. Urethane rubbers of the Vulcollan type are used as a structural material in machine building, in transport, in ore mining and petroleum industry, and in other fields of engineering. Oil- and gasoline-proof packings, sealing collars, parts of elastic hinges, limiting dampers, sealing rings for pipes, membranes and packings for diverse purposes, gear wheels for engines, pedals, diverse starting devices, etc., are produced by molding of urethane rubbers.

Thin-walled products, as, for example, ozone-stable coatings of wires and cables, seamless connecting blocs for diverse coupling systems, etc., are produced by dipping, using dimethylformamide as a solvent. Urethane rubbers of the Adiprene type are practicable for the production of the greatest part of the objects mentioned above. Owing to its workability on the equipment of rubber plants, this type of ure-

thane rubber is more easily practicable for the production of conveyor belts, sealing collars, and membranes. Tires, experimentally prepared with a urethane rubber tread, have shown a very high run, surpassing by more than 2 times the run of tires with a divinyl styrene rubber tread. Liquid urethane rubbers are used for the production of different complicatedly shaped objects by molding, for application of decorations and protective coatings by spraying and dipping, for the protection of electric equipments, for impregnation, and for other purposes.

References: Kauchuki spetsial'nogo naznacheniya [Fubbers for Special Purposes] Collection of Papers, edited by I.V. Garmonov, Moscow, 1961; Sinteticheskiy kauchuk [Synthetic Rubber], edited by G. Whitby, translated from English, Leningrad, 1957.

I.V. Borodina

VACUUM AND PNEUMATIC FORMING – methods for processing plastics into articles from sheet or film-like thermoplastic material heated to a highly-elastic state, with a difference in pressures above and below the thermoplastic sheet. In vacuum forming the pressure difference is created by producing a vacuum in the mold, while in pneumatic forming this is done by supplying compressed air. The equipment and tools used in vacuum and pneumatic forming are less expensive and simpler than those used in other methods of thermoplastic material processing; production of an article with larger overall dimensions has a relatively minor effect on the increase in the cost of equipment and tools, which makes these two processes more advantageous for production of articles with large overall dimensions. However, the cost of the sheet material is somewhat higher than that of granules and powder, which are the starting materials in processing thermoplastic materials by pressure casting or compression molding. The assortment of articles produced by vacuum and pneumatic forming is very extensive: the internal shell, door panel and trays of refrigerators, mask and protective cap in television sets, guards and protective covers for machinery, pumps and their gaskets, illuminants, wall facing panels, [small] washable tanks, variety of containers for packing of foord products and technological articles, negative-developing baths, consumer goods of every description, etc. Several versions of vacuum forming are in existence: a) negative, b) positive with preliminary mechanical cupping and c) forming by a male die. In negative forming (Fig. 1) the thermoplastic material sheet 1 is fastened on form 2 by clamping frame 3 and a sheet 4 made from

spongy rubber and it is brought to the forming temperature by an infrared heater. Then air is pumped out from the form through channels 5 which are about 1 mm in diameter. The heated material takes on the shape of the internal void of the form. After cooling, the clamping frame is opened and the formed product is removed. This method is usually used for obtaining relatively shallow products, whose height does not exceed half the diameter or width. In forming deeper articles the bottom (particularly in the corners) comes out much thinner than the side walls. In positive forming preceded by cupping (Fig. 2) the clamp-device 3 is produced in the form of a separate frame; the height of the frame should correspond to that of the article. The form (in this case male die 2 with rubber sheet 4 and air-evacuation channels 5) is placed inside the frame in a manner such that a space of 1-3 mm remains between them, and is connected to the hydraulic drive of the vacuum-forming machine. The thermoplastic material sheet 1 is fasted to the frame and is heated to the forming temperature. Then the male die is raised and mechanically draws the sheet, whereupon the vacuum is started up and the softened sheet clings tightly to the male die. This method makes it possible to produce articles whose height is equal to the diameter or width. The thicker part here is the bottom of the product, while the side walls (particularly in the top part) are more drawn. Forming by using a male die (Fig. 3) combines the advantages of the first two methods and ensures uniform thickness of the product's walls. In forming by using a male die the design of the form is the same as in negative forming. The male die configuration corresponds to the simplified configuration of the product. After the material is heated the male die is lowered and

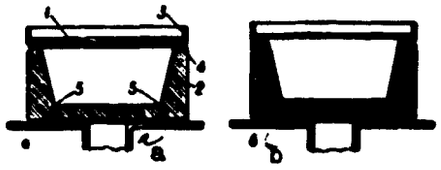

Fig. 1. Diagram of negative forming; a and b are different stages of the process.

makes an impression in the softened sheet. After preliminary forming ends, the vacuum is started up, which pulls away the thermoplastic material from the male die and presses it to the surface of the form. This method can be used for obtaining products whose height is equal to and even slightly exceeds the diameter. The majority of vacuum-forming machines are all-purpose, entirely or to a substantial extent automated and can be used for manufacture of products by various methods. Thick sheets are formed on machines which use, in addition to the vacuum, compressor-created pressure. Flow lines exist which include extrusion units for producing sheet or film and vacuum-forming machines, and in individual cases also devices for packing the products into plastic containers.

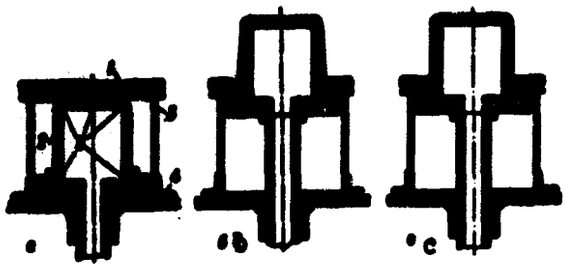

Fig. 2. Diagram of positive forming with preliminary mechanical cupping; a, b and c are different stages of the process.

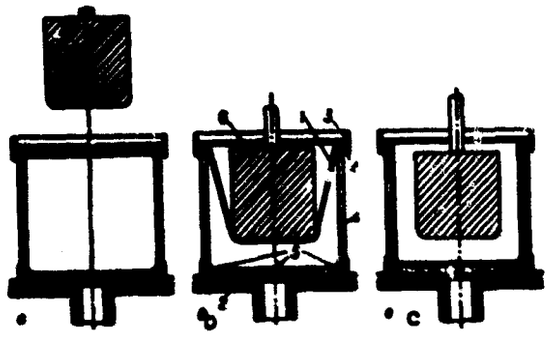

Fig. 3. Diagram of vacuum forming by using an upper male die; a, b and c are different stages of the process. 1) Sheet of thermoplastic material; 2) form; 3) clamping frame; 4) rubber sheet; 5) air-evacuation channels; 6) male die.

Processing of thermoplastic materials by pneumatic methods is similar to vacuum forming. Pneumatic forming, in addition to the forming tool (negative form or male die) requires an air-tight insulated chamber which is usually installed on the press. The material is heated outside the form, most frequently in a preheating chamber. The heated blank is placed on the form and is clamped along the perimeter of the article by lowering the upper half of a chamber fastened to the

movable platen of the press. Compressed air is supplied to the chamber, forming takes place, after which the product is cooled.

The main materials which are processed by vacuum and pneumatic forming are: 1) styrene copolymers, most frequently with rubber, produced in the USSR under the name impact-resistant polystyrene (SNR) and high-strength polystyrene (VPP); polyvinylchloride and its copolymers; pure polyvinylchloride (vinyplast) and plasticized polyvinylchloride are produced in the USSR in sheet form; 3) polymethyl methacrylate (organic glass) which, unlike styrene and polyvinylchloride copolymers, is most frequently processed by the pneumatic method; 4) high- and low-pressure polyethylene. The thickness of the sheets and films which are processed is from 0.025 to 10 mm. The temperature parameters of vacuum and pneumatic forming are presented in the Table.

The vacuum when producing articles by the vacuum-forming method is 0.8-0.95 atmospheres; the pressure in pneumatic forming is from 0.5 to 1.5 atmospheres. Forms for vacuum and pneumatic forming are made, depending on the quantity of articles to be formed, and their intended service, from: wood or gypsum (for small quantities), plastics, for example, using an epoxy or phenol resin base (when producing 10-15 thousand articles), from metals (for large quantities). Galvanized-concrete forms are economical and easy to produce. Multicell forms are made when producing small articles.

Temperature Parameters of
Vacuum and Pneumatic Forming

1	2	3
[illegible]	[illegible]	[illegible]
СНП . . 4 . . .	100—160	120—130
[illegible] 5 . .	95—15[illegible]	[illegible]
Органическое 6 . .	150—160	120—200
[illegible]	120—190	120—130

1) Material; 2) forming temperature in vacuum forming

(°C; 4) SNP; 5) vinyplast; 6) organic glass; 7) high-pressure polyethylene.

References: Lapshin, V.V. and Ivakhnenko, P.Ya. Vakuumnoye formovaniye termoplasticheskikh materialov [Vacuum Forming of Thermoplastic Materials]. "PM," No. 7, 1961; Strel'tsov, K.N., Pnevmaticheskiye metody pererabotki listovykh termoplastov [Pneumatic Methods of Processing Thermoplastic Sheets], Leningrad, 1959; Butzko, R.L., Plastic sheet forming, N.Y. – London, 1958.

P.Ya. Ivakhnenko

VACUUM CERAMICS – are ceramic materials characterized by a high density (vacuum-tightness), good thermomechanical properties and low dielectric losses in a wide interval of temperatures and frequencies. Vacuum ceramics permit to realize vacuum-tight joints with copper, iron, and their alloys. Therefore, a correspondence between the linear expansion coefficients of the ceramic and the metal must be provided when selecting the ceramic material which is in contact with the metal. The linear expansion coefficient of the vacuum ceramic in the interval from 20 to 900° must be $13\text{-}15\cdot10^{-6}$ for joints with copper and its alloys, $10\text{-}11\cdot10^{-6}$ for joints with iron and its alloys, $6\text{-}7\cdot10^{-6}$ and $3\text{-}4.5\cdot10^{-6}$ degrees^{-1} for joints with Covar. Corundum and steatite ceramics are the most widely used ones; they are delivered by the industry under diverse names and trademarks. The vacuum ceramics are incorporated into the large class of radioceramic materials (Ceramic Materials for Radio Engineering). The properties of vacuum ceramics used inside of vacuum apparates are standardized by GOST 5458-57, class VI. Some properties of the main vacuum-tight high-frequency ceramics are listed in the Table.

TABLE

1 Материал	2 Термомеханические свойства	3 Термостойкость	4 Временная электрическая прочность (кв/мм)	Объемное удельное электрическое сопротивление	Тангенс угла диэлектрических потерь 6	
					10^6 гц	10^8–10^{10} гц
8 Керамика электровакуумная	11 Хорошие	11 Хорошая	1100–1400	8–10	2–4	3–6
9 Стеатитовая керамика	12 Плохие	12 Плохая	900–1700	5.5–7	2.5	12–15
10 Керамика стеатитовая электровакуумная	13 Удовлетворительные	13 Удовлетворительная	1000–3200	7–8.5	3–4	10–15

1) Material; 2) thermomechanical properties; 3) heat endurance; 4) tem-

porary bending strength (kg/cm^2); 5) dielectric constant; 6) tangent of the loss angle; 7) cps; 8) corundum ceramics; 9) steatite, forsterite, and celsian ceramics; 10) corundum-mullite ceramics and ultra-porcelain; 11) good; 12) poor; 13) sufficient.

References: Cole V., Tekhnologiya materialov dlya elektrovakuumnykh priborov [Technology of Materials for Electric Vacuum Devices], translated from English, Moscow-Leningrad, 1957; Bogoroditskiy N.P., Pasynkov V.V., Materialy v radioelektronike [Materials Used in Radio Electronics], Moscow-Leningrad, 1961.

V.L. Balkevich

VACUUMED STEEL – high-quality, usually alloyed steel with a reduced content of gases and nonmetallic inclusions, which is obtained by using a vacuum in the smelting or teeming process. During ordinary metallurgical processes of steel production (Bessemer, open-hearth, electric furnace, etc.), the metal is saturated by gases (oxygen, nitrogen, hydrogen) which impairs the service qualities of components made from it. Due to the low solubility of oxygen in iron (0.04%) it is contained in the steel almost exclusively in the form of oxide inclusions and hence can impair its properties (particularly mechanical). The effect of nitrogen is expressed primarily in the steel's tendency to aging and to intercrystalline corrosion. The saturation of steel by hydrogen results in formation of pores, friability, flakes, and also in a sharp decrease in plasticity. Hence elaboration and adaptation of methods for obtaining steel with a reduced gas content by using vacuuming in smelting the steel in furnaces or in the pouring process is of great significance. Smelting of steel under vaccum involves certain difficulties which are due primarily to the need of hermetizing the working space of the furnace which is situated in a high-temperature zone. This, in part, is responsible for the fact that only a relatively moderate amount of liquid metal can be smelted under vacuum. Hence the vacuum smelting method is used primarily in producing special alloys.

In mass production it is more efficient to vacuum the steel in the ladel. For this the molten steel in the teeming ladle is placed in a chamber (container) in which a vacuum of the order of 10^{-1}-10^{-3} mm of Hg is created, and it is held for a time sufficient for substantially

reducing the gas content and ensuring satisfactory teeming. Sometimes vacuuming is also performed in the teeming process, by placing the ingot molds or forms with the molten metal in special chambers, the vacuum in which is maintained within the limits of several millimeters of mercury.

Vacuuming in the ladle substantially improves the properties of rail and ball-bearing steel which is used for making components which must be wear-resistant under a high contact pressure. In this case the reduction in the quantity of nonmetallic inclusion sharply improves the service endurance of the rails, bearings, and similar components.

Particular importance is acquired by vacuuming attendant to the smelting and teeming of high-strength steels(σ_b higher than 200 kg/mm^2) and electrical iron. Reduction in the quantity of inclusions (gases) results in a substantial increase in mechanical properties, high effect of strength-increasing treatments, (for high-strength steels), in improved indicators of wattage losses, magnetic permeability, etc., (electrical iron).

M.L. Bernshtein, I.N. Kidin

VACUUMING OF ALUMINUM ALLOYS – refining of aluminum alloys for removal of nonmetallic admixtures by holding the molten metal (before pouring) in a vacuum chamber (0.1-2.0 mm of Hg) (Table 1). Vacuuming of aluminum alloys is the most efficient refining method. Vacuuming of aluminum alloys is accompanied by intensive separation of hydrogen bubbles from the melt. Particles of hard nonmetallic inclusions on which the hydrogen bubbles are adsorbed float to the surface of the metal or settle at the melting pot bottom. The rate of vacuuming of aluminum alloys can be increased by covering the metal surface by a moderate amount (up to 0.2% by weight of the metal) of flux which adsorbs the aluminum oxide. The vacuuming method makes it possible to decrease the gas porosity of castings by approximately two (scale) divisions and to substantially increase their density and strength (Table 2). Unlike the majority of other refining methods, vacuuming of aluminum alloys aids in providing healthier work conditions in foundries and can be used after modification (see Silumin). The technology of vacuuming aluminum shaping alloys is [presently] being developed. The hydrogen content of the metal after vacuuming is reduced by 50-80%; here this reduction is the greater, the higher the starting hydrogen content of the metal. The composition of alloys, for example, AV, D1, D16, AK8 with respect to their main alloying elements practically does not change after vacuuming. Zinc, which is contained in amounts of 5-10% in alloys V93, V95, V96, etc., is re-

TABLE 1

Time During Which the Metal is Kept Under Vacuum as a Function of Its Weight.

Вес (кг) 1	2 Время (мин.)
50–100	3
100–150	5
150–300	8
1500–2000	15–20

1) Weight (kg); 2) time (min.).

duced after vacuuming by 0.8-2.0%.

TABLE 2

Changes in the Properties of Cast Specimens as a Function of the Treatment Given to the Metal Before Pouring Into Moulds

Сплав 1	Обработка металла перед заливкой 2	3 Механические свойства			Балл пористости 5	γ (г/см³) 6
		σ_b (кг/мм²)	δ_{10} (%)	HB (кг/мм²) 4		
АЛ9-Т5 7	8 Не вакуумированный	16	1,0	75	3	2,687
	9 Вакуумированный	18	1,5	85	1	2,712
АЛ4-Т6 7	Не вакуумированный	17	2,0	60	4	—
	Вакуумированный	20	3,0	75	2	—

1) Alloy; 2) treatment of metal before pouring; 3) mechanical properties; 4) (kg/mm^2); 5) division on porosity scale; 6) (g/cm^3); 7) AL; 8) not vacuumed; 9) vacuumed.

References: Liteynyye alyuminiyevyye splavy [Aluminum Casting Alloys]. In the collection under the editorship of I.N. Fridlander and M.B. Al'tman, Moscow, 1961; Primeneniye vakuuma v metallurgii [The Use of Vacuum in Metallurgy], (Collection of Articles), Moscow, 1960.

M.B. Al'tman, V.A. Zasypkin, A.Ye. Semenov

VACUUM MATERIALS – materials used in vacuum apparatus and instruments.

The basic requirement put to vacuum materials is low vapor pressure at working temperatures and ease of outgassing. The other requirements put to vacuum materials are determined by their field of application, for example, materials for the fabrication of vacuum tubes should be sufficiently strong at high temperatures and should have high insulating properties or, conversely, high electrical conductivity. Vacuum materials are divided into the following main groups: materials of construction, getters (gas absorbers), vacuum oils (fluids for high-vacuum installations), vacuum putties, lubricants, lacquers and cements. The main properties of the more important materials of construction used in vacuum equipment are presented in the Table.

References: see article entitled Getters.

Ye.N. Martinson

Main Properties of Materials Used in the Manufacture of Vacuum Equipment

Материалы 1	2 Темп-ра плавления (°С)	Темп-ра, при к-рой упругость пара составляет $1 \cdot 10^{-6}$ мм рт. ст., и соответствующая скорость испарения 3		4 Уд. вес при 20°	5 Коэф. линейного расширения $\alpha \cdot 10^6$ (0—100°)	6 Предел прочности при растяжении (кг/мм²)	7 Теплопроводность при 20° (кал/см × сек·°С)	8 Уд. электрич. сопротивление при 20° (ом·см)
		темп-ра (°С) 9	скорость испарения (г/см²·сек) 10					
11 Металлы						13		
12 Алюминий	658	724	$9.60 \cdot 10^{-9}$	2.7	23.8	15—25 (Н*) 8—11 (О**)	0.50	2.69
14 Вольфрам	3410	2554	$1.47 \cdot 10^{-7}$	19.3	4.4	180—415 (Н) 110 (О)	0.48	5.5
15 Железо	1535	1094	$1.29 \cdot 10^{-7}$	7.86	11.9	60 (Н) 18—25 (О)	0.17	10.0
16 Медь	1083	946	$1.33 \cdot 10^{-7}$	8.95	16.5	40—50 (Н) 22 (О)	0.92	1.56
17 Молибден	2625	1923	$1.29 \cdot 10^{-7}$	10.2	5.5	140—280 (Н) 80—120 (О)	0.35	5.17
18 Никель	1452	1157	$1.18 \cdot 10^{-7}$	8.9	13.3	63—77 (Н) 42—53 (О)	0.215	6.8
19 Палладий	1554	1156	$1.59 \cdot 10^{-7}$	12.16	11.6	—	0.167	10.8 (18°)
20 Платина	1773.5	1606	$1.88 \cdot 10^{-7}$	21.4	9.0	20—35 (Н) 15 (О)	0.167	10.8 (18°)
21 Серебро	960.5	767	$1.88 \cdot 10^{-7}$	10.5	18.9	30 (Н) 15 (О)	1.01	1.5 (18°)
22 Тантал	2996	2407	$1.55 \cdot 10^{-7}$	16.6	6.5	90—120 (Н) 35—50 (О)	0.13	14.6
23 Титан (иодидный)	1725	1134	$1.08 \cdot 10^{-7}$	4.5	8.09 (20—200°)	68—75 (Н) 27—34 (О)	0.036	42
24 Цирконий (иодидный)	1845	1527	$1.31 \cdot 10^{-7}$	6.5	5.4 (20—200°)	52—80 (Н) 25—43 (О)	0.04	41
25 Сплавы								
26 Латунь Л-68	938	—	—	8.6	18.4	33 (О)	0.26—0.28	6.8—7.2
27 Монель	1250	—	—	8.9	13.7	65	0.06	42
28 Нихром	1400	—	—	8.4	12.8	90	0.03	110
29 Сталь нержавеющая 1Х18Н9 (ЭЯ-1)	1400	—	—	7.9	16.0	60	0.039	70
30 Сталь нержавеющая 1Х18Н9Т. (ЭЯ-1Т)	1400	—	—	7.9	16.0	56	0.04	71
31 Фернико (ковар)	1450	—	—	8.35	4.5—5.5 (20—300°)	63 (О)	0.046	49
32 Различные материалы								
33 Электрографит	3800 3900	2129 (углерод)	$4.13 \cdot 10^{-9}$	2.22—2.24	0.8—1.8 (продольный)	0.5—0.8	0.05	600—1100
36 Слюда (мусковит)	1300	—	—	2.8	3.0	—	0.001	10^{16} (объемн.; ом·см) 37
38 Кварц плавленый	1700	—	—	2.2	0.59	7—12	0.003	10^{18} (объемн.; ом·см)
39 Стекло	—	—	—	2.5—4.0	3.0—12.0	3—9	0.002—0.003	10^{13}—10^{16} (объемн.; ом·см)
40 Керамика гафнокорундовая	2000	—	—	2.5—3.5	4.6—7.0 (20—100°)	4—6	0.002—0.003	10^{14}—10^{17} (объемн.; ом·см)
41 магнезиальная	1600	—	—	2.5—2.8	7.0—8.0 (20—100°)	4—9	0.0052—0.008	10^{14}—10^{16} (объемн.; ом·см)
42 Резина (пластины)	—	—	—	1.2—1.5	200.0 (объемн.)	0.4—1	0.0004	10^{15}—10^{16} (объемн.; ом·см)

* N denotes nonannealed material.

** Denotes annealed material.

1) Materials; 2) melting temperature, °C; 3) temperature at which the vapor pressure comprises $1 \cdot 10^{-5}$ mm of Hg and the corresponding vaporization rate; 4) specific weight at 20°; 5) coefficient of linear expansion $\alpha \cdot 10^{6}$ (0-100°); 6) ultimate tensile strength (kg/mm^2); 7) thermal conductivity at 20° (cal/cm-sec-°C); 8) specific electric resistivity at 20° (microohms-cm); 9) temperature (°C); 10) rate of vaporization (g/cm^2-sec); 11) metals; 12) aluminum; 13) N; 14) tungsten; 15) iron; 16) copper; 17) molybdenum; 18) nickel; 19) palladium; 20) platinum; 21) silver; 22) tantalum; 23) titanium (iodide); 24) zirconium (iodide); 25) alloys; 26) L-68 brass; 27) monel; 28) nichrome; 29) IKh18N9 (EYa-1) stainless steel; 30) LKh18N9T (EYa-1T) stainless steel); 31) Fernico (Kovar); 32) various materials; 33) electro-graphite; 34) (carbon); 35) (longitudinal); 36) mica (muscovite); 37) (by volume; ohm-cm); 38) melted quartz; 39) glass; 40) alumina ceramics; 41) magnesium; 42) rubber (hoses); 43) (by volume).

VALVE STEEL— is a steel for the production of the inlet and exhaust valves of internal-combustion engines. Valve steel must have a high strength and hardness at working temperatures, it must be resistant to the effect of the combustion products of the fuel, including fuels containing ethyl fluid (the higher aggressivity of the combustion products of fuel containing tetraethyl lead is explained by the presence of lead oxide and of the corrosion-actives hydrochloric and hydrobromic acids in them). The great hardness of valve steel is necessary in order to increase the wear-resistance of the valves, and also to crush the combustion products when the face of the valve touches the seat. The hardness of valve steel must be not lower than 120 kg/mm^2 (HB) at working temperature. Hard alloys, the steelites VZK or VKhNI, or the Nichrome Kh20N80 are brazed to the face or the disc of the valve in order to increase the durability of the valve steel. An intense calorizing (coating with aluminum) of the valve's working surface is also carried out for this purpose. The burning-out of the valve increases considerably when a gap appears between the valve and the seat. The brazing of the relatively soft, although heatproof Nichrome on the face of the valve curbs the formation of gaps which are seats of destruction, owing to the plastic deformation of the Nichrome. Hence, the combination of the hard stellite and the soft Nichrome efficiently solves the problem. In order to reduce the heating temperature of the material, the valves are sometimes designed with a hollow body filled with metallic sodium which due to its circulation conducts the heat via the valve stem to the body of the engine (Figs. 1, 2). The chemical composition

of valve steel, according to GOST 5632-61, is quoted in Table 1.

The hardness of Silchrome steels is rapidly reduced at temperatures higher than 550-600° (Fig. 3). The Nichrome alloy Kh20N80 used

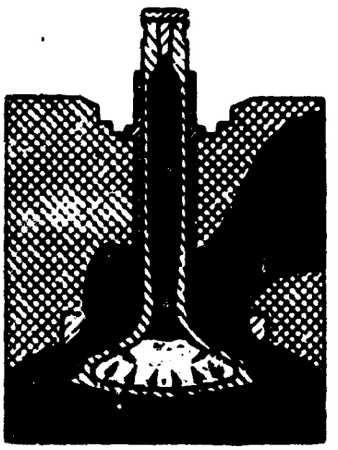

Fig. 1. Scheme of heat conduction in a valve cooled with sodium.

for the brazing on valve faces retains a sufficient hardness when heated to 700-750°. The nickel-chromium-titanium alloy Kh20N77TYu2, harden-

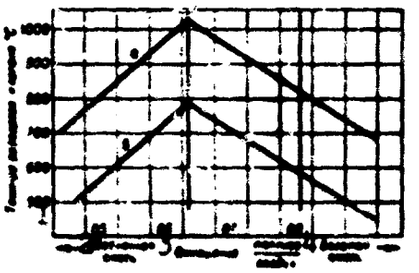

Fig. 2. Variations in the heating temperature of the valve due to the fuel – air ratio: a) Valve without cooling; b) valve cooled with sodium. 1) Heating temperature of the valve; 2) poor mixture; 3) fuel-air ratio; 4) rich mixture.

ing by dispersion, has a maximum hardness at high temperatures. The mechanical properties of valve steel and of certain materials used for brazing on the faces of valves are quoted in Table 2.

The steels 4Kh9S2 and 4Kh10S2M are used for the valves of automobile and tractor engines, the steels 3Kh13N7S2 and 4Kh14N14V2M with

brazed-on stellite or nichrome are used for the exhaust valves of aircraft engines, the steel 4Kh14N14V2S2 is used for valve seats, and the

TABLE 1

Chemical Composition

Сталь, сплав по ГОСТ 1	Заводская марка 2	3 Содержание элементов (%) C	Si	Mn	Cr	Ni	Mo	Fe	Другие элементы 4
5 4Х9С2	6 9СХ8	0,85—0,45	2,0—3,0	≤0,7	8,0—10,0	—	—	7 Основа	≤0,025S ≤0,030P
8 4Х10С2М	9 ЭИ107	0,85—0,45	1,9—2,6	≤0,7	9,0—10,5	—	0,7—1,0	Основа	≤0,025S ≤0,030P
10 3Х13Н7С2	9 ЭИ72	0,25—0,34	2,0—3,0	≤0,7	11,5—14,0	6,0—7,5	—	Основа 7	≤0,020S ≤0,035P
11 4Х14Н14В2М	9 ЭИ69	0,40—0,50	≤0,8	≤0,7	13,0—15,0	13,0—15,0	0,25—0,40	Основа 7	2,0—2,75W ≤0,020S ≤0,035P
12 4Х14Н14В2С2	9 ЭИ481	0,4—0,5	2,75—3,25	≤0,7	13,0—15,0	13,0—15,0	0,25—0,40	Основа 7	1,75—2,75W ≤0,020S ≤0,030P
13 Х20Н77Т2Ю	14 ЭИ437А	≤0,06	≤0,6	≤0,4	19,0—22,0	Основа 7	—	≤1,0	0,55—0,95Al 2,3—2,7Ti ≤0,01Ce ≤0,015P ≤0,02S
15 Сплавы для напайки на К с.									
16 Х20Н80	9 ЭИ336	≤0,25	≤0,6	0,20—1,5	20,0—23,0	72,0—78,0	—	—	0,06Al 0,50 Cu 1,70Fe
17 ВЗК	17 ВЗК	0,9—1,3	1,75—2,75	—	28,0—32,0	≤2,0	—	≤2,0	58,0—63,0Co 4,0—5,0W ≤0,070S
18 ВХН1	18 ВХН1	0,5—1,2	1,5—2,5	≤0,5	35,0—40,0	50,0—60,0	—	≤5,0	≤0,07oS ≤0,030P

1) Steel, alloy according to GOST; 2) trademark; 3) percentage of the elements; 4) other elements; 5) 4Kh9S; 6) EsKh8; 7) basis; 8) 4Kh10S2M; 9) EI..; 10) 3Kh13N7S2; 11) 4Kh14N14V2M; 12) 4Kh14N14V2S2; 13) Kh20N77T2Yu; 14) EI437A; 15) alloys for brazing on valve steel; 16) Kh20N80; 17) VZK, 18) VZK; 18) VKhN1.

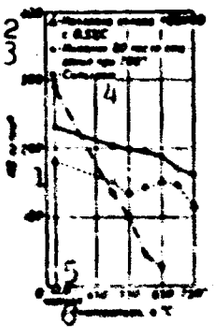

Fig. 3. Variations in the hardness of steels and alloys for valves due to the temperature. 1) kg/mm^2; 2) brazed with the Kh20N80 alloy with 0.5% C; 3) Nimonic 80 after aging at 700°; 4) Silchrome; 5) room temperature; 6) temperature, °C.

TABLE 2

Mechanical Properties and Conditions of the Heat Treatment

1 Сталь, сплав по ГОСТ	2 Заводская марка	3 Термическая обработка	НВ ($d_{отп.}$, мм) 4	$\sigma_в$ (кг/мм²) 5	$\sigma_{0,2}$ (кг/мм²) 5	δ (%)	ψ (%)	$\alpha_к$ (кг/см²) 5а	Температура начала интенсивного окисления (°С) 6
4Х9С2 7	8 ЭСХ8 9	Закалка с 1050° в масло, отпуск при 680—700°, охлаждение на воздухе	25—35 HC	90	60	20	55	—	925
	10	Отпуск при 650±10°, охлаждение на воздухе	~3.7	~75	~50	~15	~30	3.0	925
	11	Закалка с 1000° в масло, отпуск при 800°, охлаждение в воде	—	87	69	24	56	6.5—7.2	925
4Х10С2М 12	13 ЭИ107	14 Закалка с 1010—1050° в масло, отпуск при 750°±30°, охлаждение в масло	3.3—3.7	~95	~75	~10	~35	~2.0	850
3Х13Н7С2 13 15	ЭИ72	16 Закалка с 1050°, отжиг при 860—880°, охлаждение до 700° в течение 2 час. и затем с печью; нормализация при 660—680° в течение 30 мин., охлаждение на воздухе, закалка с 790—810° в масло	≤3.05	≥120	~80	~8	~20	≥2	1000
4Х14Н14В2М 17	ЭИ69	18 Отжиг при 820° не менее 5 час., охлаждение на воздухе	3.6—4.3	~70	~32	~20	~35	≥5	899
4Х14Н14В2С2 19	ЭИ260	Горячекатаный материал после 5-часового отжига при 820°, охлаждение на воздухе 20	3.9—4.7	~70	—	≥20	≥35	—	1000
Х20Н77Т2Ю 21	22 ЭИ437А	23 Закалка с 1080±10°, выдержка 8 час., охлаждение на воздухе, старение при 700°±10° в течение 16 час., охлаждение на воздухе	3.65—3.8	62*	—	5*	12*	—	950—1000
ВЗК	ВЗК	Литой 25	5 600 кг/мм² 40—50 RC	—	—	—	—	—	1000
ВХН1 26	ВХН1	Литой 25	20—30 RC	—	—	—	—	—	1100

* at 700°.

1) Steel, alloy according to GOST; 2) trademark; 3) heat treatment; 4) d_{otp}, mm; 5) kg/mm^2; 5a) kg/cm^2; 6) temperature at which intense oxidation begins; 7) 4Kh9S2; 8) ESKh8; 9) hardening from 1050° in oil; tempering at 680-700°, cooling in air; 10) tempering at 650±10°, cooling in air; 11) hardening from 1000° in oil, tempering at 800°, cooling in water; 12) 4Kh10S2M; 13) EI..; 14) hardening from 1010-1050° in oil, tempering at 750±30°, cooling in oil; 15) 3Kh13N7S2; 16) hardening from 1050°, tempering at 860-880°, cooling to 700° within 2 hrs and then in furnace; normalizing at 660-680° for 30 min, cooling in air, hardening from 790-810° in oil; 17) 4Kh14N14V2M; 18) hardening at 820° for at least 5 hrs, cooling in air; 19) 4Kh14N14V2S2; 20) hot-rolled material, after tempering at 820° for 5 hrs, cooling in air; 21) Kh20N77T2Yu; 22) EI437A; 23) hardneing from 1080±10°, tempering for 8 hrs, cooling in air, aging at 700±10° for 16 hrs, cooling in air; 24) VZK; 25) cast; 26) VKhN1.

alloy Kh20N77T2Yu for hollow exhaust valves of aircraft engines (abroad, the alloy Nimonic 80 is used).

References: Khimushin F.F., Zharouporyye stali dlya aviatsionnykh dvigateley [Heatproof Steels for Aircraft Engines]. Moscow, 1942; Modford R.D., Ball F.A., Exhaust Valve Life, Henry Wiggin Comp. Limited, 1955/1956.

F.F. Khimushin

VANADIUM V – chemical element of the 5th group in Mendeleyev's periodic system, atomic number 23, atomic weight 50.95. Naturally occurring vanadium consists of two isotopes: V^{51} (99.75%) and V^{50} (0.25%). Radioactive vanadium isotopes have been obtained artificially; the more important of them is V^{48} ($T_{1/2}$ = 16 days). Vanadium is most extensively used in the industry as an alloying element in the fabrication of high-quality special steels. Its prevalence in the earth's crust is the same as copper, chrome and nickel and comprises 0.015% by weight. The vanadium industry of the USSR is based primarily on titanium-magnetite iron ore deposits and disposes of a powerful raw-materials base. At the present time about 90% of vanadium is used in the form of ferrous alloys, about 7% is used in the form of chemical compounds (catalysts, dyes, chemical poisons), and the balance is used for alloys on different bases (aluminum, titanium, niobium). As a component of titanium alloys vanadium is used in aviation and rocket technology. The use of pure vanadium and alloys based on it is limited primarily to research work in aviation, nuclear engineering, chemical industry, etc. A serious limitation on the use of vanadium (especially in an oxidizing atmosphere) is the lower melting temperature of its pentoxide and the toxicity of vanadium and its compounds. Prospects exist for the use of vanadium as a material of construction at high temperatures (300-600°).

Production Process Properties of vanadium depend on the content of admixtures, primarily gases, and also on the structure and quality of the casting. Pure vanadium (99.9%) is extremely plastic and easily worked by all the known methods: forging, rolling, stamping, pressing, ma-

chining (similar to copper) and welding in an inert atmosphere. The forging temperature of vanadium lies in the interval between 1000-1450°. Nonalloyed vanadium is cold-rolled, the need for intermediate annealing and its frequency is primarily determined by the structure rather than by reduced plasticity. Thin-walled tubes can be obtained from vanadium. Vanadium products are etched in a water solution of 30% HNO_3 and 3% HF. Hydrogen brittleness appears here which is easily eliminated by vacuum annealing at 1000°. Vanadium can be protected from oxidizing by galvanic coatings; the best results are obtained by nickel plating. Vanadium is arc-welded in an inert atmosphere; annealing after welding is not required.

Main Physical Properties

Cross section for capture of thermal neutrons	4.7 ± 0.2 barns
First ionization potential	6.71 ev
Crystallic lattice	body-centered cubic
Crystal lattice parameter	3.0282 A
γ_0 at 20°	6.11 g/cm^3
$t°_{pl}$	1900 ± 25°
$t°_{kip}$	3400°
Vapor pressure in the temperature interval 20-1900°	$\lg p = \frac{26650}{T} - 0.112 \times 10^{-3} T + 10.815$ (T is the temperature in °K, p is the pressure in mm of Hg)
Specific heat (298-1900°K)	$c_p = 5.40 + 2.00 \cdot 10^{-3} T$ cal/mole·°C
λ at 100°	0.074 cal/cm·sec·°C
λ at 500°	0.088 cal/cm·sec·°C
ρ at 20°	24.8 micro-ohm·cm
Temperature coefficient of electrical resistivity (0.200°)	5.03°K
Work function of electrons	3.79 ev
Photoelectric threshold	326
Hall's coefficient	less than 10^{-13} w·cm/amp·erg

Standard electrode potential (V^{2+})	1.5 volts
Compressibility under a pressure of 10,000 kg/cm^2	V_p/V_0 = 0.99417
μ	0.36
E	13,869 kg/mm^2
Shear modulus G	4730 kg/mm^2
Magnetic susceptibility at 25°	$5 \cdot 10^{-6}$ electromagnetic units/g
at 1700°	$4.57 \cdot 10^{-6}$ electromagnetic units/g

The mechanical properties depend to a large extent on the content of admixtures, primarily, nonmetallic. The hardness of vanadium serves as a measure of its purity (Table 1). Addition of up to 0.25% of carbon does not increase the hardness and does not substantially effect the plasticity. The oxygen and nitrogen content effects the strength and plasticity; here the total limiting quantity of oxygen and nitrogen for

TABLE 1

Effect of Admixtures on the Mechanical Properties of Vanadium

Содержание примесей (%) 1			σ_b 2	δ	ψ	HV 2
O	N	C		(%)		
0.012	0.008	—	22.1	17	75	84
0.08	0.04	0.05	38.5	32	72	150
0.044	0.0018	0.224	—	—	—	100
0.1	0.05	0.06	46.2	38	82	172
0.09	0.07	0.1	52.2	26	68	163
0.033	0.7	—	—	—	—	431
0.18	0.10	0.12	28	0	0	—
0.09	0.08	0.25	58.7	10	25	—

1) Content of admixtures; 2) (kg/mm^2).

which plasticity is retained is, according to certain authors, 0.2%.

Plastic vanadium retains its strength when heated to 400-450° (Table 2); the increase in the yield limit as the temperature rises attests to the presence of aging which is due to admixtures contained in the metal. Vanadium is work-hardened (Figs. 1, 2); annealing following the shaping operation results in reducing the hardness and increasing

the grain size (Fig. 3).

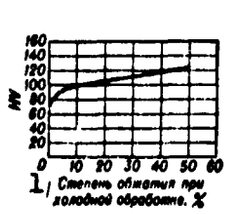

Fig. 1. Effect of cold working on the hardness of annealed vanadium iodide. 1) Degree of compression in cold working, %.

TABLE 2

Properties of Vanadium Annealed at 1000° as a Function of the Temperature

Темп-ра испытания (°C) 1	σ_b (кг/мм²) 2	δ(%)
−195	108.1	3.4
−98	65.3	13.6
27	42.43	14.2
227	35.2	9.7
427	46.2	12.6
627	17.6	36.9
827	8.5	17.9
1027	5.4	37.2
1227	3.4	48.1

1) Testing temperature (°C); 2) (kg/mm^2).

Chemical properties. Water, water solutions of alkalies and of hydrochloric acid do not effect vanadium; hydrofluoric, concentrated

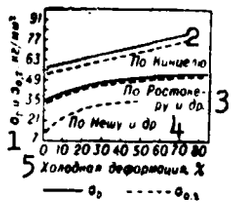

Fig. 2. Increase in the strength of vanadium by cold-rolling. 1) σ_b and $\sigma_{0.2}$, kg/mm^2; 2) according to Kintzel; 3) according to Rostoker et al; 4) according to Nash et al; 5) cold shaping %.

sulfuric (hot), perchloric and nitric acids, as well as aqua regia dissolve vanadium. Molted alkalies potash, saltpeter dissolve vanadium with the attendant formation of vanadic salts. The action of diluted acids and salts at various temperatures is shown in Table 3, and the

effect of molten metals is shown in Table 4. When heated, vanadium interacts with hydrogen, oxygen, nitrogen, chlorine, sulfur and carbon.

TABLE 3
Corrosion Resistance of Vanadium in Acid and Salt Solution

Среда, условия 1	Скорость коррозии (потеря в весе) мг/дм²× ×сутки 2
10% HCl, 70°, аэрация 3	36
20% HCl, 70°, аэрация 4	220—330
20% HCl, 70°, пробулькивание азотом 5	275—720
37% HCl, комнатная темп-ра, без аэрации 6	130—180
10% H_2SO_4, 70°, аэрация 7	30—38
10% H_2SO_4, кипение 8	150—180
10% H_2SO_4, пробулькивание азотом 9	18
5% $FeCl_3$, 10% NaCl, комнатная темп-ра 10	3600—3800
20% NaCl, опрыскивание 11	Не оказывает влияния 12
Промышл. атмосфера 13	Нек-рое разъедание 14

1) Medium and conditions; 2) decimeter-day; 3) 10% HCl, 70°, aeration; 4) 20% HCl, 70°, aeration; 5) 20% HCl, 70°, bubbling through with nitrogen; 37% HCl, room temperature, without aeration; 7) 10% H_2SO_4, 70°, aeration; 8) 10% H_2SO_4, boiling; 9) 10% H_2SO_4, bubbling through with nitrogen; 10) 5% $FeCl_3$, 10% NaCl, room temperature; 11) 20% NaCl, sprinkling; 12) has no effect; 13) industrial atmosphere; 14) some pitting.

Hydrogen is absorbed by the metal up to 300° in amounts of up to 157 cm^3/g with attendant formation of the hydride, but decomposes easily when heated in a vacuum to 900°. Vanadium is an excellent getter for nitrogen, for which reason it is enriched by nitrogen when in leaking furnaces. At temperatures below 675° vanadium is covered by a dense film which clings closely to the metal and protects it from rapid oxidation. Above 675° vanadium does not have self-protection against oxidation (Tables 5 and 6).

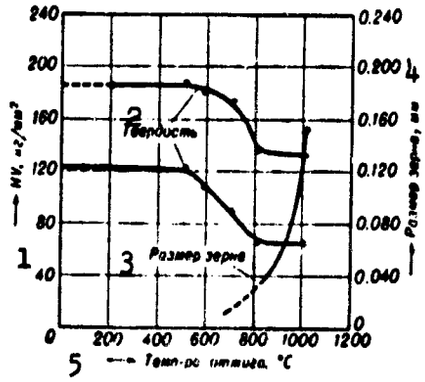

Fig. 3. Effect of the annealing temperature on the hardness and grain size. 1) kg/mm^2; 2) hardness; 3) grain size; 4) grain size, mm; 5) annealing temperature, °C.

TABLE 4

Corrosion of Vanadium in Liquid Metals

Жидкий металл 1	Темп-ра испытания (°C) 2	Коррозионная стойкость 3
Натрий 4	500	Хорошая стойкость, скорость коррозии 0,2 мг/см^2 · месяц 5
55.5% Bi, 44.4% Pb	650	Хорошая стойкость при статич. испытаниях в течение 500 час. 6
52% Bi, 32% Pb, 16% Sn	650	То же 7
52.3% Bi, 21.3% In, 25.8% Pb	650	"
49.5% Bi, 21.3% In, 17.6% Pb, 11.6% Sn	650	"
57.5% Bi, 25.2% In, 17.3% Sn	650	"
55.5% Bi, 44.5% Pb	482	Хорошая стойкость при динамич. испытаниях в течение 1008 час.; вес образцов возрастает 8
52% Bi, 32% Pb, 16% Sn	650	При динамич. испытаниях в течение 1008 час. скорость коррозии 20 мг/см^2 × × месяц 9

1) Liquid metal; 2) test temperature (°C); 3) corrosion resistance; 4) sodium; 5) good resistance, corrosion rate 0.2 milligrams/cm^2. ·month; 6) good resistance under static tests during 500 hours; 7) same as above; 8) good resistance in dynamic tests during 1008 hours; the weight of the specimens increases; 9) the corrosion rate in dynamic tests during 1008 hours is 20 milligrams/ /cm^2·month.

TABLE 5

Vapor Pressure of V_2O_5 at Different Temperatures

1 Темп-ра (°С)	700	900	1000	1100	1200
2. Упругость пара (мм рт.ст.)	0.0337	0.3078	1.36	3.94	8.97

1) Temperature (°C); 2) vapor pressure (mm of Hg).

TABLE 6

Properties of Vanadium Oxides

Окислы 1	γ (г/см³) 2	t°пл 3 (°С)	4 Растворяется в:
V_2O_3	3.3	670	5 HF, HCl, HNO_3, щелочах
VO_2	4.3	1967	6 Кислотах
V_2O_4	4.84	1970	HNO_3, HF
VO	5.23—5.76	2000	Разбавл. кислотах

7

1) Oxides; 2) (g/cm^3); 3) $t°_{pl}$ (°C); 4) is soluble in; 5) HF, HCl, HNO_3, alkalies; 6) acids, HNO_3, HF; 7) diluted acids.

Vanadium alloys. Vanadium-rich alloys with the exception of V-U, V-Ti, V-Fe, V-Nb and V-Zr have not been sufficiently studied.

The radius of the vanadium atom (1.36 A) differs insignificantly from the atomic radius of many other elements (Fig. 4) for which reason vanadium is an efficient solvent for the majority of metallic elements and, therefore, it can be expected that alloys with it as a base will come into extensive use (Fig. 5). It should be noted that the majority of alloying additives highly increases the hardness of vanadium. Annealing of cast vanadium frequently appreciably reduces its hardness (Fig. 6).

Study of a number of double alloys has shown that vanadium alloys with an addition of up to 3-5% of: Zr, Al, Nb, Co, Cr and Si; of up to

10% of: Fe, Ni, Mn and Mo, and of up to 50% of Ti are forgeable. Certain positive effects on the forgeability of double alloys is exerted by carbon, which prevents the formation of a columnar structure when the casting cools. The V-Ti and V-Zr alloys are most plastic (Table 7).

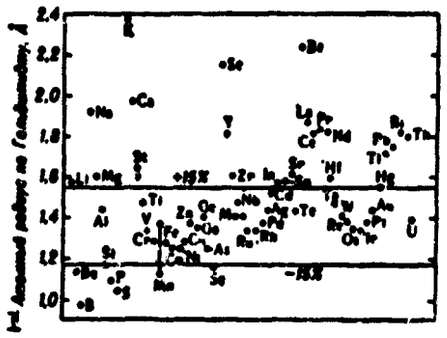

Fig. 4. Comparison of atomic radii of vanadium and other elements. 1) Atomic radius according to Goldschmidt, A.

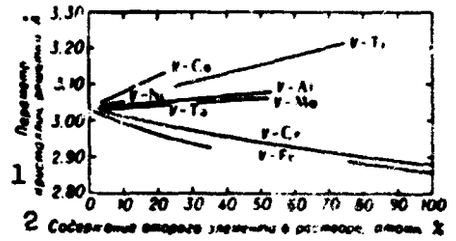

Fig. 5. Parameters of crystal lattices of certain solid solutions with vanadium as a base. 1) Crystal lattice parameter, A; 2) content of the second element in the solution, atomic %.

TABLE 7

Mechanical Properties of the V-Ti and V-Zr Alloys

Второй компонент 1		σ_b	δ	ψ	HV
Наименование 2	Содержание (%) 3	4	(%)		4
Титан 5	1.0	69.7	0	0	292
	2.5	63.4	12.5	33.7	191
	5.0	55.2	26.8	77.0	172
	7.5	56.5	25.0	70.5	190
	10	65.3	27.4	66.5	194
Цирконий 6	1.0	36.8	34.1	51.5	119
	2.5	37.8	23.1	76.4	109

1) Second component; 2) name; 3) content (%); 4) (kg/mm^2); 5) titanium, 6) zirconium.

Ingots of certain (previously mentioned) vanadium alloys are sen-

sitive to the rate of shaping, for which reason smith forging is preceded by forging in closed dies to destroy the cast structure.

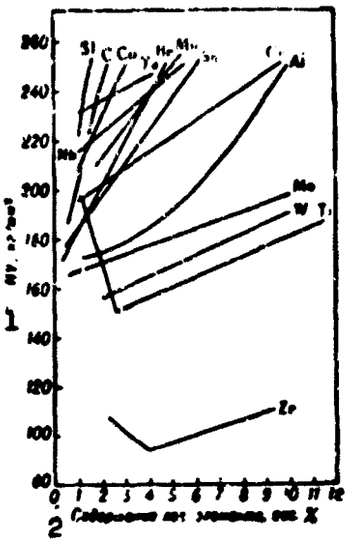

Fig. 6. Hardness of certain annealed vanadium alloys. 1) kg/mm^2; 2) content of alloying element by weight, %.

Vanadium-based alloys demonstrate valuable mechanical properties at high temperatures (500-700°). For example, alloys of vanadium with 5-20% of Ti combine low-temperature strength and high plasticity with high strength at high temperatures and low rate of creep. Sheets of

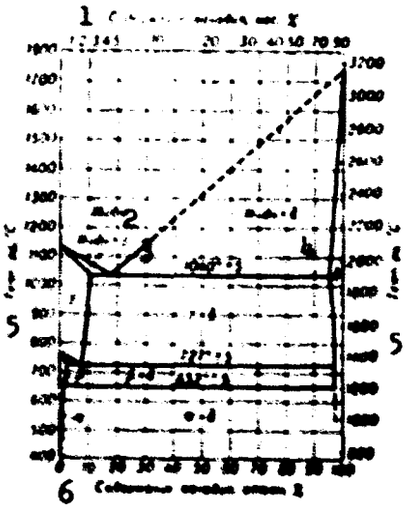

Fig. 7. Constitution diagram for the vanadium-uranium system. 1) Weight content of vanadium, %; 2) liquid; 3) liquid + λ; 4) liquid + β; 5) temperature, °C; 6) atomic content of vanadium, %.

this metal are easily welded. To improve the heat resistance of vanadium, attempts are made to introduce alloying elements which increase

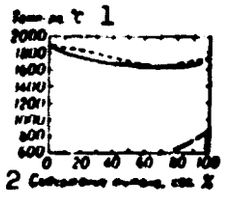

Fig. 8. Constitution diagram for the vanadium-titanium system. 1) Temperature, °C; 2) weight content of titanium, %.

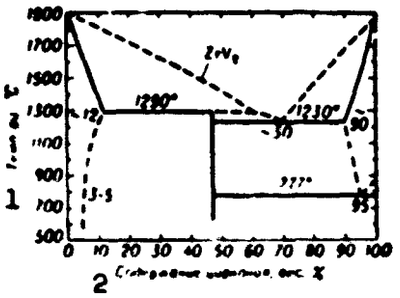

Fig. 9. Constitution diagram for the vanadium-zirconium system. 1) Temperature, °C; 2) weight content of zirconium, %.

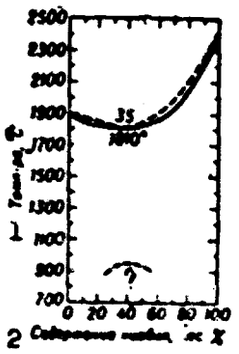

Fig. 10. Constitution diagram of the vanadium-niobium system. 1) Temperature, °C; 2) weight content of niobium, %.

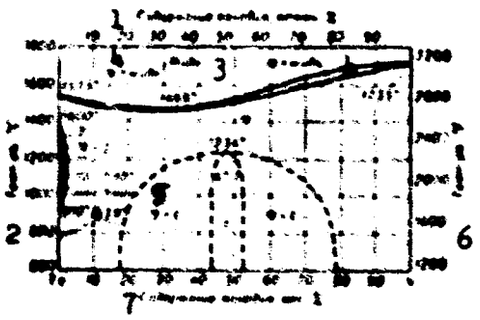

Fig. 11. Constitution diagram of the vanadium-iron system; 1) Atomic content of vanadium, %; 2) temperature, °C; 3) liquid; 4) α + liquid; 5) Curie point; 6) temperature, °F; 7) weight content of vanadium, %.

the melting temperature of vanadium pentoxide and use is made of surface saturation or electroplating. Positive results are obtained from nickel plating. For certain constitution diagrams, see Figs. 7-15.

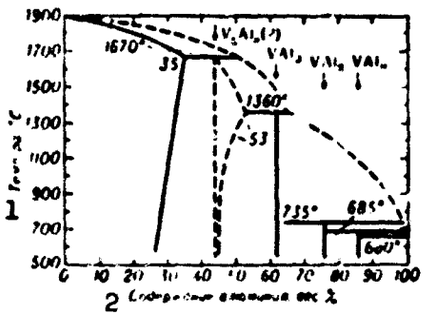

Fig. 12. Constitution diagram of the vanadium-aluminum system. 1) Temperature, °C; 2) weight content of aluminum, %.

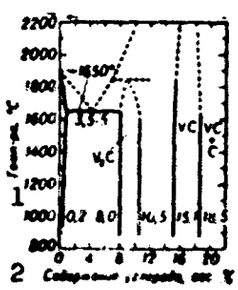

Fig. 13. Constitution diagram for the vanadium-carbon system. 1) Temperature, °C; 2) weight content of carbon, %.

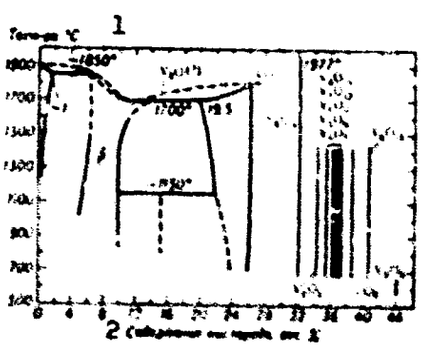

Fig. 14. Constitution diagram of the vanadium-oxygen system. 1) Temperature, °C; 2) weight content of oxygen, %.

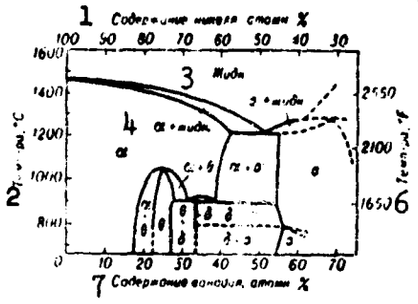

Fig. 15. Constitution diagram of the vanadium-nickel system. 1) Atomic content of nickel, %; 2) temperature, °C; 3) liquid; 4) α + liquid; 5) σ + liquid; 6) temperature, °F; 7) atomic content of vanadium, %.

References: Yadernye reaktory [Nuclear Reactors], translated from English, Vol. 3, Moscow, 1956 (Materials of the Atomic Energy Commission of the USA); W. Rostoker, Metallurgy of Vanadium, translation from English, Moscow, 1959; Polyakov, A.Yu., Osnovy metallurgii vanadiya [Fundamentals of Vanadium Metallurgy], Moscow, 1959; Rare Metals Handbook, ed. by C.A. Hampel, 2 ed. L., 1961.

V.A. Sinel'nikova

VANADIUM ALLOYS -- see Vanadium.

VARNISHED ELECTRIC INSULATION CLOTH is cloth which is impregnated with special lacquers which form on the surface of the cloth a thin elastic film which has high dielectric properties. This cloth is used as electric insulating material (for insulation of armature windings and excitor windings, stators, connections and lead ends, casings, inter-lamina, inter-phase and slot insulation, etc.). These cloths are prepared from cotton, silk (natural and artificial) and glass cloths, and also from the cloths made from the synthetic fibers (polyamide, polyethylene terephthalic, polyacryl nitrile, etc.). As the impregnating compositions, use is made of the bituminous-butyric lacquers and the lacquers made from the synthetic resins (polyurethane, polyester, epoxy, acrylic, polytetrafluorethylene, silicone, etc.). In the USSR the varnished electric insulation cloth is produced in the form of strip wound into rolls or tape in roll form. The strips are cut lengthwise or at an angle to the warp threads, the latter are termed diagonal varnished cloths.

The cotton fabrics are impregnated with butyric (clear varnished electric insulation fabric) and bituminous-butyric lacquers (dark fabric). With regard to heat resistance, these fabrics fall in class A. The thicknesses are 0.10; 0.12; 0.15; 0.17; 0.20 and 0.24 mm; the clear fabrics are also produced in 0.30 mm thickness. The tensile strength in the warp direction is 3.5-6.0, in the fill direction it is 2.5-4.5, and in the diagonal direction it is 2.0-5.0 kg/mm^2; the relative breaking elongation is respectively 2.5-6.0, 10-20 and 20-45%. The electrical strength E_{pr} of the clear cotton varnished electric insulation cloth at

20 ±5° is 35-55 kv/mm; the volumetric resistivity ρ_v is 10^{13}–10^{14} ohm-cm. After moistening for 24 hours with relative humidity of the air of 95±3% the E_{pr} diminishes to 15-40 kv/mm; ρ_v decreases to 10^9–10^{11} ohm-cm. At 105° E_{pr} is 25-45 kv/mm; ρ_v is 10^9–10^{12} ohm-cm. Continued heating leads first to an increase of the electrical strength and then to a gradual reduction of the electrical strength and an increase of the stiffness of the material, for example, E_{pr} at the bend location in the varnished cloth subjected to aging at 105° for 18 hours diminishes by 25-70 percent.

The dark cotton varnished cloths are characterized by higher electrical characteristics and higher moisture resistance as well as lower dielectric losses, particularly at elevated temperature. Therefore, they are used primarily for the insulation of high-voltage electrical machines. The E_{pr} for these materials at 20±5° is 40-60, at 105° it is 35-50, after moistening for 24 hours with an air relative humidity of 95±3% it is 20-45 kv/mm; ρ_v is respectively 10^{14}–10^{15} ohm-cm, 10^{11}–10^{12} ohm-cm, and 10^{10}–10^{12} ohm-cm. The tangent of the dielectric loss angle is equal to 0.03-0.05.

The clear cotton varnished insulation cloths have the highest gasoline and oil resistance. The dark materials are not oil resistant and are not used in machines, apparatus or other devices subjected to the action of mineral oils and solvents.

The silk varnished electric insulation cloths are natural silk or kapron fabrics impregnated with butyric lacquers or by lacquers made from the polyester resins. With regard to heat resistance they are in class A. They differ from the cotton insulation cloths in having considerably less thickness, improved dielectric characteristics and higher breaking elongation in the warp and diagonal directions. They are widely used when the requirements demand a thin insulating layer

with high values of the breakdown voltage. They come in thicknesses of 0.04; 0.05; 0.06; 0.08; 0.10; 0.12 and 0.15 mm. The tensile strengths in the warp, fill and diagonal directions respectively are 2.2-3.8, 1.8-3.5 and 2.0-3.8 kg/mm^2. The relative breaking elongation of the natural and kapron fabric in the warp and fill directions respectively is 6-10% and 25%, the elongation in the diagonal direction is 30-50% and 55%. The E_{pr} for the silk varnished cloths of 0.04-0.06 mm thickness does not exceed 15-40 kv/mm and for a thickness of 0.08-0.15 mm does not exceed 60-90 kv/mm; ρ_v is 10^{13}–5.10^{14} ohm-cm; at 105° E_{pr} is 35-60 kv/mm, ρ_v is 10^{10}–10^{11} ohm-cm.

The low hygroscopicity of the silk materials (water absorption after 24 hours of the silk materials is 3.5-5.0%, for the clear cotton materials it is 4.0-7.0%) leads to less reduction of the electrical characteristics with moistening. Thus, with moistening of specimens 0.08-0.15 mm thick for 24 hours with relative humidity of the air of 95 ± 3%, E_{pr} is reduced to 25-50 kv/mm, ρ_v to $5\cdot10^{10}$–10^{12} ohm-cm.

The glass varnished insulating cloths are fabricated from alkaline-free glass fabrics. The following types are produced (see Table).

In its properties the LSM glass insulating cloth is close to the clear cotton cloth; it is used for the same purposes. The black LSB glass cloth, just as the black cotton cloth, has inadequate oil and gasoline resistance but does have high heat and moisture resistance. The LSE glass cloth falls in the rubber-glass varnished cloth group; as a result of its high elasticity the electrical strength diminishes little with stretching and bending; it is relatively rapidly oxidized by atmospheric oxygen (ages). Of all the electrical insulation cloths, the silicone glass cloth LSK has the highest heat resistance. The impregnating compositions based on the polyorganosiloxanes provide for low variation of the electrical characteristics as a function of the action

of elevated temperature and humid medium. The type LSKL glass cloth is adhesive, thanks to which a good strength of the bond between the individual layers of the insulation is achieved. Its electrical properties increase considerably afte. thermal treatment at 180°. This glass cloth is used as winding insulation (turbogenerators), and for insulating any

Characteristics of the Glass Varnished Insulating Cloths

Марка 1	Пропиточный состав 2	Класс нагревостойкости 3	Цвет 4	Номинальная толщина (мм) 5	Электрическая прочность (кв/мм) при 20±5° 6	при повышенной температуре 7	после увлажнения в течение 24 час при относительной влажности воздуха 95±3% 8	Удельное объемное сопротивление (ом·см) при 20±5° 9	при повышенной температуре 10	после увлажнения в течение 24 час при относительной влажности воздуха 95±3% 11
ЛСМ	Масляный лак 11	А	Желтый	0,15; 0,17; 0,20; 0,24	35–70	20–35 (105°)	20–40	$1\cdot10^{13}$–$1\cdot10^{14}$	$5\cdot10^{12}$–$1\cdot10^{13}$ (105°)	$1\cdot10^{12}$–$1\cdot10^{13}$
ЛСЭ	Лак на основе эскапона 12	Е 18	Темно-коричневый	0,13; 0,15; 0,17; 0,20; 0,24	40–80	30–45 (130°)	10–25	$1\cdot10^{14}$–$5\cdot10^{14}$	$1\cdot10^{13}$–$1\cdot10^{14}$ (130°)	$1\cdot10^{12}$–$1\cdot10^{13}$
ЛСБ	Алкидно-битумно-масляный лак 13	В	17 Черный	0,11; 0,13; 0,15	45–65	30–55 (130°)	20–50	$1\cdot10^{13}$–$1\cdot10^{14}$	$1\cdot10^{12}$–$1\cdot10^{13}$ (130°)	$1\cdot10^{12}$–$1\cdot10^{13}$
ЛСК	Кремнийорганический лак 14	Н	20 Светло-желтый	0,12; 0,20; 0,24; 0,06; 0,08; 0,11; 0,15; 0,20	40–80	20–50 (180°)	20–50	$5\cdot10^{13}$–$5\cdot10^{14}$	$1\cdot10^{13}$–$1\cdot10^{14}$ (180°)	$1\cdot10^{12}$–$1\cdot10^{13}$
ЛСКР	Раствор кремнийорганического каучука 15	Н	19 Темно-коричневый	0,11; 0,15; 0,17; 0,20	20–60	20–40 (200°)	10–25	$1\cdot10^{14}$–$5\cdot10^{14}$	$1\cdot10^{13}$–$1\cdot10^{14}$ (200°)	$1\cdot10^{12}$–$1\cdot10^{13}$
ЛСКЛ	Кремнийорганический лак 16	Н	21 То же	0,12; 0,15	5–15	–	–	$5\cdot10^{12}$–$1\cdot10^{13}$	–	–

1) Type; 2) impregnating composition; 3) heat resistance class; 4) color; 5) nominal thickness (mm); 6) electrical strength (kv/mm); 7) at 20 ± 5°; 8) at elevated temperature; 9) after moistening for 24 hours with relative humidity of the air 95 ± 3%; 10) volumetric resistivity (ohm-cm); 11) LSM butyric lacquer; 12) LSE eskapon-base lacquer; 13) LSB alkyd-bitumen-butyric lacquer; 14) LSK silicone lacquer; 15) LSKR solution of silicone rubber; 16) LSKL silicone lacquer; 17) yellow; 18) dark brown; 19) black; 20) light yellow; 21) same.

electrical machinery parts. It is produced in rolls of widths 10, 15, 20, 25 and 30 mm.

The tensile strength of the glass varnished cloths is: along the warp 10-30, along the fill 3.5-14.0, and along the diagonal 5.0-15.0 kg/mm^2. Relative breaking elongation in the warp direction is 4-7%, in the diagonal direction it is 35-50%.

References: Spravochnik po elektrotekhnicheskim materialam [Handbook on Electrical Materials], Vol. I, pt. 1, M.-L., 1958; Yarden-burg, S.S., et al., Novyye elektroizolyatsionnyye materialy [New Electrical Insulation Materials], M., 1961.

M.B. Fromberg

VENEER – is a flat sheet obtained by shelling, shaping or sawing wood. Shelled veneer is the raw material used for the production of plywood, multilayer wood plastics, glued and bent objects, plywood pipes and barrels. Veneer is made mainly of birch and alder, rarely of beech and pine; the thickness is 0.55-4.7 mm, the width 150-1600 mm and the length 750-1900 mm. The length of the veneer sheet is measured across the grain. The standards of the admissible defects of the wood and of the manufacture are fixed by GOST. The mechanical properties of birch veneer at 9% moisture are quoted in the Table.

1	2			3		
		4	5		4	5
0.3	760	35	20	118000	11000	3300
1.15	1200	65	25	156000	8000	3500
4.7	720	30	10	150000	6700	2300

1) Thickness (mm); 2) tensile strength (kg/cm^2); 3) modulus of elasticity on drawing (kg/cm^2); 4) along the grain; 5) at an angle of 45°; 6) across the grain.

Storage-battery veneers are made of alder or Siberian ceder and are used in the dividing walls of lead storage batteries. Depending on the manner of manufacture, the storage-battery veneer is divided into riffled and smooth veneer, the former having ribs along the grain. Veneer obtained by shaping or sawing is used as a facing material for wooden objects. Shaped veneer is made of oak, beech, nut, maple, platan, elm, karagach-elm, chestnut, plane, Amur cork tree, pear, apple, poplar, cherry, acacia and other trees. The dimensions of shaped ven-

eer are: 100 mm and longer, 0.8-1.5 mm thick, 100-250 mm wide.

References: Lebedev, V.S., Fanernoye proizvodstvo [Veneer Manufacture], Moscow-Leningrad, 1956; Fanera i fanernyye izdeliya [Veneer and Veneer Ware], Moscow, 1961, pages 63-80.

V.S. Lebedev

VERDELITE – see Tourmaline.

VEREL – modified carbon-chain fiber based on a triple copolymer, that is, cyanide of acrylic acid, vinylidene-chloride and a monomer which improves the color retention of the fiber. It is produced in the USA as a staple fiber (N_m el. 4500, 3000, 1800 and 1120 with a different length of pieces); the cross section of the fiber is elongated in shape. Verel is noncombustible, is resistant to natural light, biological effects, to acids, alkalies, bleaching agents, oxidizing agents; the fiber retains color well but is not sufficiently elastic. The specific weight of the fiber is 1.37; moisture absorption under standard conditions is 3.5-4%. Verel becomes charred and sintered in a flame (as a result of the high chlorine content of the copolymer). When held for 30 weeks in open air its strength does not change; after 50 weeks the strength losses comprise 45%. Verel is dyed by neutral, mordant, dispersion and basic dyes. Shrinking in boiling water comprises 1-3%; at 110° it is 2-5%; shrinking can be increased to 9-11% and 15-17% (Verel-I for obtaining artificial fur), and also to 19-23% and 25-28% (Verel-II for the production of high-volume cloth). The breaking strength of Verel is 22.5-25.2 km [sic]; the elongation is 33-35%. The initial modulus of the fiber comprises 4.93 kg/mm^2. The elasticity (reversible deformations) in 4% elongation comprises 88%, in 10% it is only 55%. Verel is used for the production of filtering materials, protective work clothing, sport clothing, etc. Addition of 30-50% of Verel to cotton or wool appreciably improves the stability of the shape of the products thus obtained.

L.M. Musichenko-Vasil'yeva

VERMICULITE – a micaceous mineral with a composition $(Mg, Fe^{\cdot\cdot\cdot})_3$ $[(Si, Al)_4O_{10}](OH)_2 \times 4H_2O$. It crystallizes in a monoclinical system, forms lamellar aggregates or large gold-brown colored lamellar crystals. Specific weight 2.4-2.7; Mohs hardness 1-1.5; perfect cleavability along the {001} [plane], indices of refraction $N_g = N_m = 1.580$; $N_p = 1.560$; vermiculite has a high tendency to cation exchange (150-170 mg/ /equivalent per 100 grams), which exceeds the exchange capacity of the best bentonites by almost a factor of two. Compression strength is 1.0-1.5 tons/cm^2; powder vermiculite does not rub off and its lubricating properties are similar to those of graphite. Decomposes in acids at room temperature, is stable in alkalis. When fired it swells in a direction perpendicular to the cleavage planes and its voluem increases by a factor of 30-40. Swelling starts at 160-170) and rises highly after 200). When fired, minute air layers are formed between the lamellae, which are responsible for its low specific weight and high thermal and sound insulating properties. In industry the term vermiculite is usually used to denote not only the vermiculite mineral proper, but also its mixtures with varieties of magnesium-iron micas hydrated to different degrees (hydrobiotite, hydrophlogopite), which are not so highly apt to swell on heating. Vermiculite is swelled in furnaces at 800-900). Blown-up vermiculite has a low specific weight (60-150 kg/m^3) and high thermal, heat and sound insulating properties. Large fractions (12.7-6.4 mm) of blown-up vermiculite have a lower specific weight (60 kg/m^3) than the finer fractions (0.8 mm – 144 kg/m^3). The thermal conductivity coefficient of blown-up vermiculite changes as follows, de-

pending on the temperature: 0° – 0.04, 20° – 0.045, 100° – 0.051, 250° – 0.066, 500° – 0.096 kcal/m·hour·°C. The coarse-grained and lighter kinds of blown-up vermiculite have better heat insulating properties at temperatures below 90°, while the fine and dense kinds have better heat insulating properties at higher temperatures. The sound conductivity coefficient is 0.02–0.08 (in decibels 17-11), only slightly lower than that of cork. The melting temperature of vermiculite is 1370-1390°. The hygroscopicity of blown-up vermiculite (in air whose relative humidity is 79%) comprises 1%. The dielectric properties of vermiculite are not too good and it is not used as a dielectric. Blown-up vermiculite is chemically inert, has no smell and is biologically stable. Fired vermiculite crumbs should have a low specific weight, certain fraction size and a low brittleness, which are responsible for the low thermal conductivity coefficient, high sound-absorption capacity, etc. The use of vermiculite in the form of crumbs and powder is based primarily on the physical properties of blown-up vermiculite which are: high thermal resistance, low sound and thermal conductivity, low specific weight, lamellar structure and high cation exchange capacity. Vermiculite is used in construction as a super-light filler for concretes; in the production of heat and sound insulating heat-resistant materials (cements, fillers, plasters, slabs, blocks, etc.) in the construction of refrigerators and power generating stations, etc.; in ceramics for obtaining light-weight articles; as a filler in rubber, plastics, dye stuffs; in the production of lubricants which are equivalent in value of graphite lubricants, and of antifriction materials; as a carrier of insecticides, herbicides and catalizers in the chemical industry; for improving the structure of soils, in the production of wall coverings and linoleum (instead of cork); as a water softener (as permutite); in the atomic industry for recovery of uranium and the radioactive isotopes of Zr, Sr,

Ru, Cs and Ce from the waste water; in the production of special filters; in storage of fruits as a packing, biologically stable nonhygroscopic material; in the drilling of oil wells, and also for other purposes. The industry uses practically all kinds of blown-up vermiculite.

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V.I. Fin'ko

VETRELON – A synthetic hetero-chain modified fiber made from a mixed polyamide which is a product of condensation polymerization of caprolactam (30-45%) and salt TG (70-55%). It is produced in the German Democratic Republic; by its properties it occupies an intermediate position between capron and terylene. Specific weight 1.17; moisture absorption capacity under standard conditions 5%, $t°_{pl}$ is 245°, the breaking length is from 27 to 45 km. Vetrelon is characterized by high volume elasticity. In comparison with terylene it has a lower specific weight, better rubbing resistance and good color retention; it is inferior to capron and terylene with respect to strength and has a large shrinkage as compared with them (13% in boiling water).

References: Rogovin, Z.A. Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of the Production of Chemical Fibers], Second eidtion, Moscow, 1957; Piller, B. and Travnichek, Z. Sinteticheskiye volokna i osobennosti ikh pererabotki v tekstil'noi promyshlennosti [Synthetic Fibers and Features of their Processing by the Textile Industry], translated from Czechoslovakian. Moscow, 1960.

E.M. Ayzenshteyn

VIBRATION INSULATING MATERIALS – materials with a low modulus of elasticity ($E < 1000$ kg/cm^2) used in the form of continuous or individual liners for insulation from vibrations and noise: air (noise that arises in the atmosphere) and impact (sound which arises in manufacturing materials on impacts, walking, etc.). The following are used as vibration insulating materials: various kinds of rubber (spongy and continuous); asbestos sheet; plates and mats from mineral fiber (for example, from fiberglass) cemented by various binders; elastic materials

TABLE 1

Dynamic Moduli of Elasticity E_D of Certain Vibration Insulating Materials

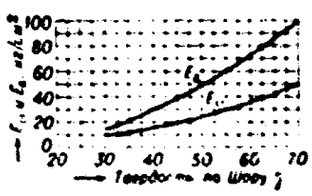
Материал 1	Объемный вес (г/см³) 2	Толщина прокладки δ (см) 3	Удельная нагрузка (г/см²) 4	Модуль упругости $E_д$ 5	6 Применение
7 Губчатая резина	0.75	–	–	28	8 Прокладки под моторы, насосы, приборы, чувствит. к вибрациям, и т. п.
9 Изоляционная древесно-волокнистая плита ..	0,14–0.20	1.2–2.4	5–30	12–18	Сплошные или отдельные прокладки в различных конструкциях для изоляции от вибрации и шума
10 Пенопласт ПХВ	–	–	30	2	
11 Стекловолокнистые плиты на фенольной связке	0.05	–	20	1	
12 Минераловатные маты на синтетич. связке ..	–	–	20	1.5	

1) Material; 2) specific weight (g/cm^3); 3) thickness of liner δ (cm); 4) specific load (g/cm^2); 5) modulus of elasticity E_D; 6) application; 7) porous rubber; 8) liners placed under motors, pumps, instruments which are vibration-sensitive, etc.; 9) insulating wood-fiber plate; 10) PKhV foam plastic; 11) fiberglass plates with phenol as a binder; 12) mineral wool mats with a synthetic binder; 13) continuous or individual liners in various designs for vibration and noise insulation.

from plastics (solid or porous); plates and mats from organic fibers (for example, insulating and half-hard wood-fiber plates).

To a certain approximation a vibration-insulating liner can be regarded as a shock absorbing spring. The rigidity of such a spring is de-

fined by the modulus of elasticity E while the losses coefficient η denotes the loss of vibration energy due to friction, that is, the damping of the vibrations. Vibration insulation of machines by using vibration insulating materials is used effectively in combating vibrations of structures which are induced by operation of these machines. Vibration insulation decreases appreciably the transfer to the supporting structure of dynamic loads and housing noises which arise attendant to the operation of machines or are due to shocks, and also eliminates the detrimental effect of vibrations and the shaking of the supporting structure on the machines and instruments. For effective insulation the natural frequency of the system must be sufficiently low, for which reason the rigidity of vibration insulating materials must be reduced to a minimum. The lower the rigidity of the elastic foundation, the less vibration is transmitted. The rigidity of the vibration insulating liner is directly proportional to the modulus of elasticity, the area of the liner and inversely proportional to its thickness. The dynamic modulus of elasticity E_D is greater than the static modulus E_{st}. As an example the figure shows graphs of E_D and E_{st} for rubber. For the majority of vibration insulating materials E_D increases substantially with an increase in the static loads. The value of E_D of certain vibration insulating materials is different for different frequencies. The values of dynamic moduli of elasticity and of the coefficient of losses for certain vibration insulating materials are presented in Tables 1 and 2.



Dependence of the moduli of elasticity of rubber on its hardness. 1) E_{st} and E_D, kg/cm^2; 2) shore hardness.

The rigidity of a vibration insulating liner is reduced if it is free to expand sidewise when loaded. For example, in individual cases the rigidity of liners from continuous rubber increases by a factor of

δ in constrained compression; hence grooved or perforated rubber liners are recommended for vibration insulation. During a certain time interval when the machine is accelerated or stopped the vibrations pass the resonance zone. In the case when the time during which the machine is accelerated or stopped is sufficiently long for the occurrence of substantial resonant vibrations, use should be made of vibration insulating liners with a high degree of internal damping. In using steel

TABLE 2

Coefficient of Losses η of Certain Vibration Insulating Materials

Материал (1)	η	Частота (2) (гц)
(3) Изоляционная древесно-волокнистая плита (δ = 1,2 см)	0.10	225
(4) Изоляционная древесно-волокнистая плита (δ = 2,4 см)	0.06	144
(5) Губчатая резина	0.12	132
(6) Войлок волосяной	0.23	115
(7) Минеральный войлок на синтетич. связке	0.27	78
(8) Шлаковойлок	0.10	78
(9) Пенопласт ПХВ	0.56	75

1) Material; 2) frequency (cps); 3) wood-fiber insulating plate (δ = 1.2 cm); 4) wood-fiber insulating plate (δ = 2.4 cm); 5) spongy rubber; 6) hair felt; 7) mineral felt using a synthetic binder; 8) slag felt; 9) PKhV foam plastic.

springs it must be kept in mind that even when the wire cross section is small, steel is a good conductor of high-frequency noise components. Hence it is recommended that springs be supported on both sides on rubber liners to insulate them from the high-frequency noise components. The elastic properties of vibration insulating materials become poorer with time (for example, in the so-called aging of rubber), hence a provision is made in vibration insulating devices for replacement of liners.

References: I.I. Proizvodstvennyy shum i bor'ba s nim [Industrial Noise and its Elimination], Moscow, 1955; Zaborov, V.I. Teoriya zvukoizolatsii ograzhdayushchikh konstruktsiy [The Theory of Sound Insulation of Protective Structures], Moscow, 1962; Kontyurı, L., Akustika v

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E.M. Lalayev

VICALLOY – see Magnetically hard shaping alloy.

VICARA – see Protein Fiber.

VICKERS HARDNESS – standard physicomechanical characteristic of a material, which determines its ability to resist local plastic deformation which is produced by statically forcing into the specimen or product surface a regular tetrahedral diamond pyramid with a dihedral vertex angle alpha of 136°. The methods for determining Vickers hardness are presented in GOST 2999-59. The Vickers hardness (or the hardness number) HV is defined as the ratio of the load P when making the impression to the area f of the side face of the pyramid-shaped indentation, whose diagonal is measured after the load is removed:

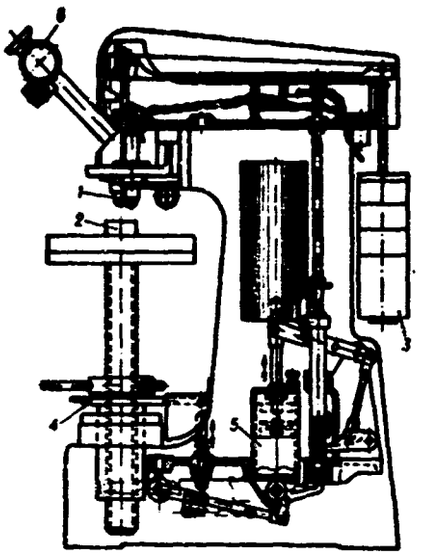
$$HV = \frac{P}{f} = \frac{2P \sin \frac{\alpha}{2}}{d^2} = 1.8544 \frac{P}{d^2},$$

where d is the arithmetic mean of the diagonals of the impression (in mm). The hardness number has units (kg/mm^2) and represents the mean specific pressure at the surface of contact between the pyramid and product when the impression is made. Unlike Brinell Hardness, the Vickers hardness number is independent of the indenting load, since pyramid-shaped impressions are geometrically similar. For medium hardness materials, approximately up to HV (or HB) 400, the Vickers and Brinell hardness numbers are approximately equal, which is due to the proper selection of the value of the dihedral vertex angle of the pyramid.

References: Shaposhnikov, N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Testing of Metals], 2nd Edition, Moscow-Leningrad, 1954.

I.V. Kudryatsev and D.M. Shur

VICKERS METHOD – determination of hardness, primarily of metals, by pressing into the surface of a specimen or a product a diamond indenter (tip), which has the shape of a regular tetrahedral pyramid with a dihedral vertex angle of 136°] The Vickers hardness number (or the pyramid impression hardness) HV represents the mean specific pressure at the impression surface (it is calculated as the ratio of the load to the lateral surface of the impression). The load in making the impression is selected depending on the thickness and hardness of the specimen or product under test (5, 10, 20, 30, 50, 100 kg). The conditions for hardness tests by the Vickers method are established by the GOST 2999-59. The Vickers hardness is determined by hardness testers which make it possible to make pyramid-shaped impressions under standard conditions and to measure (with an accuracy of 0.001 mm) each of the two diagonals of the impression by a rotating head equipped with a measuring microscope. The figure shows a schematic diagram of a domestic TP brand hardness tester. When the pedal is depressed, the diamond tip is pressed into the surface of the specimen under test under the action of the force exerted by the changeable weights. The duration of load application is maintained automatically and is established by adjusting the oil damper.



TP Hardness. 1) Diamond tip; 2) specimen under test; 3) changeable weight; 4) pedal; 5) damper; 6) rotating head with a measuring microscope.

References: Shaposhnikov, N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Testing of Metals], 2nd edition, Moscow – Leningrad, 1954; O'Neil, G. Hardness of Metals and Its Measurement, translated from English, Moscow-Leningrad, 1940.

I.V. Kudryatsev, D.M. Shur

VINIPLAST – see Polyvinyl chloride plastics.

VINIPROSE – a material obtained by heat treating a nonplastified copolymer of vinyl chloride and methyl methacrylate with added stabilizers (zinc or lead stearate, etc.). Copolymerization with methyl methacrylate makes the materials elastic at temperatures lower than those required for elasticity of vinyl polychloride. At a temperature of –30° and when bent by 180° Viniprose does not crack; it is distinguished by dimensional stability under moisture and temperature variations. The industry produces brand "S" and "transparent" Viniprose sheets; the sheet thickness is 0.25-0.45 mm, the dimensions are 1300 × 500 mm. The sheet surface is mat on one side. Properties of "S" Viniprose (TU MKhP 3399-52): specific weight 1.35, tensile strength not less than 500 kg/cm^2, relative elongation not more than 12%, frost resistance not higher than –30°. "Transparent" Viniprose (TU MKhP 3019-55) is more elastic, specific weight 1.34-1.4, tensile strength 400 kg/cm^2, bending strength 900 kg/cm^2, compression strength [illegible] kg/cm^2, relative elongation 20%. Martens heat resistance [illegible]°. Other copolymers of vinyl polychloride with methyl methacrylate also exist. The "Igelit-M" copolymer is distinguished by its high impact viscosity, which is as high as 100 kg-cm/cm^2. The plastic is used [illegible] in the manufacture of chipboard furniture (tables, chairs, shelves, lamps, folding panels).

References: Champetier G. and Rabateau G., Chemistry of Lacquers, Dies and Pigments, translated from French, Vol. 1, Moscow, 1960; Arkhangel'skiy, B.A., Plasticheskiye massy [Plastics], Leningrad, 1961.

N. P. Gashnikova

VINYLON – synthetic carbon-chain fiber made from polyvinyl alcohol. It is characterized by high strength, and hygroscopicity (close to that of cotton fiber), low specific weight, high initial modulus (by a factor of 3-4 higher than that of polyamide and by a factor of 1.5-2 higher than that of polyester fibers), high wear resistance and high resistance to the action of chemicals at 20° (with the exception of concentrated phosphorus and 80% formic acids), sea water and grease, has high thermal and fading resistance, low thermal conductivity (close to that of wool) (for more details on properties see Fiber from Polyvinyl Alcohol). It is used for fishing nets, ropes, filtering materials, rugs, consumer goods.

Z.A. Zazulina

VINYLPYRIDINE LATICES are latices which are obtained by emulsion copolymerization of one of the vinylpyridines or alkylvinylpyridines with divinyl or divinyl and styrene; they are used for impregnation of cord and to provide a strong bond between the elements of rubber-fabric products - tires, drive belts, transporter belts, etc.

With regard to colloidal and chemical properties, the vinylpyridine latices are basically similar to the divinylstyrene latices. Among the properties of the polymer we must note the satisfactory cold resistance (brittle temperature -40 to -70° depending on the amount of bound styrene and alkylpyridine), and also the capability of sulfur vulcanization and interaction with certain organo-haloid compounds (benzylchloride, methyl iodide, etc.) and with the alkysulfates (diethyl sulfate, etc.) with the formation of polymeric salts of the quaternary pyridine bases. Reactions of the latter type lead to considerable increase of the oil and heat resistance of the polymer. In composing recipes for the latex mixtures based on the vinylpyridine latices, we must take into account that the pyridine groups appearing in the composition of the polymer are themselves accelerators of the sulfur vulcanization. Compositions containing these latices provide maximal (in comparison with the other compositions used in industry) values of the adhesion between various types of cord and rubbers, in particular those made from natural rubber, during the operation of the products. This is explained by the good compatibility of the latex polymer with the general purpose rubbers and the interaction of the pyridine nitrogen atoms with the hydroxyl groups of the resin and with the polar

groups of the viscose or polyamide cord.

References: Cook P.G., Latex natural and synthetic, [L., 1956]; Reeves L.W., "Rubber World", 1955, v. 132, Sept., p. 764-65; Tsaylingol'd V.L., et al., KiR, 1959, No. 3, p. 6-9.

A.I. Yezriyelev, A.V. Lebedev

VINYL SILOXANE RUBBER – is the product of hydrolysis of dimethyl dichlorosiloxane with methyl vinyl dichlorosilane, and a subsequent polycondensation of the hydrolyzate in the presence of catalysts. It is well miscible in diverse ratios with natural rubber and diverse synthetic rubbers. It is delivered in the USSR under the mark SKTV. Reduced quantities of benzoyl peroxide, the weakly active peroxides of dicumyl and ditertiary butyl, and also sulfur and its compounds are used to vulcanize vinyl siloxane rubber. The technology of the production of vinyl siloxane rubbers is similar to that of the production of dimethyl siloxane rubbers. The vulcanization can be carried out at atmospheric pressure. The properties of vulcanized vinyl siloxane rubbers depend on the proportion of vinyl groups. The vulcanization of vinyl siloxane rubbers may be carried out at reduced temperature which results in a decreased shrinkage of 1-3% instead of 3-10% during the forming of the products. The properties of vinyl siloxane rubbers are given in Tables 1-3

TABLE 1

Properties of Vinyl Siloxane Rubbers with Diverse Proportion of Vinyl Groups After Vulcanization by Dicumyl Peroxide

Содержание винильных групп (мольн. %) 1	Прочность на разрыв (кг/см²) 2	Относительное удлинение (%) 3	Свойства после старения 4: 4 прочность на разрыв (кг/см²) после 3 суток при 200°	5 относительное удлинение (%)	6 прочность на разрыв (кг/см²) после 3 суток при 300°	7 относительное удлинение (%)	Остаточная деформация (%) после сжатия на 30% в течение 24 часов при 7: 150°	200°	250°
0.0	20	200	Хруп.	0	Хруп.	0	50	100	100
0.07	21	270	22	210	21	100	13	25	—
0.15	21	1000	20	110	—	—	11	21	—
0.33	23	1150	—	—	21	70	—	20	20
0.50	23	1150	—	—	21	20	7	18	20
1.0	20	1150	21	90	Хруп.		6	14	20

1) Proportion of vinyl groups in the rubber (mole-%);

2) tensile strength (kg/cm^2); 3) relative elongation (%); 4) properties after aging; 5) tensile strength (kg/cm^2) after 20 days at 250°; 6) tensile strength (kg/cm^2) after 3 days at 300°; 7) residual deformation (%) after compression to 20% for 24 hours at; 8) brittle.

TABLE 2

Change in the Hardness and Elasticity of Vinyl Siloxane Rubbers after Aging in Absence of Air

1	2							
	6 час. 3		8 час. 3		12 час. 3		24 час. 3	
	4 твердость	5 эластичность	4 твердость	5 эластичность	4 твердость	5 эластичность	4 твердость	5 эластичность
0.0	62	49	10	12	6 Полное разрушение — образец клейкий			
0.1	60	48	54	20	50	24	25	26
0.5	76	60	71	60	75	60	75	57
1.0	76	59	76	58	76	59	75	56

1) Proportion of vinyl groups in the rubber (mole-%); 2) properties after aging in absence of air at 200° during; 3) hours; 4) hardness; 5) elasticity; 6) total degradiation, the specimens become sticky.

TABLE 3

Properties of Covulcanizates of Butyl Rubber with Vinyl Siloxane Rubber

1 Содержание каучука (%)		4	5	6	7 Свойства после старения в течение 24 час. при:						8
					100°		150°		200°		
2 бутил	3 винил										
100	—	100	850	37	100	840	14	880	9 Порошок	—	61
75	25	137	700	32	101	850	77	810		—	68
50	50	59	600	30	84	690	70	200	13	—	68
0	100	22	440	7	41	870	41	130	39	130	76

1) Proportion of rubber (%); 2) butyl rubber; 3) vinyl siloxane rubber; 4) tensile strength (kg/cm^2); 5) relative elongation (%); 6) tear resistance (kg/cm); 7) properties after aging for 24 hours at; 8) brittleness point (°C); 9) powder.

Vinyl siloxane rubbers do not differ from dimethyl siloxane rubbers (with regard to frostproofness, dielectric properties, stability to solvents, intoxicity, etc.). In contrast to them, however, vinyl siloxane

rubbers have the following advantages: a lower plasticity when compressed at 200-250°, absence of decomposition when heated in a vacuum at high temperatures, and a higher heat resistance in thermal aging. Vinyl siloxane rubbers with a proportion of 0.07% vinyl groups maintain their mechanical indices after aging at 250° for 30 days, whereas dimethyl siloxane rubbers lose their elasticity totally after 15 days under the same conditions. The main advantage of vinyl siloxane rubbers is the absence of degradation when aged at high temperatures in absence of air.

The covulcanizate of divinyl nitrile rubber and vinyl siloxane rubber in a ratio of 50:50 is not degradated under the action of ozone for 8 hrs, whereas divinyl nitrile rubbers are degradated within a shorter time than a half an hour. The preparation of compounds from vinyl siloxane rubber and other rubbers does not require special equipments and formulae. Usually, vinyl siloxane rubber with 3-4 mole-% vinyl groups is used for these purposes.

The vinyl siloxane rubber is the main type of rubber for the rubber industry; it is used for diverse packers working at temperatures within −250° to +300°, under conditions of static compression, in circulating air and without it, in aviation, in vacuum industry and other industrial branches.

References: Stavitskiy I.K., Svetozarova V.M., Sintez i svoystva vinilsiloksanovogo kauchuka [Synthesis and Properties of the Vinyl-Siloxane Rubber], "Kauchuk i rezina," 1960, No. 5, page 6; Borisov S.N., Stavitskiy I.K., Vinilsoderzhashchiy kremniyorganicheskiy kauchuk [Silicon-organic Rubber Containing Vinyl], "Kauchuk i rezina," 1958, No. 2, page 1.

F. A. Galil-ogly

VINYON HH – a synthetic carbon-chain fiber made from a copolymer of vinyl chloride and vinyl acetate (86-90; 14-10 parts by weight). It is formed from acetone solutions of the copolymer by the dry method. It is produced in the USA in the form of a staple fiber with N_m 4500, 3000, 1650. The physico-chemical and mechanical properties of Vinyon HH are as follows: specific weight 1.33-1.36, moisture content under standard conditions 0%, limiting water absorption less than 0.1%, softening temperature 52-60°, melting temperature 132°, shrinking temperature 65°, shrinkage in boiling water 60-70%, difficulty combustible and self-extinguishing, dielectric constant 3.2 at 60 cps, 3.1 at 1000 cps, tangent of the dielectric loss angle at 25° and 50% relative humidity is 0.013 at 60 cps and 0.015 at 1000 cps, specific volume resistivity (at 50°) $5.2 \cdot 10^{14}$ ohm-cm, breakdown voltage 25 kv/mm, refraction index 1.535, high fading resistance, resists the effect of decomposition organisms and bacteria, less resistant than polyvinyl chloride fiber to the action of concentrated acids and alkalis, and also of organic solvents, resistant to the effect of alcohols and aliphatic hydrocarbons, is soluble in acetone, chloroform and methylene chloride, can be dyed by acetate fiber dyes. Vinyon HH is used for the production of rubber-impregnated elastic cloth, binding fibers in pressed felts and in special brands of paper.

References: Rogovin, Z.A. Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fiber Production], 2nd edition, Moscow, 1957; Fibers from Synthetic Polymers, edited by R. Hill, transl. from Eng., Moscow, 1957.

Z.A. Zazulina

VISCOSE CORD FIBER – artificial cellulose hydrate filament fiber. It is produced under the designations: standard, strong (cord material, Tenasco); high-strength (super cord material); super-high strength [super, super-super (England), Tirex, New-Rayon (USA)], with numbers (metric) 8.2, 7.65, 5.45 and 4.75. The specific weight of viscose cord fibers are: strength, elongation and resistance to the effect of temperature (120-130°) and dynamic loads, which arise in the use of cord fabric (for example, when a tire travels ~ 30,000 km, each threat of the tire body withstands more than 1.2 million flexures).

Physicomechanical Properties of Standard, Strong, and High-Strength Viscose Cord Fiber

Механич. свойства 1	2 Обычное	Упрочненное 3	Высокопрочное 4
Разрывная длина (км) . 5.	27—30	30—32	40—45—55
Временное сопротивление разрыву (кг/мм²) . . . 6.	35—40	45—48	65—75
Потеря прочности (%) 7.			
а) мокрое состояние 8. . .	35—40	30—35	25—30
б) петля . . . 9.	15—20	15—20	20
Удлинение (%) 10.			
а) сухое состояние . . .	10	12	15
б) мокрое состояние . . .	15	20	25
Эластичность (%) 12.			
при растяжении на 4% 13.	60	65	—
при растяжении на 10% 14.	84	87	—
Модуль упругости (кг/мм²) 15.	600—800	800—900	1200—2400
Модуль сдвига при кручении (кг/см²) . . . 16.	24000	27000	45000
Долговечность (выносливость при нагрузке 5 кг/мм² до разрыва) 17.	1000	1000	—
Износостойкость в зачетных (выносливых циклах при нагрузке 50 г) . . . 18.	170	200	600

1) Mechanical properties; 2) standard; 3) strong; 4) high-strength; 5) rupture length (km); 6) ultimate tensile strength (kg/mm^2); 7) strength losses (%); 8) in the wet state; 9) in a loop; 10) elongation (%); 11) in the dry state; 12) elasticity (%); 13) in 4% elongation; 14) in 10% elongation; 15) modulus of elasticity (kg/mm^2); 16) torsion shear modulus (kg/cm^2); 17) longevity (number of flexures at a load of 5 kg/mm^2 to rupture); 18) wear resistance

(number of cycles at a load of 30 g).

The physicomechanical properties of viscose cord fibers depend on the technological parameters; the indicators of this fiber are substantially better than those of viscose rayon (swelling in water is lower by 35-50%). High-strength viscose fibers have a strength close to synthetic fibers (capron, nylon, dacron), and they even exceed them at high rates of deformation. The fatigue characteristics of high-strength cord fiber are by a factor of 8-10 higher than those of standard cord fiber or viscose rayon. For other properties of viscose cord fiber see Viscose Rayon. In comparison with cotton cord viscose cord fibers are characterized by lower friction and heat generation in service and a longer tire-thread service life. Viscose cord fibers and the cord fabric which are made from them are used as a carcass in the production of pneumatic tires, conveyor belts and sleeves.

References: Demina, N.V. [et al.], "KhV," No. 5, page 40, 1960; Caswell, E.R., Textile Fibers, Yarn and Fabrics, translated from English. Moscow, 1960.

G.G. Finger

VISCOSE RAYON – an artificial hydrate-cellulose filament fiber. It is produced as shiny, mat (0.2-2.0% of titanium dioxide) or painted in the mass (0.5-3.0% of dyeing agent) from N_m 14 to N_m 150. Viscose rayon is heat resistant (withstands prolonged heating at 100-110° and short duration heating – up to 3 minutes – at 150° without loss of strength), but is relatively weak (exceeds only protein, acetate and cuprammonium fibers). Specific weight of viscose rayon is 1.50-1.54, moisture content under standard conditions 12.5-13.5%, at 95% relative humidity it is 27-33.0%. The fiber does not melt or soften; is easily flammable at 180°. The specific heat of viscose rayon is 0.320-0.330 cal/g-degree, the heat of wetting of the dry fiber by water is 21.0-25.0 cal/g, when subjected for a prolonged period of time to low temperatures (from –30° to –50°) the breaking length increases with a simultaneous reduction in the rupture elongation. When subjected to ultraviolet radiation for 20-24 hours, photochemical destruction takes place (the strength loss comprises 20-35%), the refraction index along the axis of the fiber is 1.548 and in the transverse direction it is 1.527. As a result of high hygroscopicity, viscose rayon has a low specific electric resistivity. Viscose rayon is destroyed in hot dilute (loss of strength) and in cold concentrated acids (swelling and loss of strength), in water it swells in the longitudinal direction by 3-5% and in the cross section by 35-50%, loss of strength, of wear resistance, of resistance to multiple bending and to an increase in the rupture elongation are obtained simultaneously with the above. Loss of strength is also observed when the fiber is treated for long periods of time even by weak alkalis. Viscose

rayon resists the effects of many organic solvents, it is soluble in cuproaminohydrate, cuproethylenediamine, phosphorous acid, it breaks down when subjected to the prolonged action of oxidizers (H_2O_2, NaClO, $NaClO_2$), and also to the action of aerobic and anaerobic bacteria and fungi, it is destroyed by termites but is not effected by moths. Viscose rayon is characterized by a relatively low rupture length (13.5-22.0 km) and an ultimate tensile strength comprising 20.5-27.4 kg/mm^2. Wet strength loss is 45-55%, in a loop 25-35% and in a node 45-55%. Elongation in the dry state 18-30%, in the wet state 25-35%. The initial modulus of viscose rayon (for 1% elongation) comprises 7-8 kg/mm^2, the torsion shear modulus is 100-150 kg/mm^2 and the specific rupture moment 2.5 kgm/g.

Viscose rayon has an insufficiently high elasticity; the degree of elasticity in 4% elongation compreises 35-45%, in 10% elongation it is from 30 to 35%, the maximum recoverable elongation is 1.5-1.7%. The longevity of the fiber (number of flexures before rupture under a stress of 5 kg/mm^2) is 150-400, wear resistance (number of cycles under a load of 30 g) is 125-450. The coefficient of friction on steel is 0.15-0.38, on porcelain it is 0.1-0.43, on a viscose fiber it is 0.17-0.19.

The shortcomings of viscose rayon (low resistance to crumpling, hydrophilic nature and combustibility) are to a substantial extent eliminated by treating the fiber by various reagents. Viscose rayon is used primarily in the textile industry for the production of cloth, knitted fabric, hosiery and in tulle curtain production.

References: Dëmina, N.V. [et al], "KhV," No. 5, page 40, 1960; Caswell, E., Textile Fibers, Yarns and Fabrics, translated [from English], Moscow, 1960; Spravochnik po analiticheskomu kontrolyu v proizvodstve iskusstvennykh i sinteticheskikh volokon [Handbook on the Sta-

tistical Control in the Production of Artificial and Synthetic Fibers],
edited by A.B. Pakshver [et al.], Moscow, 1957.

G.G. Finger

VISCOSITY – property of liquid and solid amorphous bodies which characterizes the resistance to the development of residual deformations within them (internal friction). In the elementary case of uniform shear the viscosity coefficient (or the viscosity) η of low-molecular fluids is determined from Newton's formula $P = \eta\varepsilon$, where P is the shear stress, and ε is the rate of strain. The units of viscosity in the absolute system of units are $[\varepsilon]$ = g/cm·sec. This unit of measurement is called poise. Amorphous polymers, dispersion systems, consistent lubricants and glass have viscosity which is highly dependent on the shear stress. The process of flow of various substances is governed by various empirical quantitative relationships. While the viscosity of gases increases with an increase in temperature in proportion to $\sqrt{T}$, for liquids and glass it is inversely proportional to the self-diffusion coefficient and drops sharply with an increase in the tempera-

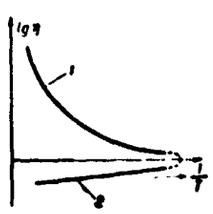


Fig. 1. Temperature dependence of the viscosity of liquids (1) and gases (2). The dashed line denotes the junction of both states.

ture (Fig. 1) according to the law $\eta = Ae^{U/kT}$, where A, the pre-exponential multiplier, is a weak function of the temperature T, while U is the activation energy of the viscous flow. Since the structure of an amorphous substance above the second-order transition temperature T_g changes with temperature, while below it it does not change in the vit-

reous state, the activation energy of the viscous flow U is differently dependent on the temperature in the liquid and vitreous states, which is reflected in the temperature-viscosity curve (Fig. 2). The difference between the viscosity of ordinary liquid and amorphous bodies (see Table) reduces basically only to differences (of the order of 12-15) in

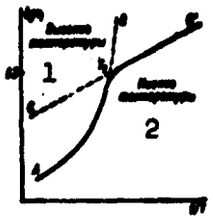


Fig. 2. Relationship between the logarithm of the viscosity and the reciprocal of absolute temperature in the liquid and vitreous states. 1) High temperatures; 2) low temperatures.

1 Вещество	Вязкость при 20° (пуазы) 2
Воздух . . 3	0,00018
Вода 4	0,01
Каучуки 5	10^{14}—10^{15}
Стекла неорганические . .	10^{14}—10^{16}
6	

1) Substance; 2) viscosity at 20° (poises); 3) air; 4) water; 5) rubbers; 6) nonorganic glass.

the magnitude of viscosity. The viscosity or organic substances increases with the molecular weight and with the introduction of polar groups into the molecule. The formation of space structures in polymers and their solutions, brought about by the cross-linking of macromolecules, results in a sharp increase in the viscosity, which is called structural viscosity to distinguish it from Newtonian. When such space-structure systems flow, the work of the external force is expended not only in overcoming the true viscosity, but also in breaking up the structure of the body. Dispersion and other complex systems are characterized by structural viscosity. Linear polymers which are subjected to high temperature in the viscous-fluid state easily exhibit a tendency to flow which is based on the segmental mobility of macromolecules.

While cross-linked polymers (whose molecules are connected by crossed chemical bounds) can flow only under substantial shear stresses, linear polymers flow already at low stresses, since the flow process is not accompanied by the destruction of chemical bounds. The concept of viscosity is applied in engineering to solid bodies to estimate the capacity of the body to absorb energy under plastic deformation. Viscosity is measured in units of work (kgm), referred to a specimen of the given shape and dimensions, or, conventionally, referred to the specimen cross section (kgm/cm^2). Viscosity which is juxtaposed to brittleness is mainly a useful property of materials of manufacture. A distinction is made between static viscosity, obtained when the load is applied slowly, impact viscosity, ordinarily obtained in impact flexure, and cyclical viscosity (see Internal Friction).

References: Frenkel', Ya.I. Kineticheskaya teoriya zhidkostey [The Kinetic Theory of Fluids], Moscow-Leningrad, 1945; Hatschek, E., The Viscosity of Liquids [Bell, London, 1928], translated from the 2nd edition, Moscow-Leningrad, 1934; Rebinder, P.A., "IAN OKhN" [Bulletin of the Academy of Sciences, Chemical Sciences Section], No. 11, 1957; Deryagin, B.V. Chto takoye treniye [What is Friction?], Moscow, 1952; Kargin, V.A. and Slonimskiy, G.L. Kratkiye ocherki po fiziko-khimii polimerov [A Brief Outline of the Physical Chemistry of Polymers], Moscow, 1960.

G.M. Bartenev, Ya.B. Fridman

VISUAL METHOD OF FLAW DETECTION – detection of flaws in materials and products by inspection by the naked eye or by optical means. The human eye has an insignificant resolving power, which is defined as the minimum angle at which two points should be visible in order that a difference between them could be detected. For a normal eye this angle is about 1'; here the minimum distance between two points which are seen separately from the normal sighting distance (250 mm) is, approximately, 0.07-0.08 mm. This is the quantity which is used as the limiting sensitivity of the visual method of flaw detection by a naked eye. The sensitivity of the visual method of flaw detection is increased by the use of various optical instruments: the MBS-2 binocular stereoscopic microscope for inspection of specimens and components, the MIM-8 horizontal metallographic microscope, the MIM-7 vertical metallographic microscope for the study of the microstructure of metals and other nontransparent materials, the RVP-13 instrument for inspection of the internal surfaces of pipes and hallow shafts with a diameter from 37 to 400 mm, the Ts-13 inspection cystoscope for inspection of the internal surfaces of holes 8-20 mm in diameter. The MBS-2 binocular stereoscopic microscope is the one most widely used. It ensures good access to the object being inspected, it gives a sharp projected image and makes it possible to rapidly change the magnification. The visual method of flaw detection makes it possible to expose surface flaws of metallurgical origin, that is, pores, blow holes, hair cracks, flakes, laps, cracks; flaws in welded and soldered joints, to determine the grain size and the presence of nonuniformity of grain size; to establish the character

of damage due to corrosion, etc.

References: Shmal'ts, G., Kachestvo poverkhnosti [Surface Quality], translated from German, Moscow-Leningrad, 1941; Metallovedeniye i termicheskaya obrabotka stali i chuguna [Metal Science and Heat Treatment of Steel and Pig Iron], Handbook, Moscow, 1956.

S.I. Kalashnikov

VITALLIUM – cobalt-base heat-resistant alloy. It is used for precision casting of false teeth by the lost-wax process; in 1942 it was used for casting of tubine buckets for jet engines, which has made it possible to increase the temperature level of heat resistance of these components by 125° in comparison with other heat resistant steels available at that time. Here the carbon content of the alloy was reduced from 0.50 to 0.30%. The chemical composition of vitallium, which is known in the USA under the brand name HS-21, is: 0.20-0.35% C, 25-30% Cr, 4.5-6.5% Mo, 1.5-3.5% Ni, the balance being cobalt. The domestic alloy LK4 has somewhat different limits of the alloying elements composition (see Cobalt Casting Alloys).

Vitallium is used primarily in the as-cast state without heat treatment. The hardening phase (of the LK4 alloy) is a type $Me_{23}C_6$ carbide of the following chemical composition (referred to electrolitically dissolved carbide-precipitating metal): 1.40% Cr, 0.40% Mo, 0.80% Co. Vitallium is weldable. The ultimate creep strength in the as-cast state is moderate: 14-15 kg/mm^2 for 100 hours at 800° and 9.5 kg/mm^2 at the same temperature for 1000 hours. The ultimate creep strength of this material can be increased by introducing 0.02% of boron.

N.F. Lashko

VITRIFICATION TEMPERATURE – the temperature characterizing the transition of low- or high-molecular amorphous substances to the solid or vitreous state on cooling. In melts and liquids the rate of atomic and molecular regrouping processes decreases with temperature and becomes so large at the vitrification temperature T_g that no changes in the short-range ordering or flow of the material are observed during experiments. The structure of an amorphous substance consequently remains unchanged during further cooling from T_g, persisting in the form "frozen" at T_g. Thus, structural vitrification produces glass, a solid with a definite amorphous structure that depends on the T_g and nature of the substance. This process is treated as occurring in the absence of external forces. In contrast to other amorphous substances, polymers have still another definition of T_g associated with testing under periodic mechanical factors.

Provided that crystallization does not occur, the usual structural vitrification characteristic of all substances is observed when a polymer melt is cooled. The structural vitrification temperature is determined from the thermal shrinkage or linear expansion curve or from the curves for temperature versus heat capacity or other thermodynamic and kinetic characteristics dependent on structure (e.g., the curve of temperature versus speed of ultrasound above and below T_g). The vitrification temperature depends on the cooling rate.

A polymer exhibits three physical states under the action of external forces – viscous flowing, highly elastic, and solid elastic. When a polymer is cooled it first passes from the viscous flowing to the

highly elastic state and then to the vitreous (solid elastic) state. The transition to the latter state always takes place at a point above the structural vitrification temperature T_g, the temperature required increasing with the deformation frequency. The mechanical vitrification temperature is determined from the loss of high-elasticity characteristics and is of enormous practical importance in evaluating the frost resistance of rubbers (see Frost resistance and Thermal shrinkage).

References: Kargin, V.A., Slonimskiy, G.L., Kratkiye ocherki po fiziko-khimii polimerov [Brief Outline of the Physical Chemistry of Polymers], Moscow, 1960; Kobeko, P.P., Amorfnyye veshchestva [Amorphous Substances], Moscow-Leningrad, 1952; Bartenev, G.M., Mekhanicheskiye svoystva i teplovaya obrabotka stekla [Mechanical Characteristics and Heat Treatment of Glass], Moscow, 1960; Idem, O dvukh protsessakh steklovaniya [Two Vitrification Processes], DAN SSSR [Proceedings of the Academy of Sciences USSR], 1956, Vol. 110, No. 5; Shishkin, N.I., Zacteklovaniye zhidkostey pod davleniyem [Vitrification of Liquids Under Pressure], ZhTF, 1955, Vol. 25, No. 2, page 188; Idem. Zavisimost' kineticheskikh svoystv zhidkostey i stekol ot temperatury, davleniya i ob'yema [Kinetic Characteristics of Liquids and Glasses as a Function of Temperature, Pressure, and Volume], Ibid., 1956, Vol. 26, No. 7, page 1461.

G.M. Bartenev

VOLATILE CONTENT is the weight loss (in %) of a sample of material (resin, lubricant, etc.) as a result of heating it for specified time at specified temperatures indicated in GOST or TU. The volatile content is computed from the formula

$$x = \frac{a-b}{a} \cdot 100,$$

where x is the volatile content (%), a is the initial weight of the material sample, b is the weight of the material sample after heating.

M.S. Krol'

VOLCANIC GLASS – glass-like ingenous rock, primarily of volcanic origin, which forms upon rapid cooling of a natural silicate melt. Depending on the composition a distinction is made between ultra-basic, basic, medium and acid volcanic glass; the SiO_2 content correspondingly varies from 35 to 73%. Only acid volcanic glass is used industrially. Volcanic glass containing 1% of water is called obsidian (0), when it has a higher water content and in the presence of a characteristic spherical jointing it is called perlite. The specific weight of obsidian is 2.2-2.413. The refraction index is 1.4845-1.495. Increasing the water content increases the refraction index. The compressibility of obsidian ($-\Delta v/v$) at a pressure of 600 bars and temperature of 25° is $18 \cdot 10^{-4}$, at a pressure of 1000 bars and temperature of 294° it is $27.46 \cdot 10^{-4}$. The shear modulus of obsidian subjected to all-sided pressure of 1 atm is $3.03 \cdot 10^{11}$ dynes/cm^2, in all-sided pressure of 4000 atm it is $2.97 \cdot 10^{11}$ dynes/cm^2. Young's modulus (dynes$\cdot$cm$^{-2} \cdot 10^{11}$) in the temperature interval 20-30° is 6.56, t_{pl} is 1400-1500°. Softening interval 950-1500°. Changing the temperature from 800 to 1200° results in a change in viscosity from 10^{12} to 10^7 poises. The viscosity at 1400° is $1.7\text{-}4.4 \cdot 10^6$ poises. The thermal conductivity [(watt/cm$\cdot$degree) $\cdot 10^{-3}$] at 0° is 13.4, at 100° it is 14.6, at 400° 17.8 and at 500° it is 18.9. The resistivity of obsidian is 10^{10} ohm$\cdot$cm. The dielectric constant of obsidian is $13 \cdot 10^4$. The building industry uses obsidian chips (fractions of 0.5-15 mm) to produce artificial pumice. In the glass and ceramics industry it serves as a substitute for quartz. Pulverized obsidian can be used as an abrasive. Unique grades of obsidian

with a low thermal expansion coefficient are used in the production of mirrors for telescopes and other optical apparatus.

References: Birch, F., Sherer, D. and Spicer, G., A Geologist's Handbook of Physical Constants, translated from English, Mowcow, 1949; Zavaritskiy, A.N., Izverzhennyye gornye porody [Igneous Rocks]. Moscow, 1956; Petrov, V.P. and Nasedkin, V.V., "Tr. In-ta geol. rudnykh mestorozhdeniy petrografii, mineralogii i geokhimii" [Trans. of the Institute of Geology of Mineral Deposits, Petrography, Mineralogy and Geochemistry]. No. 84, 1961.

V.V. Nasedkin

VOLOKNIT - molding material with a high mechanical strength and antifriction properties; it is a cellulose (cotton) fiber base material, impregnated with a phenolformaldehide resols with addition of lubricants, dyes, talc, lime or roasted magnesium. The fiber (bleached and unbleached (cotton) linter or lint) is impregnated and mixed with the additives in a twin-blade mixer and dried at 60-90° in belt dryers. In external appearance it is a flock of tangled fibers. The Raschig fluidity is 40-140 mm, design shrinkage 0.3-0.6%. Voloknit is made into products either by direct hot extrusion (specific pressure 300-600 kg/cm^2, temperature 160-180°, curing time 0.3-1.5 min/mm), or by compression molding (specific pressure 1400-1600 kg/cm^2). Specific weight 1.45, impact ductility not less than 9 $kg \cdot cm/cm^2$, ultimate strength in static flexure 600-800, in compression 1200, in tension 300-600 kg/cm^2, relative tensile elongation 0.38%, modulus of elasticity 85,000 kg/cm^2; Brinell hardness 25 kg/mm^2, Martens heat resistance not less than 140°, coefficient of linear expansion $3-3.5 \cdot 10^{-5}$ $°C^{-1}$, thermal conductivity 0.18-0.20 kcal/m·hour·°C, specific heat 0.3-0.34 kcal/kg·°C, coefficient of friction 0.33. After being held for 24 hours in oil or gasoline the oil resistance is 0.11%, gasoline resistance is 0.025%, specific volume resistivity not less than $1 \cdot 10^{10}$ ohm-cm, specific surface resistivity $1 \cdot 10^{10}$ ohms, electric strength not less than 4 kv/mm. The material is almost unsusceptible to aging. The service temperature is 100°. Voloknit is recommended for molding of reinforced and nonreinforced components subjected to flexure and torsion (switches, flanges, handles, supports, cams, gears, guiding sleeves, etc.).

M.S. Krol'

VOROBYEVITE – see Beryl.

VULCANIZED FIBER – is a solid material formed from a special paper basis impregnated with a concentrated solution of zinc chloride, sometimes sulfuric acid (for the production of thin fiber) or a solution of calcium thiocyanate mixed with a solution of calcium chloride. Vulcanized fiber is manufactured in the form of 0.1-76 mm thick sheets, pipes with 7-76 mm inner diameter and 11-100 mm outer diamter, and rods with round, quadratic and rectangular cross section. Round fiber rods are the most widely used. The sheets and pipes are manufactured on appropriate machines by impregnation of the paper with zinc chloride, winding of a number of layers (according to the required thickness) on a cylinder or rod, forming under pressure at raised temperature and subsequent removal of the zinc chloride from the fiber by diffusion up to a residual content of not more than 0.15-0.20%. The washed vulcanized fiber is dried and finished by pressing. The mechanical properties of the vulcanized fiber are similar to those of brass, bronze and aluminum, and this material is used to substitute nonferrous metals. Vulcanized fiber possesses a higher maximum tensile, compression and static bending strength, and a considerably higher breaking elongation percentage than textolite of the PT grade, celluloid, organic glass, viniplast and fibrous plastic. The low density (1.0-1.5 g/cm^3) is a specific peculiarity of the vulcanized fiber; the physicomechanical and electric insulating properties of the vulcanized fiber are characterized by the following values: strength of the adhesion between the layers 60-120 kg/cm^2; maximum strength: compression strength 1500-3000 kg/cm^2, bending strength 800-1600 kg/cm^2; specific

resilience 50-120 kg•cm/cm^2; modulus of elasticity $5 \cdot 10^4$-$8 \cdot 10^4$; Brinell hardness 10-30 kg/mm^2; Brinell hardness 10-30 kg/mm^2; heat conductivity at 50° $2.1 \cdot 10^{-3}$-$3.3 \cdot 10^{-3}$ cm^{-2}•sec^{-1}; specific heat 0.32-0.34 kcal/kg•°C; heat resistance according to Martens 60-70°; thermal expansion coefficient $27 \cdot 10^{-7}$; specific volume resistance 10^8-$5 \cdot 10^{11}$ ohm•cm; surface resistance 10^8-10^{12} ohm•cm; tan of the loss angle 0.04-0.07; coefficients of friction: calendered vulcanized fiber on calendered vulcanized fiber 0.16-0.17; on pine wood (planed and ground with emery cloth) up to 0.18, on cast iron 0.13-0.14, on steel 0.13. Dry vulcanized fiber is not attacked by mold and insects. Vulcanized fiber is impregnated with fungicides (sodium pentachlorophenolate, etc.) when used in torrid zones. Vulcanized fiber is insoluble in kerosene, gasoline, alcohol, acetone and mercury; it is decomposed by sulfuric, nitric and hydrochloric acids. The mechanical strength of vulcanized fiber kept for a long time at 100° is diminished as follows: the tensile strength by 30-40%, the compression strength by 50%, and the bending strength by 30-40%. Vulcanized fiber becomes brittle at temperatures higher than 150° and catches fire (glows) at 343-347°; at higher temperatures, vulcanized fiber burns almost smokeless. Vulcanized fiber does not carbonize in the electric arc, it becomes decomposed liberating a great quantity of gases which promotes the extinguishing of the arc.

Vulcanized fiber is readily machinable by cutting, sawing, drilling, planing, milling, grinding, punching and drawing; it may be readily bent, glued, riveted, threaded, and formed (after being soaked in hot water). The high hygroscopicity (many times surpassing that of Pertinax and textolite) is the main disadvantage of vulcanized fiber. Water absorption reduces the mechanical and dielectric characteristics of the vulcanized fiber considerably. The most rapid change of the ten-

sile strength occurs at a moisture content of 2-14%. An increase of the moisture content by 1% within these limits involves a loss in the tensile strength on an average of 4%. The strength of the vulcanized fiber does not drop significantly when the moisture content changes within 14-35%. Change of the moisture content within 1-12% causes an increase of the resilience by 10%. The resilience drops rapidly under a further increase of the moisture content up to 21%, remaining practically unchanged at higher moisture contents up to 35%. Moistening of the vulcanized fiber strongly reduces its specific volume resistance, the tangent of the loss angle, the dielectric constant, and the electric strength. Vulcanized fiber is impregnated with transformer or linseed oil, paraffin, or resins in order to reduce the hydroscopicity. Vulcanized fiber sheets (GOST 6910-54) are available in the following grades: FT – commercial vulcanized fiber for the manufacture of parts in machine building, electrical machine building and instrument manufacture; FE – electrotechnical vulcanized fiber as an insulating material in electrical machine building; FK – peak vulcanized fiber for the manufacture of cap peaks; FP – article vulcanized fiber for the manufacture of suitcases, photographic dishes, diverse containers and other articles: FPK – oxygen-resistant packing vulcanized fiber for the manufacture of parts which come in contact with oxygen. The thickness (in mm) of the sheets is: 0.6-25.0 for FT; 0.6-12.0 for PE; 1.0 for PK; 0.6-3.0 for FP; and 0.6-5.0 for FPK. Vulcanized fiber with a thickness from 0.6 to 8 mm is manufactured in one piece, and with a thickness from 8.0 to 12 mm either in one piece or by adhesive-bonding, and with a thickness higher than 12 mm by adhesive-bonding. The adhesive-bonding of the thin (3-6 mm) vulcanized fiber sheets is carried out by means of the phenol-formaldehyde resin S-1. The monolithic vulcanized fiber is available with a length from 850 to 2300 mm, and a width from 550

to 1400 mm; the bonded fiber has a length from 1600 to 1900 mm and a width from 400 to 600 mm.

No cracking of the surface must occur when a vulcanized fiber sheet with a thickness up to 3 mm is bent around a rod whose diameter is 10-20 times greater than the thickness of the sheet.

Technical Characteristics of the Vulcanized Fiber

Показатели 1	Марка 2 ФТ 3	ФЭ 4	ФК 5	ФП 6	ФПК 7
8 Предел прочности при растяжении (кг/см², не менее): в продольном (числитель) и поперечном (знаменатель) направлениях при толщине (мм):					
0,8 и 0,8	600 / 400	650 / 450	—	550 / 350	550 / 350
1,0—3,0 9	650 / 450	700 / 450	650 / 400	550 / 350	550 / 350
3,5—5,0	600 / 350	650 / 400	—	—	—
6,0—12,0	500 / 300	500 / 300	—	—	—
13,0—25,0	500 / 300	—	—	—	—
10 Объемный вес (г/см³, не менее)	1,05—1,15	1,10—1,20	1,20	1,05—1,10	1,05—1,10
11 Удельное объемное сопротивление при темп-ре 20±5° (ом·см, не менее)	—	10^9	—	—	—
12 Электрич. прочность при темп-ре 20±5° (кв/мм, не менее) при толщине (мм):					
0,8—1,0	—	7	—	—	—
1,1—2,0	—	5	—	—	—
2,2—12,0	—	3,5	—	—	—
13 Коэфф. склейки (г/см, не менее)	160	160	160	150	150
14 Содержание хлористого цинка (%, не более)	0,2	0,15	0,2	0,2	0,2
15 Зольность (%, не более)	2,0	1,5	2,0	2,0	2,0
16 Водопоглощаемость за 24 часа (%, не более) при толщине (мм):					
0,8 и 0,8	65	65	—	65	65
1,0—3,0	60	60	60	60	60
3,5—5,0	50	50	—	—	—
6,0—12,0	40	40	—	—	—
13,0—25,0	35	35	—	—	—
17 Маслопоглощаемость за 24 часа (%, не более)	—	—	3,0	—	—
18 Влажность (%)	6—10	6—10	6—10	6—10	6—10

1) Characteristics; 2) grade; 3) FT; 4) FE; 5) FK; 6) FP; 7) FPK; 8) tensile strength (kg/cm^2, not less than): in longitudinal direction (numerator) and in transverse direction (denominator) at a thickness of (in mm); 9) and; 10) density (g/cm^3, not less than); 11) specific volume resistance at a temperature of 20 ± 5° (ohm·cm, not less than); 12) electric strength at a temperature of 20 ± 5° (kv/mm, not less than) at a thickness of (in mm); 13) adhesion coefficient (g/cm, not less than); 14) percentage of zinc chloride (not more than); 15) percentage of ash (not more than); 16) water absorption within 24 hrs (%, not more than) at a thickness of (in mm); 17) oil absorption within 24 hrs (%, not more than); 18) percentage of moisture.

Vulcanized fiber of the FLAK grade (vulcanized fiber sheet for aviation constructions, GOST 3335-46) is used for the manufacture of aircraft tanks; it is available in black and in red color with the di-

mensions of 1800 x 1200 mm and a thickness of 1-3 mm; it may be readily punched and possesses a high mechanical strength; it must withstand a heating at 100-105° for 24 hours and also a dipping into water of 10-30° for 24 hours without delamination, cracking or bubbling; it must be airproof at an air pressure up to 0.3 atm. The technical characteristics of FLAK are listed in the following Table.

Technical Characteristics of FLAK

1 Показатели	2 Норма
3 Объемный вес (г/см³, не менее)	1.25
4 Предел прочности при растяжении (кг/см², не менее):	
5 для Ф, толщиной до 2 мм в продольном и поперечном направлениях	950 * / 525
6. для Ф, толщиной более 2 мм в продольном и поперечном направлениях	900 / 475
7 Удлинение в момент разрыва в продольном и поперечном направлениях (%, не менее)	10 / 12
8 Коэфф. сцепления (г/см, не менее)	100
9 Влажность (%)	6—10
10 Содержание хлористого цинка (%, не более)	0.2
11 Маслопоглощение при погружении в трансформаторное масло на 24 часа при темп-ре 15—20° (%, не более)	1.3
12 Бензинопоглощение при погружении в авиационный бензин на 24 часа при темп-ре 15—20° (%, не более)	1.5

*The numerator is valid for the longitudinal direction, and the denominator for the transverse direction.

1) Characteristics; 2) standards; 3) density (g/cm^2, not less than); 4) ultimate tensile strength (kg/cm^2, not less than); 5) in longitudinal and transverse directions for a vulcanized fiber with a thickness up to 2 mm; 6) in longitudinal and transverse directions for a vulcanized fiber with a thickness greater than 2 mm; 7) breaking elongation in longitudinal and transverse directions (%, not less than); 8) coefficient of adhesion (g/cm, not less than); 9) moisture percentage; 10) percentage of zinc chloride (not more than); 11) oil absorption during immersion into transformer oil for 24 hrs at 15-20° (%, not more than); 12) gasoline absorption during immersion into aviation gasoline for 24 hours at 15-20° (%, not more than).

Leatheroid is a variety of thin-sheet vulcanized fiber. It is available in a gray or dark-gray color with a thickness of 0.1-0.5 mm. It is characterized by a high mechanical strength and flexibility. The main characteristics are: 1.3 g/cm^3 density; ultimate tensile strength in longitudinal direction 700, and in transverse direction 400 kg/cm^2; electric strength 10 kv/mm before bending and 8 kv/mm after bending; percentage of moisture 8. It is used in electrical engineering for the insulation of windings, inserts in grooves, and winding packings.

KGF is a soft leatherlike vulcanized fiber sheet obtained by impregnation with castor oil and glycerol. It is used as a packing in diverse joints to prevent the leakage of water, oil, kerosene and gasoline.

Vulcanized fiber pipes are used for the manufacture of fuses and of various bushes. The main technical characteristics are: specific gravity 1.3; water absorption within 24 hours 15-30%; electric strength 3-7 kv/mm; moisture content 8-10%; ash percentage not more than 3%; percentage of zinc chloride not more than 0.2%; the surface must be smooth, without folds, bubbles, hollows, and abrasions; the ovality is ±0.2-1.0 mm (depending on the pipe diameter). A deviation of the pipe axis from the straight line by not more than 2 mm per 250 mm pipe length is allowed. The pipes are manufactured in the lengths of 400-1100 mm with various wall thickness and diameter sizes (the most widely used external diameters are: 10, 15, 20, 25, 30, 40, 50, and 60 mm).

Vulcanized fiber is widely used: in machine buildings as a packing material in steam turbines, hydraulic presses, pumps, carburetors, valves, in gasoline and oil pipelines, in high-pressure pipelines (up to 400 atm) for diverse fluids and gases; vulcanized fiber is used for the manufacture of cups for compressors and hydraulic presses, noiseless gears, abrasion discs for the grinding of crankshafts, etc.; in the textile industry for basins, shuttles, bobbins, rolls, parts of

looms, combs, bearing bushes, etc.; in electric engineering for diverse insulating packings, button switches, pipelike fuses, handels, pole arms of knife switches, dischargers, packings for the rotors and stators of electric motors, parts of wireless sets, telephone and lighting equipment, cut-outs, screws, nuts, pins, etc.; in the automobile industry for pipes for the ignition-wire manifold, parts of the electric equipment, diverse linings, packings, and washers; in aircraft designing for gasoline and oil tanks, pilot seats, and parts of the control and measuring equipment; in the railroad transport for parts of the automatic block signaling system, for the guides of the locomotive boxes, insulation parts of rail joints: pads, laps, and bolt bushes. Fiber is also widely used for the manufacture of commodities.

References: Vasil'yev, D.N., Proizvodstvo fibry [Manufacture of Fiber], Moscow-Leningrad, 1959; Frolova, Z.I., Fibra, yeye svoystva, primeneniye i protses proizvodstva [Vulcanized Fiber, Its Properties, Application and the Process of Manufacture], Moscow, 1958; Spravochnik po elektrotekhnicheskim materialam [Handbook of Electric Engineering Materials], Vol. 1, Part 1, Moscow-Leningrad, 1958.

S.Sh. Ryvlin

Manuscript Page No.	[Transliterated Symbols]
4368	ФТ = FT = fibra tekhnicheskaya = commercial fiber
4368	ФЭ = FE = fibra elektrotekhnicheskaya = electrical-engineering fiber
4368	ФК = FK = fibra kozyrechnaya = peak fiber
4368	ФПК = FPK = fibra prokladochnaya kislorodostoykaya = oxygen-resistant packing fiber
4369	ФЛАК = FLAK = fibra listovaya aviatsionnaya konstruktsionnaya = sheet fiber for aviation constructions

WATER ABSORPTION CAPACITY – the capacity of materials to absorb water when they are held in water or in water solutions. The quantity of water which is absorbed depends on the porosity, swelling capacity and the hydrophilic nature of the material. The magnitude of water absorption capacity for a given material usually exceeds the maximum moisture absorption capacity due to filling of through macrocapillaries of the bodies and increasing the osmotic absorption. See also Moisture Absorption Capacity, Moisture, Swelling.

S.A. Reytlinger

WATER IMPERMEABILITY – resistance of materials to water penetration through them. It is characterized by the minimum excess pressure which results, at the given rate of increase or during a specified time in the appearance of a specified number of drops on the opposite side of a specimen. Sometimes the water impermeability indicator is the time after which the first (third) drop of water or a specified volume of water passes through the material at constant water pressure or attendant to the falling of drops from a certain height or other method of sprinkling. Unlike water permeability indicators, which express the rate of the steady-state process of water conduction by the material, water impermeability indicators characterize the initial stage of the process, the conditions (pressure drop, time, temperature), under which the material ensures water impermeability and water absorption. Water impermeability depends on the structure of the material, the degree and character of porosity, swelling ability, thickness, and, in the case of anisotropic metals, on the impregnation direction (water impermeability of laminated wood-base plastics is greater perpendicular to the layers than along them). Water impermeability of of importance primarily for porous materials, for example, fabrics, and for materials which are used in above-ground or underwater devices which undergo short-duration high hydraulic pressure.

References: Ekspluatatsionnyye svoistva tkqney i sovremennyye metody ikh otsenki [Service Properties of Fabrics and Modern Methods of Their Evaluation], Moscow, 1960; Kukin, G.N. and Solov'yev, A.N. Tekstil'noye materialovedeniye [Textile Materials Science], Part 1, Moscow, 1961.

B.I. Panshin

WATER PERMEABILITY – capacity of materials to pass water (water vapor). In the case of polymers a necessary condition for water permeability is their capacity to dissolve water. The constants of permeability (P), solubility σ, and diffusion (D) for a steady-state process are interrelated by the relationship: $P = D\sigma$; here P is usually expressed in terms of $cm^2/sec/atm$, σ is given in terms of cm^3 of gas per cm^3 of polymer at 0° and 760 mm of Hg, and D is in cm^2/sec. Solubility is retarded by the presence of surface friction and the possibility of limited wetting of the polymer's surface by water. A necessary condition for the demonstration of water permeability is the presence of a gradient of partial water vapor pressure to both sides of the material (polymer film, plate, etc.).

Permeability increases with the temperature in relation to the reduction in surface tension. The temperature dependence of D is given by the expression:

$$D = D_0 e^{-E_D/RT},$$

where D_0 is a constant which depends on the oscillation frequency of the diffusing water molecule, E_D is the diffusion activation energy which depends on the nature of the polymer, the flexibility of its molecules, structure and density of the three-dimensional lattice, etc., T is the absolute temperature, R is the gas constant. The temperature dependence of σ is given by the relationship: $\sigma = \sigma_0 e^{-\Delta H/RT}$, where σ_0 is a constant, ΔH is the heat of dissolution of a mole of water vapor in the polymer (it may be either positive or negative), the values of T and R

are the same as before.

Water permeability of engineering polymer materials can be substantial even if the water is weakly soluble in the polymer, provided that fillers, plastifiers, etc., are present which are hygroscopic in nature and form structures penetrating the entire thickness of the polymer material (for example, silicates, proteins, etc.).

Water permeability in technology can be a positive (filtering materials) and a negative (insulating materials) factor. The allowable water permeability of a material is determined by the applicable GOST. The technical parameters, for example, the thickness of filtering materials, diameter, number of and shape of pores depend on the degree of water permeability. The hydrophilic and hydrophobic nature of materials is of substantial significance, that is, water permeability can be reduced by increasing the hydrophobic nature of the materials.

References: Burrer, R., Diffusion in Solid Bodies, translated from English, Moscow, 1948; Reytlinger, S.A. "UKh," Vol. 20, Issue 2, page 213, 1951.

N.N. Lezhnev

WATERPROOF CARDBOARD – is a material characterized by a low water absorption; it is made from a mixture of unbleached sulfite cellulose, waste paper, and bitumen emulsion. The bitumen emulsion diminishes the water absorption of the cardboard, makes it thermoplastic and improves in this way the possibility of pressing it in a hot state. The water absorption of waterproof cardboard depends, moreover, on its composition, the method of production and the thickness; it decreases at rising density. Thick cardboard is more stable than thin, the other conditions being constant. Waterproof cardboard possesses a sufficient mechanical strength, and stretchability, and shows almost no linear deformation when moistened, it does not break, does not crack when bent for 180° about a rod, it does not warp when stored in a dry, closed storage. It is produced by calendering, with a smooth or impressed surface, with a natural (dark-brown) color or colored in another tint, appointed with the comitter, in sheets, in the grades A and B. The dimensions of tne sheets (in mm) are: 750 × 750; 800 × 1180; 950 × 740; 1000 × 1000; 1000 × 1580; 1350 × 1000; 1500 × 750; 1500 × 950.

The technical characteristics of waterproof cardboard are listed in the Table.

Waterproof cardboard is widely used especially in the motorcar (for internal lining of cabs and hoods of the cars) and in shipbuilding. It is delivered according to GOST 6659-53.

TABLE

1 Показатели	2 Марка А	3 Марка В	Допускаемые отклонения 4
5 Толщина (мм)	1,00; 1,25; 1,50; 1,75; 2,00; 2,50; 3,00; 3,50; 4,00	1,0; 1,25; 1,50; 1,75; 2,00; 2,50; 3,00; 3,50; 4,00	±8%
6 Объемный вес (г/см³, не менее)	1,0	0,9	—
7 Предел прочности при растяжении в среднем по двум направлениям (кг/мм², не менее)	2,0	1,6	—
8 Водопоглощаемость (%, не более):			
9 за 30 мин.	3,5—4,0	5—7	—
9 за 90 »	7,0—8,0	8—12,0	—
10 Линейная деформация при увлажнении (%, не более):			
11 в продольном направлении . . .	0,30—0,35	0,40	—
12 в поперечном направлении . . .	0,50—0,60	0,70—0,75	—
13 Влажность (%) . . .	7,0	7,0	+1,—2

1) Indices; 2) grade A; 3) grade B; 4) allowances; 5) thickness (mm); 6) weight by volume (g/cm3, not less than); 7) ultimate strength in stretching as the average of two stretching directions, kg/mm2, not less than; 8) water absorption (%, not more than); 9) within .... min; 10) linear deformation when moistened (%, not more than); 11) along; 12) across; 13) moisture content (%).

S. Sh. Ryvlin

WATERPROOFING – see **Bituminous Materials.**

WATER RESISTANCE – the property of materials to resist the action of water and water vapor. The concept of water resistance includes the concept of water permeability and wetting (swelling) in water. Processes which take place under the action and with the participation of water, primarily hydrolysis of polymeric materials (PM), result in the breakdown of the latter, in destruction of their molecules. Biologically, the destruction of PM under the action of bacteria, fungi, including mildew, also usually takes place in a water medium. Hydrolytic processes take place easiest in heteropolymers such as polyamides, proteins, polyesters, cellulose; they are accelerated substantially in the presence of acids, alkalis and certain salts. The water resistance of polymeric materials is determined by the character of the heterochain bound, the nature of the hydrolizing agents and the conditions under which the process takes place, primarily the temperature. Polymeric materials most susceptible to hydrolysis are those with a cellulose base, polyamides are less susceptible and polysulfides and polyesters are even less susceptible. Of substance to biological destruction is the presence of nutrients which are needed for the activity of bacteria, fungi, etc. The water permeability of engineering polymeric materials depends to a large extent on the ratio of various additives (fillers, plastifiers, stabilizers) to the water, a part of them can dissolve in the water or participate in various chemical reactions which take place in the water medium. The water resistance of polymeric coatings which protect surfaces of metals, lumber and chemically-unstable polymeric materials is substantial; swelling in water, these coatings lose not only their me-

chanical properties, but also their adhesion to the surface they protect. In addition, corrosion of metal, for example, of iron or copper, once started, can substantially accelerate the reduction destruction of polymeric materials of which the coating is made as a result of formation of reduction-oxidation systems which include the ions of the metal with variable valence. In the water medium it is also possible to have formation of hydrogen peroxide, which is highly destructive to polymeric materials. Adsorption weakening with swelling and wetting of walls, cracks and discontinuities is of substance for a number of materials. Water resistance is improved by introducing hydrophobic agents and surface-active substances into the polymeric materials; coating the surface of polymeric materials which is subjected to hydrolysis or oxidation in the water medium by water-resistant materials and also by impregnating the polymeric materials by antiseptics, which prevent biological destruction. Such, for example, is the impregnation of railroad crossties by products of the coke-byproduct industry, in particular by cresoles. Methods of rapid determination of water resistance are based on conducting the process either at a high temperature, or under other severe conditions.

References: Rogovin, Z.A. and Shorygina, N.N., Khimiya tsellyulozy i ee sputnikov [The Chemistry of Cellulose and Members of Its Group], Moscow-Leningrad, 1950; Grassy, N., Chemistry of Polymer Destruction Processes, translated from English, Moscow, 1959.

N.N. Lezhnev

WATER RESISTANT FACING MATERIALS - see Nonflammable Materials.

WEAR – is the result of the chafing of working pieces caused by friction processes on the surface; it is evaluated by the change in size or weight of the piece. Wearing is caused both by plastic deformation and destruction of the surface layers. The latter is termed abrasive wear (effect of hard, mostly nonmetallic particles which are moving relatively to the surface of the body). It concerns the friction of metal on rocks, cutting and boring of soils, grinding, scratching, friction of a rough shaft on the weaker bearing, sandblasting processes, etc.). Wear is in the most cases not a purely mechanical process. Corrosion and adsorption affect the wear intensely, the abrasion wear of the steel grade 35, for example, is 30 times higher in distilled than in tap water, whereas the wear of Kh18N9 stainless steel is 6 times higher in tape water than in distilled water. Depending on the correlation between mechanical and abrasion effects, all intermediate cases, beginning with a pure abrasion wear and ending with corrosion and mechanical wear, are possible. Therefore, increasing of the mechanical strength as well as increase of the corrosion resistance at the given conditions are used for the increase of the wear resistance.

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WEAR-RESISTANT CAST IRON – is a cast iron, the microstructure and chamical composition of which involve a high resistance to wearing, i.e., to destruction caused by contact with friction surfaces. The type of destruction by wearing depends on the type of friction, and the latter, in turn, depends on the linking conditions of the parts and on working conditions: sliding friction, rolling friction of metal on lubricated or nonlubricated metal, and also a combination of both types of friction; moist or dry sliding friction of metal on nonmetal or on an abrasive; rolling friction or a combination of the latter with sliding friction under the same conditions as before; friction of metal on a fluid, on vapor or gases, causing an erosion effect on the metal surface, etc. Sometimes the wearing of the cast iron occurs in an aggressive medium; in such cases, the cast iron must be also corrosion-resistant.

There exist a number of groups, characterized by the purpose and the working conditions of the parts made of them. Based on the type of fracture, on the chemical composition, and on the microstructure, the wear-resistant cast irons are subdivided into alloyed, low-alloy, medium-alloy, and high-alloy gray and high-strength cast iron; nonalloyed malleable iron; nonalloyed, low-, medium-, and high-alloy chilled cast iron or white iron; and gray and high-strength cast iron with austenitic metal base. The latter is at the same time corrosion-resistant (see Corrosion-resistant cast iron).

Depending on the working conditions, the wear-resistant cast iron is subdivided into the following groups: Antifriction cast iron, Fric-

tion cast iron; Cast iron for piston rings; Chilled cast iron or white iron. The former 3 groups belong to the gray, high-strength (magnesium-alloy) or malleable irons (see Gray iron, Malleable iron).

The antifriction iron is characterized by a sufficient wear-resistance to sliding friction at different combinations of the sliding rate at the specific pressure (not higher than 200 kg/cm^2). Malleable iron is used in the cases of extreme specific pressures. Friction iron is characterized by a high friction coefficient, by the capability of withstanding the formation of seizings during the braking, and by some other specific properties. The iron for piston rings must be of the antifriction grade with a high elasticity. Chilled iron must easily withstand wearing under abrasive friction conditions at high specific pressures. The wear-resistance of cast irons is mainly determined by their structure and hardness, which in turn depend on the content and the type of the alloying elements, the cooling rate of the casting, and the conditions of the heat treatment (Table 1).

TABLE 1

Relative Wear of Cast Irons by Abrasives

1	2 НВ (кг/мм²)	3 Относит. износ
4	90	1
5	200	0.71
6	312	0.50
7	550–750	0.18–0.12
8	200 600	0.50–0.00 0.01–0.71
9		

1) Cast iron; 2) kg/mm^2; 3) relative wear; 4) gray ferritic iron, nonalloyed; 5) gray pearlitic iron, nonalloyed; 6) gray acicular-troostitic iron, low-alloy; 7) gray martensitic iron, medium-alloy; 8) gray austenitic iron, high-alloy (12% Mn); 9) white nonalloyed iron.

TABLE 2

Wear-Resistance of Automobile Cylinders Made of Gray Iron

1 Микроструктура металлич. основы и распределение графита	2 Износ (мм на 10000 км)
3 Пластинчатый, равномерно распределенный графит; перлит; нек-рое количество избыточных карбидов	0,0084
4 Графит такой же; около 100% перлита	0,0105
5 Графит такой же; перлит; небольшое количество массивного феррита	0,0333
6 Графит такой же; массивный феррит	0,0635
7 Графит междендритный; перлит; нек-рое количество массивного феррита	0,0589

1) Microstructure of the base metal and distribution of the graphite; 2) wear (mm per 10,000 km); 3) lamellar, uniformly distributed graphite; 2) wear (mm per 10,000 km); 3) lamellar, uniformly distributed graphite; pearlite, some surplus quantity of carbides; 4) the same graphite; about 100% pearlite; 5) the same graphite; pearlite; a small quantity of massive ferrite; 6) the graphite; massive ferrite; 7) interdendritic graphite; pearlite; some quantity of massive ferrite.

The wear-resistance of gray irons depends also on the distribution of the graphite. The presence of ferrite in the cast-iron structure, and the distribution of the graphite precipitations between the dendrites reduce the wear-resistance of iron castings (Table 2).

Modifying (see C[illegible]fying of cast iron) improves the distribution of the lamellar graphite and increases the wear-resistance of the gray iron in the cast of metal-on-metal friction, or metal-on-abrasive friction. Under equal working conditions, the wear of the modified gray iron is 30-40% lower than that of the non-modified gray iron.

Mofified gray iron surpasses manganese steel in the resistance to wear by abrasives; this is proved by the data of the Table 3.

In order to increase the wear resistance, the castings of gray, high-strength, and malleable iron are submitted to heat treatment: normalization, hardening and tempering, surface hardening, etc. (see Heat treatment of cast iron).

TABLE 3

Wear-Resistance of Modified Cast Iron

Материал 1	Срок службы (недели) 2		
	дробильных молотков 3	валков для дробления щебня 4	шестерен 5
Модифицированный чугун 6	12	12	60
Марганцовистая сталь 7	3	4	12

1) Material; 2) life (weeks) of; 3) crushing hammers; 4) rolls for rubble crushing; 5) pinions; 6) modified cast iron; 7) manganese steel.

Pearlitic or pearlite-ferritic cast iron (gray, high-strength, or malleable iron) are used for the manufacture of parts which work in bearings and in other friction joints; gray iron castings are used for low and moderate specific pressures; castings of high-strength and malleable iron are used in the case of raised and high specific pressures. The following grades are used for the production of parts working in friction joints (excluding bearings): gray nonalloyed iron for machine beds, pinions, flywheels, etc.; gray low-alloyed iron for cylinder blocks of automobile engines, piston rings for cylinders of tractor engines, cams, coupling discs, pinions, punchs, etc.; low-alloy iron with sorbitic structure for the frames of diesel and automobile-engine cylinders, crankshafts, gears, etc.; low-alloy iron with acicular structure for cylinders, dies, punchs, crankshafts, compressors, etc.; malleable iron with pearlitic structure for diesel-engine pistons, valve arms, and also for transmission shafts and for the drive of the rocking shaft and the planet gear of truck automobiles, etc.

For the manufacture of automobile-cylinder cases, sleeves for pumps, plungers, and similar parts, the nitridized low-alloy gray iron with the following composition is used: 2.8-3.0% C; 2.3-2.6% Si; 0.6-1.0% Mn; 0.8-1.3% Al; 0.8-1.2% Cr, and 0.15-0.3% Mo. Blanks of this

iron are rotary casted into a chill mold heated at 350-450° and then covered with a fireproof paint. The casted blanks are normalized at 930-950°, tempered at 700-720°, and then machined. Further, the blanks are tempered at 580-625° in order to remove the stresses caused by the first machining, and then nitridized at 520-530° for 80 hrs. The thickness of the nitridized layer is 0.1-0.15 mm; the hardness is 500-700 HV under a load of 5 kg.

Many parts submitted to wear are casted from malleable iron or copper-alloy gray iron; the copper increases the hardness and strength of the iron, causing a hardening by dispersion and thus improving the wear-resistance and the antifriction properties of the parts (Table 4).

TABLE 4

Chemical Composition and Field of Application of Copper-Alloy Wear-Resistant Iron Grades

Чугун 1	2 Содержание элементов (%)						3 Область применения
	C	Si	Mn	Cr	Cu	Ni	
Низкоуглеродистый ковкий 4	2,0—2,2	0,8—1,0	—	0,4—0,5	0,5—0,7	1,4—1,6	Коленчатые валы автомоб. двигателей 6
Ковкий * 5	2,8	1,5	—	0,5	2,0	0,6	
Ковкий марки ЧМ-1,3 7	2,8—3,0	0,5—1,1	0,6—1,2	—	1,0—1,5	—	8 Детали, работающие на износ в условиях высоких уд. давлений до 200 кг/см²
Серый марки ЧМ-1,8 9	2,8—3,6	1,3—1,9	0,6—0,9	0,2—0,4	1,5—2,0	—	10 Детали, работающие на износ при уд. давлениях до 5 кг/см² и при скоростях скольжения до 25 м/сек

*Typical mean composition.

1) Cast iron; 2) percentage of elements; 3) field of application; 4) malleable low-carbon; 5) malleable*; 6) crankshafts of automobile engines; 7) malleable, ChN-1.3 grade; 8) parts submitted to wear at high pressures, up to 200 kg/cm^2; 9) gray, ChM-1.8 grade; 10) parts submitted to wear under a specific pressure up to 5 kg/cm^2 at sliding rates up to 25 m/sec.

In order to increase the wear-resistance of gray-iron castings, the friction surfaces are saturated with tellurium which, being an active carbide-forming agent, causes the formation of a thin hard, chilled layer (less than 1 mm). This is achieved by covering the correspond-

ing surfaces of the mold with a tellurium-containing paste before pouring in the metal. The core of the casting remains gray. Bolts of automobile-engine bushes, for example, are manufactured in this way.

High-alloy chrome-nickel-copper austenitic irons, Ni-Resists (see Corrosion-resistant cast iron) are used for parts working under combined corrosive and wearing conditions. Castings of chilled iron with a pearlite-carbide structure, which causes a high hardness and wear-resistance, are used in the case of abrasion wear. The cast iron may be nonalloyed, middle-alloy, or high-alloy, depending on the purpose (Table 5).

TABLE 5

Chemical Composition and Application of Chilled and White Iron

Чугун 1	2 Содержание элементов (%)								5	6 Применение
	C	Si	Mn	P 3 не более	S 3 не более	Cr	Ni	Др. элементы 4	HB (кг/мм²)	
Нелегированный 7	3,0—4,0	0,6—1,0	0,6—1,2	0,5	0,1	—	—	—	—	Твердые чавунные литые детали, шары для мельниц и др.
То же 8	2,8—3,0	1,0—1,2	0,8—1,2	0,2	0,1	—	—	—	500—550 18	То же
Низколегированный 9	3,4—3,5	0,8—0,9	0,4—0,5	0,4	0,1	0,4—0,5	1,0—1,2	—	— 8	
Среднелегированный (нихард): 10										
твердый 11	3,2—3,6	0,5—0,8	0,5—0,7	0,4	0,1	1,8—2,6	4,0—5,0	0,1—0,5 Mo	650—725 (при отливке в кокиль)	Чистовые прокатные валки, фильеры, шары для мельниц, кольца и ролики подшипников, мельницы тонкого помола и др. 19
мягкий 12	2,8—3,2	0,5—0,8	0,5—0,7	0,4	0,1	1,8—2,6	4,0—5,0	0,3—0,5 Mo	525—625 575—675 (при отливке в кокиль)	
Среднелегированный хромистый 13	2,3—2,5	1,5—1,8	0,5—1,0	0,05	0,05	3,2—3,7	0,4	0,2—0,7 Mo	50—52 (RC)	Седла клапанов дизелей и т. п. 20
Среднелегированный никелебористый 14	2,5—3,25	0,5—1,5	0,5—1,2	0,05	0,05	—	3,5—4,5	0,7—1,0	58—62 (RC)	Втулки насосов и др. 21
Высоколегированный хромистый 15	1,8—4,0	1,5—3,0	0,5—0,8	0,05	0,05	17—28	0—3	до 1,5 Mo	25—60 22	Детали, работающие на абразивный износ

1) Cast iron; 2) percentage of elements; 3) not more than; 4) other elements; 5) kg/mm²; 6) application; 7) nonalloyed; 8) the same; 9) low-alloy; 10) medium-alloy (Ni-Hard); 11) hard; 12) soft; 13) medium-chrome-alloy; 14) medium nickel-boron alloy; 15) high-chrome-alloy; 16) when casted in a chill mold; 17) hard machine castings; 18) millstones, balls for mills, etc.; 19) planishing rolls, draw plates, balls for mills, rings and roller bearings for fine-grinding mills, etc.; 20) valve seats for diesel engines, etc.; 21) bushes of pumps, etc.; 22) parts working under abrasive wear.

White-iron castings are usually submitted to heat treatment: the middle-alloy Ni-Hard (Cr-Ni-Mo) is annealed at 800-930° to remove the casting stresses; the hardness of the high-alloy chrome-iron (17-28%

Cr) is increased by hardening at 1000-1100°.

Rollers for metal rolling, etc., and also rollers for flour-mills, wheels of railroad-cars, crusher jaws, beaters of coal-mills, and other parts submitted to wear are manufactured from gray-iron castings with a chilled surface layer, the latter having the pearlite-carbide structure of white iron (see Chilled iron).

High-alloy white iron, known as Sormite, is build-up on the friction surfaces in order to repair worn castings (Table 6).

TABLE 6

Chemical Composition and Hardness of the Sormite Iron

Сормайт[1]	Содержание элементов (%)					RC	Обработка[3]
	C	Si	Mn	Cr	Ni		
[4] Твердый	2,5—3,5	2,5—3,5	1,0—1,5	28—35	3—5	47—52	[5] Абразивом
[6] Мягкий	1,8—2,2	1,5—2,0	1,0—1,5	14—18	3—5	58—61*	[7] Механическая

*After quenching in oil from 870-880°.

1) Sormite; 2) percentage of the elements; 3) machining; 4) hard; 5) by abrasives; 6) soft; 7) mechanical.

Sormite is built-up by an oxyacetylene torch with a reducing flame and without a flux. The casting is heated up to 600-700° and cooled in the oven before the welding.

References: Hall, A.M., Nikel' v chugune i stali [Nickel in Cast Iron and Steel], translated from English, Moscow, 1959; Grozin, B.D., Iznos metallov [Wear of Metals], Kiev, 1951; Vasilenko, A.A. and Grigor'yev, I.S., Modifitsirovannyy chugun v mashinostroyenii [Modified Cast Iron in Machine Building], Kiev, 1950; Kudryavtsev, I.V. and Zhukov, A.A., Kolenchatyye valy iz vysokoprochnogo chuguna [Crankshafts of High-Strength Cast Iron], in the book: Spravochnik po mashinistroitel'nym materialam [Handbook of Machine-Building Materials], Vol. 3, Moscow, 1959; Grechin, V.P., Iznosostoykiye chuguny i splavy [Wear-Resistant Cast Irons and Alloys], Moscow, 1961; the same, Legiro-

vannoye chugunnoye lit'ye [Alloyed Cast Iron], Moscow, 1952; Berg, P.P., Chugun kak konstruktsionnyy material [Cast Iron as a Structural Material], in the book: Mashinostroyeniye [Machine Building], an encyclopedic handbook, Vol. 4, Moscow, 1947; Barton, R., "BCJRA Journal," 1960, Vol. 8, No. 6, pages 857-882; Metals Handbook, 1948, Cleveland, 1948, pages 216-222.

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WELDABLE ALUMINUM SHAPING ALLOYS – alloys which retain unaltered or almost unaltered mechanical properties in fusion-welded joints and which have the requisite technological characteristics for fabrication of welded structures. Aluminum shaping alloys can be divided into those which can be hardened by heat treatment and those which cannot be hardened thermally (see Aluminum shaping alloys). Both groups are characterized by: ready oxidizability, which leads to formation of destable, high-melting oxide Al_2O_3, which melts at a temperature substantially higher than the melting point of aluminum and is insoluble in liquid Al; a low melting temperature coupled with a rather high thermal conductivity and a high coefficient of thermal expansion ($>22 \cdot 10^{-6}$); a tendency toward formation of crystallization cracks.

Interaction between the molten metal and gases is prevented by welding in an inert atmosphere or under a layer of flux (see Welding of aluminum alloys).

A tendency toward formation of crystallization cracks is a specific characteristic of these alloys and its extent is determined by their chemical composition, grain size, and strength and plasticity in the solid and liquid states. The chemical composition of an alloy governs its type, crystallization-temperature range, crystallization rate, strength, and plasticity. Alloys of the eutectic type exhibit little tendency to crack, a narrow crystallization-temperature range, a slower increase in the quantity of crystallized alloy at low temperatures, and little tendency to absorb gases; they are fine-grained, rather strong, and especially plastic at temperatures between the liquidus and room

temperature. The tendency to crack can be reduced in certain alloys by proper selection of rod material and welding regime.

The structure of the melt zone depends on the degree of alloying. In low-alloy, thermally unhardenable ligatures the melt zone usually consists of dendrites of a supersaturated aluminum solid solution with a small number of eutectics arrayed in isolated colonies. The strength and plasticity of this structure are close to those of the base alloy; on the whole, a joint between thin weldable sheets is as strong as for the base alloy. In thermally hardenable ligatures, which are usually highly alloyed, the melt zone contains a considerable number of eutectics arranged along the grain boundaries and separating the grains, in addition to dendrites of the supersaturated solid solution. In this case the plasticity and strength of a fusion-welded seam are substantially less than those of the deformed, heat-treated base alloy and depend on the character and form of the eutectic structure.

The structure of the heat-effect zone adjoining the melt zone is an important factor governing the properties of a welded joint. Several areas can be distinguished as the distance from the melt zone increases: an area of fusion of the grain boundaries, with considerable consolidation of the grains, an area of local fusion of the individual structural constituents of the alloy, a zone of overheating, and an area of structural changes in the solid phase. These changes negate the effects of preliminary heat treatment and cold working of the alloy and the characteristics of welded joints in cold-worked and non-cold-worked alloys are identical.

The roles and states of the three areas differ for alloys of the two groups. In thermally unhardenable alloys the first area is not extensive and sometimes is entirely lacking, being replaced by an area of large grains with local flashing. The third area exhibits no substan-

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TABLE 1

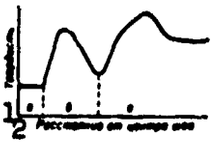
Mechanical Properties

ГОСТ, ТУ 1	Сплав 2	Состояние полуфабриката 3	σ_b (кг/мм²) 4	$\sigma_{0.2}$ (кг/мм²)	δ (%)
		Листы 6			
5 ГОСТ 7869—56	АД, АД1	отожженные 7	11	—	20—28
		нагартованные 8	13—15	—	4—5
9 АМТУ 252—57	АМц 10	отожженные	10—15	—	20—22
		нагартованные	19	—	4
АМТУ 252—57	11АМг	отожженные	17—23	—	16—18
		нагартованные	27	—	3—4
12 СТУ	13АМг3	отожженные	20	—	15
		горячекатаные 14	15	10*	5
15 то же	16АМг6В	отожженные	28	—	15
		горячекатаные	28	13*	15**
то же	17 АМг6	отожженные	32	—	15
		горячекатаные	32	16	15
АМТУ 252—57	18 АВ	отожженные	15	—	15—20
	20	закаленные и искусственно состаренные 19	30	—	8—10
—	АД 31	отожженные	9	5	25
	21	закаленные и искусственно состаренные	23	18	10
—	АД 33	отожженные	13	5	23
		закаленные и искусственно состаренные	20	24	10
СТУ	М40	отожженные	28	—	17
		закаленные и искусственно состаренные	36—38	24—30	8—17
		закаленные нагартованные и искусственно состаренные	42—45	38—33	8
АМТУ 395—57	Д20	отожженные 22	20	—	25
		закаленные и искусственно состаренные	38	28	8
СТУ	ВАД1	отожженные	25	—	10
		закаленные и естественно состаренные 25	41	27	12
		Профили прессованные b			
АМТУ 258—55	АМц	отожженные	17	—	20**
АМТУ 422—57	АМг6В	то же	27	12	15
о же	АМг6	"	32	16	15
АМТУ 258—55	АВ	закаленные и искусственно состаренные	30	23	10
СТУ	АД 31	то же	20	15	8
—	АД 33	"	27	24	10
СТУ	М40	"	40	27	10**
АМТУ 378—57	Д20 23	"	36	23	8**
		Плиты горячекатаные c			
АМТУ 332—53	АМц	горячекатаные	12	—	15
АМТУ 347—55	АМг	то же	16—18	—	6—7
то же	АВ	закаленные и искусственно состаренные	28—30	—	6—7
СТУ	М40	то же	37	30	13
		26 **Трубы** d			
ГОСТ 4773—49	АД, АД1	холоднотянутые	10—12	—	4—20
то же	АМц	нагартованные	14	—	—
"	АМг	то же	23	—	—
АМТУ 413—57	АМг3	полунагартованные 27	22	13*	8
СТУ	АМг3В	отожженные	28	15	15
ГОСТ 4773—49	АВ	закаленные и естественно состаренные	21	—	14
		28 **Прутки** e			
ГОСТ 4784—49	АД, АД1	отожженные или прессованные	11	—	25
то же	АМц	то же	17	—	20
"	АМг	"	22	—	10
АМТУ 426—57	АМг3	"	18	8	15
то же	АМг3АВ	"	27	12	15
"	АМг6	"	32	16	13
ГОСТ 4783—49	АВ	закаленные и естественно состаренные	36	—	12
		Штамповки. Поковки f			
АМТУ 282—55 и 349—55	АВ	закаленные и искусственно состаренные	27—30	—	4—12
СТУ 29	М40	то же	33—37	—	6—8

*$\sigma_{0.2}$ – facultatively.

**δ_0 = 5 d.

1) GOST, TU; 2) alloy; 3) state of semifinished product; 4) kg/mm^2; 5) GOST; 6) AD, AD1; 7) annealed; 8) cold-worked; 9) AMTU; 10) AMts; 11) AMg; 12) STU; 13) AMg3; 14) hot-rolled; 15) the same; 16) AMg5V; 17) AMg6; 18) AV; 19) quenched and artificially aged; 20) AD31; 21) AD33; 22) quenched, cold-worked, and artificially aged; 23) D20; 24) VAD1; 25) quenched and naturally aged; 26) cold-drawn; 27) semi-cold-worked; 28) annealed or extruded; 29) and. a) Sheets; b) extruded shapes; c) hot-rolled plates; d) tubes; e) bars; f) stampings and forgings.



Change in hardness over width of welded joint: a) Melt zone; b) flash zone; c) area of structural changes in solid phase. 1) Hardness; 2) distance to center of seam.

TABLE 2

Mechanical Properties of Welded Joints (argon-arc welding)*

Темп-ра испытания (°С) 1	$\sigma_в$ сварного соединения (кг/мм^2) 2					
	АМг3 3	АМг5В 4	АМг6 5	Д20 6	М40	ВАД1 7
20	22.5	29.5	31.5	29.0	32.0	34.0
100	22.0	28.0	29.0	27.0	—	—
150	—	—	25.0	25.0	—	—
200	13.5	18.0	19.5	22.0	29.0	31.0
250	—	—	16.5	16.0	21.5	24.0
300	6.5	8.5	13.0	11.0	16.0	17.0

*Sheets 2 mm thick.

1) Test temperature (°C); 2) σ_b of joint (kg/mm^2); 3) AMg3; 4) AMg5V; 5) AMg6; 6) D20; 7) VAD1.

tial structural changes and its properties are the same as those of the initial soft (annealed) material. These factors explain why welded joints in soft alloys are equal in strength to those in thermally unhardenable alloys. All three areas are quite distinct in thermally hardenable alloys. In welding fully heat-treated materials sharp changes in hardness and other properties take place over these areas. The figure shows the change in hardness in a welded joint. At room tempera-

ture the weakest point in a weld is the area of grain fusion, which has the lowest plasticity and strength and a low hardness. The second area, that of local fusion, is more plastic and has a higher hardness as a result of the quenching which occurs during the heating and subsequent cooling involved in welding. The structural changes in the second area of the heat-effect zone have virtually no influence on the properties of the weld. The third area (structural changes in the solid phase) is marked by processes which cause contrasting changes in the properties of the alloy: softening of the material as a result of high-temperature annealing and, farther from the melt zone, hardening as a result of additional artificial aging. The area of softening usually limits the strength of the weld at elevated temperatures.

Thermally unhardenable alloys can be divided into two groups: 1) technical aluminum (AD1, AD) and aluminum-manganese alloys (AMts); 2) magnalium (AMg1, AMg2, AMg3, AMg5 and AMg6). The mechanical and technological properties of weldable aluminum shaping alloys are shown in Tables 1-3.

Types AD1 and AD technical aluminum and the aluminum-manganese alloy AMts have high plasticity, good corrosion resistance, and good weldability, but, because of their low strength, cannot be used for structural bearing elements. Additional hardening can be obtained by cold-working, but the effect of this process is completely negated in the heat-effect zone during welding. Technical aluminum and AMts alloy weld well in thin sheets, but large sheets sometimes exhibit a tendency to crack as a result of the inevitable impurities of Fe and Si.

Magnalium is the principal weldable structural material. It is widely used in construction, for low-stress welded structural elements (AMg2, AMg3) and important bearing members (AMg5V, AMg6) in aircraft- and ship-building, and as a decorative material. It is rather strong

and capable of withstanding impact loads. Diffusion in Al-Mg-Mn alloys proceeds slowly, so that the supersaturated α solid solution and eutectoid phases persist. The properties of magnalium depend to a large extent on the presence of Si, Fe, and Na. Fe and Si form intermetallic compounds, which reduce the corrosion resistance of the alloy. AMg1, AMg2, AMg5V and AMg6 alloys have a high corrosion resistance under atmospheric conditions and on exposure to fresh and salt water, but alloys containing more than 5% Mg (AMg5V and AMg6) exhibit a tendency toward corrosion cracking under stress and toward intercrystalline corrosion on prolonged exposure to sunlight if there is any departure from the established annealing regime. The production technology of these alloys involves a number of difficulties: a tendency toward formation of large grains during casting, which can be overcome by introducing Ti, V or Zr into the alloy (see Modification of alloys), and ready oxidizability during melting, casting, and heat treatment, which leads to stratification in sheets and plates. The tendency toward oxidation can be reduced by adding beryllium. The alloys of this group also exhibit a tendency toward intradendritic and interdendritic porosity. It has been established that magnalium is extremely sensitive to impurities of Na, which hamper hot-working under pressure and reduce corrosion resistance. The presence of 0.001% Na in alloys containing more than 2% Mg causes local cracking during rolling, while a Na content of 0.008% causes the ingots to crumble. Crystallization cracking during fusion welding can be eliminated and the hermeticity of the weld increased by additional alloying (silicon reduces cracking in AMg3 alloy) or proper selection of rod material and welding regime. Annealing is the only type of heat treatment to which magnalium is subjected. Despite its comparatively high strength, which results from its Mg content, magnalium has a low yield strength and hot strength. Additional hardening at room tempera-

ture can be obtained by cold working. The increase in strength on cold working is greater for the high-magnesium alloys AMg5V and AMg6. The tendency toward cold working increases with the Mg content, reducing plasticity and hampering cold-deformation processes (rolling, stamping, bending, and flanging). Magnalium has the highest weld plasticity and strength-retention coefficient of any high-strength structural alloy. At room temperature the strength of welded joints amounts to 90-95% of that of the base material.

Thermally unhardenable alloys (AD31, AD33, D20, VAD1, M40 and AV) have the specific welding characteristics noted above.

D20 alloy is good for all types of welding, but the welds have a low corrosion resistance and must be protected with varnish coatings. It has little tendency to crack. Welded joints have a strength equivalent to 70% of that of the base material (approximately 90% after repeated quenching and natural aging). Weld plasticity is comparatively low, which makes it difficult to align welded structures.

VAD1 alloy belongs to the duralumin group and is good for argon-arc welding and satisfactory for contact welding. For joints in weldable sheets 2 mm thick σ_b is approximately 80%. Such joints have a low corrosion resistance and tend to intercrystalline corrosion. Quenching of the joint improves its corrosion resistance and eliminates the intercrystalline corrosion. It can be protected against corrosion by anodizing and varnish-coating. This alloy is recommended for welded structures which must function at 250-300°.

M40 alloy, which has properties similar to those of duralumin, is good for spot welding and satisfactory for argon-arc welding. When the base material is used for the rod this alloy has little tendency to crack and provides satisfactory weld plasticity. Use of a AMg6 rod improves plasticity, but intensifies cracking. The ultimate strength of

TABLE 3

Technological Characteristics

1 Сплав	2 Способ упрочнения	3 Режим термич. обработки	4 Свариваемость	5 Угол загиба сварного соединения° (градусы)
6 АД1, АД	7 Нагартовка	8 Отжиг при 350—410°, охлаждение на воздухе	9 Хорошая всеми видами сварки	180
АМц 10	•	Отжиг при 350—410°, охлаждение на воздухе 8	Отличная всеми видами сварки 11	180
АМг 12	•	Отжиг при 350—410°, охлаждение на воздухе 8	Хорошая точечной и роликовой сваркой; при сварке плавлением образуются кристаллизац. трещины, к-рые устраняются при сварке с присадкой АМг3 · 13 · · ·	180
АМг3 14	•	Отжиг при 270—280°, охлаждение на воздухе 15	Хорошая всеми видами сварки 9	90—120
АМг5В 16	•	Отжиг при 270—280°, охлаждение на воздухе 15	Хорошая точечной и роликовой, удовлетворительная сваркой плавлением · · · · · 17	100—150
АМг6 18	•	Отжиг при 300—350°, охлаждение на воздухе 19	Хорошая аргоно-дуговой сваркой, удовлетворительная точечной и газовой · · · · · · · 20	90—120
М40	Закалка, искусственное старение, нагартовка (листы, профили) 21	1) Закалка с 505+7°, охлаждение в воде, искусств. старение 2) Отжиг при 380—420°, медленное охлаждение до 270—280°, затем на воздухе 22	Хорошая точечной сваркой, удовлетворительная аргоно-дуговой · · · · · · · · · · · 23	60—80
Д20 24	Закалка, искусственное старение 25	1) Закалка с 535±5°, искусств. старение при 145—175° в течение 10—16 час. или при 200—220° в течение 12 час. 2) Отжиг при 350—370°, охлаждение на воздухе 26	Хорошая точечной, роликовой и аргоно-дуговой сваркой · · 27	60—70
АВ 28	Закалка, старение 29	1) Закалка с 515—525°, охлаждение в воде, естеств. или искусст. старение при 150° в течение 6 час. 2) Отжиг при 350—370°, охлаждение на воздухе 30	Хорошая точечной и атомно-водородной сваркой, удовлетворительная газовой с присадкой АК 31	—
АД31, АД33 32	Закалка, старение 29	1) Закалка с 520±5°, охлаждение в воде, естеств. или искусст. старение при 150° в течение 12 час. (АД31) и 16 час. (АД33) 2) Отжиг при 380—425°, охлаждение со скоростью 30° в час. до 260°, затем на воздухе 33	Хорошая точечной и роликовой сваркой, удовлетворительная аргоно-дуговой с присадкой АК 34	—
ВАД1 35	Закалка, естеств. старение 36	Закалка с 510$^{+3°}_{-5°}$, охлаждение в воде, естеств. старение не менее 10 суток 37	Хорошая аргоно-дуговой сваркой, удовлетворительная точечной и роликовой 38	—

*Sheets 2 mm thick.

1) Alloy; 2) hardening method; 3) heat-treatment regime; 4) weldability; 5) bending angle of welded joint* (degrees); 6) AD1, AD; 7) cold working; 8) annealing at 350-410°, air-cooling; 9) good for all types of welding; 10) AMts; 11) excellent for all types of welding; 12) AMg; 13) good for spot and bead welding; crystallization cracking occurs during fusion welding and can be eliminated by use of a AMg3 rod; 14) AMg3; 15) annealing at 270-280°, air-cooling; 16) AMg5V; 17) good for spot and bead welding, satisfactory for fusion welding; 18) AMg6; 19) annealing at 300-350°, air-cooling; 20) good for argon-arc welding, satisfactory for spot and gas welding; 21) quenching, artificial aging, and cold working (sheets, shapes); 22) 1 - quenching from 505 ± 7°, water-cooling, and artificial aging; 2 - annealing at 380-420°, slow cooling to 270-280°, followed by air-cooling; 23) good for spot welding, satisfactory for argon-arc welding; 24) D20; 25) quenching and artificial aging; 26) 1 - quenching from 535 ± 5° and artificial aging at 165-175° for 10-16 hr or at 200-220° for 12 hr; 2 - annealing at 350-370° and air-cooling; 27) good for spot, bead, and argon-arc welding; 28) AV; 29) quenching and aging; 30) 1 - quenching from 515-525°, water-cooling, natural or artificial aging at 150° for 6 hr; 2 - annealing at 350-370°, air-cooling; 31) good spot and atomic-hydrogen welding, satisfactory gas welding with AK rod; 32) AD31, AD33; 33) 1 - quenching from 520 ± 5°, water-cooling, and natural or artificial aging at 160° for 12 hr (AD31) or 16 hr (AD33); 2 - annealing at 380-420°, cooling at 30° per hr to 260°, followed by air-cooling; 34) good for spot and bead welding, satisfactory for argon-arc welding with AK rod; 35) VAD1; 36) quenching and natural aging; 37) quenching from 510^{+20}_{-5}°, water-cooling, and natural aging for no less than 10 days; 38) good for argon-arc welding, satisfactory for spot and bead welding.

welded joints is 80-90% of that of the quenched and artificially aged base material. Welds can be protected against corrosion by varnish-coating. This alloy is recommended for welded structures which must function at temperatures of up to 250°.

Alloys AD31, AD33 and AV are Al-Mg-Si systems. AV alloy is good for spot welding, but has a tendency toward crystallization cracking in argon-arc welding, which can be eliminated by use of AK rod (4.5-6% Si and the remainder Al); however, in the latter case it is impossible to obtain a uniform color in the seam and base metal after anodizing. The strength of a joint not subjected to subsequent heat treatment amounts to 60% of that of the base material. AD31 and AD33 alloys contain the same constituents as AV, but have a higher plasticity and corrosion resistance and a highly decorative appearance (AD31). They are

good for spot, bead, and butt welding and satisfactory for argon-arc and gas welding when AK rod (5% Si) is used. The weld strength amounts to 60-70% of that of the base material and can be raised to 90-95% by subsequent quenching and aging. Use of AK alloy as the rod material gives the weld a dark color after anodizing. Butt welding without a rod is recommended for production of finished products with a good decorative appearance.

The rod material should improve the melting characteristics of the metal to be welded, ensure sufficient weld strength and technological plasticity, maintain or improve the corrosion resistance of the metal in the seam, and cause minimal changes in the microstructure of the metal in the area adjoining the weld. On the basis of the requirements imposed on the rod material the melting temperature of the rod should be less than that of the metal to be welded, decrystallization-temperature range for single-phase alloys should be reduced, and sufficient eutectic or peritectic liquid should be formed to reduce the alloy's tendency toward hot cracking. Alloys containing 20-40% eutectic structures are the most resistant to crystallization cracking. Alloys containing 5-10% eutectic liquid and having a very broad crystallization-temperature range exhibit the greatest tendency toward cracking. In order to ensure sufficient weld strength and technological plasticity an attempt should be made to obtain alloys with the lowest possible eutectic content (when the phase composition and the size and shape of the phases in the eutectics are favorable).

Aluminum and its alloys can be welded with rods of the same composition as the base material. This is true of pure Al and of Al-Mn (up to 1.25%) alloys. Rods containing >5% Mg or fabricated from AMg3 or AK alloy are recommended for alloys of the magnalium type, which contain from 2 to 7% Mg. Rods of AMg3 and AK alloys eliminate cracking, but re-

duce the corrosion resistance of the weld and cause deterioration of its appearance. Rods of Al-Si alloys are recommended for welding AV, AD31, and AD33 alloys, ensuring a Si content of no less than 2.5% in the weld. In welding high-alloy, thermally hardened high-hot-strength alloys it is necessary to use the requirements described above as a basis for experimental determination of the rod material which ensures welds with the requisite complex of physical, chemical and technological characteristics.

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WELDABLE TITANIUM SHAPING ALLOYS – alloys which weld well by argon-shielded and other welding method; here the strength and plasticity of the welded joint are close to these properties of the base metal. Heat treatment after welding, as a rule, is not required, only annealing is performed to relieve stresses produced in the welding process. Among weldable titanium shaping alloys are: VT1-00, VT1-0, VT-1, VT-2, OT4-1, OT4, VT4, VT5, VT5-1, VT6S, VT6, OT4-2, AT-3, AT-4. These are single-phase alloys with the α phase as a base (VT1-00, VT1-0, VT1-1, VT1-2, VT5, VT5-1) or they have as their base the α structure with a moderate amount of the β phase (OT4-1, OT4, VT4, AT-3, AT-4, VT6S, VT6, OT4-2), which do not perceptibly affect the weldability.

TABLE 1

Mechanical Properties of Weldable Titanium Shaping Alloys*

Сплав 1	2 Технич. условия	σ_b (кг/мм²) 3	δ (%) 5 не менее	Угол загиба** (град.) 4 не менее
6 ВТ1-00	8 АМТУ 475-1 А-63	30—45	25	80
ВТ1-0	АМТУ 475-1 А-63	40—55	25	80
ВТ1-1	АМТУ 475-1-61	45—60	25	80
ВТ1-2	АМТУ 475-2-61	55—70	20	70
ОТ4-1	АМТУ 475-4-61	60—75	15	60
ОТ4	АМТУ 475-3-61	70—90	12	50
ВТ5-1	АМТУ 475-7-61	75—95	10	40
ВТ4	АМТУ 475-6-61	85—105	10	40
7 ВТ6С	АМТУ 475-9-64	85—100	12	30
ВТ6	АМТУ 475-8-61	90—110	8	40
ОТ4-2	АМТУ 475-25-61	100—120	10	30
АТ-3	СТУ	70—85	16	45
АТ-4	9 СТУ	85—100	14	40

*Annealed sheets 2 mm thick.
**In testing the VT1-00, VT1-0, VT1-1 and VT1-2 alloys the mandrel radius is equal to one sheet thickness; for other alloys it is equal to one and one half sheet thickness (OST 1683).

1) Alloy; 2) technical specifications; 3) (kg/mm^2); 4) bending angle** (degrees); 5) not more than; 6) VT; 7) VT6S; 8) AMTU; 9) STU.

TABLE 2

Mechanical Properties of Weldable Titanium Shaping Alloys at Various Temperatures (°C)

Сплав 1	$\sigma_в$ (кг/мм²) 2					$\sigma_{0,2}$ (кг/мм²)					δ_{10} (%)					$\tau_{ср}$ (кг/мм²) 3	$a_н$ (кгм/см²) 4			σ_{-1} (кг/мм²) 2		
	−196°	−70°	20°	300°	400°	−196°	−70°	20°	300°	400°	−196°	−70°	20°	300°	400°	20°	−196°	−70°	20°	20°	150°	400°
5 ВТ1-1 (листы и прутки)	90	60	45	32	15	—	—	38	18	15	—	20	25	30	35	30	—	—	7**, 5**	27	—	15
6 ВТ1-2 (листы и прутки)	110	76	61	28	32	—	—	47	22	19	5	17	22	28	30	40	—	—	5**, 3,5**	23	—	17
7 ОТ4-1 (листы)	115	—	65	35	31	97	—	47	29	26	13°	15°	20°	23°	17°	—	2,5	5	7	34	—	19
ОТ4 (листы)	122	87	75	49	46	103	73	60	43	40	—	24°	38°	36°	32°	—	2	3	8	38	—	20
8 ВТ5 (прутки и поковки)	123	94	80	48	—	120	90	70	38	35	5	13	15	16	12	85	1	3	4	27	24	—
9 ВТ5-1 (листы, поковки и штамповки)	135	95	75	52	48	125	85	65	46	—	8	8	15	16	—	80	3	—	7,5	40	35	—
АТ-3 (листы и прутки)	122	113	75	55	50	—	—	70	47	40	8°	9°	20°	24°	24°	—	3	—	6	40	—	—
10 АТ-4 (листы и прутки)	110	—	90	68	60	—	—	85	60	55	3°	—	15°	17°	20°	—	3	—	6	50	—	—

*Foreshortened specimens (δ_5).

**The first number pertains to longitudinal specimens, the second is for transverse specimens.

***Forged bar stock.

****The endurance limits were determined in uniform flexing of a rotating specimen for $2 \cdot 10^7$ cycles.

1) Alloy; 2) (kg/mm^2); 3) τ_{sr} (kg/mm^2); 4) kgm/cm^2); 5) VT1-1 (sheets and bar stock); 6) VT1-2 (sheets and bar stock); 7) (sheets); 8) VT5 (bar stock and forgings); 9) VT5-1 (sheets, forgings and stampings); 10) (sheets and bar stock).

TABLE 3

Creep Resistance (on the Basis of 0.2% Deformation) and the Creep Strength of Weldable Titanium Shaping Alloys at Different Temperatures (°C)

Сплав 1	$\sigma_{0,2/100}$ (кг/мм²) 2				$\sigma_{0,2/100}$ (кг/мм²)		σ_{100} (кг/мм²)				σ_{100} (кг/мм²)	
	300°	350°	400°	450°	300°	350°	300°	350°	400°	450°	300°	350°
ОТ4-1 (листы) 3	—	—	18*	—	—	—	—	34	20	—	—	—
ОТ4 (листы)	—	30	18	5	35	27	—	46	28	—	46	46
4 ВТ5 (прутки и поковки)	42	—	30	—	—	—	30	46	—	37	—	—
5 ВТ5-1 (листы, поковки и штамповки)	60	33	24	—	35	30	—	45	—	—	67	46
АТ-3	—	—	10	20	—	—	—	—	18	35	—	—
АТ-4	—	—	—	30	—	—	—	—	40	—	—	—

*For 50 hours.

1) Alloy; 2) (kg/mm^2); 3) (sheets); 4) VT5 (bar stock and forgings); 5) VT5-1 (sheets, forgings and stampings).

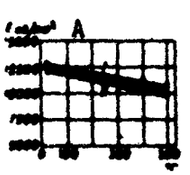

Fig. 1. Temperature dependence of the dynamic modulus of elasticity. 1) The OT4-1 alloy; 2) the VT1-1, VT1-2, OT4, VT5 and VT5-1 alloys. A). kg/mm^2.

TABLE 4

Thermal Conductivity of Weldable Titanium Shaping Alloys

1	2 Температура (°С)								
Сплав	25	100	200	300	400	500	600	700	800
	3 λ (кал/см·сек·°С)								
4 ВТ1-00, ВТ1-0, ВТ1-1, ВТ1-2	0,046	0,045	0,044	0,043	0,043	0,043	0,043	0,045	0,047
ОТ4-1, ОТ4	0,024	0,025	0,027	0,029	0,032	0,035	0,039	—	—
ВТ5	0,018	0,021	0,024	0,028	0,032	0,036	0,040	0,043	—
ВТ5-1	0,021	0,023	0,026	0,029	0,032	0,035	0,038	0,041	0,045

1) Alloy; 2) temperature (°C); 3) λ (cal/cm·sec·°C); 4) VT.

Weldable titanium shaping alloys are made primarily in the form of sheets, ribbons, strips, bar stock, shapes, pipes, wire, as well as forgings and stampings. The VT5 alloy is only to be used for forgings, stampings, bar stock and shaped stock. For the chemical composition of weldable titanium shaping alloys see Titanium alloys.

The mechanical properties of alloys at room temperature are presented in Table 1. According to technical specifications, as the sheet thickness increases (from 0.5 to 10 mm) a certain reduction in δ and in the bending angle is permitted; σ_b should be the same for all the sheets. The mechanical properties of forgings and stampings (AMTU 487-59) and rolled bar stock (AMTU 452-59) from weldable titanium shaping alloys are approximately the same as those of sheets.

The VT1-1, VT1-2, OT4-1 and OT4 alloys are made for making pipes with diameters from 6 to 54 mm and with wall thicknesses from 1 to 2 mm (AMTU 386-59). The mechanical properties of pipes are close to the properties of sheets from these alloys. The VT1-1, OT4 and VT5 alloys are used for making wire which is utilized as an additive in argon-shielded arc welding and other welding methods. The wire diameter varies from 1.2 to 7.0 mm (AMTU 449-59).

Typical mechanical properties of the VT1-1, VT1-2, OT4-1, OT4,

VT5, AT-3, AT-4 and VT5-1 alloys at various temperatures are presented in Table 2. In static tension these alloys are insensitive to stress concentrations in the presence of a sharp notch (α_k = 6.5). When the test temperature is raised from 20 to 400° the endurance limit is reduced on the average by 40%. The above alloys are characteristic by an insignificant effect of temperature and time on the rupture strength (creep strength) and, conversely, by a strong effect of these factors on the creep resistance (Table 3). The dynamic modulus of elasticity of weldable titanium shaping alloys is insignificantly dependent on the temperature (Fig. 1). The Poisson ratio for these alloys comprises 0.33-0.34. For typical mechanical properties of the VT4, VT6S, VT6, and OT4-2 alloys see also Medium strength titanium shaping alloys.

Weldable titanium shaping alloys have the following physical properties: the specific gravity varies within the limits 4.52-4.55, the thermal conductivity is given in Table 4.

Linear expansion coefficient $\alpha \cdot 10^6$ ($^\circ C^{-1}$) of the OT4 alloy comprises: 8.0 (20-100°); 8.6 (100-200°); 9.1 (200-300°); 9.6 (300-400°); 9.4 (400-500°); 9.8 (500-600°). Specific heat c (cal/g-°C) is 0.14 (100°); 0.14 (200°); 0.15 (300°); 0.16 (400°); 0.18 (500°) and 0.19 (600°). The values of α and c for other weldable titanium alloys are close to those given for the OT4 alloy. The specific electrical resistivity ρ (ohm·mm^2/m) at 20° is 0.48 for the VT1-1 alloy, 1.08 for the VT5 alloy and 1.38 for the VT5-1 alloy. For the physical properties of the VT6S, VT4, VT6 and OT4-2 alloys see Medium strength titanium shaping alloys.

Weldable titanium shaping alloys have a high corrosion resistance in the majority of aggressive media (see Titanium). In the hot state alloys VT1-00, VT1-0, VT1-1, VT1-2, OT4-1, OT4, VT6S, VT4, AT-3, AT-4 have a good and alloys VT5, VT5-1 and OT4-2 have a satisfactory plas-

tivity.

The temperature range of hot pressureworking (forging, rolling) comprises 1000-750° for the VT1-00, VT1-0, VT1-1, VT1-2 and OT4-1 alloys; 1100-850° for the OT4, VT5, VT5-1, AT-3, AT-4, VT6S, VT4, and VT6 alloys and 1150-900° for OT4-2. The regimes and methods of ingot and billet heating and the forging technology of these alloys are given in Heat resistant titanium shaping alloys.

Finished sheets from weldable titanium shaping alloys are obtained by hot rolling in the temperature range of 750-500° or by cold rolling of hot rolled blanks 10-6 mm thick. The degree of deformation permitted in cold pressureworking of the VT1-0 and VT1-00 alloys is 50-80% and for the VT1-1, VT1-2, OT4-1 and OT4 alloys it is 30-50% (cold rolling deformation).

Weldable titanium shaping alloys are used extensively for making components by stamping from sheets, bending and other pressureworking methods. The main sheet stamping operations (extrusion, bending, flanging, etc.) of the VT1-00, VT1-0, VT1-1, VT1-2, OT4-1 and OT alloys are performed in the cold state. Stamping of components, particularly of intricate shape, can be performed in several passes with intermediate annealing or by preheating the metal to 550-750°. When the degree of deformation is moderate, certain operations for sheet stamping of components is moderate, certain operations for sheet stamping of components from the VT5-1, VT4, VT6, VT6S and OT4-2 alloys can be performed in the cold state. However, the majority of operations requires heating to 600-800°. The machining (turning, milling, drilling, etc.) regimes are the same as for machining stainless steels.

The VT1-00, VT1-1, VT1-0, VT1-2, OT4-1, OT4, VT5, VT5-1, VT4, AT-3, AT-4, VT6S and OT4-2 alloys weld well by all welding methods used for titanium. The molten titanium actively reacts with the atmosphere

dissolving oxygen and nitrogen. Hence titanium and titanium alloys can be welded only when the molten and the adjoining heated zone are protected from the surrounding medium. This is achieved by welding in a medium of neutral gases (argon, helium or their mixture) or in a vacuum chamber.

Blanks and components with large cross sections are welded by submerged arc and molten slag arcless electric welding (butt joints). Sheets and components made from them are welded by resistance (spot, seam) and argon-shielded arc welding. The latter can be achieved with and without the use of a welding rod. For short and curvilinear seams in materials with thickness less than 1.5 mm use is made primarily of manual welding without a welding rod, while it is recommended that curvilinear seams in material thicker than 1.2-1.5 mm be made by using a welding rod. Automatic argon-shielded arc welding without a welding rod is used for butt joining sheets 0.8-3.0 mm thick by longitudinal and annular seams. Mechanized argon-shielded arc welding using a welding rod is used for all types of joints more than 1.2-1.5 mm thick by longitudinal and annular seams. Automatic arc consumable electrode welding is used for connecting sheets 3 mm thick by butt and lap joints using longitudinal and annular welds. Automatic welding always yields a joint of higher quality than manual welding. In argon-shielded arc welding use is made of a nonconsumable tungsten electrode, and the filler material is wire or a strip of the alloy being welded or from an alloy which is somewhat less alloyed. Thus, it is recommended that the VT1-1 or OT4-1 alloy be used as the filler material when welding the OT4-1 alloy, that the VT1-1 or OT4-1 alloy be used as filler for welding the OT4 alloy, etc. (see Welding of titanium alloys).

The strength and plasticity of joints made by argon-shielded arc welding are practically the same as those of the base materials (it is

assumed in calculations that the strength of welded joints is equal to 90-95% of the strength of the base material). As the test temperature in testing welded joints is increased the seam weakening coefficient does not change. The shearing strength of a welded spot 5 mm in diameter obtained by resistance welding of sheets 2 mm thick comprises: 1450 kg for the VT1-1 alloy, 1500 kg for the VT1-2 alloy, 1550 kg for the OT4-1, 1650 kg for the OT4, 1750 kg for the VT4, 1800 kg for the VT5-1 and 1800 kg for the OT4-2 alloy. The static endurance of welded joints depends to a large extent on the weld type (Fig. 2).

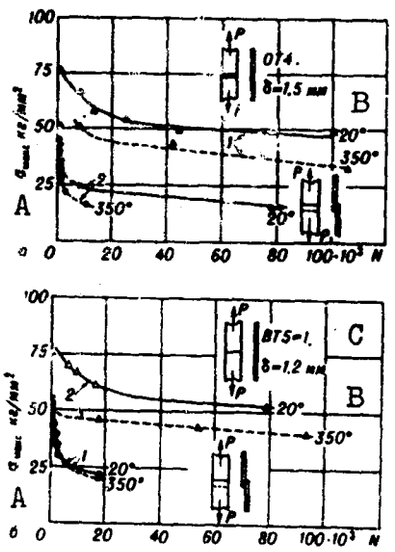

Fig. 2. Static endurance in assymetric tension of welded specimens from the OT4 and VT5-1 alloys ($\sigma_{min}/\sigma_{maks}$ = 0.1). 1) Fusion welding; 2) seam welding. A) σ_{maks}, kg/mm^2; B) mm; C) VT5-1.

To relieve internal stresses which arise on machining, sheet stamping, welding and other kinds of processing, the components are annealed for 30-60 min at the following temperatures: 465° (the VT1-00, VT1-0, VT1-1, VT1-2 alloys), 565° (OT4), 600° (VT6S, VT6), 620° (VT5-1, OT4-2). To remove hardening, semifinished sheet products are annealed at temperatures: 530° (VT1-00, VT1-0, VT1-1, VT1-2), 650° (OT4-1), 670° (OT4), 700° (VT4, OT4-2), 750° (VT5-1) and 800° (VT6S). The annealing

time for sheets up to 1.5 mm thick is limited to 20-25 min, for sheets 1.5-5.0 mm thick it is 30 min for thicker sheets the annealing time is 40-60 min. The annealing temperature for forgings, stampings and bar stock is by 50-100° higher than for sheets. The annealing time depends on the maximum cross section of the semifinished products or components. If the material from which the components or semifinished products are made contains an elevated quantity of hydrogen (above 0.015%), then it is recommended that it be removed by annealing at 700-800° in vacuum not less than 10^{-3} mm of Hg for 1-2 hours. Weldable titanium shaping alloys are distinguished by good thermal stability, i.e., their mechanical properties remain unchanged under service conditions at temperatures up to 550°. Alloys of the given group are used for making products operating for extended periods of time at temperatures up to 350-450° and made by welding as well as stamping, bending and other pressureworking methods. Sheets are used for sheathing of aircraft as well as in chemical machine building for making vessels, filters, coils, autoclaves, heat exchangers, pipelines where high corrosion resistance is needed.

References: see at the end of article Titanium alloys.

S.G. Glazunov, V.N. Moiseyev and Yu.S. Danilov

Manuscript Page No.

[Transliterated Symbols]

4404 ср = sr = sredniy = average

4409 макс = maks = maksimum = maximum

4409 мин = min = minimum = minimum

WELDABLE WROUGHT MAGNESIUM ALLOYS are magnesium alloys which are applicable for the production of weld details and structural components. As a result of the high affinity of magnesium and its alloys for oxygen, and also the great difference of the specific weights of liquid magnesium and its oxide (1.65:3.65), which hinders the removal of the oxides from the seam melt zone, during fusion welding it is necessary to provide effective protection of the weld zone from contact with the oxygen in the air. The wide crystallization range of the majority of the magnesium alloys (Table 1) leads to the formation of crystallization cracks during welding. Only the MA1 alloy (having the narrowest crystallization range) is satisfactorily gas welded, while gas welding of the MA8 alloy is less satisfactory.

TABLE 1

Crystallization Ranges of Some Weldable Wrought Magnesium Alloys

1 Сплав	2 Темп-ра ликвидуса (°С)	3 Темп-ра солидуса (°С)	Интервал кристаллизации (°С)
МА1	650	645	5
МА2	632	565	67
МА3	620	545	75
МА5	602	482	120
5 ВМ65-1	630	400	230

1) Alloy; 2) liquidus temperature; 3) solidus temperature; 4) crystallization range; 5) VM65-1.

Slight additions of cerium (MA8 alloy) and calcium (MA9 alloy) to the MA1 alloy impair its weldability considerably.

Gas welding of the alloys of the Mg – Al – Zn – Mn system in the presence of up to about 5% Al and up to 1% Zn is difficult, and with increase of their content is practically impossible. All the industrially used magnesium alloys with the exception of the VM65-1 alloy can be argon-arc welded. The high zinc content in this alloy causes a wide crystallization range and the formation of cracks during

welding. This method is more satisfactory for the alloys MA1, MA2, MA2-1, MA8 and MA13, which can be used for the fabrication of complex weld details and structural components. The VMD1 alloy welds satisfactorily and can be used for less complex weld details and components. The MA11 alloy has a high tendency to crack formation during welding. Only details of simple form can be welded from the alloys MA9, MA10, MA3, MA5 and VM17. Use of fluxes or inert media to protect the metal from oxidation is not required in resistance spot and seam welding of the magnesium alloys; these forms of welding do not lead to any difficulties in application. The alloys which are easily argon-arc welded are also easily resistance welded (Table 2).

The low relative strength of weldments of the alloys MA1, MA8 and MA13 is explained by the grain growth in the heat affected zone, which is not observed in the alloys MA2 and MA2-1 of the Mg – Al – Zn – Mn system. The high-temperature strength of weldments of the MA13 alloy made using filler of the same alloy is equivalent to the strength of the parent material. When welding with a filler of the magnesium-thorium alloy with zinc and zirconium (Mg + 3.3% Th + 2.7% Zn + 0.7% Zr) the relative strength of the weldments at room temperature is 95-100% of the parent material but is reduced at elevated temperatures. The strength of weld joints of the MA1, MA8 and MA13 alloys can be increased by 20-30% by peening the weld seam.

The relative strength of spot welds of the MA1 and MA8 alloys with machine welding using alternating current is 70-76% – about 50% when welding on a condenser machine and about 30% when welding on an electromagnetic machine (Table 3). This reduction is associated with liquation of the manganese.

TABLE 2

Relative Strength of Weld Joints* (σ_b of weld seam/ σ_b of parent material)

1 Сплав	2 Вид сварки	3 Относит. прочность
МА1	4 Газовая	0,5—0,6
	5 Аргонодуговая	0,55—0,65
МА8	4 Газовая	0,55—0,65
	5 Аргонодуговая	0,60—0,70
МА2, МА2-1	6 То же	0,90—1,0
МА13	"	0,65—0,70

*Filler of same material

1) Alloy; 2) form of welding; 3) relative strength; 4) gas; 5) agron-arc; 6) same.

TABLE 3

Shear Strength of Weld Spots Made on Alternating Current Machines

1 Толщина листов (мм)	2 Диаметр ядра точки (мм)	3 Разрушающая нагрузка на точку при сварке (кг)	
		4 Сплав МА1	4 Сплав МА8
0,8 + 0,8	5,0 ± 0,3	90	100
1,0 + 1,0	5,5 ± 0,5	120	130
1,5 + 1,5	6,0 ± 0,5	150	160
1,5 + 1,5	6,5 ± 0,75	230	250
2,0 + 2,0	7,5 ± 1	300	320
1,5 + 2,0 + 1,0	8 ± 0,5	300	350

1) Sheet thickness (mm); 2) diameter of spot nucleus (mm); 3) failure loan on weld spot (kg); 4) alloy.

The U-strength of weld spots is on the average from 50% (for thin sheet) up to 80% (for thick sheet) of their shear strength. The endurance limit in bending of weld spot joints made from the MA8 alloy is reduced up to 50% from the endurance limit of the parent metal. Just as in the case of argon-arc welding, the low relative strength of these alloys is explained by the formation of a coarse crystalline structure in the thermally affected zone. The strength and the fatigue limit of the spot weld joints can be improved by plastic deformation (peening). The alloys which are not prone to formation of coarse-crystalline structure have higher relative strengths and endurance limits.

References: see article Wrought Magnesium Alloys

A.A. Kazakov

WELDING AND SOLDERING OF BERYLLIUM. The ready oxidizability of beryllium at high temperatures, its low plasticity, and its high heat capacity and melting point make this metal difficult to weld or solder. Its surface should be carefully treated in a solution consisting of 53 g of chromic anhydride, 450 ml of orthophosphoric acid, and 26.5 ml of concentrated sulfuric acid at 60° in order to remove the beryllium oxides. Welding and soldering of beryllium must be carried out in a vacuum or an inert-gas atmosphere in order to avoid oxidation.

Welding can be conducted with a tungsten electrode in a neutral atmosphere, with or without a beryllium welding rod. The principal drawbacks to fusion welding of beryllium are the grain growth and high thermal stresses which arise in the weld zone and cause cracking. Additional heating of the component is necessary to avoid such cracking. In arc welding the best results are obtained by using dc current.

Diffusion welding is more reliable for beryllium, since it produces a seam with a fine-grained structure, but the process is complex and inefficient and requires cumbersome equipment. This type of welding is carried out in a vacuum (less frequently, in an argon atmosphere) at 800-1250°, with the articles to be welded in close contact, usually under an applied pressure of 10-300 kg/cm^2. The lower the temperature, the greater the pressure required. The components are kept under pressure for from 1 to 24 hr. Before welding the surfaces to be joined are polished and degreased with acetone and alcohol.

Diffusion welding of beryllium bars under a pressure of 235 kg/cm^2 at 850° for 2 hr makes it possible to obtain a weld with σ_b = 30 kg/mm^2.

Cracking and grain growth do not occur during electron-beam welding of beryllium, which is conducted in a vacuum of 10^{-4}-14^{-5} mm Hg with a sharply focused electron beam less than 3.2 mm in diameter at a voltage of 20,000-30,000 v, using narrow fusion zones. Use of a higher vacuum leads to considerable evaporation of the beryllium. The strength of an electron-beam-welded seam amounts to 0.7 of that of the base metal.

Satisfactory results are obtained in the resistance welding of beryllium (by the spot, projection, seam, bead, and butt methods), but this technique has not progressed beyond the laboratory stage.

High-temperature soldering (with solid solder) is the most widely employed procedure for joining beryllium to beryllium and other metals, although the resistance of soldered joints to elevated temperatures is unsatisfactory (the beryllium near the seam is highly porous as a result of nonuniform mutual diffusion).

Such solders as Al, an alloy of Al and 12% Si, Ag, and a Cu-Ag (up to 50%) alloy have yielded the best results in soldering beryllium. Use of these solders restricts the porosity near the seam. Wetting of beryllium by aluminum is facilitated by use of an intermediate magnesium layer. In soldering with solid solder, using a consummable or tungsten electrode, the best results are obtained with aluminum-silicon solder. The strength of such joints is equal to that of the sauter.

Furnace soldering yields good results, but is limited by the complexity of the process and the cumbersomeness of the equipment. This type of soldering is carried out in a vacuum of 10^{-5}-10^{-6} mm Hg, using Ag as the solder. Al and eutectic Al-Ag and Al-Cu alloys give somewhat poorer results. Furnace soldering of beryllium with silver solder is conducted at 900-1070° with a holding time of 5-10 min. A higher temperature or longer holding time causes formation of blowholes as a re-

sult of diffusion of the beryllium into the soldering zone. In order to reduce diffusion to a minimum the components must be heated and cooled rapidly. This technique can be used for soldering beryllium to beryllium, nickel, copper, titanium, stainless steel, or monel.

The sheer strength of joints furnace-soldered with silver solder amounts to 19 kg/mm^2 for beryllium-beryllium, 13 kg/mm^2 for beryllium-titanium, and 13 kg/mm^2 for beryllium-stainless steel.

References: Berilliy [Beryllium], edited by D. White and J. Berk, translated from English, Moscow, 1960; J. Metals, 1960, Vol. 12, No. 10; Metalwork. Product., 1961, Vol. 105, No. 1.

I.A. Akopov, S.B. Kostogarov, and K.P. Yatsenko

WELDING OF ALUMINUM ALLOYS. Aluminum and its alloys are joined by various fusion-welding methods (arc, oxyacetylene, etc.) and by resistance welding. The surface of aluminum alloys is always covered with a thin film of the high-melting, dense oxide Al_2O_3 (t°_{pl} = 2050°). This film makes it difficult to strike an arc, prevents fusion of the edges, adsorbs moisture, promotes pore formation, and reduces the hermiticity of the joint. Fusion welding is carried out in an atmosphere of inert gases, the oxide film first being carefully removed from the edges to be joined and from the rod material. Oxyacetylene welding of aluminum alloys is carried out with fluxes, while coated electrodes are used in arc welding. However, joints made with fluxes and coatings containing alkali-metal chlorides have a reduced corrosion resistance.

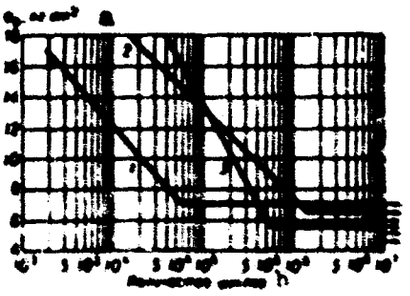

Fig. 1. Bending-fatigue curves for welded joints (with stress relieved) of D20 alloy (sheets 2 mm thick): 1) Without heat treatment; 2) after aging; 3) after quenching and aging. a) σ_b, kg/mm^2; b) number of cycles.

The increased tendency of welded aluminum-alloy seams toward porosity results from the consisiderable difference in the solubility of hydrogen in liquid and solid aluminum. An effective technique for prevention of development of porosity in welds made from magnalium-type

alloys, which are alloyed with >4% Mg, is addition of approximately 0.01-0.005% Be. The high α and λ of aluminum alloys result in a strong tendency toward warping during welding, especially in an oxyacetylene flame.

It is principally heat-treatable and non-heat-treatable alloys that are used in welded assemblages. In order to eliminate defects aluminum-alloy castings are usually welded. Shaping alloys, particularly those which are heat-treatable, tend toward formation of cracks around or in the seam and toward reduced weld strength. The strength coefficient

$$K = \frac{\sigma_{\text{соед.}}}{\sigma_{\text{осн.}}} \cdot 100$$

of heat-treatable alloys (with a thickness δ = 2 mm, welded in the heat-treated state) averages 55% for alloys of the AB type, 60-70% for duralumins and D20 alloy, 80% for VAD1 alloy, and more than 95% for V92 alloy. The strength coefficient of welds made from alloys used in the annealed state (magnalium, AMTs, technical-grade aluminum) amounts to more than 95% (Table 1). Welded aluminum alloys do not retain the strength imparted to them by cold working.

Certain alloys tend toward formation of crystallization cracks when welded (AV, AD31, AD33, and, particularly, D1, D16, V95). Special weldable aluminum shaping alloys or special rod alloys differing in composition from weldable alloys are consequently employed (AMg3 rod alloy is used for welding AMg2 alloy). Figures 1-3 present data on the fatigue strength of D20, AMg6, and V92 alloys and welds made from them. Fusion welding of thin-walled aluminum alloy assemblages (1-6 mm) is commonly carried out by argon-arc welding, which is conducted both with nonfusable (tungsten) electrodes and welding rods and with fusable electrodes, using hose-type or semi-hose-type semiautomatic

welding machines. Submerged-arc welding is also employed for welding assemblages with walls >4 mm thick. Thin-walled assemblages are sometimes produced by oxyacetylene welding, using AF-4A flux and then carefully washing the weld to remove any flux residue.

TABLE 1

Mechanical Characteristics of Base Metal and Welded Joints*

1 Марка материала	2 $\sigma_в$ при 20° (кг/мм²)			6 Угол загиба (градус)	7 Присадочный материал
	осн. материал 3	сварное соединение 4	сварное соединение после термич. обработки 5		
8 АМц М**	11—14,5 / 12,1	11,7—12,2 / 12,1	—	—	АМц 19
9 АМц П**	14,5—20 / 19	11,8—12,1 / 12	—	—	20 "
10 АМг2 М	19,5—20,5 / 20	19,5—19,5 / 19,5	—	—	АМг3
11 АМг3 М	23,5	22—23 / 22,5	—	—	21 "
12 АМг6 М	35—38 / 36,8	37,5—37,5 / 37,5	—	—	АМг-6
13 АМг6 П	43—44 / 43,3	37—38,5 / 37,5	—	—	22 "
14 Д20-Т1	44—46,4 / 45,2	27,5—32 / 27,8	28—30 / 28,6	43—47 / 30	Д 20
15 ВАД1Т закалка + + естеств. старение	44,9—47,3 / 45,9	30,6—39,9 / 36,4	43,2—46,8 / 45	60—81 / 69 18 (закалка + старение)	23 ВАД1
16 В92 АТ (закалка + + естеств. старение — 30 суток)	39—39 / 39	36,5—39 / 37,3 (430 суток естеств. старения) 17	—	87—114 / 97	24 В92

*АМТсМ is 1.5 mm thick, while all other materials are 2 mm thick.
**Manual argon-arc welding for AMTs alloy and automatic tungsten-electrode welding for all other alloys.

1) Type of material; 2) $\sigma_в$ at 20° (kg/mm^2); 3) base material; 4) weld; 5) weld after heat-treatment; 6) bending angle (degrees); 7) rod material; 8) AMTs M; 9) AMTs P; 10) AMg2 M; 11) AMg3 M; 12) AMg6 M; 13) AMg6 P; 14) D20-T1; 15) VAD1T, quenched and naturally aged; 16) V92 AT (quenched and naturally aged for 30 days); 17) naturally aged for 30 days; 18) quenched and aged; 19) AMTs; 20) AMg3; 21) AMg6; 22) D20; 23) VAD1; 24) V92.

The most sensible type of joint for aluminum alloys (in fusion welding) is a butt joint, which ensures a high strength coefficient. A manual welding speed of approximately 1 m/hr or an automatic speed of 4-40 m/hr is employed (depending on the thickness of the material).

Pure argon (type B, 99.95% Ar), helium, and mixtures of the two

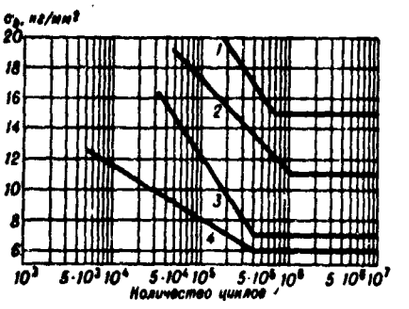

Fig. 2. Fatigue curves for AMg6 alloy on repeated static extension of welds and base metal (sheets 2 mm thick): 1) Base metal; 2) weld with stress relieved; 3) stressed weld. a) σ_b, kg/mm^2; b) number of cycles.

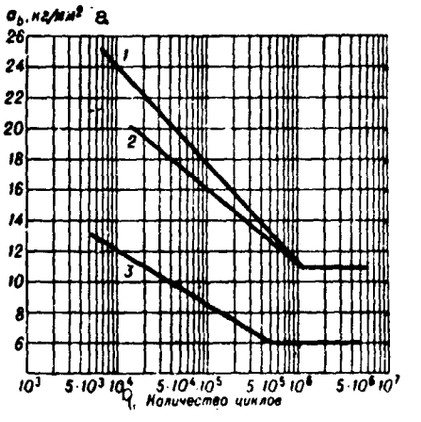

Fig. 3. Fatigue curves for AMg6 and V92 (after natural aging for 30 days) on repeated static extension of base metal and welds: 1) V92 (base metal); 2) AMg6 (base metal); 3) V92 (weld); 4) AMg6 (weld). a) σ_b, kg/mm^2; b) number of cycles.

are used as inert gases. Welding aluminum in a mixture of 60% He and 40% Ar makes it possible to obtain tigher joints than welding in argon.

Resistance welding of aluminum alloys entails more serious technological and design difficulties than resistance welding of other materials (steel, titanium, high-melting metals), requiring large, complex, high-power equipment, good surface preparation, careful assembly, and precision welding regimes. These difficulties increase with the thickness and rigidity of the joint. The weldability of aluminum

is governed by their deformation capacity, the effectiveness with which they utilize energy, and their reaction to the thermomechanical cycle. Alloys with a $\sigma_{0.2} < 20$ kg/mm^2 (20°) or 6 kg/mm^2 (300°) are readily welded; alloys with a $\sigma_{0.2}$ = 20-50 kg/mm^2 (20°) or 6-12 kg/mm^2 (300°) can be welded satisfactorily; alloys with a $\sigma_2 > 50$ kg/mm^2 (20°) or >12 kg/mm^2 (300°) are difficult to weld in rigid closed structures when they are more than 2 mm thick. At 20° alloys with $\rho < 4$ μohm·cm and $\lambda >$ 0.4 cal/cm·sec·°C tend toward nonfusion; those with ρ = 4-8 μohm·cm and λ = 0.25-0.4 cal/cm·sec·°C can be welded satisfactorily; those with $\rho > 8$ μohm·cm and $\lambda < 0.25$ cal/cm·sec·°C are readily welded. A combination of high structural strength and weld rigidity with thermal and electrical conductivity reduces the weldability of the metal. Aluminum-alloy components which differ in thickness by a factor of more than 3 or whose properties (at 20°) differ by a factor of more than 2 for $\sigma_{0.2}$, 1.5 for ρ, or 1.2 for λ cannot be welded to one another or Ti, Fe, Cu, Mg, Ni, or their alloys. Aluminum alloys with a reserve strength and plasticity of from 0.3 to 0.5 can be lap-welded satisfactorily, while those for which this index is greater than 0.5 weld well.

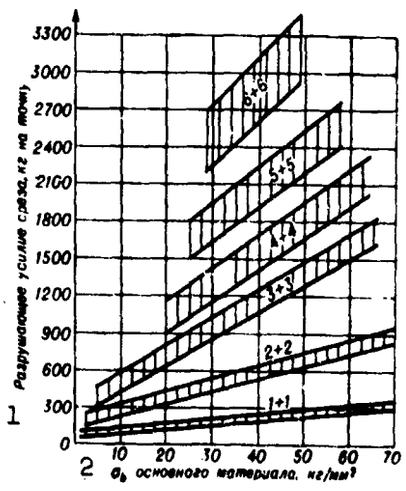

Fig. 4. Sheer stress required to fracture spot welds as a function of σ_b of base material and sheet thickness. 1) Sheer stress required for fraction, kg per spot-weld; 2) σ_b of base material, kg/mm2.

The characteristics of welded joints and the stability of their properties depend principally on the type of equipment used and the thermomechanical welding parameters. Aluminum alloys are welded with soft-percussive (MGPT, MShShT) and hard-percussive (MTK-75, SAUK-900) welders. Hard-percussive welding ensures higher weld characteristics, but is often technologically inefficient.

The welding current is adjusted on the basis of technical specimens and the macrostructure of the spot-welds, being the last parameter determined.

Plated and unplated sheets up to 2 mm thick are protected against slit corrosion (under lap welds) with ALG-1 and ALG-2 raw primers. A raw primer also stabilizes plastic deformation resulting from cold contact by reducing the coefficient of friction, thus increasing the reliability and quality of the weld. Welding along nonmetallic layers (primers, cements, sealers) is carried out under the usual regimes. When spot-welding rigid closed assemblies of high-strength (quenched and aged or cold-worked) aluminum alloys it is necessary to subje the conctact surface to preliminary heating to 150-200°. High-hot-strength alloys are heated during crystallization and compaction (forging) of the nugget metal. Components with large differences in thickness or properties are spot and seam welded with the aid of heat shields. Cermet (SAP) and similar aluminum alloys are welded through a thin layer of aluminum.

The characteristics of spot welds include: fusion depth $z = (0.2-0.6)\delta$ (δ – thickness), nugget diameter $d_t = 2\delta + 2\sqrt{\delta}$, spot spacing $c = (3-4)d_t$, lap width of double joint = $(4.5-5.5\ d_t)$, distance between rows of spots = $(2-2.5)\ d_t$, and distance to edge of sheet = $(0.8-1)\ d_t$. Figure 4 shows the sheer stress required to fracture spot welds in sheaths with thicknesses (δ) of from 1 + 1 mm to 6 + 6 mm when lap-

welded. The plasticity coefficient, $k_t = S_{otr}/S_{sr}$, amounts to 0.5-0.65 for AMts, AMg, AMg3, AMg5V, AMg6M, AD31, and AD33 alloys, 0.3-0.5 for the heat-treated alloys D1, D16, D19, D20, M40, and V92, 0.2-0.3 for the heat-treated or cold-worked alloys D16, V95, V96, and VAD23, and 0.15-0.20 for SAP. The reserve static tensile strength of 1 running meter of a double lapped spot-weld amounts to more than 0.6 with respect to the strength of a sheet of D16AT up to 3 mm thick (less than 0.45 for an analogous rivited joint). Cemented joints with $\tau_{kl} = 100$ kg/cm^2 have a reserve static strength of approximately 1 and provide reliable hermeticity; anodizing and application of protective lacquers or paints is permissible.

The ability of welded and cemented joints to withstand repeated static overloads (up to 0.7 of the fracture load) is 10-15% of that of rivited joints of the same type, since the latter are more rigid and exhibit better stress concentration. The characteristics of tight, strong joints include: width of fusion zone $d_{sh} = (3.5-4.5)\delta$, spot overlap = $(0.3-0.5)d_{sh}$, width of overlap for 1 seam = $(2-2.5)d_{sh}$, layering from edge of overlap = $(0.5-0.75)\ d_{sh}$, and distance between seams = $(2-4)\ d_{sh}$.

Table 2 shows the fracture stress, softening, and decrease in plasticity and coefficient of static reserve strength (K_r) for welds. The σ_b of single-seam lap welds is markedly lower than that of the base metal (Table 2). The decrease in the σ_b of a weld becomes greater as the thickness and σ_b of the base metal increase. Thermal (aging or quenching and aging) and mechanical (cold working) treatment after welding raises σ_b. Use of double seam or combined spot-seam welds or of butt welds with two thin overlaps is recommended to increase reserve strength.

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TABLE 2

Mechanical Characteristics of Tight, Strong Welds in Aluminum Alloys

Сплав 1	Лист толщиной 1 мм 2					Лист толщиной 3 мм 8				
	основного металла 3	внахлестку с накладкой 4	встык с накладкой 5	разупрочнение 6	$\alpha_p = \sigma_b/\sigma_{b_0}$ (%)	основного металла	внахлестку с накладкой	встык с накладкой	разупрочнение	$\alpha_p = \sigma_b/\sigma_{b_0}$ (%)
	σ_{b_0} 7 (кг/мм²)			$\sigma_{b_0} - \sigma_b$ 7		σ_{b_0} (кг/мм²)			$\sigma_{b_0} - \sigma_b$	
9 АМцМ	13	14	13	—	100	12.5	12	12	—	100
10 АМгМ	19	19	19	—	100	19.5	19	20	—	100
11 АМг3М	23	23	22	—	100	23.6	22	24	—	100
12 АМг5В	29	29	29	—	100	29.0	24	29	—	83
13 АМг6М	35	33	34	—	95	35.4	25	33	3	72
АМг6Н 14	40	31	33	8	77	44.2	18	37	7	42
АД33 15	29	23	25	4	80	—	—	—	—	—
Д16АТ 16	46	27	32	15	58	44.4	20	37	7	45
Д20АТ 17	40	26	31	10	65	40.0	16	28	12	42
М40 18	34	27	28	6	80	34.5	14	30	4	40
В95АТ 19	54	25	33	22	52	50.9	18	38	12	37
В96АТ 20	66	20	35	31	30	64.5	12	40	24	21

1) Alloy; 2) sheet 1 mm thick; 3) base metal, σ_b; 4) overlap with 1 seam, $\sigma_{b'}$; 5) faced sheet, $\sigma_{b''}$; 6) softening, $\sigma_b - \sigma_{b''}$; 7) kg/mm^2; 8) sheet 3 mm thick; 9) AMTsM; 10) AMgM; 11) AMg3M; 12) AMg5V; 13) AMg6M; 14) AMg6N; 15) AD33; 16) D16AT; 17) D20AT; 18) M40; 19) V95AT; 20) V96AT.

The ability of tight, strong joints to withstand bending is 20-30% lower than that of the base metal in sheets with welded facings and 30-40% less than that of lap welds. Welded joints in alloys with a high durability are no better than those in alloys with low and moderate durabilities. The strength of strong, tight welds at 200-300° approximates that of the base material at equivalent temperatures. The hermeticity of such joints is equal to that of the base metal at room temperature and at 200-300°, both in a vacuum (10^{-5}) and at overpressures under static and cyclic loads.

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V.R. Verchenko and A.I. Pugachev

WELDING OF CAST IRON – a process conducted in order to correct defects in iron castings. We can distinguish hot, semihot, and cold welding methods. In the hot method the casting to be welded is heated to 700-750° and held at this temperature throughout the entire operation. In the semihot method the casting is subjected to general or local heating to 300-400°. In the cold method the defect is corrected without heating.

The hot method of welding cast iron utilizes arc and gas welding with cast-iron electrodes and rods for welding-up with molten metal (foundry welding). The semihot method employs arc welding with steel for cast-iron electrodes, while the cold method utilizes arc welding with steel, iron-clad copper, ferrocopper, or ferronickel electrodes or bundles of copper and steel electrodes, gas welding, soldering with cast-iron rods or solder, or molten-slag welding with cast-iron rods or plates. Any defect in castings, including those intended for critical applications, can be welded up with cast iron. The hot method makes it possible to obtain a seam equal in strength to the base metal in all types of welding with cast iron. Semihot arc welding with steel electrodes produces a seam whose properties are similar to those of the base metal, although it is not uniform in hardness over its cross section. Use of electrodes containing copper and nickel in cold arc welding of cast iron prevents chilling of the weld metal, since copper and nickel promote segregation of free graphite.

None of the varieties of soldering produce fusion zones in the joint. Soldering is employed for closing shallow defects, for joining

fractured castings (low-temperature gas welding, or soldering with cast-iron rods), and for eliminating all defects in castings whose strength is not affected by such correction (using solders).

Hot gas welding, hot arc welding, and low-temperature welding or soldering are employed for gray iron. Joints produced by these methods are equal in strength to the base metal. Cast iron containing spheroidal graphite is subjected to gas welding with electrodes of the same material followed by heat treatment or to arc welding with monel electrodes or ferronickel electrodes, heating the casting to 300-350° and then slowly cooling it, a procedure necessary to prevent cracking (steel electrodes should not be used to weld cast iron containing spheroidal graphite). Cast iron containing spheroidal graphite can be joined to unalloyed steel by arc welding with monel electrodes. Austenitic cast iron containing spheroidal graphite is arc-welded with nickel or ferronickel electrodes, heating the component to 300° and then slowly cooling or tempering it at 650° after welding. Stainless-steel electrodes are used when it is necessary to produce a nonmagnetic weld; electrodes of the same material as the components to be welded are employed in gas welding.

White-iron castings intended to be annealed to forging pig are arc- or gas-welded with rods of the same material, followed by annealing at 850° and furnace cooling (welding of white iron is limited, since graphitization is possible). Forging pig can be welded with or without subsequent repeated annealing; when subjected to repeated annealing it is arc-welded with electrodes of white iron or forging pig. Gas welding with brass rods or arc welding with monel electrodes is employed when the casting is not subjected to repeated post-welding annealing.

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A.A. Simkin

WELDING OF HIGH-MELTING METALS (tungsten, niobium, molybdenum, tantalum, and chromium). The high activity of high-melting metals with respect to nitrogen, oxygen, and hydrogen means that they must be reliably protected from contact with the atmosphere during welding. Joint formation is satisfactory in fusion welding (argon-arc or electron-beam welding), but heating these metals in the deformed state causes recrystallization and grain growth in and around the weld, which somewhat reduces the plasticity of niobium and tantalum joints and causes brittleness in molybdenum and tungsten joints.

Argon-arc fusion welding can be conducted in a stream of protective gases or in a chamber containing a protective-gas atmosphere. Pure argon, high-purity helium, or supplementally purified technical-grade hydrogen is used as the protective gas. There have been reports on the use of carbon tetrafluoride as a protective gas in the arc welding of Ta and Nb. In welding in a gas stream the heated metal on the outside of the seam is protected by fitting an additional hood (corresponding to the configuration of the component) on the welding-torch nozzle; this hood usually has an independent protective-gas supply system. The reverse side of the weld is protected by supplying gas to a channel in the support backing. Some gas saturation of the heated portions of the metal is inevitable when the gas-stream method is employed; it is consequently used in welding Ta and Nb, which are less sensitive to atmospheric gases, as well as in cases where severe requirements are not imposed on the mechanical properties of the welded joints. Fuller protection is afforded by welding in an inert-gas-filled chamber

after evacuation to $5 \cdot 10^{-4}$ mm Hg or less or by welding in soft-walled chambers from which the air has been expressed. Welding is carried out with direct current, using the tungsten electrode as the negative pole. Use of high welding speeds promotes an increase in weld plasticity. Vacuum electron-beam welding is the most advanced technique.

Absorption of gases by the weld is almost completely eliminated in electron-beam welding. This method permits production of joints with narrow fusion and thermal-influenced zones, which increase their mechanical characteristics. Welding is conducted under a vacuum of $3 \cdot 10^{-4}$ mm Hg or less, in special equipment fitted with appropriate attachments.

Before welding the edges to be joined and adjacent areas should be freed of oxides and other contaminants (by pickling or mechanical cleaning) and degreased. The Table shows certain of the mechanical characteristics of welds in high-melting alloys.

Argon-arc welding of unannealed deformed VN-2 niobium alloy produces seams with a low, unstable plasticity, which is substantially increased by vacuum annealing of the joints (1350° for 2 hr). Argon-arc welding of unalloyed niobium and annealed VN-2 alloy yields more plastic seams (using a welding speed of 70 m/hr or more for VN-2). Electron-beam welding (at speeds of more than 60 m/hr) of unannealed and annealed VN-2 alloy permits production of welds that can withstand 180° bending and subsequent straightening. Seam formation is satisfactory when niobium alloys are welded to tantalum, titanium, copper, and zirconium alloys, but welding niobium alloys to nickel alloys results in crack formation and production of very brittle seams.

Argon-arc welding of molybdenum alloys in a protective-gas stream yields seams which cannot withstand bending at room temperature but exhibit increased plasticity when heated. Welds made in argon in a pre-

Characteristics of welds in High-Melting Metals

1 Сплав	2 Вид сварки	3 σ_b (кг/мм²)	4 Угол загиба (град)
5 Ниобиевый (ВН-2)	Аргоно-дуговая 11	52—56 (20°)	90—120 (20°)*
6 То же	То же	22 (1100°)	20—60 (20°)*
» »	» »	5—5,5 (1500°)	—
» »	Электронолучевая 12	—	180 (20°)
7 Технич. ниобий	Аргоно-дуговая	39—41 (20°)	120—180 (20°)
То же	То же	15—16 (1100°)	—
8 Ниобиевый (ВН-2)	Контактная стыковая и роликовая 13	45—52 (20°)	—
9 Молибденовый (ВМ-1)	Аргоно-дуговая	34—43 (20°)	0 (20°)
То же	То же	То же	90 (150°)
» »	Электронолучевая	33—34 (1200°)	20—60 (20°)
» »	То же	22 (1500°)	45—90 (80°)
» »	» »	14,5 (1800°)	165—180 (100°)
» »	» »	То же	180 (150°)
10 Техничт. тантал	Аргоно-дуговая	52—63 (20°)	75—145 (20°)
То же	То же	9 (1500°)	—

*Sheets 1 mm thick.
**The radius of the bending angle equals the sheet thickness.
***With annealing.
****Without annealing.

1) Alloy; 2) type of welding; 3) σ_b (kg/mm^2); 4) bending angle (degrees); 5) niobium (VN-2); 6) the same; 7) technical-grade niobium; 8) niobium (VN-2); 9) molybdenum (VM-1); 10) technical-grade tantalum; 11) argon-arc; 12) electron-beam; 13) butt and seam resistance welding.

liminarily evacuated chamber can withstand 10-20° bending at 20°. The bending angle of electron-beam-welded joints (1 mm thick) reaches 20-60° at room temperature and 180° at 200°. It is possible to weld molybdenum to niobium alloys or tungsten, but such joints are very brittle. Joints of the soldered type are formed when molybdenum alloys are welded to nickel alloys (the molybdenum alloy remains unfused).

In argon-arc welding of tantalum and its alloys the strength and plasticity of the weld are somewhat less than those of the base metal. Tantalum is readily welded to copper, titanium, niobium, and zirconium; welding to molybdenum and tungsten is possible.

Fusion welding of tungsten can be conducted in a neutral-gas protective atmosphere or with an electron beam under vacuum conditions, although cracking frequently occurs. In order to prevent cracking welding should be carried out with the components loosely clamped and heated (to 500° or more). Such joints are very brittle at room temperature,

but exhibit substantially increased plasticity when heated to temperatures above 700°. It is possible to weld tungsten to molybdenum, niobium, and tantalum.

Fusion welding of chromium can be conducted in an argon protective atmosphere, but the joints obtained are very brittle.

Butt resistance welding of high-melting metals can be carried out in atmospheres of argon, helium, hydrogen, and air. Carbon tetrachloride, water, and a mixture of powdered zirconium oxide, molybdenum, and graphite are used for protection from atmospheric gases in the resistance welding of Mo and W alloys. Vacuum-welded joints have the highest plasticity. The strength of butt welds in Nb and Mo is close to that of the base metal.

In spot and seam welding the high melting temperature of the alloys causes the electrodes to stick to the components, while the high thermal and electrical conductivity of the Mo and W make it necessary to use high-power welding equipment.

Facings of molybdenum or tungsten foil 0.05–0.2 mm thick are placed between the electrodes and the components to prevent sticking. The facings are removed after welding; if they stick to the electrodes they are used for welding the next spot. Sticking can also be prevented by coating the surface of the component with graphite at the contact points of the electrodes. The surfaces to be joined are roughened to concentrate the heat and reduce the welder power required; tantalum or niobium foil is placed between the contact surfaces for this purpose. Before welding the components are cleaned of oxides and other contaminants by general or local (at the lap sites) pickling. Projection welding along preliminarily made flanges is also employed for joining high-melting metals.

D.S. Balkovets

WELDING OF MAGNESIUM ALLOYS. The high activity of magnesium with respect to O_2 (ignition is possible when the metal is heated to near its melting point) makes it necessary to protect the heated area with inert gases during welding, especially when the metal is molten. The principal techniques used for magnesium alloys are fusion welding (chiefly tungsten-electrode arc welding in argon or fusable-electrode welding, less frequently oxyacetylene welding) and various types of resistance welding.

Tungsten-electrode welding is carried out with ac current, while inverted dc current is used for fusable-electrode welding. Helium is employed in addition to argon for ac welding; dc welding is best conducted in a helium atmosphere, in view of its greater ionization capacity. Butt welds are usually used, but lap and T joints are permissible (when the walls of the components are more than 1 mm thick). Fusion welding is conducted with the same equipment as for aluminum alloys (see Welding of aluminum alloys).

Mixtures of alkali-metal chlorides and fluorides are used as fluxes for gas welding of magnesium alloys, being applied to the welding rod. The flux residue is removed after welding by rinsing the components in hot water or, more reliably, by boiling them for 1-2 hr in 5% potassium bichromate, which neutralizes the flux. Pure fluoride fluxes are less corrosive, but more difficult to remove from the surface of the weld. Before welding the marking paint, protective grease, and oxide film are removed from the edges to be joined. The oxide film is removed mechanically 3 hr before welding or by pickling no

more than 5 days before welding. Degreasing is carried out in organic solvents (RD, acetone, gasoline, carbon tetrachloride) or in alkali baths (with a composition of 300-600 g/liter NaOH, 150-200 g/liter $NaNO_2$, 40-70 g/liter $NaNO_3$, and the remainder water) at 70-100°, followed by rinsing in water. The oxide film is removed by pickling in aqueous CrO_3 (150-200 g/liter) at 20° for 7-15 min, followed by rinsing in water and drying at 50-60°. The finished welds are subjected to oxidation.

Magnesium's high thermal coefficient of linear expansion causes it to have a strong tendency to warp during welding.

Most magnesium alloys used in welded assemblages are in the deformed state. Cast magnesium-blanks are only welded to correct casting defects. The majority of magnesium alloys alloyed with Al, Zn, Ce, and Ca have a tendency toward crystallization cracking as a result of their broad crystallization range, while alloys containing Al and Zn also tend to develop pores in the weld and the area around it. Alloys containing Mn (MA1, ML2), which have a narrow crystallization range, do not tend to crack during welding; however, considerable grain growth may occur in the area around the weld and it is consequently necessary to avoid material overheating during welding and to employ intermediate cooling in multilayer welding or when welds are made close together. In order to avoid overheating, oxidation, and cracking magnesium alloys must be welded at as high a speed as possible and with a minimum arc length (1-2 mm) in manual and automatic rod welding.

The strength coefficient, ($K = \sigma_{bsvarn}/\sigma_{bosn}$) of joints made in MA1 alloy by manual argon-arc welding amounts to 55-65%; for joints made in MA8 alloy by automatic argon-arc tungsten-electrode welding with MA8 wire (with stresses unrelieved) K = 60-70%, i.e., the area around the weld is considerably weakened in gas welding.

Magnesium-alloy castings are welded with a rod of the same composition as the base metal; in order to avoid development of porosity and cracking all defects are first removed, completely eliminating the surrounding unsound areas and the casting skin. Small castings with complex shapes must be preliminarily heated to 250-350° and heat-treated (by homogenization or, for certain alloys, quenching) after welding. Large castings with simple shapes are welded with local heating to 250-270° and no subsequent heat treatment.

Spot and seam welding of magnesium alloys is carried out with the same machines as for aluminum alloys. Before resistance welding the surface of the components is degreased and then freed of oxides and films mechanically or chemically, e.g., in baths containing an aqueous solution of CrO_2 (200 g/liter) and Ca $(NO)_3$ (30 g/liter) at 20-30° for 10-15 min. Particles of metal and oxides remain on the surface after mechanical cleaning, contaminating the contact surface of the electrodes and thus reducing weld quality. Transfer of copper particles from the electrodes to the surface to be welded reduces the corrosion resistance of the joint; the seam surface must consequently be cleaned with special care in resistance welding. Joints made in magnesium alloys by spot welding are cleaned and coated with ALG-1 or ALG-12 primer.

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V.R. Verchenko

WELDING OF NICKEL ALLOYS. The principal techniques for welding nickel and its alloys are tungsten- and fusable-electrode arc welding in argon or a mixture of argon and 3-5% hydrogen, submerged-arc and molten-slag welding, manual arc welding using electrodes with high-quality coatings, and spot, seam, and butt resistance welding. The first two methods provide the highest mechanical and anticorrosion characteristics.

TABLE 1

Mechanical Characteristics of Welds made in Technical-Grade Nickel with Different Types of Electrodes (at 20°)

1 Электроды	2 σ_b (кг/мм²)	3 Угол загиба (град)	δ (%)	$a_н$ (кгм/см²)
Н10	30—35	120—180	35—40	15—18
Н37	35—40	90—120	30—35	16—20
Н37К	41—46	90—120	25—32	17—19
Н30К	46—49	120—180	31—45	22—26
Прогресс-50	50—52	180	40—45	25—30

1) Electrode; 2) kg/mm^2; 3) bending angle (degrees); 4) N10; 5) N37; 6) N37K; 7) N30K; 8) Progress-50.

The weldability of nickel is governed by its freedom from detrimental impurities (C, O, H, S, P, Pb, and B). The difficulties involved in welding technical-grade nickel are associated with the development of pores and hot cracks in the weld and the increased tendency of the latter to corrode.

Pores may be produced in welded nickel joints by hydrogen, which undergoes a sharp change in solubility during crystalliztion of the fused metal, and by carbon monoxide, which is formed in the molten

during reduction of NiO by carbon and by reaction of the carbon with dissolved oxygen. In argon-arc welding addition of 3-5% hydrogen to the argon aids in preventing pores, increasing the time for which the fused metal remains molten by raising the arc voltage and, through its reducing properties, lowering the probability that carbon monoxide will be produced. However, when the arc atmosphere contains higher hydrogen concentrations, which usually occurs in manual arc welding, as a result of dissociation of the paired hydrogen atoms in the electrode coating, this gas becomes a serious pore source. Electrode coatings based on TiO_2-CaF_2-NaF (Progress-50) are used to fix the hydrogen and remove it from the arc atmosphere in the form of HF. The coatings of these electrodes also contain SiO_2, Na_2O, and powdered Mn, Ti, and Al. Progress-50 electrodes ensure higher plasticity, density, and long-term strength than electrodes with coatings based on CaF_2-$CaCO_3$ slag, such as N10, N37, N30K, and N37K (Table 1).

These coatings also contain SiO_2, FeMn, FeSi, Mn, Al, and a Ni-Mg ligature. Wire of technical-grade nickel of the same type as the base metal or of NMts25 or NMts5 alloy is used as the electrode core.

Molten modified oxygen-free halide fluxes based on CaF_2 or CaF_2-$BaCl_2$ with NaF and SrF_2 added (ANF-5, IMET-9, IMET-29, and IMET-33) are used for submerged-arc welding of nickel and its alloys. Ceramic fluxes based on CaO-$5CaO \cdot 3Al_2O_3$-CaF_2 containing strong reducing agents (ZhN) can be used for welding technical-grade nickel.

Hot cracks in welds in nickel and its monophasic alloys usually develop along the polygonization boundaries, which are dislocational in origin and are formed at temperatures below the solidus after crystallization. These boundaries are a conglomeration of defects in the crystal lattice and foreign atoms and consequently have very low plasticity and strength at high temperatures. However, hot cracking may

occur during crystallization at contents of as little as 0.001 to 0.01% of Pb, B, S, P, and other low-solubility detrimental impurities, resulting from the concentration of low-melting eutectic constituents along the boundaries of the primary crystallities in the weld metal and along the grain boundaries of the base metal in the area of partial fusion around the weld. Rod materials spectrally free from Pb and B and with limited contents of S, P, and a number of other impurities are consequently employed in order to avoid crystallization in the welding of nickel and most of its alloys. In order to avoid polygonization-induced hot cracking in the welding of monophasic alloys the weld metal is alloyed with high-melting elements (Mo, W, and Ta), which, when present in concentrations of more than 10-15%, prevent polygonization by sharply increasing the activation energy of diffusion in the solid solution. At the same time, restrictions are imposed on the Al (up to 2-3%), Ti (up to 3-5%), and Si (up to 0.3-0.4%) contents, since these elements promote polygonization of the fused metal. It is also necessary to try to maintain an (Al): (Ti, Mo): (W, Ta) ratio in the weld metal such that polygonization does not occur during post welding cooling or during subsequent aging, to completion of the dispersion-hardening phase.

For these reasons alloys of nickel and 20-30% Mo or W of the hasteloy type (EI460, EI461, etc.) can be joined without difficulty by any arc-welding method. The electrode wire is chosen in such fashion that it has the same composition as the base metal or a somewhat higher Mo or W content; for example, wire of EI461 alloy (30% Mo) is used for welding EI460 alloy (20% Mo). Manual arc welding is conducted with electrodes of these wires with ENKhM-101 and ENKhD-10 coatings, which are based on $CaCO_3$-CaF_2 slag with FeSi, FeTi, kaolin, etc. added.

Arc welding of nickel alloys containing 30% Cu (monel type) or

TABLE 2

Mechanical Characteristics of Welds in Certain High-Hot-Strength Nickel-Chromium Alloys

1 Сплав	2 Толщина (мм)	3 Проволока	4 Способ сварки	5 Электродное покрытие	6 Флюс	7 $V_{кр}$, (мм/мин)	8 Термообработка после сварки	9 Механические свойства при 20°С: $\sigma_{0,2}$ (кг/мм²)	$\sigma_в$ (кг/мм²)	δ_5 (%)	ψ (%)	13 Жаропрочность: температура (°С)	напряжение (кг/мм²)	время до разрушения (час)
ЭИ435	60	ЭИ435	ЭШС	–	АНФ-1	–	–	2н	21–25	58–64	60–68	21–52	700	14	100
16 •	•	•	25 •	–	35 •	–	40 1000°, охлаждение на воздухе	7нв	18–24	74–78	24–32	39–66	–	–	–
								2н	25–27	65–68	34–37	39–46	–	–	–
ЭИ435	10	ЭИ435	РДС	ЭНМЕТ-4М	–	3,5–4,5	–	20	–	63–67	19–25	–	600	14	96
•	•	•	26 •	29 ЭНМЕТ-4П	–	5,0–6,0	–	20	49–51	58–63	2–5	4–9	600	24	19
				30									800	34	6,8
													800	35	0,16
													800	37	0,1
17 ЭИ437	12	ЭИ437	27 ДСФ	–	АНФ-5	2,4–3,2	41 закалка + старение	2н	65–74	78–81	5–8	8–13	700	44	23–30
•	•	•	•	–	36			550	64–65	88–91	14–24	18–25	750	24	20
•	•	•	•	–	ЭНМЕТФ-7	3,2–3,5	•	7нв	56–59	73–78	12–13	27–28	750	14	33–61
•	•	23 ЭП216	•	– 37	ЭНМЕТФ-33	4,0–4,3	•	2н	66–68	78–82	5–8	8–14	750	20	102
•	•	•	•	–	ЭНМЕТФ-7	5,0–5,4	•	20	67–74	79–83	6–7	9–15	750	24	150
								20	79–81	95–102	4–5	8–13	–	–	–
ЭИ437	10	ЭИ437	РДС	31 ЭНМЕТ-7	–	0,5–1,0	–	2н	–	81–83	14–19	18–23	650	24	0
														32	2,6
														25	7,4
														27	11
18 ЭИ602	3	ЭИ435	АДС–W	–	–	–	–	2н	–	91–96	–	–	–	–	–
			28					7нв	–	67–69	–	–	–	–	–
								9нв	–	16–18	–	–	–	–	–
ЭИ602	3	ЭИ435	РДС	32 НЖ-4	–	–	–	2н	–	78–83	–	–	–	–	–
								7нв	–	37–44	–	–	–	–	–
								9нв	–	15–18	–	–	–	–	–
19 ЭИ652	3	ЭИ652	АДС–W	–	–	–	–	2н	–	94	–	–	–	–	–
								9нв	–	16	–	–	800	3	34–46
20 ЭИ437Б	100	ЭИ437Б	ЭШС	–	38 АНФ-5	–	закалка + старение	2н	59	76	18	14	700	64	2н–2б
								7нв	81	87	18	25	750	44	5н
21 ЭИ868	16	ЭИ868	ДСФ	–	ЭНМЕТФ-29	4,0–5,0	–	2н	–	84–86	14–18	24–27	750	24	50–84
ЭИ868	3	ЭИ868	АДС–W	–	39 –	–	–	2н	–	83–92	–	–	–	–	–
								9нв	–	19	–	–	–	–	–
								1000	–	11	–	–	–	–	–
								1200	–	6,5	–	–	–	–	–
ЭИ868	10	ЭИ868	РДС	33 ЭНМЕТ-9	–	3,5–4,5	–	2н	–	87–89	13–15	18–21	650	24	1,4
•	3	•	•	ЕИ-4	–	–	–	2н	–	91–94	–	–	–	–	–
				34				1200	–	6,5	–	–	–	–	–
ЭИ719	12	24 ЭП199	АДС–W	–	–	–	закалка + старение	6нв	–	72–76	–	–	900	22	>100

*EShS – molten-slag welding, DSF – submerged-arc welding, ADS-W – argon-arc tungsten-electrode welding, RDS – manual arc welding.

**V_{kr} – the critical rate of linear deformation of the weld metal during crystallization and subsequent cooling, at which hot cracking occurs (an index of weld-metal resistance to hot cracking, determined by the IMET method).

1) Alloy; 2) thickness (mm); 3) wire; 4) welding method; 5) electrode coating; 6) flux; 7) V_{kr} (mm/min); 8) heat treatment after welding; 9) mechanical characteristics; 10) temperature (°C); 11) $\sigma_{0,2}$ (kg/mm²); 12) σ_b (kg/mm²); 13) hot strength; 14) stress (kg/mm²); 15) time to fracture (hr); 16) EI435; 17) EI437; 18) EI602; 19) EI652; 20) EI437B; 21) EIo68; 22) EZhL8; 23) EP216; 24) EP199; 25) EShS; 26) RDS; 27) DSF; 28) ADS-W; 29) IMET-4M; 30) IMET-4P; 31) IMET-7; 32) NZh-4; 33) IMET-9; 34) YeZh-4; 35) ANF-1; 36) IMETF-7; 37) IMETF-33; 38) ANF-5; 39) IMETF-29; 40) 1000°, cooling in air; 41) quenching and aging.

20% Cr (nichrome type, EI435) also presents no special difficulties

and is carried out with a rod metal of the same composition.

Deformed high-hot-strength nickel-chromium alloys containing Al

(EI652, EI559) or Al and Ti (EI437) have a tendency toward hot cracking when welded. Alloys also containing Mo (EI602), W (VZh85, EI868), or Mo and W (EI894) weld somewhat better. When these alloys are welded by any method, using an electrode or rod wire of the same composition as the base metal, the strength of the joints amounts to approximately 90% of that of the base metal at both room and elevated temperatures. Fracture occurs along the weld metal, which, because of its course cast structure, is not strengthened to the level of the base metal during aging.

The greatest difficulties are presented by arc welding of dispersion-hardening high-hot-strength nickel-chromium alloys of the nimonic type (EI437B, etc.), which contain B in addition to Al and Ti. This results from the strong tendency of such alloys toward hot cracking in and around the weld, especially in rigid assemblages of moderately thick and thick metal. Even addition of Mo and W to the alloy (EI617, EI598, EP220, EP199, EI867, EI827) does not prevent hot cracking in the presence of B. Use of electrode wires of alloys of the same composition but with no B (EI437) or with very low Al and Ti contents (EI435) often fails to prevent hot cracking in and around the weld. In addition, they do not ensure that the weld and the base metal will be equal in strength. Rod materials which supplementally alloy the weld metal are consequently employed in welding: 1) Mo, W, and Ta to suppress polygonization and strengthen the solid solution: IMET-10 electrodes with a core of Ni alloyed with 20% Mo and a coating which alloys the seam (Cr); IMET-4M and IMET-7M electrodes with cores of EI435 and EI437 and a coating which alloys the seam (18-20% Mo); IMET-4P electrodes with a core of EI435 and a coating which introduces even more Mo into the weld metal; IMET-5 electrodes with a core of EI868 alloy containing 15% W; NIAT-7 electrodes with the same core and a coating which supple-

mentally alloys the weld (10-15% Mo); wire of EP220 alloy containing Mo and W but no B. 2) Nb and C in a ratio of 10:1 to promote formation of primary carbides and their nickel eutectic during crystallization, this modifying the weld metal and preventing development of a columnar structure and polygonization: EP216 electrode wires of type EI437 containing 0.15-0.22% C and 1.5-2.2% Nb; EP217 wire of type EI435 containing 0.25-0.32% C and 2.5-3.2% Nb; EP240 wire of type EI435 containing 1.9-2.5% Nb (used with a coating which alloys the weld with 0.19-0.25% C). 3) Combinations of these elements: IMET-9 electrodes with an EI868 core and a coating which alloys the seam (0.25-0.3% C and 2.5-3% Nb).

However, as a result of their reduced AL and Ti contents none of these rod materials make it possible to obtain joints equal in strength to the high-hot-strength alloys EP199, EI867, EI827, etc. (Table 2).

Cast nickel-chromium alloys containing B, Al, and Ti (VZh36-L2, ZhS3, etc.) are still more difficult to weld than deformed alloys. However, those containing no B and large quantities of Co and Mo (IK4) exhibit no tendency to hot-crack during welding.

It is necessary to try to weld Ni alloys at as low a specific arc energy as possible. In order to intensify the passage of strengthening alloying elements (Al, Ti, Mo, W, etc.) into the weld these electrodes carry coatings with an elevated CaF_2:$CaCO_3$ ratio and high Mn, Al, and Ti contents, this ensuring a low oxidizing power. In submerged-arc welding with halide fluxes the NaF content of the latter is limited to 5-10%, since this compound reacts with Al and Ti; such restriction of the NaF content also intensifies the modification effect and increases the resistance of the weld to hot cracking.

The parameters for resistance welding of nickel and its alloys are similar to those for stainless steel and differ from those for

carbon steel principally in the higher electrode pressure employed.

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M.Kh. Shorshorov

WELDING OF STEEL – the inseparable joining of steel to other metals and nonmetals. Electric-arc welding (E) is the most commonly employed technique, the proportion of gas welding having decreased. A fuel-oxygen flame serves as the heat source in gas welding (a variety of fusion welding). Acetylene, propane-butane mixtures, methane, and kerosene-vaporization products are used as fuel gases. In arc welding the metals are joined as a result of an interatomic interaction. We can distinguish electric fusion and electric pressure welding, but there are also combined methods. The heat source in electric fusion welding may be an arc discharge (arc welding), an ionized plasma (plasma welding) an electrically-conductive molten flux or slag (molten-slag welding), or a concentrated beam of electrons (electron-beam welding) or ions (ion-beam welding). We can also distinguish ar welding with fusable (steel) and nonfusable (carbon, tungsten) electrodes. The area encompassed by the arc and fused metal can be protected from the atmosphere with coatings applied to fusable electrodes, with fluxes applied to the edges to be welded, with gases which drive the air away from the arc, or with combinations of fluxes and gases, etc. Active gases (hydrogen, nitrogen, and carbon dioxide) interact with the liquid metal and alter its composition and characteristics in the desired manner, while neutral gases (argon, helium) merely protect it from the atmosphere. In electric pressure welding the components to be welded are heated by passing an electric current through their contact surface (resistance welding), by electromagnetic inductio (induction welding), or by discharge of stored electrical energy (capacitor and pulse weld-

ing). The principal method for the fusion welding of steel is the arc technique, which was discovered at the end of the 19th Century by the noted Russian inventors N.I. Bernardos and N.G. Slavyanov. The most efficient fusion-welding technique is automatic submerged-arc welding. This method was developed in the USSR in 1940, under the supervision of Ye.O. Paton. The most efficient method for the electric welding of very thick steel is the molten-slag technique, which was developed by Soviet scientists. Metal of virtually unlimited thickness (2 m) can be welded in a single pass by this method.

Welding in a stream of argon (developed in the USA) or carbon dioxide (proposed in the USSR) is a very promising method for the electric welding of thin and moderately thick steel. These two techniques have completely replaced gas welding. Argon-arc welding is carried out with fusable or nonfusable electrodes, while welding in carbon dioxide is generally conducted with fusable electrodes.

The principal technique for the pressure welding of steel is resistance welding. We can distinguish butt, spot, and seam resistance welding. This procedure is most widely employed in the automobile, aviation, and defense industries. It is also used in assembling piping, for welding railroad rails into long continuous lengths (so-called seamless rails), in rolling (for continuous rolling), and in ship building. Resistance welding is easily automated. Completely automated resistance welders with programmed control are now employed commercially. In view of its high productivity, resistance welding has bright prospects for further development.

Virtually all the steel and alloys used in the national economy undergo fusion and pressure welding. In order to avoid cracking, pore formation, etc., the welding materials (electrodes, wire, fluxes, active gases) are selected so as to produce a seam which is quite similar in

chemical composition to the steel to be welded and free of various defects. High-purity steels are used in the manufacture of especially critical welded assemblages and components.

The USSR occupies 1st place with respect to the scale on which modern welding techniques are employed and the level to which welding has been mechanized (up to 47% in 1962-63). Welding (especially electric welding) permits fuller utilization of the properties of various steels and other structural materials, thus ensuring high structural reliability and durability and minimal weight. Since progress in welding science and technology will provide solutions to the extremely important technical problems facing many branches of the national economy, the July Planem of the Central Committee CPSU (1960) planned special measures for the accelerated development of welding technology.

Mechanized electric welding will enable substantial progress to be made in heavy machine building (forging and pressing machinery), ship building (all-welded ships), the piping industry (welded gas pipes with diameters of 1020 mm and pipes of other sizes), chemical machine building (equipment for synthetic-alcohol and rubber plants, for the manufacture of polymers, etc.), power engineering (high-power steam boilers, as well as steam, gas, and hydraulic turbines), rocket and jet technology, instrument building and electronics (welding of micromodules, etc.), metallurgy (building up of worn rolling rollers), transportation (welding of rails, building up of car-wheel facings), etc.

Totally new welding methods, friction and vacuum-diffusion welding, have been developed in the USSR in recent years. In vacuum-diffusion welding the steel is not brought to the melting point. An inseparable joint is formed by interaction of the atoms at the content surfaces. Vacuum heating is usually carried out by the induction method, but ra-

diation or resistance heating is also possible. A comparatively low pressure (1-2 kg/mm^2) is required to produce a welded joint. A technique has been developed for welding with a coherent light beam, using optical quantum generators or lasers.

Ultrasound is also employed in welding technology. In nonfusion welding, i.e., pressure welding, ultrasound is used to break down the strong surface oxide film, which hampers welding. In fusion welding ultrasound promotes breakdown of the weld-metal structure and increases its quality.

In addition to steels and iron-based alloys, it is possible to weld light metals (titanium, aluminum) and their alloys, nonferrous metals (copper, nickel), and heavy and rare metals (tungsten, molybdenum, niobium, tantalum, etc.).

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B.Ye. Paton

WELDING OF THERMOPLASTS – inseparable joining of assemblages, components, sheets, films, and other thermoplast articles by heating the joint site to a plastic state and applying an external force. This process is characterized by mutual diffusion of the surfaces to be joined and is based on the ability of thermoplasts to become viscous over a temperature range specific for each material and to regain their initial properties on cooling. The advantages of welding over other methods for joining thermoplasts include identical properties in the seam and the base material, hermeticity and high joint strength, the fact that it is possible to produce strong joints in uncementable polymers (fluoroplast-4, polyethylene, polypropylene), to mechanize and automate the process, and to make decorative seams and cuts during welding, and the rapidity with which joints can be made.

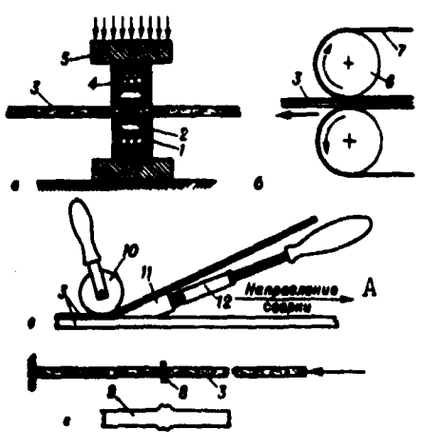

Fig. 1. Diagrams of devices for welding plastics with heated element (a, b, c – heat transfer; d – radiation): 1) Heater; 2) water-cooling jacket; 3) components to be welded; 4) electric heater; 5) press crosshead; 6) electrically heated rollers; 7) endless belt; 8) strip heater; 9) welded component; 10) pressure roller; 11) heated wedge; 12) electric heating element. A) Welding direction.

In welding thermoplasts the seam is heated by thermal contact, high-frequency current, gaseous heat-transfer agents, an extruded flange, ultrasonic energy, friction, or fusion. The choice of a method is dictated by the physical characteristics of the material, the structure of the component, the welding conditions, the requirements imposed on the seam, and safety considerations.

Thermal-contact welding is general-purpose, ensuring high joint strength with simple equipment; it is widely employed for joining components, sheets, films, etc. The seam is heated with heating elements of varying design and shape (strips, slides, wedges, rollers, etc.), by heat transfer (Fig. 1a, b, and c), or by radiation (Fig. 1d). A pressure of the order of 0.5-5 kg/cm^2 is applied to the seam during or after heating. The electrodes are usually heated with an electric heating element. The seam is cooled naturally or artificially. Equipment for thermal-contact welding is varied in design (presses, roller and belt machines, automatic equipment). In a roller machine the rollers extend and compress the material, while heating is carried out with a heating element in the weld zone. Thermal-impulse machines are used for making straight seams in films. The heating element is a thin (0.03-0.3 mm) strip of high-resistance alloy, which is fastened to an electrode through which (when coupled electrodes are used) high-strength current pulses are passed at short intervals. The strip quickly heats up and transfers its heat to the seam. Thermal-impulse machines are simple and convenient to operate and provide a high welding speed and good seam quality.

Welding of thermoplasts with high-frequency currents is based on dielectric capacitor heating. The electrodes provide pressure against the material in the weld zone and form a capacitor, in whose electric field the material is heated. A thermal field develops in the material

as a result of the dipole losses and relaxation processes caused by the interaction of the external high-frequency electric field (acting between the electrodes) with the internal molecular electric charges. Heating lasts several seconds and the heat is uniformly distributed throughout the material (the principal advantage of high-frequency heating). Machines for high-frequency welding of thermoplasts consist of a vacuum-tube generator and press (Fig. 2) or a roller device (Fig. 3). The press may have an electrical, mechanical, hydraulic, or pneumatic drive and manual, pedal, or automatic control. Both fixed and portable machines are used. The latter are equipped with movable clamp-type electrodes (Fig. 4) for welding difficult-to-reach areas. In press welding the entire joint or segments of it are made with electrodes, one of which reproduces the seam configuration. These electrodes may vary in profile (Fig. 5). Press welding ensures consistant seam quality and a high welding speed and makes it possible to decorate the seam (by imprinting letters or patterns). In roller machines the electrodes are two rollers, which extend and compress the material. Such machines are intended for welding PK-4 polyamide film.

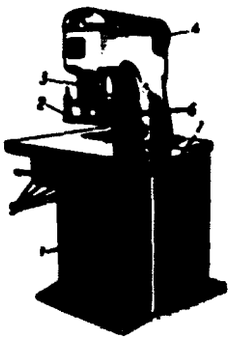

Fig. 2. Press for welding plastics with high-frequency current: 1) High-frequency generator; 2) electric motor; 3) press stock; 4) electric motor for feeding press stock; 5) generator and press controls; 6) insulators; 7) press plate.

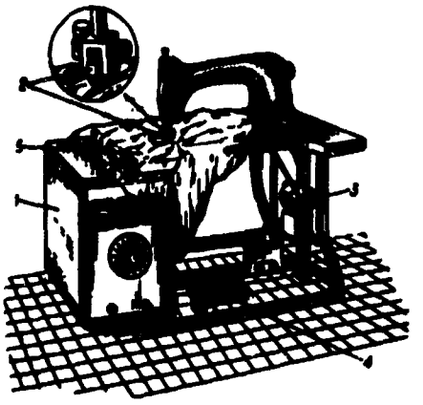

Fig. 3. Roller machine for welding plastics with high-frequency current: 1) High-frequency generator; 2) rollers; 3) drive motor; 4) control pedal; 5) film to be welded.

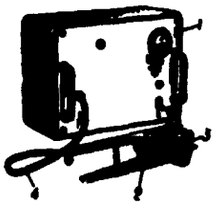

Fig. 4. Portable apparatus with movable electrodes for welding plastics with high-frequency current: 1) High-frequency generator; 2) clamp; 3) electrodes; 4) high-frequency cable.

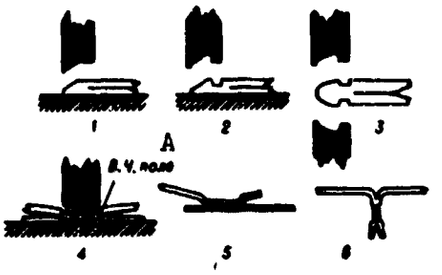

Fig. 5. Profiles of electrodes and seams: 1, 2, 3) Electrodes for welding and simultaneous indentation; 4) distribution of high-frequency field between electrodes; 5) lap seam; 6) T seam. A) High-frequency field.

High-frequency welding machines are screened, since they create radio and television interference when operating.

Welding with gaseous heat-transfer agents is employed for structural components (containers, tanks, apparatus, plastic floor and ceil-

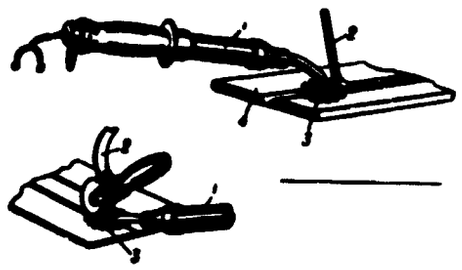

Fig. 6. Welding of thermoplasts with gasous heat-transfer agents: 1) Welding torch; 2) rod material; 3) heating zone; 4) material to be welded.

ing coverings, assembly of communications equipment, lining of apparatus with thermoplast sheets, etc.) and is conducted with added material (rod or strip) (Fig. 6). Soft sheet materials (polyisobutylene or polyvinylchloride) are lap-welded with hot gas, using no added material. In this type of welding the joint zone is heated with hand-held torches of various designs (Fig. 7). Air or an inert gas is used as the heat-transfer agent, since the surface of certain thermoplasts is oxidized in the presence of oxygen, which reduces their weldability and the strength of the joint. The temperature of the gas coming from the nozzle is adjustable and is kept at a constant level for a given material during welding (see Table). The average welding speed of a single seam is 10-12 m/hr. Butt welding with preliminary trimming of the edges to be welded is recommended for sheets and tiles (Fig. 8). Selection of a seam profile is dictated by the joint structure, location, and accessibility and the thickness of the material. When the welding regime is correctly selected and welding is properly executed the tensile strength of the joint amounts to 80-90% of that of the base material.

A portable manual extruder supplied with a polyethylene rod or strip is usually employed for welding polyethylene films, sheets, and as emblages (extrusion welding). Molten material from the extruder is

1 Материал	2 Температура сварки (°С)	3 Тангенс угла диэлектрич. потерь при частоте 10⁶ гц	4 Способы сварки: 5 ТВЧ: 6 пресс	7 ролик	8 Тепловая: 9 ТК	10 ролик	11 импульсная	12 Газовые теплоносители	13 Экструдированный присадочный пруток	14 Ультразвуковая сварка	15 Трение
16 Полиэтиленхлорид пластифицир.	110—175	0,09—0,1	С*	—	С	С	С	С/воздух 29	—	С	С
17 Винипласт	200—250	0,006—0,04	С	—	С	—	—	С/воздух	—	С	С
18 Поливинилиденхлорид	110—150	0,05—0,08	С	—	С	С	С	С/воздух	—	С	С
19 Полиэтилен ВД	200—220	0,0005	—	—	С	С	С	С/азот 30	С	С	С
20 Полиэтилен НД	220—240	0,0004	—	—	С	С	С	С/азот	С	С	С
21 Полипропилен	230—240	0,0006	—	—	С	С	С	С/азот	С	С	С
22 Поликарбонат	235—250	0,005	—	—	С	С	С	С/азот	С	С	С
23 Полистирол	130—140	0,0001—0,0003	—	—	С	—	С	С/воздух	С	С	С
24 Полиамиды	250—275	0,04—0,13	С	С	С	С	С	С/азот	—	С	С
25 Оргстекло	130—140	0,02—0,03	С	—	С	—	—	С/воздух	—	С	С
26 Фторопласт-4	380—390	0,0001—0,0003	—	—	С	—	—	—/—	—	—	—
27 Этрол	110—135	0,01—0,2	С	—	С	—	—	С/воздух	—	С	—

*S — Weldable.

1) Material; 2) welding temperature (°C); 3) tangent of angle of dielectric loss, at 10^6 cps; 4) welding method; 5) high-frequency; 6) press; 7) roller; 8) thermal; 9) thermal-contact; 10) roller; 11) thermal-pulse; 12) gaseous heat-transfer agents; 13) extruded flange; 14) ultrasonic energy; 15) friction; 16) plasticized polyvinylchloride; 17) viniplast; 18) polyvinylidine chloride; 19) polyethylene VD; 20) polyethylene ND; 21) polypropylene; 22) polycarbonate; 23) polystyrene; 24) polyamides; 25) organic glass; 26) fluoroplast-4; 27) etrol; 28) S; 29) air; 30) nitrogen.

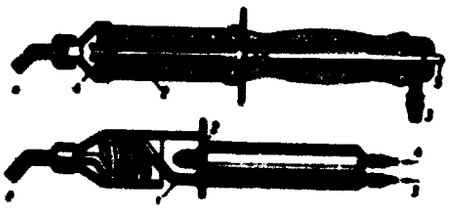

Fig. 7. Torches for welding plastics with gaseous heat-transfer agents: a) With electric heating element (1 — ceramic insulators; 2 — helix; 3 — connecting sleeve for supplying gaseous-transfer agent; 4 — insulator tie-rod; 5 — power lead); b) with gas heating (1 — coil; 2 — gas-torch nozzle; 3 — connecting sleeve for supplying gaseous-transfer agent; 4 — connecting sleeve for supplying hot gas).

Fig. 8. Trimming of weld edges: 1) V-shaped seam; 2) X-shaped seam; 3) order of applying added material during welding.

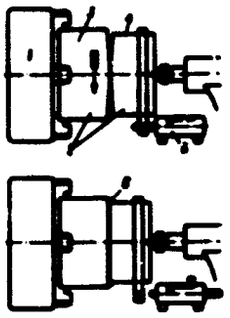

Fig. 9. Friction welding: 1) Holding device; 2) components to be joined; 3) rotating component; 4) fixed components; 5) stop; 6) welded joint.

forced into the weld zone through a head which furnishes a flange with a given profile. The screw feed can be electrical or pneumatic. Extrusion welding is conducted at speeds of up to 100 m/hr.

Ultrasonic welding of thermoplasts is employed to produce components with complex shapes. In this type of welding stresses leading to plastic deformation and thus to a rise in temperature are created in the surfaces to be butt-welded. The work piece is placed between the end of a converter waveguide and a clamp to which the force necessary to create the desired pressure at the seam is applied. Heating occurs only in the butt area (the principal advantage of ultrasonic welding).

Friction welding is used for face-welding of round components (Fig. 9). One component is rigidly clamped and the other is rotated and pressed against the stationary component. The resultant friction produces heat, which melts the contact surfaces. Lathes are used for this type of welding. The pressure perpendicular to the friction plane is 4-6 kg/cm^2 and the relative angular velocity ranges up to 30 m/min. Friction welding is not used commercially, since it has a number of drawbacks: the principal parameter (temperature) of the welding process cannot be regulated, the seam obtained has a microporous structure, and there is a considerable scattering of strength indices.

Fig. 10. Diagram of fusion welding of films: 1) Section iron; 2) radiant heater; 3) welded films.

Fusion welding of thermoplasts is employed principally in the manufacture of various containers from polyethylene film (Fig. 10); seams made by this method function poorly under bending loads (breaking) as a result of the partial destruction of the material in the seam zone.

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M.M. Vysotskiy and N.A. Grishin

WELDING OF TITANIUM ALLOYS. The high activity of titanium and its alloys with respect to O_2, N_2, and H_2 at temperatures above 650° makes it necessary to protect the weld zone, which is heated to higher temperatures during welding, with inert gases or halide fluxes. The principal techniques used for welding titanium alloys are tungsten-electrode arc welding in argon without added metal (for sheets from 0.3 to 3 mm thick) or with added metal (for sheets from 0.8 to 30 mm thick), fusable-electrode arc welding in an argon-helium mixture (for sheets from 3 to 30 mm thick), submerged-arc welding (for sheets from 2.5 to 30-50 mm thick), molten-slag welding with additional argon shielding of the slag bath (for sheets more than 50 mm thick), unshielded spot and seam resistance welding (for sheets from 0.8 to 3 mm thick), and shielded butt fusion welding (for components from 100 to 10,000 mm^2 in cross section).

As a result of the negative influence of gases on the plasticity and impact strength of welds in titanium argon containing 0.01-0.02 + + N_2 and 0.005% O_2 is employed. The gas content of alloys consisting of α- or α + β-titanium should not exceed 0.15-0.20% O_2, 0.03-0.05% N_2, and 0.005-0.01% H_2. Restriction of the H_2 content is also necessitated by the danger of cold cracking during welding as a result of hydride transformation, which occurs at temperatures below 300° and is accompanied by an increase in volume. Vacuum annealing of the rod wire and reduction of its H_2 content to 0.002% are consequently necessary in welding α-alloys and certain α + β-alloys. The H_2 content of α + β-alloys containing a large amount of β-phase may be as high as 0.015%,

since H_2 is highly soluble in β-titanium.

The welding method and regime is selected in accordance with the alloying elements present and the content of detrimental impurities. It is also necessary to take into account the tendency of titanium alloys toward grain growth and toward hardening and formation of a heterophasic structure in the area around the weld, which leads to a decrease in plasticity. The principal criterion in selecting a welding regime is provision of a cooling-rate range in the area around the weld which will ensure an optimum ratio of mechanical characteristics (see Table).

Titanium alloys are divided into two groups: 1) alloys which can be heat-treated after welding (α-alloys, α + β-alloys), containing stabalizing elements, especially Fe, Cr, and Mn, in concentrations no higher than their maximum α-phase solubility (usually no more than 2-3%), and β-alloys with a stable β-phase; 2) alloys which can be heat-treated after welding (the majority of α + β-alloys).

Alloys of the 1st group (α-alloys) are readily welded when they contain up to 5-5.5% Al and up to 2.5% Sn (VT5 and VT5-1). The mechanical characteristics of welds in these alloys are similar to those of the base metal. Welding of α-alloys must be conducted at the lowest possible specific arc energy (the greatest possible cooling rate) within the limits of the optimum cooling-rate range. Welds in alloys containing 2-5% Al and 1-2% Mn (OT4-1, OT4, VT4) or a total of 1-2% Cr, Fe, and Si (AT3 and AT4) have a slightly lower plasticity than the base metal. A Al content of more than 5.5% (OT4-2) greatly reduces weld plasticity. These alloys are not hardened by heat treatment. When welding assemblies of these alloys tempering is recommended to relieve the residual stresses (see Heat treatment of titanium alloys).

Welds in alloys of the 2nd group (α + β-alloys) containing a total of from 3 to 7% Mo and V (VT14 and VT16) also exhibit satisfactory

Mechanical Characteristics of Welds in Titanium Alloys and Optimum Cooling Rates in the Around-the-Weld Zone

	1 Сплав	2 Св-ва осн. металла в отожженном состоянии: 3 предел прочности (кг/мм²)	4 относительное удлинение (%)	5 угол загиба при R=δ (град)	6 ударная вязкость (кгм/см²)	7 Способ сварки и толщина листа	8 Св-ва сварных соединений: 3 предел прочности (кг/мм²)	5 угол загиба при R=δ (град)	6 ударная вязкость шва (кгм/см²)	9 Интервал оптимальных скоростей охлаждения при 900° (град/сек)
10	ВТ1-1	45—60	30—25	180—140	7—10	АДС[3] (1—3 мм)	45—60	180—120	—	15—300
11	ВТ1-2	55—70	25—20	140—90	5—8	23 То же 24	55—70	125—80	—	10—100[4]
12	ВТ5	70—95	15—10	90—60	3—6	" "	70—90	90—50	—	1—600[4]
13	ВТ5-1	75—95	25—12	90—60	4—9	25 " "	75—95	100—60	—	1—600[4]
						ДСФ[3] (10 мм)	75	—	3	1—600
14	ОТ4-1	60—75	40—20	150—90	5—10	АДС (1—3 мм)	60—75	140—80	—	10—300
15	ОТ4	70—85	40—15	100—60	3,5—6,5	АДС (1—3 мм)	70—85	90—40	—	10—300
						ДСФ (5 мм)	75	80—70	4	10—300
16	ВТ4	85—105	22—15	80—30	—	АДС (1—3 мм)	85—100	50—30	—	10—200
17	ВТ6	90—100	15—10	60—30	4—8	АДС (1—2 мм)	90—100	30—25	—	26 нет
18	ВТ3-1	95—120	18—10	—	3,5—8	АДС (1—2 мм)	95—100	30—20	—	то же
19	ВТ14	90—110	14—8	190—60	6—12	АДС (1—3 мм)	90—110	50—30	—	1—(15÷40)
		95—105[5]	16—12	—	5—8	—	—	—	—	1—(15÷40)
		115—140[6]	10—6	—	2,5—3,5	—	—	—	—	1—(15÷40)
20	ВТ16	110—125[6]	12—7	—	—	АДС (1—2 мм)	95	90	—	80—600
21	АТ3	75—90	24—16	120—60	4—9	АДС (1—3 мм)	75—90	100—50	—	10—300
						ДСФ (3 мм)	75	—	5	10—300
22	АТ4	85—100	20—10	90—50	4—8	АДС (1—3 мм)	85—100	80—40	—	10—200
						ДСФ (3 мм)	90	—	5	10—200

*R — straightening radius, δ — sheet thickness.

**Fracture of welds under tension occurs along the base metal.

***ADS — argon-arc welding, DSF — submerged-arc welding with DT1-alloy wire.

****There is no optimum range, but over the indicated range the bending angle and elongation of welds are no less than 50–60% of those of the base metal.

*****After quenching.

******After quenching and aging.

1) Alloy; 2) characteristics of annealed base metal; 3) ultimate strength (kg/mm^2); 4) relative elongation (%); 5) bending angle at R = = δ (degrees); 6) impact strength (kg-m/cm^2); 7) welding method and sheet thickness; 8) characteristics of welds; 9) optimum cooling-rate range at 900° (degrees/sec); 10) VT1-1; 11) VT1-2; 12) VT5; 13) VT5-1; 14) OT4-1; 15) OT4; 16) VT4; 17) VT6; 18) VT3-1; 19) VT14; 20) VT16; 21) AT3; 22) AT4; 23) ADS; 24) the same; 25) DSF; 26) none.

plasticity after welding and are usually strengthened by heat treatment (aging or quenching and aging).

An intermediate position between these two groups is occupied by α + β-alloys containing 4.5–6.5% Al and 3–4.5% Mo or V (VT6 and VT8). Those β-alloys containing a stable β-phase (e.g., 25% Mo) are readily welded; the plasticity of the weld is virtually the same as that of the base metal.

Titanium can be fusion-welded to zirconium, niobium, tantalum, molybdenum, and vanadium, with which it forms solid solutions. Welding of titanium to other metals requires an intermediate coating, facing, or lining. For example, tantalum facings are used in arc-welding titanium to copper, vanadium-foil facings are employed in spot and seam resistance-welding titanium to steel, etc.

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M.Kh. Shorshorov and G.V. Nazarov

WELER'S CURVE – see Endurance.

WHISKERS – conventional designation of artificially obtained metallic and nonmetallic threads, primarily monocrystals. The diameter of whiskers is from tenths to hundredths of a micron, the ratio of the length to the diameter may be as high as a thousand. The strength of whiskers increases with a reduction in length. Whiskers are usually tested in flexure or tension. Certain mechanical properties of whiskers have the standard magnitude (modulus of elasticity), but the strength and the highest deformation of whiskers substantially exceed those obtained in large cross sections of the same materials; for example, the

Mechanical Properties (in kg/mm^2) of Whiskers and Monocrystals of Certain Metals

1 Металл	2 Усы			3 Обычные монокристаллы	
	4 диаметр (мк)	$\sigma_{0,2}$	σ_b	$\sigma_{0,2}$	σ_b
Железо 5	1,60	364	1340	4,5	18–23
Медь 6	1,25	82	300	0,10	12,9–35
Серебро 7	3,80	72	176	0,06	—

1) Metal; 2) whiskers; 3) ordinary monocrystals; 4) diameter (microns); 5) iron; 6) copper; 7) silver.

strength of whiskers comprises 1000-2000 kg/mm^2, which by approximately a factor of 10 exceeds the maximum strength obtained in specimens from the strongest metals in large cross sections; the elastic elongation is 1-2%, sometimes 5-6%. Due to the high elastic deformation capacity, deviations from Hooke's law are observed in whiskers. The creep rate in whiskers is by a factor of hundreds lower than in specimens with large dimensions. Admixtures reduce the mechanical properties of whiskers.

The causes for the high strength of whiskers are still not clear, they can be attributed to the perfection of structure and surface, small cross-sectional dimensions and high simultaneity of strength disturbances, etc. The strength of whiskers is by a factor of 8-80 higher than the ultimate strength and by a factor of 80-1200 higher than the yield strength of crystals of the same materials.

When using the high strength of whiskers under actual conditions it is necessary to take into account their high elastic deformability and deviations of the elastic branch of the stress-strain diagram from linearity.

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Ya.B. Fridman

WILLEMITE – mineral, a zink silicate $Zn_2[SiO_4]$. The crystal structure of willemite is formed by close-packed tetrahedrals with Si and Zn located in their centers. Troostite is a variety of willemite in which a part of the zink is replaced by manganese. The elementary rhombohedral space-lattice unit of the mineral contains 6 molecules of $Zn_2[SiO_4]$. The specific weight of willemite is from 3.89 to 4.18. Cleavageability along {1120} is perfect, along {0001} it is imperfect. The fracture is conchoidal to irregular, brittle. The Mohs hardness is 5.5. The color changes depending on the manganese and iron admixture from colorless, white, yellowish-brown, cinnamon to blood-red or darkish-brown. The color of troostite is greenish-brown, reddish. The streaks are colorless. The luster is oily to glass-like. The refraction index is N_e 1.720-1.723; N_o 1.691-1.693. Single-axis, positive. Melting temperature 1465°. Thermal expansion coefficient in heating $32 \cdot 10^{-7}$. Willemite is highly luminescent in x- and ultraviolet rays, emitting yellowish-green light, if the mineral contains even a moderate percentage of manganese. It emits a green glow when a cathode beam is shined upon it. The manganese ions serve as luminescence centers. Luminescence spectra of single crystals of $(Zn, Be)_2[SiO_4]$, activated by manganese shift the maximum from 5250 A (for pure $Zn_2[SiO_4]Mn$) to 5310 A. For a specific concentration of beryllium in manganese-activated willemite it is possible to obtain white glow. Infrared absorption spectra are characterized by absorption maxima at 10.25 and 10.74 microns, and also by additional maxima at 11.10 and 11.52 microns. Willemite is synthesized by passing $SiCl_4$ vapor over ZnO; by interacting ZnO and SiO_2 at 365°, and

a pressure of 200 atm; by roasting ZnO and SiO_2 in stoichiometric quantities with an addition of $Mn(NO_3)_2$; from the waterless gas phase in the ZnO-BeO-SiO_2 system using NaF and BeF_2 as mineralizers, and also by other methods. Single crystals with the composition $(Na, Be)_2[SiO_4]Mn$ were recently obtained. Manganese-activated willemite and solid solutions with the composition $(Zn, Be)_2[SiO_4]Mn$ are used as luminophors in the manufacture of: cathode oscillographs, television tubes, radar installation screens, low-pressure luminescent lamps, which have a maximum light yield in the visible part of the spectrum. Zinc is extracted from the willemite ore. Willemite in the form of transparent topaz-yellow crystals is used as a precious stone.

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M.D. Dorfman

WOLLASTONITE – a mineral, a metasilicate of calcium $CaSiO_3$ (48.25% CaO and 51.75% of SiO_2), sometimes contains up to 9% FeO and MgO. Low-temperature wollastonite) (β-wollastonite) is formed in two versions: triclinic (wollastonite) and monoclinic (parawollastonite), the properties of which are close to one another. Wollastonite forms flat lamellar crystals, radiating or shell-like aggregates. The color is white, gray, sometimes pink. The whiteness of ground wollastonite is sometimes as high as 94-96% of the whiteness of a barium plate. Specific weight 2.80-2.85, Mohs hardness 4.-4.5. Refraction indices N_g = 1.631, N_m = 1.623, N_p = 1.616. Perfect cleavability along {100} and good cleavability along {001} and {102}. Solubility in water comprises 0.095 g per 100 cm^3 at 20°. At 1150 ± 10° it becomes monoclinic α wollastonite. The specific weight of α-wollastonite is 2.90, Mohs hardness 5. Refraction indices N_g = 1.651, N_m = 1.611 and N_p = 1.610. It forms a eutectic with tridymite (63% SiO_2) at 1436 ± 5°. When heated to 1540° wollastonite melts into a brown glass, with a viscosity of 2.70 at 1550° of 2.40 at 1600° and of 2.38 poises at 1650°. Wollastonite has high dielectric properties. The tangent of the dielectric losses angle of β-wollastonite at f = 10^6 cps and 100° is $42 \cdot 10^{-4}$, at 200° it is $50 \cdot 10^{-4}$, at 300° it is $72 \cdot 10^{-4}$; for α-wollastonite this tangent is $1.2 \cdot 10^{-4}$ at 100°, $3 \cdot 10^{-4}$ at 200° and $6 \cdot 10^{-4}$ at 300°.

Wollastonite is used extensively in ceramics, since it imparts a number of specific properties to the products. It is used as an additive to porcelains and glazes or as the basic component of a mass. Addition of moderate quantities of wollastonite to fieldspar porcelain reduces

the porosity of the body, increases the contraction and improves the electric insulation properties and the color of products. Wollastonite with bentonite as the binder is used for obtaining tiles or facing plates 0.5-1.0 cm thick, which have a high strength, can be drilled and are capable of holding nails just as well as wood. Wollastonite is used for obtaining of ceramics used in radio engineering and high-voltage porcelain which has high dielectric properties, particulary at elevated temperatures. Wollastonite ceramics used in radio engineering have a dielectric permeability of 6-6.5; the tangent of the dielectric losses angle at $f = 1 \cdot 10^6$ cps and 20° is 0.0005-0.0008, at 80° it is 0.0006-0.0012; the specific volume resistivity at a temperature of 20° is higher than 10^{14} ohm-cm, the electric strength is 30-50 kv/mm, coefficient of linear expansion in the interval of 20-100° is $5 \cdot 10^{-6}$, ultimate flexural strength is 1300-1800 kg/cm^2 and the sintering temperature is 1220-1250°. Wollastonite is used extensively by itself and together with argillaceous components as a filler for paper (it imparts it a silky luster). Due to its low oil number and good body wollastonite is used extensively as a paint pigment and intensifier; in polyvinylacetate paints it acts as a buffer, maintaining pH values in the paint system of about 7.5-8.0, at which corrosion phenomena are reduced; pirgments which are not suitable for an acidic medium (ultramarine, etc.) can in this case be used together with wollastonite; moreover, wollastonite imparts an effective silky luster to the painted surface. Wollastonite is used also in glass manufacture instead of chalk and lime additives in the fusing of glass; in metallurgy as a component of the grease coating of welding electrodes and as a flux used for adjusting the viscosity of slag; as a filtering and heat insulation material and also as an additive to and substitute for asbestos in asbestos-cement compositions; as a filler of synthetic and natural rubbers and

plastics (first treated by chloridizing agents); as a binder in the production of artificial abrasives; for obtaining light-colored mineral wool, special cements, which after roasting can be drilled, sawed and pierced by nails; as a fertilizer for liming of acidic soils. Wollastonite is a valuable chemical raw material. Finely ground wollastonite together with sulfuric acid gives a paste which, as a result of an exothermic reaction increases substantially in volume; the resulting product (silica gel mixed with calcium sulfate) has a high absorptivity.

The industry makes use of concentrates which are obtained by beneficiation of wollastonite ores. The basic requirements put to them are: low content of iron and titanium oxides (not more than 0.5%), invariability of the chemical and grain composition. The paint industry of the USA uses concentrates with a grain size less than 30 microns, while the ceramics industry uses coarser grain sizes.

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V.I. Fin'ko

WOODOLITE – pressed in a single piece or composite wood plastic material. Is obtained in molds from pulverized wood particles inpregnated by solutions of phenolformadehyde and other resins. Monolitic products or blanks of the specified shape are formed by pressing. Brands of woodolite differ by the size of the wood particles and the type of resin used for their impregnation. The physicomechanical properties of various brands of woodolite are given in Table 1.

In comparison with ordinary phenolformaldehyde-base pressed materials from molding compositions, woodolite has a higher strength bending and a high impact ductility. Woodolite has a lower water resistance than ordinary pressed materials. The properties of woodolite as a function of wood particle size are given in Table 2.

TABLE 1

Physicomechanical Properties of Woodolite

1 Показатели	2 Марки древолита		
	3 на спирторастворимой смоле	4 на водорастворимой смоле	5 на спирторастворимой смоле, из предварительно выщелоченного шпона
6 Объемный вес (г/см³) . .	1,30	1,38	1,36
7 Предел прочности (кг/см²):			
8 при сжатии	1200	1150	1200
9 при статическом изгибе	1200	1100	1100
10 Модуль упругости при сжатии (1000 кг/см²) .	150	160	140
11 Ударная вязкость (кг·см/см²)	18	16	25
12 Твердость по Бринеллю (кг/мм²)	20	23	26
13 Водопоглощение за 24 часа (%)	1,0	1,2	1,8

1) Indicators; 2) woodolite brands; 3) alcohol-soluble resin-base; 4) water-soluble resin-base; 5) alcohol-soluble resin-base from preleached veneer sheets; 6) specific weight (g/cm^3); 7) ultimate strength

(kg/cm^2):; 8) in compression; 9) in static bending; 10) modulus of elasticity in compression (1000 kg/cm^2); 11) impact ductility ($kg/cm/cm^2$); 12) Brinell hardness (kg/mm^2); 13) water absorption in 24 hours (%).

TABLE 2

Properties of Woodolite as a Function of the Wood Particle Size

1 Показатели	Свойства древолита, изготовленного 2 из древесных частиц	
	3 мелких от 0,3 до 3 мм	4 крупных от 3 до 10 мм
5 Объемный вес ($г/см^3$)	1.34	1.34
6 Предел прочности ($кг/см^2$):		
7 при сжатии	1390	1010
8 при статическом изгибе	1380	1810
Уд. ударная вязкость 9 ($кг \cdot см/см^2$)	16	24
Твердость по Бринеллю ($кг/мм^2$) 10	23	30
Водопоглощение за 24 часа (%) 11	1.0	1.7

1) Indicators; 2) properties of woodolite made from wood particles; 3) finefrom 0.3 to 3 mm; 4) coarse from 3 to 10 mm; 5) specific weight (g/cm^3); 6) ultimate strength (kg/cm^2):; 7) in compression; 8) in static bending; 9) specific impact ductility ($kg-cm/cm^2$); 10) Brinell hardness (kg/mm^2); 11) water absorption in 24 hours (%).

Table 3 shows the properties of woodolite as a function of the synthetic resin content.

TABLE 3

Properties of Woodolite as a Function of the Resin Content

1 Показатели	2 Содержание смолы (%):		
	20	25	30
3 Объемный вес (г/см³)	1,36	1,36	1,35
4 Предел прочности при сжатии (кг/см²):			
5 в направлении плоскости прессования	1350	1300	1290
6 перпендикулярно направлению плоскости прессования	1270	1200	1150
7 вдоль волокон	1830	1730	1500
8 Предел прочности при статическом изгибе (кг/см²)	1800	1580	1320
9 Уд. ударная вязкость (кг·см/см²)	26	22	18

1) Indicators; 2) resin content (%):; 3) specific weight (g/cm^3); ultimate compressive strength (kg/cm^2):; 5) in the direction of the pressing plane; 6) perpendicular to the direction of the pressing plane; 7) along the fibers; 8) ultimate strength in static bending (kg/cm^2); 9) specific impact ductility ($kg\text{-}cm/cm^2$).

Table 4 shows the properties of woodolite as a function of the pressing pressure.

TABLE 4

Properties of Woodolite as a Function of the Pressure

1 Показатели	2 Удельное давление при прессовании (кг/см²):			
	250	400	600	800
3 Предел прочности при сжатии (кг/см²)	1080	1050	1190	1290
4 Уд. ударная вязкость (кг·см/см²)	19	20	18	19
5 Твердость по Бринеллю (кг/мм²)	28	36	—	35

1) Indicators; 2) specific pressing pressure (kg/cm^2):; 3) ultimate compressive strength (kg/cm^2); 4) specific impact ductility ($kg\text{-}cm/cm^2$); 5) Brinell hardness (kg/mm^2).

The dielectric properties of woodolite are given in Table 5.

TABLE 5

Dielectric Properties of Woodolite

1 Показатели	Диэлектрические свойства древолита после выдержки образцов 2 в течение 48 час. в атмосфере с относительной влажностью воздуха (%):	
	65	100
3 Удельное электросопротивление:		
4 объемное S_v (ом·см)	$4.0 \cdot 10^{10}$	$1.2 \cdot 10^{11}$
5 поверхностное S_s (ом)	$2.5 \cdot 10^{10}$	$3.6 \cdot 10^{10}$
6 внутреннее S_i (ом·см)	$3.2 \cdot 10^{11}$	$1.8 \cdot 10^{9}$
7 Тангенс угла диэлектрических потерь при 50 гц	0.086	0.140
8 Диэлектрическая проницаемость при 50 гц	7.4	8.2
9 Средняя пробивная напряженность (кв/мм) . .	6.5	6.2

1) Indicators; 2) dielectric properties of woodolite after specimens were held for 48 hours in an atmosphere with a relative air humidity (%) of: 3) specific electrical resistivity:; 4) volume S_v (ohm-cm); 5) surface S_s (ohms); 6) internal S_i (ohm-cm); 7) tangent of dielectric losses angle at 50 cps; 8) dielectric permittivity at 50 cps; 9) average breakdown voltage (kv/mm).

Woodolite has good antifriction properties. The friction coefficient of woodolite mated with various materials under a specific pressure of 100 kg/cm^2, peripheral speed of 0.012 m/sec and water lubrication comprise:

Ferritic iron 0.09

Carbon Steel 0.07

Brass 0.09

Duraluminum 0.07

According to different data, the friction coefficients of woodolite when mated with carbon steel comprise 0.03-0.06 under a specific pressure of 3 kg/cm^2 and machine-oil lubrication, and 0.02-0.04 under a specific pressure of 70 kg/cm^2 and water lubrication.

The start-up torques and start-up friction coefficients of woodolite bearings are quite high. Data on the wear of woodolite, depending on the lubrication, obtained experimentally comprise 0.22% for water; 0.30% for lubricant grease and 0.31% for brand D machine oil.

Possessing high physicomechanical properties, woodolite successfully replaces bronze, tin-containing alloys, babbit and textolite in bearing liners of rolling mills, engine-axle bearings of trolleycar engines, guide and frame bearings of looms, overhead crane and crusher-roll mill sleeves, etc. Woodolite is used for making loom bodies and gears for the textile industry, components of the electrical equipment and cable industries (current-insulated clamps, cable joints).

References: Sheydin, I.A., Smirnov, A.V and Demidova, L.A., Tekhnologiya drevesnykh plastikov (Wood Plastics Technology), Moscow - Leningrad, 1956; Genel', S.V., Drevesnyye plastiki v tekhnike (Wood Plastics in Technology), Moscow, 1959; Spravochnik fanershchika (Plywood Maker's Handbook), vol. 2, Moscow – Leningrad, 1959.

P.T. Romanov

WOOD'S METAL – fusible alloy named after its inventor, the American physicist R.W. Wood. Wood's metal contains 50% Bi, 25% Pb, 12.5% Sn and 12.5% Cd. The melting temperature of the alloy is 68°. Is used for making of models, for pouring of microsections, for soldering of sprinkler heads, etc.

O.Ye. Kestner

WORKING OF CHROMIUM BY PRESSURE. The form and the nature of the distribution of the impurities in chromium are decisive factors for the plasticity of this metal at room temperature. Chromium and its low-alloys, plastic at room temperature, are obtainable by increasing the purity of the initial metal, by the use of melting methods which do not cause a considerable contamination of the metal, by plastic deformation and hot treatment.

The plastic properties and also the impact resilience of chromium increase considerably above 250-300° (Table). The temperature of transition of chromium from the brittle into the plastic state, however, is considerably increased at high loading rates (hammer, drop hammer, etc.) together with a simultaneous increase of the resistance to deformation (a_H, ε_k, P_k). This hampers the deformation of chromium by means of hammers and other types of quick-acting equipment. Because of this property the deformation of chromium must be carried out with a reduced speed (hydraulic press, static drawing of specimens, etc.).

Chromium tends to become considerably tougher during the process of plastic deformation.

Although the end temperature of recrystallization of chromium lies on the level of 900-1000° for a metal deformed by more than 50% and tempered for 30-60 min, the metal retains traces of the cold hardening up to 1500°. This proves that the weakening processes proceed slowly in chromium. The hardness (HB) of chromium deformed by 75-85% at a temperature below 900° increases from 120-130 kg/mm^2 (in cast or tempered state) to 190-220 kg/mm^2, and after a deformation at 1500° – to 130-145

kg/mm^2. This peculiarity of chromium requires frequently repeated intermediate tempering and heating of the blanks during the working by pressure.

Characteristics of the Plasticity of Pure Chromium

1 Свойства	2 Темп-ра (° С)							
	300	500	700	800	900	1100	1300	1500
δ (%)	30–40	55–60	70–72	75–80	80–83	80–85	85–90	–
ψ (%)	–	60	70	80	80	–	–	–
3 Допустимая степень деформации при осадке на гидравлич. прессе $\varepsilon_{пр} = \frac{H_0 - h}{H_0} \cdot 100\%$								
4 (статич. нагружение)	35–45	55–65	70	70	70	80	–	–
5 То же при осадке на копре (динамич. нагружение) $\varepsilon_k = \frac{H_0 - h}{H_0} \cdot 100\%$	–	50–60	65–75	70–75	60–65	50–35	35–40	60–70
6 $a_н$ с надрезом (кгм/см^2)	1,5–2,5	9–11	15–17	4,5–7	3–3,5	1,5–2,5	1,5–2,5	3,5–4,0
7 $a_н$ без надреза (кгм/см^2)	1,5–2,5	9–11	15–17	24	12–15	1,5–2,5	1,5–2,0	3–3,5
8 $\sigma_в$ (кг/мм^2)	27–30	24–28	18–20	–	10–15	3–5,5	–	–
9 Сопротивление деформированию при осадке на гидравлич. прессе $P_{пр}$ (кг/мм^2)	65–70	55–60	40–50	47–52	35–40	20–30	–	–
10 То же при осадке на копре								
11 $P_к$ (кг/мм^2)	–	60–65	45–55	55–65	55–65	60–70	40–55	30–40
12 Сопротивление деформированию при прессовании на гидравлич. прессе с обжатием на 85% из контейнера $\varnothing$ = 50 мм (кг/мм^2)	–	–	–	160–170	–	135–145	110–125	80–90
13 То же, $\varnothing$ = 100 мм (кг/мм^2)	–	–	–	100–110	–	–	70–80	30–40

1) Properties; 2) temperature (°C); 3) permissible degree of deformation by compression on a hydraulic press $\varepsilon_{pr} = H_0 - h/H_0 \cdot 100\%$; 4) (static load); 5) the same in the case of compression by a drop hammer (dynamic load) $\varepsilon_k = H_0 - h/H_0 \cdot 100\%$; 6) a_H, with a notch (kgm/cm^2); 7) a_H, without a notch (kgm/cm^2); 8) σ_b (kg/mm^2); 9) resistance to deformation in the case of compression on a hydraulic press, P_{pr} (kg/mm^2); 10) the same in the case of compression by a drop hammer; 11) P_k (kg/mm^2); 12) resistance to deformation by 85% compression on a hydraulic press for a container with a diameter of 50 mm (kg/mm^2); 13) the same, diameter = 100 mm (kg/mm^2).

The billets and blanks of chromium and its alloys which are to be worked by deformation are treated by abrasives in order to remove totally the contaminated surface layer and other flaws. The pressing of rods and strips at 1000-1400° from chromium billets melted by the induction or arc method is the method of preliminary deformation most recommended. The pressing of chromium and of its alloys must be carried out with a shrinkage of not less than 50%. Pressing with a smaller shrinkage re-

sults in a failure of the metal by the formation of periodically repeated ringshaped cracks. The primary deformation of ingots may be carried out also by forging on a press at 1600-700° or by a hammer at 1600-1400° with a repeated reheating of the metal. Objects with a complicated form, however, are hardly obtainable by forging, especially with a hammer. The forging of billets below 1300° is carried out in jackets of alloyed steel. A deformation by forging without jackets is possible without failures only for small-size billets from high-grade iodide chromium.

The further deformation of the deformated blanks may be carried out either by pressing at 1600-700°, by stamping in closed dies at 1550-1350°, or by rolling without jackets at 1550-1350° or jacketed in steel at 900-700°. Cold-hardened chromium possesses a significant anisotropy of its properties. Specimens cut transversally from chromium strips rolled at a temperature below 900-800° have a threshold of brittleness which is by 200° higher than that of specimens cut in the direction of rolling. An anisotropy of the properties is less observable after the recrystallization of the metal.

The resistance of pure chromium to deformation is equal to that of most of heatproof steels and alloys.

Alloying reduces the plasticity of chromium and increases considererably the resistance to deformation. Therefore, most of the chromium alloys may be efficient deformated only be pressing at 1600-1400° under high compression stresses. Heating billets and blanks higher than 900-1000° before the deformation must be carried out in furnaces with a neutral (argon or helium) or a protective (hydrogen) atmosphere, or in glass-bath or in salt-baths in order to prevent the reaction of the chromium with nitrogen, oxygen and other active gases. A heating of chromium below 700-800° in electric furnaces in air does not cause sig-

nificant oxidation or brittleness. Protection of the metal up to 1200-1300° from the effect of gases may be achieved by placing the billets and blanks into a metal jacket or by coating them with refractory enamels. In addition to the protective effect, the metal jacket also improves significantly the thermomechanical conditions of the deformation protecting the surface of the heated blank from a quick cooling in contact with the tool; further, the contact friction is reduced, and compression stresses arise in the surface layer of the blank.

A heating in a vacuum is possible only at relatively low temperatures due to the high vapor pressure of the metal. The time of heating before deformation is calculable for chromium and its alloys on the following basis: 1 minute per 1 mm diameter or thickness of the blank (billet).

Glass fabric previously greased with a graphite – machine oil compound may be used as a lubricant for the hot pressing. 0.2-0.5 mm thick blockings or jackets of soft steel must be used in addition to the above mentioned lubrication in the case of stamping chromium or pressing of chromium of a higher strength.

Tools for the hot deformation of chromium and its alloys must be made from the most fireproof stamping-steel grades, 3Kh2V8, EI-756, etc.

References: Sully, A., Khrom [Chromium], translated from English, Moscow, 1958; Problemy sovremennoy metallurgii [Problems of Contemporary Metallurgy], Collection of translated papers, 1958, No. 1 (37), pages [illegible]-92; "J. Inst. Metals," 1954-1955, Vol. 83, Part 4, pages 133-140; 1957-1958, Vol. 86, Part 6, pages 281-288.

I.G. Skugarev and Ye.I. Razuvayev

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[Transliterated Symbols]

4475 пр = pr = predel'nyy = limiting

WORK OF DEFORMATION — the energy stored in a body or unit volume (specific work of deformation) during elastic and plastic deformation; it consists of an elastic component (elastic energy) and a plastic component expended in residual distortions and structural changes, including fracture nuclei. The specific work of deformation $a=\int_0^e \sigma de$, which is defined graphically as the area bounded by the curve $\sigma(\varepsilon)$ and the corresponding segment of the axis ε. The work of deformation characterizes the viscosity of the material.

Ya.B. Fridman

WOVEN STRIP is narrow (width 8-72 mm) fabric made from cotton, flax, kapron and glass fiber. The basic properties of the industrial

Basic Properties of Woven Strip

Наименование изделий 1	2 Ширина (мм)	3 Толщина (мм)	4 Основа: природа волокна 9	4 Основа: число нитей на 1 см 10	5 Уток: природа волокна 9	5 Уток: число нитей на 1 см 10	6 Вес (г) 1 м шириной 10 мм	7 Разрывная нагрузка (кг/см)	8 Удлинение (%)
Лента стеклянная электроизоляционная 11	8—50	0.08—0.25	Стеклянное 28	18—20	Стеклянное 28	16—18	—	10 12 18 21 23	—
Лента изоляционная тафтяная 12	10—50	0.25	Хлопок 29	26—27	Хлопок	19	1	8—9	8
Лента изоляционная киперная 13	10—60	0.45	То же 30	26—27	То же	16	1.9	13	9
Лента изоляционная батистовая 14	10—20	0.16—1.12	»	3.5—4	»	35	0.66—0.74	6	4
Лента сумочная 15	50	1.0—1.1	Хлопок	24	Хлопок	110—120	3.8—4.7	27	—
Лента масочная 16	25	1.0—1.1	То же	23	То же	110—120	4—5	28	—
Лента атласная 17	15	0.50	»	172	»	250	—	32	5
Лента репсовая 18	15	0.45	» 31	116	»	140	—	15	5
Лента специальная ПЛ 19	55	0.7	Лен	27	Лен	278	—	30	2.5
Тесьма наждачная № 37 и 38 20	28 и 38	—	То же	26	Хлопок	180	4—5	30	—
Лента суровая ПЛ-44: 21 №2 и 30	30—43	27 —	»	20—32	Лен и. и хлопок 32	70—180	6—12	43—75	8—18
Тесьма хлопчатобумажная хаки 22	25 и 40	—	Хлопок	60	Хлопок	230—260	5.8—6.8	32—35	9—20
Лента подульная ПЛ-50 23	50	2.0	Лен	23	То же	7.0	14	100	15
Лента поясная: 24									
2137	28	4.2	Хлопок	44	»	3.6	29	116	—
2138	72	2.5	То же	23	»	6.0	13.2	45	—
Лента двубортовая ДК 25	48 и 65	0.62	»	45—48	»	150	4.2—5.0	22	23
Лента гоночная четырехслойная 26	32	5.3	»	37	»	120	30	187	20

1) Product name; 2) width: 3) thickness; 4) warp; 5) fill; 6) weight (g) per 1 m, width 10 mm; 7) breaking load (kg/cm); 8) elongation (%); 9) nature of fiber; 10) number of threads per 1 cm; 11) electric insulation glass strip; 12) taffeta insulating strip; 13) twill insulating strip; 14) cambric insulating strip; 15) sacking strip; 16) masking strip; 17) satin strip; 18) repp strip; 19) PL special strip; 20) No. 37 and 38 emery strip; 21) PL-44 coarse strip; 32 and 30; 22) cotton khaki strip; 23) PL-50 semi-linen strip; 24) belting strip; 25) DK double-edge strip; 26) four-layer drive belting strip; 27) and; 28) glass; 29) cotton; 30) same; 31) flax.

woven fabrics are shown in the Table. They are used for various sorts of retention.

WROUGHT BRASS (simple) is brass containing 57-97% Cu, having high plasticity and easily pressure worked. In the USSR wrought brass is produced in 7 grades (GOST 1019-47). The chemical composition and the fields of application of the wrought brasses are shown in Table 1. The wrought brasses are also produced with nonstandard composition in accordance with specialized specifications, for example, L59 with copper content of 57-61%. With the exception of the L62 brass, the structure of the wrought brasses is single-phase. In the annealed condition the L62 brass has a bi-phase structure ($\alpha + \beta$ crystals). At a temperature above 750° this brass consists only of the crystals of the β-phase. The strength and hardness of the brasses increases with increase of the zinc content (Fig. 1). The maximal plasticity is evidenced by the L68 brass which is used primarily for the fabrication of details which can be produced by stamping or other forms of working with high degrees of drawing. Of the standard brasses the widest application has been of the L62 brass which contains the minimal amount of copper and which has quite high mechanical properties and corrosion resistance. The wrought brasses used for the fabrication of details by extrusion, along with high plasticity, must have limited grain size. Coarse grain structure leads to the formation of a rough surface on the extruded products. Cracks may form during deep drawing of the wrought brasses which have a very fine grain. The best properties are evidenced by the brasses with a grain diameter in the range of 30-60 microns. The grain size depends on the degree of preliminary deformation and the annealing regime (temperature and time).

II-72k1

The diagrams (Figs. 2-5) show the variation of the mechanical properties and the grain size of L62 brass as a function of the degree of

TABLE 1

Chemical Composition and Use of Wrought Brasses (GOST 1019-47)

Сплав 1	2 Содержание элементов (%)							4 Сумма примесей	3 Применение
	Cu	Zn	Pb	Fe	Sb	Bi	P		
	5 Основные элементы	7	6 Примеси, не более						
Л96	95.0—97.0	Ост.	0.03	0.10	0.005	0.002	0.01	0.2	Радиаторные трубки 8
Л90 14	88.0—91.0	»	0.03	0.10	0.005	0.002	0.01	0.2	Листы, лента для плакировки 9
Л85...	84.0—86.0	»	0.03	0.10	0.005	0.002	0.01	0.3	Трубы гофрированные 10
Л80...	79.0—81.0	»	0.03	0.10	0.005	0.002	0.01	0.3	Листы, лента и проволока 11
Л70...	69.0—72.0	»	0.03	0.07	0.002	0.002	0.003	0.2	Полосы и лента 12
Л68...	67.0—70.0	»	0.03	0.10	0.005	0.002	0.01	0.3	Полосы, листы, лента, трубы и проволока 13
Л62...	60.0—63.5	»	0.08	0.15	0.005	0.002	0.01	0.5	Полосы, листы, лента, трубы и проволока 13

* In the L70 grade brass there must be no more than 0.005% As, 0.005% Sn and 0.002% S; in the antimagnetic brasses the iron content must be no more than 0.03%.

1) Alloy; 2) content of elements (%); 3) use; 4) total impurities; 5) basic elements; 6) impurities, no more than; 7) remainder; 8) radiator tubes; 9) sheets, ribbons for cladding; 10) corrugated tubes; 11) sheets, ribbons and wire; 12) strip and ribbon; 13) strips, sheets, ribbon, tubes and wire; 14) L.

deformation, temperature and duration of anneal. The variation of the time of beginning and end of recrystallization as a function of the degree of deformation and the annealing temperature for the L62 brass is shown in Fig. 6. The relationship between the hardness, ultimate strength and relative elongation is shown in Fig. 7. The wrought brasses, having good mechanical properties and relatively high corrosion resistance, are widely used for the fabrication of various products, machine parts and equipment.

Sheet and strip (GOST 931-52), rod (GOST 2060-60), tubes (GOST 492-52) and wire (GOST 1066-58) are made from the wrought brasses. The mechanical properties of the mill products made from the L68 and L62

brasses are shown in Table 2. The basic physical and technological properties of the wrought brasses are shown in Table 3.

TABLE 2

Mechanical Properties of Mill Products from the L68 and L62 Brasses

1 Сплав	2 Листы и полосы (ГОСТ 931–52)				3 Проволока диаметром 0,20–0,75 мм (ГОСТ 1066–59)		
	4 Состояние материала	5 $\sigma_в$ (кг/мм², не менее)	6 δ (%, не менее)	7 Глубина продавливания по Эриксену (диаметр пуансона 10 мм, толщина листа 0,5 мм)	8 Состояние материала	9 $\sigma_в$ (кг/мм²)	10 δ (%, не менее)
Л68 11	Холоднокатан. мягкий 13	30	40	>11	Мягкий	>35	25
14	Полутвердый	35	25	9,0–11,0	Полутвердый	>40	5
	Твердый 15	40	15	7,0–9,0	23 Твердый	70–95	—
Л62	Горячекатан. 16	30	30	—	Мягкий	>35	20
	Холоднокатан. мягкий 17	30	40	>9,5	—	—	—
18	Полутвердый	35	20	7,0–9,0	Полутвердый	>45	5
	Твердый 19	42	10	5,0–7,0	Твердый	70–95	—
	Особо твердый 20	60	2,5	—	—	—	—

1) Alloy; 2) sheets and strips (GOST 931-52); 3) wire of diameter 0.20-0.75 mm (GOST 1066-58); 4) material condition; 5) (kg/mm², no less than); 6) (%, no less than); 7) Erichsen penetration depth (punch diameter 10 mm, sheet thickness 0.5 mm); 8) material condition; 9) (kg/mm²); 10) (%, no less than); 11) L68; 12) L62; 13) cold rolled, soft; 14) half-hard; 15) hard; 16) hot rolled; 17) hot rolled, soft; 18) half-hard; 19) hard; 20) extra hard; 21) soft.

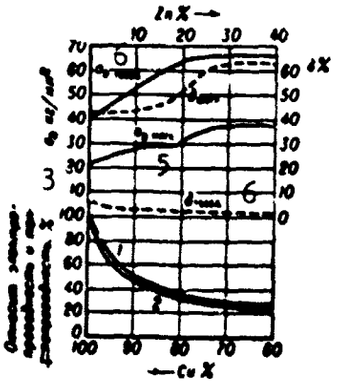

Fig. 1. Properties of wrought brass as a function of the zinc content: 1) Thermal conductivity; 2) electrical conductivity (in relation to copper). 3) kg/mm²; 4) relative electrical and thermal conductivity; 5) soft; 6) hard.

The grade L96 wrought brass, resistant to corrosion cracking and having the highest thermal conductivity, is used for the fabrication of radiator tubes (primarily for aircraft radiators) and condenser tubes.

II-72k3

The grade L90 wrought brass, having high corrosion resistance, welds well with steel and, therefore, is used for the fabrication of bimetals

TABLE 3

Physical and Technological Properties of the Wrought Brasses

Сплав 1	Темп-ра плавления (°С) 2	3 γ (г/см³)	4 ρ (ом·мм²/м)	5 E (кг/мм²) мягкая 6	5 E (кг/мм²) твердая 7	α·10⁶ (1/°С) 8	c (кал/г·°С)	λ (кал/см·сек·°С) 9	Темп-ра горячей обраб. (°С) 10	Темп-ра отжига (°С) 11
Л96 12	1070	8.85	0.043	—	11400	17	0.093	0.585	700—850	450—650
Л90	1045	8.78	0.045	—	10500	17	0.09	0.40	700—850	450—650
Л85 . . .	1025	8.75	0.047	—	10500	18.7	0.092	0.36	750—850	450—650
Л80 . . .	1000	8.66	0.054	10600	11400	18.5	0.093	0.34	750—850	450—650
Л70 . . .	950	8.62	0.069	—	11200	18.9	0.09	0.29	750—850	450—650
Л68 . . .	938	8.60	0.072	11000	11500	19	0.093	0.28	750—850	450—600
Л62 . . .	905	8.43	0.074	10000	—	20.6	0.092	0.26	750—850	450—650

1) Alloy; 2) melting point (°C); 3) (g/cm^3); 4) (ohm-mm^2/m); 5) E(kg/mm^2); 6) soft; 7) hard; 8) (cal/g-°C); 9) (cal/cm-sec/°C); 10) hot working temperature (°C); 11) annealing temperature (°C); 12) L.

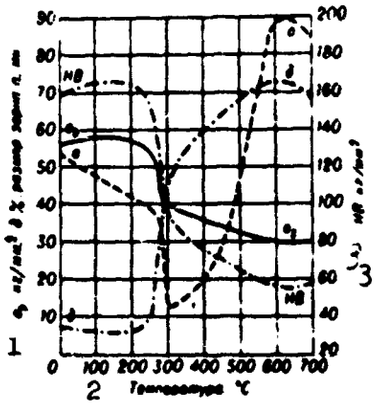

Fig. 2. Variation of mechanical properties and grain size of L62 brass with annealing temperature (predeformation 50%, anneal duration 3 hours). 1) σ_b, kg/mm^2 δ %; grain size, a, microns; 2) HB, kg/mm^2.

and thermo-bimetals of the steel-brass type. This brass accepts enameling and gilding well and has a golden color, in this connection is also used for the fabrication of furniture, artistic objects, and signs. The L96 and L90 brasses are also termed tombac. The L85 grades of wrought brasses are used for bellows of flexible hoses, details of refrigerators, and also for certain types of condenser tubes. The L80 type wrought brasses are intended primarily for wire sieves in paper making

machinery and for bellows. The L85 and L80 brasses are also termed semi-tombac. The L70 type wrought brasses, having high plasticity and

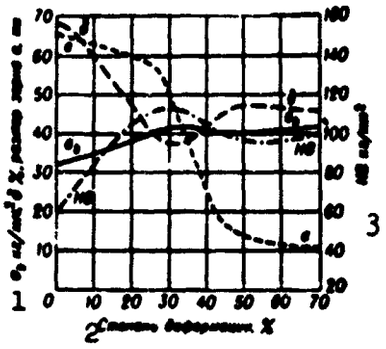

Fig. 3. Variation of mechanical properties and grain size of L62 brass annealed at 300° with degree of deformation. 1) σ_b, kg/mm^2; δ %; grain size, a, microns; 2) degree of deformation, %; 3) HB, kg/mm^2.

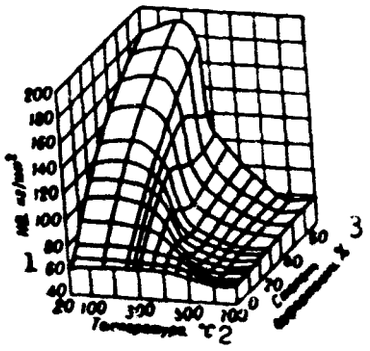

Fig. 4. Variation of hardness of L62 brass with degree of predeformation and annealing temperature (heating duration 3 hours). 1) HB, kg/mm^2; 2) temperature, °C; 3) degree of deformation, %.

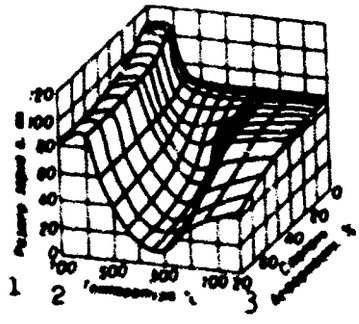

Fig. 5. Variation of average grain diameter of L62 brass with degree of deformation and anneal temperature (heating duration 3 hours). 1) Grain size, a, microns; 2) temperature °C; 3) degree of deformation, %.

good extraction, are used for all sorts of cartridges, sleeves and other special products.

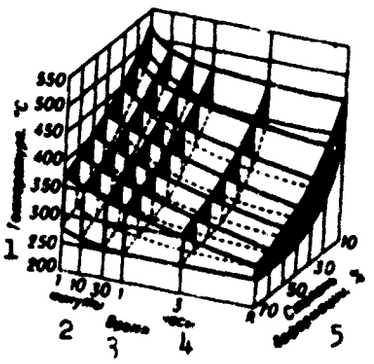

Fig. 6. Dependence of initiation and end of recrystallization of L62 brass on degree of deformation, temperature and duration of anneal. 1) Temperature, °C; 2) minutes; 3) time; 4) hours; 5) degree of deformation, %.

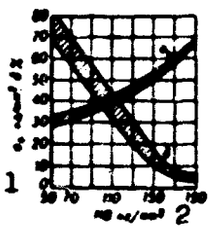

Fig. 7. Relationship between ultimate strength, relative elongation and Brinnel hardness for L62 brass. 1) σ_b, kg/mm^2, δ, %; 2) HB, kg/mm^2.

References: Mal'tsev M.V., Barsukova T.A., Borin F.A., Metallografiya tsvetnykh metallov i splavy [Metallography of Nonferrous Metals and Alloys], Moscow, 1960; Smiryagin, A.P., Promyshlennyye tsvetnyye metally i splavy [Industrial Nonferrous Metals and Alloys], 2nd ed., M., 1956; Fischer E. und Voss-kühler H., "Z. Metallkunde", 1956, Vol. 47, No. 6, pages 397-401.

Ye.S. Shpichinetskiy

WROUGHT HARD MAGNETIC ALLOYS are alloys for permanent magnets which are capable of plastic deformation. The wrought hard magnetic alloys are divided into the following groups: 1) The dispersion hardening alloys based on α-iron (Fe – Mo, Fe – Co – W, Fe – Co – Mo, Fe – Co Mo, Fe – Co – W – Mo). Among these alloys we make particular note of Comol (Remalloy), containing 12% Co, 17% Mo, remainder Fe, with coercive force H_c = 250 oe, residual induction B_r = 10,500 gauss, and magnetic energy $W = 1.1 \cdot 10^6$ gauss-oe. The similar alloys 12KMa, b, c and also 12KV and 16KVM are used as materials for rotors of hysteresis electric motors. In the alloys of this group the highly coercive state is created as a result of annealing after quenching. 2) The dispersion hardening Cu – Ni – Fe and Cu – Ni – Co alloys, For the anisotropic alloys Cunife I (60% Cu, 20% Ni, balance Fe; H_c = 590 oe, B_r = 5900 gauss, $W = 1.9 \cdot 10^6$ gauss-oe) and Cunife II (60% Cu, 20% Ni, 2.5% Co; H_c = 260 oe, B_r = 7300 gauss, $W = 0.8 \cdot 10^6$ gauss-oe) after heat treatment (solution treatment and anneal) there is required additional cold deformation (reduction of 80–90%) with additional annealing. The alloys Cunico I (50% Cu, 21% Ni, 29% Co; H_c = 700 oe, B_r = 3400 gauss, $W = 0.9 \cdot 10^6$ gauss oe) and Cunico II (35% Cu, 21% Ni, balance Co; H_c = 450 oe, B_r = 5300 gauss, $W = 1.1 \cdot 10^6$ gauss-oe) are isotropic. 3) The anisotropic alloys with γ → α-transformation whose high energy is obtained by means of cold plastic deformation with large reduction and subsequent annealing (Fe – Co – V, Fe – Cr – Ni, Fe – Mn – Ni). The alloys Vicalloy I (52% Co, 9.5% V, balance Fe) and Vicalloy II (52% Co, 13% V, balance Fe) along with Cunife and Cunico are used for the production of tapes and wires

for sound recording, small stamped magnets and magnets of complex configuration which cannot be produced in the form of castings from the alloys of the Alni type. The OKh18N9 alloy with Mo additions, after reduction of 90-95%, have good properties in fine wire, which with diameter of 0.09 and 0.05 mm is suitable for sound recording, and with diameter of 0.05 and 0.03 mm is suitable for pulse recording. The 12NG, 12GN alloys may be used for rotors of hysteresis electric motors. 4) Alloys based on the noble metals. Silmanal (8.8% Mn, 4.4% Al, 86.8% Ag) has high stability of the residual magnetism and finds application in moving magnet instruments operating under conditions of action of constant magnetic fields. The Fe – Pt (78% Pt) and Co – Pt (77% Pt) alloys havevery high magnetic properties. All these alloys, in view of their shortage, are used in particularly critical instruments.

References: Zaymovskiy A.S., Chudnovskaya L.A., Magnitnyye materialy (Magnetic Materials), 3rd ed., M.-L., 1957 (Metally i splavy v elecktrotekhnike) (Metals and Alloys in Electrical Engineering, Vol. 1); Bozort R., Ferromagnetizm (Ferromagnetism), translated from Eng., M., 1956; Rayevskaya M.N., in book Pretsizionnyye splavy (Precision Alloys), M., 1960 (collection of works of TsNIIChM)(Central Scientific Research Institute for Ferrous Metallurgy), No. 2); Dovgalevskiy Ya.N., Splavy dlya postoyannykh magnitov (Alloys for Permanent Magnets), M., 1954.

B.G. Livshits, A.A. Yudin

WROUGHT HEAT-RESISTANT NICKEL ALLOYS are nickel-base alloys which surpass nickel in resistance to oxidation at high temperatures and which have high technological plasticity and good weldability.

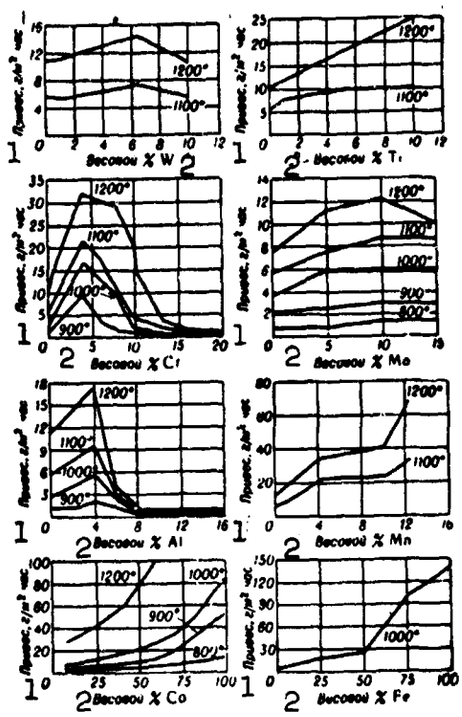

Fig. 1. Effect of element content on oxidation of nickel. 1) Weight increase, g/m^2-hour; 2) weight %.

The heat resistance of nickel may be increased by the introduction of more than 10% chromium or more than 5% aluminum (Fig. 1). With this aluminum content, a two-phase structure is formed which has an unfavorable effect on the processing properties of the alloy. Therefore, in order to improve the heat resistance of nickel use is usually made of chromium, whose solubility in nickel reaches 35%. In practice the heat-resistant alloys of nickel with chromium (nichromes) contain from 15 to

TABLE 1

Chemical Composition of Wrought Heat-Resistant Nickel Alloys (GOST 5632-61)

Сплав 1	2 Содержание элементов (%)								3		
	C	Cr	Ti	Al	Fe	Ni	Mn	Si	др. элементы	S	P
ХН78Т (ЭИ435) 4	<0,12	19—22	0,15—0,35	<0,15	<6,0	Основа 5	<0,7	<0,8	—	<0,015	<0,020
ХН75МБТЮ (ЭИ602) 6	<0,10	19—22	0,35—0,75	0,35—0,75	<8	Основа	<0,4	<0,8	1,8—2,3 Mo; 0,9—1,3 Nb	<0,012	<0,02
ХН60В (ЭИ868, ВЖ98) 7	<0,1	23,5—26,5	0,3—0,7	<0,5	<4	Основа	<0,5	<0,8	13—16 W	<0,013	<0,013
ХН70Ю (ЭИ652) 8	<0,1	26,0—29,0	—	2,6—3,5	<1	Основа	<0,3	<0,8	<0,03 Ce <0,1 Ba	<0,02	<0,02
ХН60Ю (ЭИ559А) 9	<0,1	15—18	—	2,6—3,5	Остальное	55—58	<0,3	<0,8	<0,03Ce <0,1 Ba	<0,02	<0,02

1) Alloy; 2) element content, %; 3) other elements; 4) KhN78T (EI435); 5) base; 6) KhN75MBTYu (EI602); 7) KhN60V (EI868, VZh98); 8) KhN70Yu (EI652); 9) KhN60Yu (EI559A).

30% chromium. In some cases use is made of joint alloying with chromium and aluminum.

During the oxidation of pure nickel a film of the oxide NiO which has a cubic structure of the NaCl type with an excess of oxygen is formed on the surface. It is believed that after the formation of the oxide film the oxidation of nickel proceeds primarily as a result of diffusion of the ions and electrons through the oxide layer to the oxide-atmosphere interface. The defective structure of the NiO oxide film crystal lattice (deficiency of nickel atoms) contributes to the diffusional penetrability of the film.

Two new phases may be formed in the oxide film along with NiO with introduction of chromium into the nickel – the chromium oxide Cr_2O_3 and the double oxide $NiOCr_2O_3$ with a spinel structure. Some investigators believe that the oxide films having a spinel structure have the best protective capability. Others have found that the protective film on the nichromes consists primarily of the Cr_2O_3 oxide. There are data

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which show that at 1100° with increase of the chromium content the relative amount of the spinel in the oxide film increases only up to chromium concentrations for which the heat resistance of the nickel increases slightly, while the relative amount of the Cr_2O_3 phase increases continuously up to chromium concentrations which provide for sharp increase of the nickel heat resistance.

TABLE 2

Heat Treatment Temperature Providing Optimal Operational Properties of Wrought Heat-Resistant Nickel Alloys

Сплав 1	2 Темп-ра нагрева (°С)	
	мелкое зерно 3	крупное зерно 4
5 ХН78Т 6	8 1000	1150
ХН75МБТЮ	1070	1170
7 ХН60В	Не рекомендуется	1200
ХН70Ю 9	1140	1200
ХН60Ю	1100	1150
10		

1) Alloy; 2) heating temperature (°C); 3) fine grain; 4) coarse grain; 5) KhN78T; 6) KhN75MBTYu; 7) KhN60V; 8) not recommended; 9) KhN70Yu; 10) KhN60Yu.

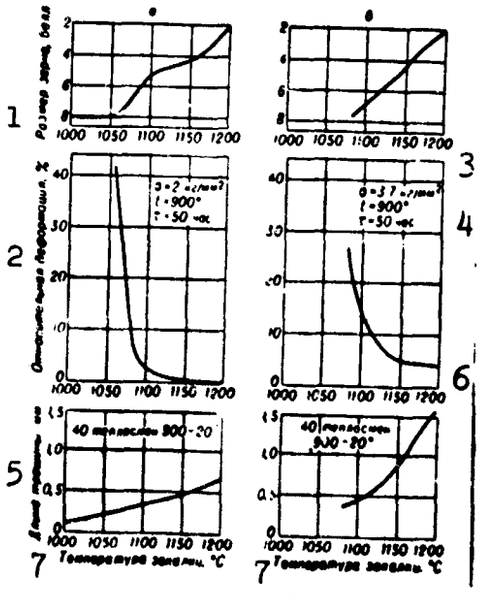

Fig. 2. Effect of heat treatment on deformation of the KhN78T (a) and KhN75MBTYu (b) alloys. 1) Grain size, number; 2) relative deformation, %; 3) kg/mm^2; 4) hours; 5) crack length, mm; 6) thermal cycles; 7) quench temperature, °C.

TABLE 3

Heat Resistance (Scale Resistance) of the Wrought Heat-Resistant Nickel Alloys*

Сплав 1	Привес (г/м² час) при темп-ре испытаний (°С) 2				
	900	1000	1100	1200	1300
3 ХН78Т	0.049	0.142	0.367	0.701	1.046
4 ХН75МБТЮ	0.062	0.264	0.517	1.102	4.189
ХН60В	—	—	0.365	0.807	—
5 6 ХН70Ю	—	—	0.067	0.16—0.48	—
7 ХН60Ю	—	—	—	0.138	—

*Continuous testing for 100 hours.

1) Alloy; 2) weight gain (g/m^2-hr) at test temperature (°C); 3) KhN78T; 4) KhN75MBTYu; 5) KhN60V; 6) KhN70Yu; 7) KhN60Yu.

TABLE 4

Mechanical Properties (sheet 1.5 mm thick) of Wrought Heat-Resistant Nickel Alloys

Сплав 1	Термич. обработка (темп-ра нагрева, °С) 2	Темп-ра (°С) 3	$\sigma_в$ (кг/мм²) 4	$\sigma_{0.2}$ (кг/мм²) 4	δ (%)
ХН78Т	1000	20	78	27.5	40
5		700	40	19	35
		800	18	10	70
		900	11	—	90
		1000	6.5	—	100
		1100	4.5	—	112
		1200	2.4	—	130
	1150	20	70	—	51
		800	25	—	77
		900	14	—	93
		1000	8.1	—	94
		1100	4.7	—	129
ХН75МБТЮ	1070	20	86	40	45
		700	56	27.5	42
6		800	29.7	15	40
		900	17.7	—	78
		1000	9.5	—	75
		1100	4.7	—	92
	1170	20	77	—	62
		800	29	—	63
7		900	18	—	74
		1000	10	—	75
		1100	5.4	—	64
ХН60В	1200	20	80	32	60
		700	53	23	47
		800	40	21	40
		900	23	12	50
		1000	14	6.5	52
		1100	8.5	—	58
		1200	4.3	—	60
ХН70Ю	1200	20	73	—	75
		700	42	—	10
8		800	26	—	14
		900	15	—	65
		1000	8.6	—	55
		1100	3.8	—	70
		1200	2.4	—	138
ХН60Ю	1100	20	72	—	60
		700	40	—	3
		800	22	—	40
9		900	11.5	—	71
		1000	7	—	68
		1200	2	—	132

1) Alloy; 2) heat treatment (heated to temperature, °C); 3) temperature

(°C); 4) (kg/mm^2); 5) KhN78T; 6) KhN75MBTYu; 7) KhN60V; 8) KhN70Yu; 9) KhN60Yu.

TABLE 5

Stress-Rupture Strength

1 Сплав	2 Термич. обработка (нагрев. °С)	3 Темп-ра	σ_{100}	σ_{200}	σ_{300}
			4 (кг/мм^2)		
ХН78Т	1000	700	10,5	5,8	—
		800	4,5	3,4	—
		900	1,5	—	—
5	1150	800	6	—	—
		900	2,7	—	—
ХН75МБТЮ	1070	700	16—17	15	—
		800	8	7	—
		900	2,8	2,2	—
6	1170	800	8,8	2,2	—
		900	4,2	—	—
7 ХН60В	1200	800	11	7,5	8,7
		900	5,2	4,3	4
8 ХН70Ю	1200	800	— 9	—	8
		900	4 (50 час.)	—	—
ХН60Ю	1100	800	8 (50 час.)	—	—
		900	4 (20 час.)	—	—

1) Alloy; 2) heat treatment (heated to temperature, °C); 3) temperature (°C); 4) (kg/mm^2); 5) KhN78T; 6) KhN75MBTYu; 7) Khn60V; 8) KhN70Yu; 9) hours; 10) KhN60Yu.

TABLE 6

Creep Limits (100 hours; deformation 5%)

Сплав 1	Термич. обработка (t° нагрев. °С) 2	Темп-ра (°С) 3	$\sigma_{5/100}$ (кг/мм^2) 4
ХН78Т	1000	800	1,8
		900	0,7
		1000	0,57
5	1150	800	2,8
		900	2,1
		1000	1,1
ХН75МБТЮ	1070	800	4,2
		900	1,4
		1000	0,8
6		1100	0,5
		1200	0,32
	1170	800	8,5
		900	3
		1000	1,1
		1100	0,55
		1200	0,35
ХН60В	1200	800	8,2
		900	3,4
7		1000	1,7
		1100	0,64
		1200	0,33
ХН70Ю	1200	800	10,5
		900	3,6
		1000	1,6
8		1150	0,57
		1200	0,29
ХН60Ю	1120	900	2,4
9		1000	1

1) Alloy; 2) heat treatment (heating °t, °C); 3) temperature (°C); 4) kg/mm^2; 5) KhN78T; 6) KhN75MBTYu; 7) KhN60V; 8) KhN70Yu; 9) KhN60Yu.

There are data indicating that the protective film on the type 80-20 nichrome at 600-700° consists of the chromium oxide Cr_2O_3. At 800° a spinel layer is formed on the outer side of the film and the relative thickness of this layer increases sharply with temperature increase to 1000°. Slight alloying of the nichrome with certain elements may have a marked influence on the structure of the oxide films. For example, the presence of silicon (1.39%) in the alloy stabilizes the Cr_2O_3 phase, while the presence of manganese (1.7%) facilitates the formation of a spinel. The introduction of aluminum considerably increases the heat resistance of nichrome. According to the available data the protective films on the ternary alloys Ni-Cr-Al have a spinel structure. Small additions of certain elements considerably increase the heat resistance of nichrome under conditions of thermal cycling; most effective are cerium, calcium, and thorium (see Fig. 10 in article on Corrosion of Nickel Alloys), and also silicon. There are several hypotheses relative to the effect of these elements, however it is most likely that the favorable influence of these additions involves improvement of the mechanical bonding of the oxide film with the basic metal, since testing for heat resistance without thermal cycling does not show any advantages of the alloys containing calcium or silicon in comparison with the simple nichrome.

The wrought heat-resistant nickel alloys are used to fabricate parts operating at 700-1100°. They are also used as heating elements (see Alloys for Heating Elements). The nichromes, which have good strength at high temperature in addition to excellent heat resistance, are usually used as constructional materials. This is achieved by alloying with the refractory metals (molybdenum, tungsten, etc.) in the limits of the solid solution, and also by using th elements which form stable carbides or carbonitrides (niobium, titanium). The nichromes in

TABLE 7

Endurance Limits (at 900° on $1 \cdot 10^7$-cycle base)*

Сплав 1	Термич. обработка (темп-ра нагрева, °C) 2	σ_{-1} (кг/мм²) 3
ХН78Т 4	1000	10
	1150	11
ХН75МБТЮ 5	1070	14
	1170	14
ХН70Ю 6	1149	11
	1200	12
ХН60В 7	1200	17

*Sheet 1.5 mm thick.

1) Alloy; 2) heat treatment (heating temperature, °C); 3) kg/mm^2; 4) KhN78T; 5) KhN75MBTYu; 6) KhN70Yu; 7) KhN60V.

TABLE 8

Physical Properties

Сплав 1	2 $\alpha \cdot 10^6$ (1/°C) в интервалах темп р (°C)				3 λ (кал/см·сек·°C) при темп-ре (°C)			
	20—100	20—400	20—700	20—900	100	400	700	900
ХН78Т 4	12.8	14.9	16.7	17.7	0.035	0.049	0.064	0.076
ХН75МБТЮ 5	12.4	13.7	15	16	0.032	0.044	0.058	0.07
ХН60В 6	12.7	14	15.8	16.4	0.025	0.039	0.056	0.067
ХН70Ю 7	13.14	15.68	22.42	21.34	0.03	0.041	0.055	0.064

1) Alloy; 2) $\alpha \cdot 10^6$ (1/°C) in temperature ranges (°C); 3) λ (cal/cm-sec-cm-°C) at temperature (°C); 4) KhN78T; 5) KhN75MBTYu; 6) KhN60V; 7) KhN70Yu.

which the increase of the high-temperature strength is achieved by means of alloying with elements which give rise to intensive aging belong to the high-temperature alloys (see Wrought High-Temperature Nickel Alloys). The wrought heat-resistant nickel alloys considered in the present article belong to the nonaging or slightly aging alloys and their chemical composition is shown in Table 1.

Heat treatment of the wrought heat-resistant nickel alloys may be performed to relieve strain hardening or to obtain optimal operational properties (Table 2). Short-term heating of the alloys to the temperature at which intensive recrystallization begins is sufficient to re-

lieve strain hardening. Heating at the following temperatures may be used in practice (subsequent air or water quench):

950-1000°	for	alloy	KhN78T
1000-1050°	"	"	KhN75MBTYu
1100-1130°	"	"	KhN60V
1050-1100°	"	"	KhN70Yu
1050-1100°	"	"	KhN60Yu

In order to obtain optimal operational properties, heat treatment is performed to obtain a specified grain size, with account for the fact that a fine-grain structure (No. 8-6 on the standard scale) provides for high resistance to thermal fatigue (resistance to failure under the action of repeated thermal cycling), but does not permit obtaining the maximal high-temperature strength, while a coarse-grain structure (No. 5-2 on the standard scale) gives the material high strength at high temperature but at the same time reduces the thermal fatigue resistance. Figure 2 shows the effect of heat treatment temperature (grain size) on deformation under the action of constant stress and on cracking under the action of thermal cycling for the KhN78T and KhN75MBTYu alloys (sheet 1.5 mm thick).

The time at the indicated temperature must amount to 1.5-2 minutes per 1 mm of part section thickness, air cool.

The heat resistance of the wrought heat-resistant nickel alloys is shown in Table 3, the mechanical properties in Tables 4-7, and the physical properties in Table 8.

The wrought heat-resistant nickel alloys have satisfactory capability for cold deformation and are suitable for fabricating detail parts from sheet by deep drawing, bending, etc. The wrought heat-resistant nickel alloys weld satisfactorily using various forms of welding (see Welding Nickel Alloys).

Applications of the wrought heat-resistant nickel alloys are: the

II-52n8

KhN78T alloy is used to fabricate flame tubes of gas turbine combustion chambers operating at 700-900°; the KhN75MBTYu alloy is used to make gas turbine combustion chamber flame tubes, afterburner chambers for jet engines operating at 800-950°; the KhN60V alloy is used for gas turbine combustion chamber flame tubes, afterburner chambers, afterburner eyelids operating at 850-1000°; the KhN70Yu and KhN60Yu alloys are used for flame tube mixing pockets which require heat resistance to 1100°.

References: Kornilov, I.I., Zheleznyye splavy [Iron Alloys], Vol. 3, Moscow, 1956; Tumarev, A.S., Panyushin, L.A., "Izv. vysshikh uchebnykh zavedeniy" [News of Higher Educational Institutions], 1959, No. 8, page 117; Ignatov, D.V. and Shamgunova, R.D., O mekhanizme okisleniya splavov na osnove nikelya i khroma [On the Mechanism of Oxidation of Nickel- and Chrome-Base Alloys], Moscow, 1960; Culbransen, E.A., McMillan, W.B., "Industr. and Engng Chem.," 1953, Vol. 45, No. 8, page 1734-44; Culbransen, E.A., Andrew, K.F., "J. Electrochem. Soc.," 1957, Vol. 104, No. 7, page 451; idem., ibid., 1959, Vol. 106, No. 11, page 941; Frederick, S.F., Cornet, I., ibid., 1955, Vol. 102, No. 6, page 285; Zima, G.E., "Trans. Amer. Soc. Metals," 1957, Vol. 49, page 924; Hickman, J.W., Gulbransen, E.A., "Amer. Instn Mining Metallurgical Engrs," 1948, Oct., No. 2372 (Metal Technology, June, 1948); Preece, A., Member, F.I.M., Lucas, G., "J. Inst. Metals," 1953, Vol. 81, page 219; Hessenbruch, W., Metalle und Legierungen für hohe temperaturen [Metals and Alloys for High Temperatures], Vol. 1, Berlin, 1940; Lustman, B., "J. Metals," 1950, Vol. 188, No. 8, page 995; Smithells, C.J., Williams, S.V., Avery, J.W., "J. Inst. Metals," 1928, Vol. 40, No. 2, page 269; Hauffe, K., "Arch. Eisenhüttenwesen" [Arch. Metallurgy of Iron], 1953, Vol. 24, No. 3/4, page 161.

M.Ya. L'vovskiy

WROUGHT HIGH-TEMPERATURE NICKEL ALLOYS are nickel- and chromium-bearing alloys with additions of the alloying elements Ti, Al, Cr, Mo, W, Nb, C, B, Ba, Ca, Zr, Ce, which are used to fabricate the most highly stressed parts of gas turbine engines and other power plants operating at high temperatures. The variation of the high-temperature strength of nickel as a function of the introduction of alloying elements into it is shown in Fig. 1. At 800° nickel has a stress-rupture strength after 100 hours of about 4 kg/mm^2, the addition of 20% Cr strengthens the solid solution relatively little, but increases the scale resistance of the alloy; the increase of the stress-rupture strength does not exceed 25-30%. The introduction of 2.5-3% Ti into the nichrome alloys together with the addition of a small amount of aluminum (0.7%) provides for a significant increase of their high-temperature strength as a result of the formation at moderate temperatures of the highly dispersed intermetallide γ'-phase; as a result of the dispersion hardening processes the resistance of the alloys to plastic deformation at both room and elevated temperatures is increased. Some increase of the aluminum content (along with the addition of titanium, increases still further the high-temperature strength properties of the nickel-base alloys as a result of the increase of the amount of the dispersed phases which are formed during heat treatment.

The presence of chromium in the nickel alloys containing aluminum and titanium does not alter the transformation mechanism in these alloys but does have an effect on the variation of the solubility curves - they are displaced in the direction of lower concentrations. Moreo-

)ver, the chromium content in these alloys alters the binding energy of the atoms in the crystal lattice, which has an effect on the chromium and titanium diffusion rate and aids in improving the high-temperature

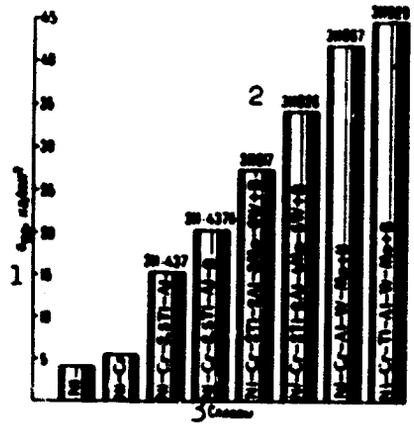

Fig. 1. Effect of alloying on the strength of the nickel alloys at 800°. 1) σ_{100}, kg/mm^2; 2) EI; 3) alloys.

TABLE 1

Chemical Composition of Wrought High-Temperature Nickel Alloys

Сплав по ГОСТ 5632-61 1	Заводская марка 2	3 Содержание элементов (%) 6												
		C	Si	Mn	Cr	Mo	Ti	Al	W	Fe	Co	B	другие элементы 5	S и P
		4 не более								4 не более				не более
ХН77ТЮ 7	ЭИ437А	0.6	0.6	0.4	19–22	–	2.3–2.7	0.55–0.95	–	4	0.01	–	–	0.007 S 0.015 P
ХН77ТЮР 9	ЭИ437Б	0.6	0.6	0.4	19–22	–	2.3–2.7	0.55–0.95	–	4	0.01	0.01	Ba<0.01	0.007 S 0.015 P
ХН67МТЮ 10	ЭИ445	0.08	0.6	0.5	17–20	4–5	2.2–2.6	1 –1.5	4–5	4	0.01	0.01	–	0.015 S 0.015 P
ХН70ВМТЮ	ЭИ617	0.12	0.6	0.5	13–16	3–4	1.9–2.3	1.7 –2.3	5–7	5	0.02	0.02	V=0.1–0.5	0.015 S 0.015 P
– 11	ЭИ826	0.12	0.6	0.5	13–16	2.5–3	1.7–2.2	2.3 –2.8	5–7	5	0.02	0.015	V=0.1–0.5	0.015 S 0.015 P
ХН70МВТЮБ	ЭИ598	0.12	0.6	0.5	16–19	4–6	1.8–2.4	1 –1.7	2–3.5	5	0.02	0.01	Nb=0.5–1.3	0.015 S 0.015 P
– 12	ЭИ867	0.1	0.6	0.3	9.5–10.5	9–11.5	–	4.2 –4.8	4–6	4	0.02	0.02	Co=4–6	–
ВЖ36-300	ЭИ929	0.12	0.5	0.5	9–12	4–6	1.4–2	3.6 –4.5	4.5–6.5	5	–	0.02	Co=12–16 V=0.2–0.8 Ba=0.1	–
13														

1) Alloy per GOST 5632-61; 2) plant designation; 3) element content (%); 4) no more than; 5) other elements; 6) S and P; 7) KhN77TYu; 8) EI; 9) KhN77TYuR; 10) KhN67MTYu; 11) KhN70VMTYu; 12) KhN70MVTYuB; 13) VZh36-300.

strength. In several of the alloys the γ'-phase is a transient metastable phase and under certain conditions (long soak at 800° and higher) is transformed into the stable η-phase of the Ni_3Ti type with hexagonal lattice; the stability of the γ'-phase depends on the degree of alloy-

ing. In addition to the formation of the Ni_3Al and γ' strengthening phases, in the chrome-nickel alloys, in spite of the small carbon content, during heat treatment titanium carbides of the TiC type, chromium carbides of the Cr_uC_3 $Cr_{23}C_6$ type, and binary carbides of the $Me^1_nMe^2_m$ type may be precipitated out. The increase of the high-temperature strength of the alloys is associated with increase of the amount of the dispersed phases which are precipitated out as a result of the action of moderate temperatures, and with their interaction with the solid so-

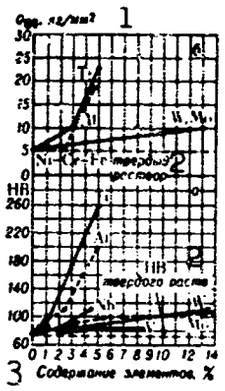

Fig. 2. Effect of alloying elements on hot hardness of the type 75-15-7 chrome-nickel-iron alloy (a) and on the stress-rupture strength at 800° (b). 1) σ_{100}, kg/mm^2; 2) solid solution; 3) element content, %.

lution. The composition of the intermetallide, carbide, and also the boride phases varies as a function of the alloying and the heat treatment. In certain cases small additions of carbon (0.1%) aid in refining the grain for the same heat treatment regimes and thus improve the fatigue resistance.

The introduction of Mo or W (or Mo and W together) into the nickel-chromium-titanium-aluminum alloys aids the further increase of the high-temperature strength in the higher temperature range; individual alloying (Fig. 2) of the nickel-chromium alloys with the various elements is not as effective as combined alloying.

In many alloys with low carbon content the W and Mo do not enter

into the composition of the strengthening phases if their content is low. These elements have a favorable effect when they are present in the solid solution, increasing the thermal resistance of the solution by means of inhibiting the weakening processes at high temperatures.

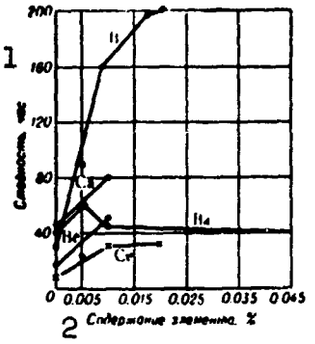

Fig. 3. Effect of boron, calcium, barium, beryllium, and cerium on the life of an alloy of the EI617 type at a temperature of 850° and stress of 20 kg/mm^2. 1) Life, hours; 2) element content, %.

They also increase the recrystallization temperature of the solid solution, moreover, molybdenum increases the chromium self-diffusion activation energy in the alloy. That is, the effect of both elements reduces to suppression or inhibition of the diffusion processes, without which there can be no interchange of atoms in the solid solution during coagulation and recrystallization. In the high-temperature chrome-nickel alloys, the tungsten is distributed along the axes of the dendrites, while molybdenum and niobium have a tendency to distribution along the grain boundaries. The addition of small quantities of boron (0.001-0.05%), and also the addition of the surface-active elements – Ce, Ca, Ba, Be (Fig. 3), Mg, and Zr – also aids in improving the high-temperature strength of the alloys. Boride phases of differing composition are formed in the high-temperature alloys, depending on the boron content: Cr_5B_3 (X phase); Cr_2B; $(Mo, Cr, W, Ni)_4B_3$; $(Mo, Cr, W, Ni)_5B_4$ (Y phase). In the presence of boron the diffusion processes along the grain boundaries are retarded, which increases the strength of the al-

loys at high temperatures. An increased content of sulfur and the low-melting metals – Pb, Sn, Sb, Bi – which enter from the charge has an unfavorable effect on the high-temperature strength of the alloys and the operational life of the parts, for example, gas turbine rotor blades made from the EI473A alloy containing 0.0015% lead had five times shorter service life than blades made from the same alloy but with only 0.0008% lead.

The wrought high-temperature nickel alloys which have found greatest application in industry are the grades EI473A, EI473B, EI617, EI-598, EI826, EI929, EI445, and EI867; their chemical composition is given in Table 1 and mechanical properties in Table 2.

In England the wrought high-temperature nickel alloys are known under the trade names Nimonic 80, [illegible], 100, 105 and 115 (see Nimonic), in the USA they are known under the names Inconel X, Incoloy 550, 700, 713C (see Inconel), Udimet 500, [illegible] 41, K42V. The majority of the Soviet wrought high-temperature nickel steels are not inferior to the foreign alloys with respect to high-temperature strength characteristics and at the same time do not [illegible], or its content does not [illegible] 5.42% (Cr).

The considerable increase [illegible] strength properties of the alloys and the operational [illegible] of parts which has taken place in the course of the last [illegible] has been achieved as a result of the use of hi, heat-[illegible] (Al, Cr, Ti, Nb, W, Mo) which are free of the [illegible] (Pb, Bi, Sn, Sb, S); increase of the content of [illegible] which case dispersion hardening; the addition of [illegible] (W, Mo, Nb), which inhibit the diffusional processes [illegible] small additions of B, Ca, Zr, Ce, Ba, which [illegible] and strengthening of the intercrystalline [illegible] improvement of the

melting technology (including the electroslag and vacuum remelting methods); improvement of the hot pressure working methods to ensure uniformity of the structure of the finished parts; elimination of the depleted layer on the surface of parts which is formed as a result of high heating during heat treatment; relief of the stresses which arise in parts as a result of strain hardening during machining.

The variation of the mechanical properties of the wrought high-temperature nickel alloys with temperature increase is shown in Fig. 4, and the variation of the fatigue strength is shown in Fig. 5, the variation of the coefficient of linear expansion and the coefficient of thermal conductivity with temperature is shown in Figs. 6 and 7.

The EI437A and EI437B alloys are used for fabricating gas turbine rotor blades and disks. The EI473B alloy differs from the EI473A alloy in the addition of small quantities of boron and higher purity of the charge materials used in its smelting.

The properties of the EI473A and EI473B alloys depend to a greater degree on the heat treatment conditions - the tempering and aging temperatures. Quenching from 1080° with rapid cooling in water provides moderate strength (σ_b = 65-70 kg/mm^2) and high plasticity (δ and $\psi \geq$ $\geq$ 45). The alloys are used in this condition to fabricate welded elements of structures which are subjected to aging after welding. In the aged condition the alloys have higher strength and hardness but lower plasticity and impact strength.

Figure 8 shows the variation of the hardness of the EI437A alloy and the amount of the γ'phase in its structure as a function of aging time and temperature after a solid solution quench, and Fig. 9 shows the effect of tempering temperature on the stress-rupture strength.

The amount of the strengthening γ'-phase depends strongly on the aging regime. Increasing aging temperature from 800° to 900° leads to

TABLE 2

Mechanical Properties of Wrought High-Temperature Nickel Alloys and Heat Treatment Regimes (fatigue limit based on 10^7 cycles)

Сталь по ГОСТ 5632—61	Заводская марка	Термич. обработка	НВ (кг/мм²)	Темп-ра (°С)	σ_b (кг/мм²)	$\sigma_{0,2}$ (кг/мм²)	δ (%)	ψ (%)	$a_н$ (кгм/см²)	σ_{-1} (кг/мм²)	E (кг/мм²)	$E_д$ (кг/мм²)
ХН77ТЮ	ЭИ437А	Закалка с 1080±10°, выдержка 8 час., охлаждение на воздухе, старение при 700±10°, выдержка 16 час., охлаждение на воздухе	255—311 ($d_{отп}$ = =3,45—3,8 мм)	20 700	100 62	60 —	25 5	28 12	8 —	36 —	19000 —	21000 —
ХН77ТЮР	ЭИ437Б	То же	255—311 ($d_{отп}$ = =3,45—3,8 мм)	20 700	100 70	65 —	20 15	21 20	5 —	37 —	19500 —	21500 —
ХН70ВМТЮ	ЭИ617	Закалка с 1100±10°, выдержка 2 час., охлаждение на воздухе, повторный нагрев под закалку до 1050±10°, выдержка 4 час., охлаждение на воздухе, старение при 800±10°, выдержка 16 час., охлаждение на воздухе	310	20 800	114 68	75 —	14,5 3	15 3	1,5— 2	— —	20000 —	21200 —
ХН70МВТЮБ	ЭИ598	Закалка с 1200±10°, выдержка 5 час., охлаждение на воздухе, повторный нагрев под закалку до 1070±10°, выдержка 8 час., охлаждение на воздухе, старение при 800±10°, выдержка 16 час., охлаждение на воздухе	302 ($d_{отп}$=3,5 мм)	20 800	105 70	70 —	16 4	16 8	— —	— —	19500 —	21000 —
—	ЭИ826	Нагрев в течение 2 час., закалка с 1210±10°, выдержка 2 час., охлаждение на воздухе, повторный нагрев под закалку до 1050°, выдержка 4 час., охлаждение на воздухе, старение при 800±10°, охлаждение на воздухе	311 ($d_{отп}$=3,45 мм)	20 850 900	105 60 50	72 — —	10 6 9	12 9 15	2 — —	38 — —	20000 — —	21350 — —
ВЖ38-300	ЭИ929	Закалка с 1220±10°, выдержка 2 час., охлаждение на воздухе, повторный нагрев под закалку до 1050±10°, выдержка 4 час., охлаждение на воздухе, старение при 850±10°, выдержка 8 час., охлаждение на воздухе	300—340 ($d_{отп}$=3,3—3,5 мм)	20 900	100—120 55	75—80 —	6—12 6	8—12 8	— —	— —	— —	22200 —
—	ЭИ867	Закалка с 1220±10°, выдержка 4—6 час., охлаждение на воздухе, старение при 850±10°, выдержка 8 час., охлаждение на воздухе	$d_{отп}$= 3,2—3,7 мм	20 900	110—125 55	75—85 —	12—25 4	15—25 8	3—5 —	— —	20300 —	23200 —
ХН67МТЮ	ЭИ445	Закалка с 1200°, охлаждение на воздухе, старение при 850°, выдержка 15 час., охлаждение на воздухе	—	20	100—110	55—75	20—30	20—30	6—12	—	24000	—

1) Steel per GOST 5632-61; 2) plant designation; 3) heat treatment; 4) HB (kg/mm^2); 5) temperature (°C); 6) (kg/mm^2); 7) a_n (kgm/cm^2); 8) E_D; 9) KhN77TYu; 10) EI; 11) quench from —, hold for 8 hours, air cool, age at —, hold for 16 hours, air cool; 12) (d_{otp} =); 13) KhN77TYuR; 14) same; 15) KhN70VMTYu; 16) quench from— hold for 2 hours, air cool, reheat for quench to —, hold for 4 hours, air cool, age at —, hold for 16 hours, air cool; 17) KhN70MVTYuB; 18) quench from —, hold for 5 hours, air cool, reheat for quench to —, hold 8 hours, air cool, age at —, hold 16 hours, air cool; 19) heat for 2 hours, quench from —, hold for 2 hours, air cool, reheat for quench to —, hold for 4 hours, air cool, age at —, air cool; 20) VZh; 21) quench from —, hold 2 hours, air cool, reheat for quench to —, hold 4 hours, air cool, age at —, hold 8 hours, air cool; 22) quench from —, hold 4-6 hours, air cool, age at —, hold 8 hours, air cool; 23) KhN67MTYu; 24) quench from —, air cool, age at —, hold 15 hours, air cool.

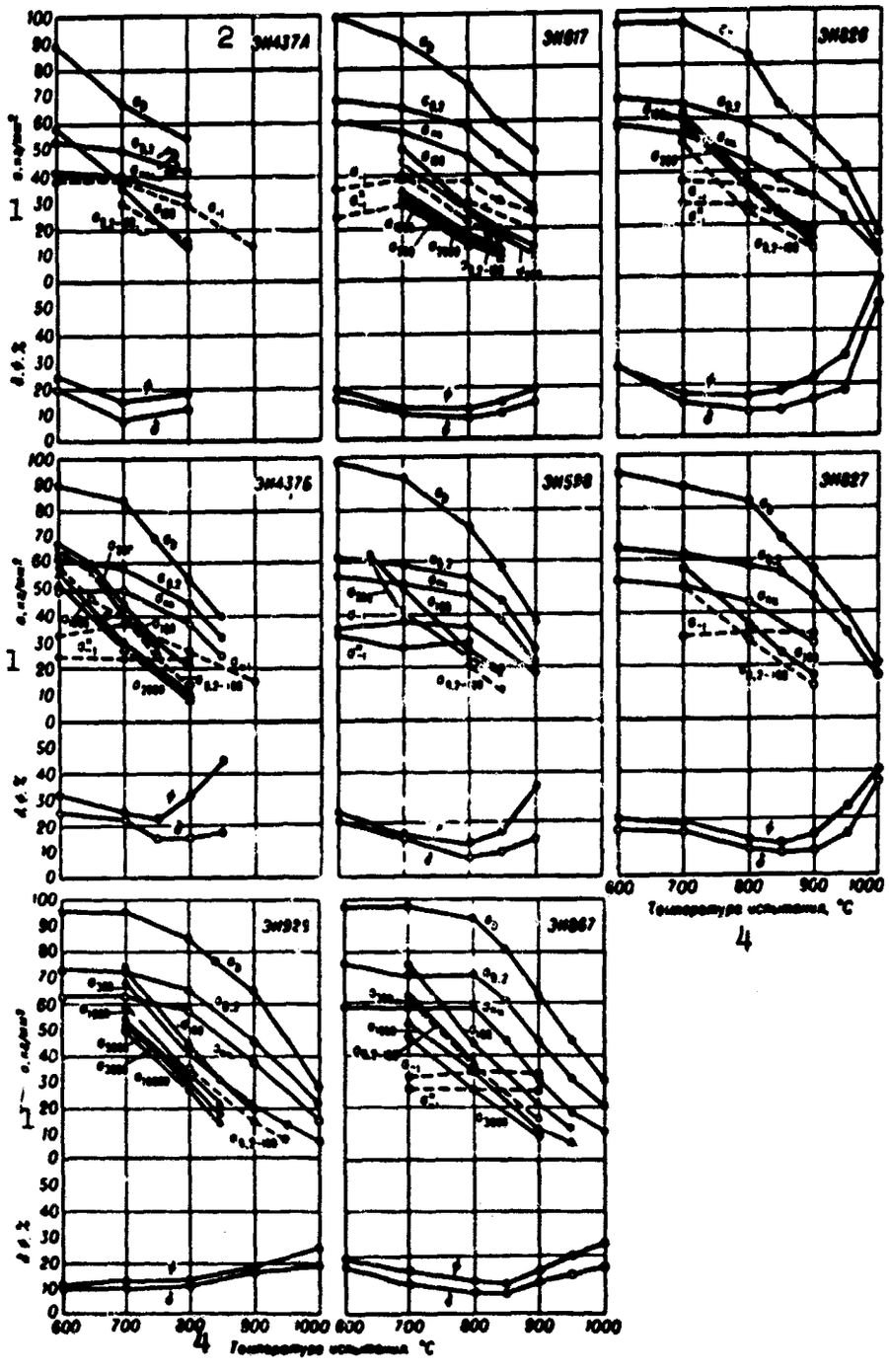

Fig. 4. Variation of mechanical properties of EI437A, EI437B, EI929, EI617, EI598, EI867, EI826, EI827 alloys with temperature increase. 1) σ, kg/mm^2; 2) EI; 3) σ_{pts}; 4) test temperature, °C.

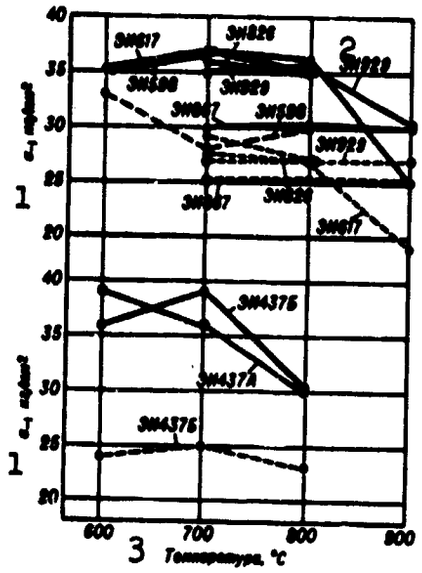

Fig. 5. Variation of fatigue limit of wrought high-temperature nickel alloys with temperature increase (solid lines are for specimens without notch, dashed lines are for notched specimens). 1) σ_{-1}, kg/mm^2; 2) EI; 3) temperature, °C.

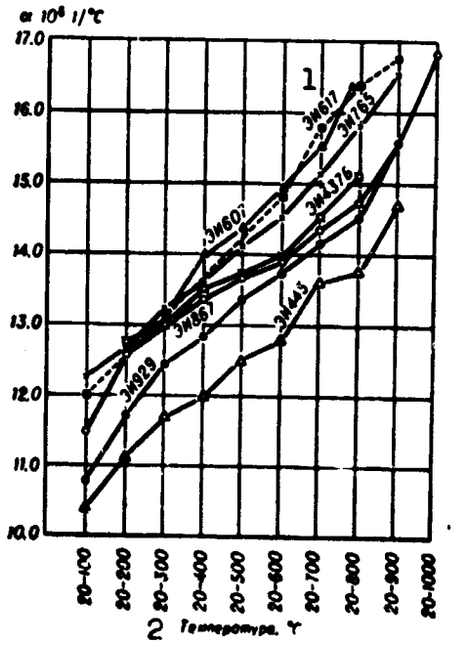

Fig. 6. Variation of α with temperature. 1) EI; 2) temperature, °C.

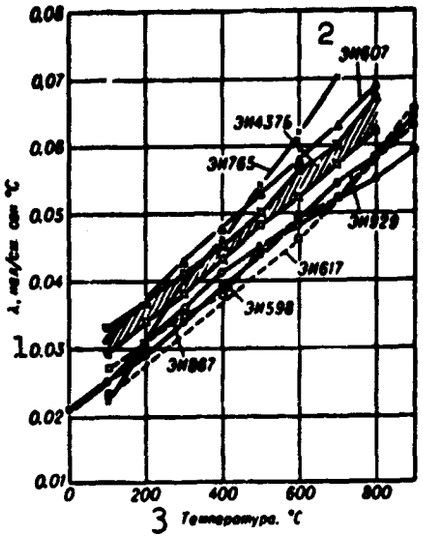

Fig. 7. Variation of λ with temperature. 1) λ, cal/cm-sec-°C; 2) EI; 3) temperature, °C.

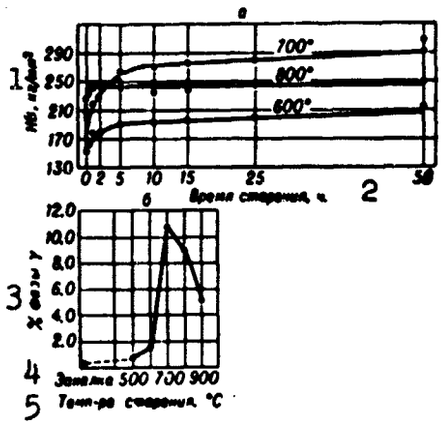

Fig. 8. Effect of aging time and temperature on the variation of hardness of the EI437A alloy after solid solution quench (a) and effect of 50-hour aging on the variation of the amount of γ-phase (b). 1) HB, kg/$/mm^2$; 2) aging time, hours; 3) % γ phase; 4) tempering; 5) aging temperature, C.

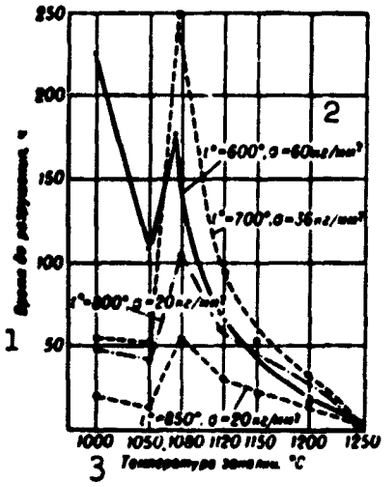

Fig. 9. Effect of quench temperature on the time-to-failure of the EI-437A type alloy. 1) Time-to-failure; 2) kg/mm^2; 3) quench temperature, °C.

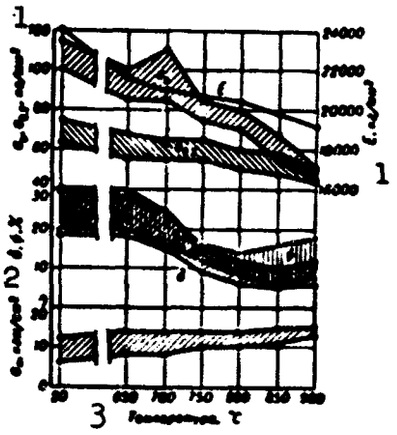

Fig. 10. Variation of mechanical properties of the EI445 alloy with temperature increase. 1) kg/mm^2; 2) a_n, kg/cm^2; 3) temperature, °C.

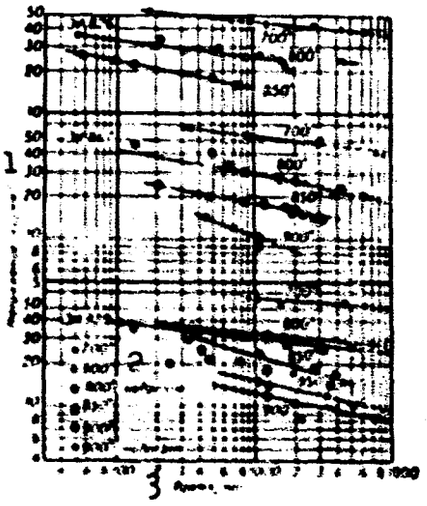

Fig. 11. Stress-rupture strength of the EI826, EI929, and EI867 alloys (data from TsKTI). 1) Stress, kg/mm^2; 2) with notch; 3) time, hours.

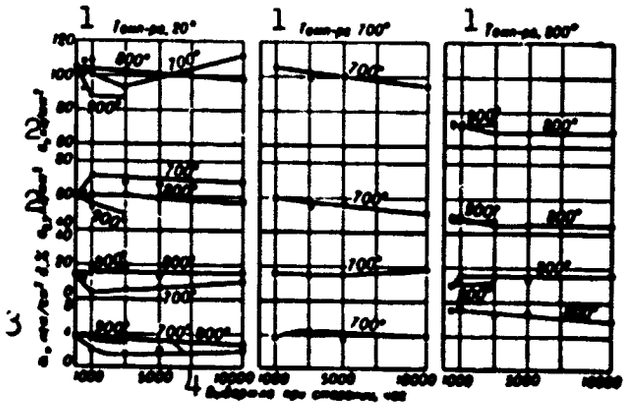

Fig. 12. Effect of aging duration on variation of the mechanical properties of the EI826 alloy. 1) Temperature; 2) kg/mm^2; 3) a_n, kgm/cm^2; 4) aging duration, hours.

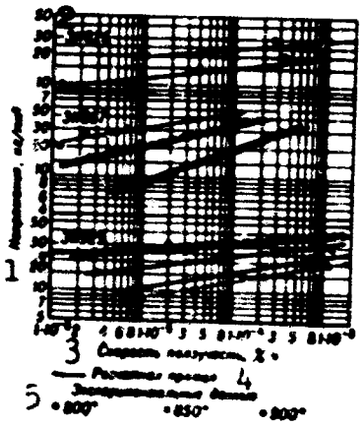

Fig. 13. Dependence of creep rate on stress for the EI826, EI929, EI867 alloys (data from TsKTI). 1) Stress, kg/mm^2; 2) EI; 3) creep rate, %/hour; 4) computed straight line; 5) experimental data.

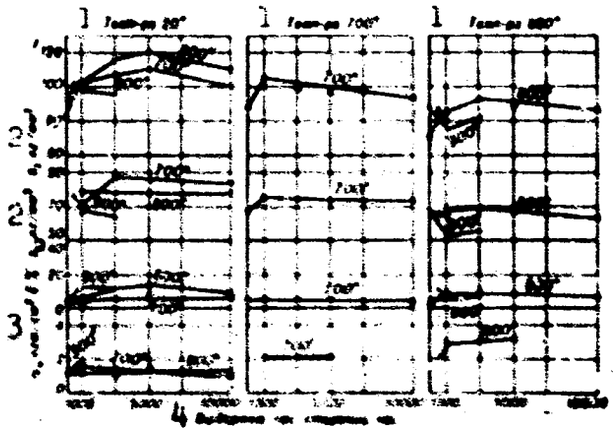

Fig. 14. Effect of aging duration on variation of the mechanical properties of the EI929 alloy. 1) Temperature; 2) kg/mm^2; 3) a_n, kgm/cm^2; 4) aging time, hours.

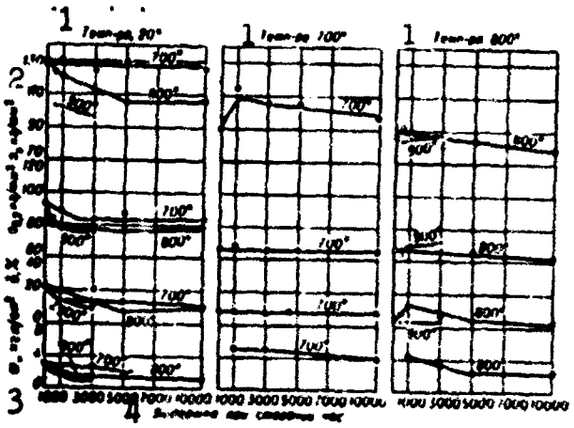

Fig. 15. Effect of long-term aging on variation of mechanical properties of EI867 alloy. 1) Temperature; 2) kg/mm^2; 3) a_n, kgm/cm^2; 4) aging time, hours.

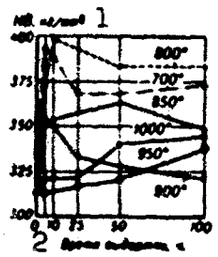

Fig. 16. Variation of hardness of EI867 alloy which has been pretreated in accordance with specifications as a function of aging time at various temperatures. 1) HB, kg/mm^2; 2) aging time, hours.

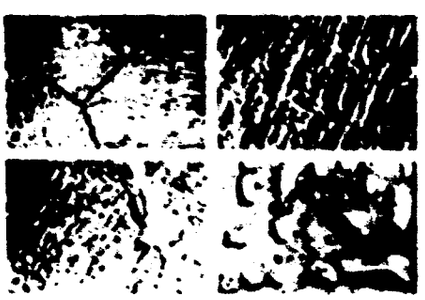

Fig. 17. Microstructure of EI867 alloy: after heat treatment per specifications; a) magnification 1000; b) amplification 10,000; after heat treatment and additional heating at 1000° for 100 hours; c) amplification 1000; d) amplification 10,000.

TABLE 3

Effect of Surface Treatment of EI473A Alloy Specimens on Stress-Rupture Strength at 700-800°

Вид обработки 1	700°, σ=36 кг/мм² 2			800°, σ=18 кг/мм² 2		
	Время до разрушения (часы) 3	δ (%)	ψ (%)	Время до разрушения (часы) 3	δ (%)	ψ (%)
Поверхностный наклеп 4						
5 Электрополирование (неналклепанные образцы)	234	1.2	3.1	70	3.6	8.5
6 Чистовое точение	120	1.1	2.6	57	2	3.5
Шлифование 7	171	2	3.4	69	3.2	4.5
Полирование после точения 8	141	1.2	3	70	3.4	5.9
Полирование после шлифования 9	186	3.5	3	71	3.2	5.8
Обкатка роликами 10	36	1.2	2	10	1.2	1.6
Обдувка дробью 11	110	2	2.4	61	1	2.8
12 Сквозной наклеп						
Растяжение до δ =0.5% 13	166	2	2	72	4.6	—
Растяжение до δ =2%	56	1.2	1.6	34	1.2	3.7
Растяжение до δ =10%	9	0.8	1.2	8.8	1	1.2

1) Form of treatment; 2) kg/mm^2; 3) time to failure, hours; 4) surface strain hardening; 5) electropolishing (specimens not strain hardened); 6) finish turning; 7) grinding; 8) polishing after turning; 9) polishing after grinding; 10) rolling; 11) shot peening; 12) through strain hardening; 13) stretching to.

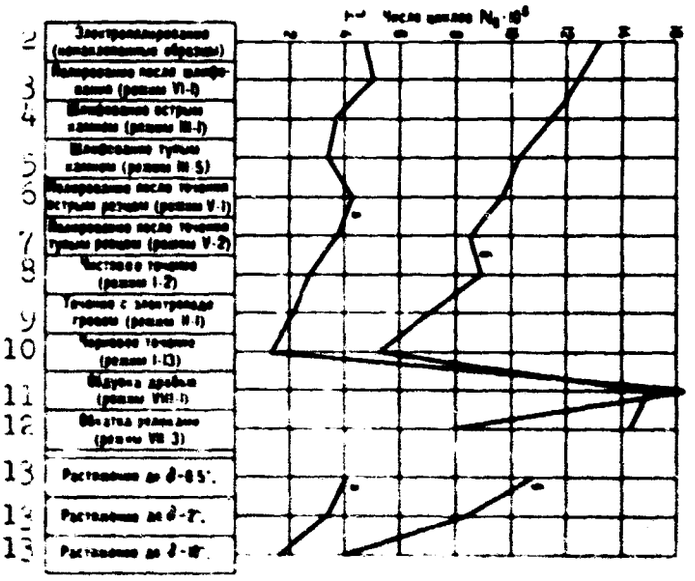

Fig. 18. Effect of strain hardening on fatigue of EI437A alloy: a) at 20°; b) at 700°. 1) Number of cycles, $N_0 \cdot 10^6$; 2) electropolishing (specimens not strain hardened); 3) polishing after grinding (regime VI-1); 4) grinding with sharp stone (regime III-1); 5) grinding with dull stone (regime III-5); 6) polishing after turning with sharp tool (regime V-1); 7) polishing after turning with dull tool (regime V-2); 8) finish turning (regime I-2); 9) turning with electric heating (regime II-1); 10) rough turning (regime I-13); 11) shot peening (regime VIII-1); 12) rolling (regime VII-3); 13) stretching to.

coagulation of the precipitated phase both within and along the boundaries of the grains. With increase of the aging time the size of the phase particles gradually increases. In this case the phenomenon of enlargement of the particles of the γ'-phase continues, for example, clear up to 1000 hours at 800°. With further increase of the aging time, along with the enlargement of the γ'-phase particles there is observed precipitation of the lamellar form as a result of its transformation into a stable η-phase of the Ni_3Ti type with hexagonal lattice. The alloys of the EI437 type have still another characteristic feature. If an alloy which has been aged at 700° is heated to a higher temperature (800° or 900°) there is considerable weakening of the material. However, with subsequent heating at 700° the properties are practically completely restored, i.e., there is a sort of recovery of the mechanical properties as a result of additional aging.

In addition to the strengthening γ'-phase and the η-phase, chromium carbides of the Cr_7C_3 type or titanium carbides of the TiC type with intermediate lattice parameters are precipitated out in the form of the so-called carbonitride phases in the EI473B alloy, depending on the conditions of the preceding treatment.

The EI473A and EI473B alloys have excellent high-temperature strength characteristics up to 750°, they also operate satisfactorily at higher temperatures (up to 850°) but with slower stresses.

At 550° the stress-rupture strength of the EI473B alloy depends strongly on the strength at room temperature, while at 750° it is less dependent on the initial strength at room temperature. A slight embrittlement of the type EI473A alloys is noted at a temperature of about 550-650°, which is associated with additional aging.

The EI473A and EI473B alloys have low notch sensitivity, high fatigue resistance, and high oxidation resistance. Tempering at 1080°

with heating for about 8 hours alters the chemical composition of the EI473B alloy in the surface layers, depleting them of chromium, titanium, and aluminum. Therefore, in fabricating gas turbine blades the depleted layer must be removed by mechanical means or by special etching, including electrolytic acid etching to a definite depth.

The EI437A and EI437B alloys have the highest high-temperature strength and operational properties with the presence of uniform grains of 0.5-1 mm diameter. Varying grain size of the alloys has an unfavorable effect on the operational life of parts and also on the long-term high-temperature strength. Strict adherence to the forging and stamping regimes must be observed to eliminate variation of grain size.

The EI617 and EI598 alloys have higher high-temperature strength characteristics than the EI437B alloy. They provide 100-hour service life at 800° and a stress of 25-28 kg/mm^2 and are used to fabricate gas turbine engine rotor blades which operate at 800-850°. Mechanically worked detail parts are subjected to heating in an argon atmosphere for 2 hours at 950° and additional aging in an ordinary air environment for 8 hours at 800°, after this they become insensitive to notching, particularly at 700°. The EI617 alloy has higher high-temperature properties and fatigue resistance with a high boron content (0.01%). Strengthening of the EI617 alloy is accomplished by the formation of the intermetallide γ'-phase, and the Y-type boride phase $(Mo, Cr, W, Ni)_5B_4$. In addition, phases of the TiC and $Me_{23}C_6$ types are found in the carbide precipitate.

The EI445 alloy is intended for gas turbine rotor blades with service life up to 1000 hours at 770-850°. The variation of the mechanical properties of this alloy as a function of temperature increase is shown in Fig. 10.

The EI826 alloy, a modification of the EI617 alloy, provides for

100-hour service life at 900° and a stress of 15 kg/mm^2. It is used to fabricate gas turbine engine rotor blades. The mechanical properties of this alloy are shown in Figs. 11-13.

The EI929 alloy provides for 100-hour service life at 900° and a stress of 22 kg/mm^2. The high aluminum content and the presence of cobalt give the alloy excellent high-temperature properties. Pressure working of the alloy is somewhat difficult in the first stage of deformation of the ingot prior to obtaining a suitable crystalline structure. It is used to fabricate gas turbine engine rotor blades. This alloy has a good combination of strength and plasticity, has higher, better, high-temperature strength properties than the EI617 and EI826 alloys and the foreign alloys Nimonic 95, Nimonic 100, Inco 700. It is one of the best of the wrought high-temperature nickel alloys. Increase of the carbon content to 0.1% improves the fatigue resistance at temperatures of 700-800° and gives the alloy a finer grained structure after heat treatment. Thermal treatment of the EI929 alloy is performed at very high temperatures, therefore in fabricating detail parts it is very important to remove uniformly the surface layer which is depleted of the alloying elements (chromium, titanium, and aluminum).

The EI867 alloy is a complex alloy with the addition of aluminum as a strengthening element. Strengthening of this alloy is accomplished by means of the Ni_3Al intermetallide phase. With regard to stress-rupture strength, this alloy is somewhat inferior to the EI929 alloy. At temperatures to 800° it has quite high plastic properties, the plasticity being lowest at 800-850°. The weakening of the alloy is slight above 850-900°, which permits using it even at 950°. The mechanical properties of the alloy at high temperatures are shown in Figs. 4, 11, 13, 15, and 16. The values of the fatigue strength obtained on smooth and notched specimens depend very little on temperature in the range

700-900°. This alloy is used to fabricate gas turbine engine rotor blades. Enlargement of the Ni_3Al phase particles and the partial dissolution of this phase is in complete agreement with the hardness variation (Figs. 16 and 17). The higher aluminum content and the high strength at high temperature make hot working of the alloy more complex than for the EI617 and EI437B alloys; in stamping detail parts use is made of a larger number of intermediate dies, heating to 1200° prior to stamping, terminate stamping at 1050°. Just as the EI929 alloy, the EI-867 alloy is significantly depleted of several of the alloying elements (Al, Cr) in the surface layers. Comparatively long heating for quench at 1200-1220° should be done in argon.

In the process of developing the wrought high-temperature nickel alloys it was found that strain hardening from mechanical working or pressure working has an unfavorable effect on the high-temperature strength characteristics and the operational properties of the EI437A, EI437B, EI617, and EI867 alloys. Figure 18 and Table 3 show the effect of various forms of working associated with strain hardening on the stress-rupture strength at 700° for the EI437A alloy. The best results are obtained by surface rolling and shot peening. Fatigue resistance at room temperature and at a test temperature of 700° depends to a great extent on the surface condition of the specimens and, in particular, on the strain hardening. Both through strain hardening resulting from stretching or twisting and surface strain hardening resulting from various forms of working (turning with dull tool, rolling, etc.), have an unfavorable effect on the strength at high temperature. The negative effect of strain hardening is noted less in short-time testing and more in long-term testing. The greater the through strain hardening resulting from stretching, the more effect it has on the stress-rupture strength at 700°.

During testing for stress-rupture strength, thermal stability, and fatigue of specimens with surface strain hardening, cracks whose number increases with the increase of the strain hardening are formed in the surface layer long before final failure. Similar cracks occur in operation at the locations of strain hardening which has not been relieved and are sometimes the cause of premature failure of the blades. It is recommended that the following thermal treatment be used to avoid the harmful effect of strain hardening and to improve operational life. For the EI437A and EI437B alloys: heating for 2 hours at 850° in argon and aging for 16 hours at 700°, air cool; for the EI617 alloy: heating in argon for 2 hours at 950°, container cool, age for 8 hours at 800°, air cool; for the EI867 alloy: heat for 2 hours at 950° in argon and air cool; for the EI929 alloy: heat for 1 hour at 950° in argon or nitrogen, container cool (regime not established for certain).

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F.F. Khimushin

WROUGHT HIGH-TEMPERATURE STAINLESS STEEL is steel which has high strength and scale resistance at high temperatures. It is intended for fabricating detail parts of power plants operating at high temperatures under high loads (gas turbine blades and discs, turbocompressor parts, fasteners, etc.). The good high-temperature strength properties of the steel are achieved by special alloying, special melting processes and complex heat treatment. Alloying the wrought high-temperature stainless steels amounts to introducing into the solid solution several alloying elements which play varying roles in the operation of the part at high temperatures under load. On the one hand, we need those alloying elements which during operation of during heat treatment will aid in developing disperion hardening and strengthening of the solid solution; on the other hand, we need alloying elements which increase the binding energy of the solid solution, inhibit the diffusional processes of a atomic interchange in the crystalline lattice which are associated with the coagulation of precipitating phases, and retard the recrystallization processes.

The role of the elements which aid in developing the dispersion hardening in alloys with carbide strengthening is played by carbon, vanadium, and chromiun, whose interaction leads to precipitation of the highly dispersed carbides VC and $Cr_{23}C_6$. The effect of carbon, vanadium, molybdenum, and niobium on the long-term strength at 800° of steel with carbide strengthening is shown in Fig. 1.

In alloys with intermetallide strengthening, the development of dispersion hardening is provided for by titanium and aluminum. During

Fig. 1. Effect of additions of carbon, vanadium, molybdenum and niobium on 1 – hour stress-rupture strength 100-hr of alloys with carbide strengthening at 800°. 1) σ_{100} kg/mm^2 2) and.

aging or during use of the alloy, these elements together with nickel form intermetallide phases of the type γ' and Ni, Al, and thereby aid in strengthening the alloy. In alloys with low nickel content (to 25%) titanium is the primary strengthening element, while in nickel-base alloys the strengthening is associated with both titanium and aluminum. The refractory metals such as tungsten, molybdenum, niobium play the role of the elements which inhibit the diffusional processes; their addition to the alloys of both indicated types increases the recrystallization temperature of the solid solutions and retards the coagulation of the precipitated phases.

The interaction with the solid solution of the intermetallide or carbide phases which precipitate out at high temperatures leads to high resistance of the alloys to plastic deformation at high operating temperatures. The addition of small amounts of boron (0.005-0.015%), and also calcium, barium, zirconium, magnesium and certain other rare-earth elements, (Fig. 2) is very useful for strengthening the grain boundaries and increasing the strength of the alloys at high temperatures. The nickel- and iron-base high-temperature alloys are very sensitive to contamination by the low-melting metal (lead, tin, antimony, bismuth) and sulfur. We need only note that the presence in the EI437

alloy of tens of thousandths of a percent of lead has a catastrophic effect on the high-temperature strength and operational stability of parts. Therefore the purity of the charge materials must be monitored very carefully.

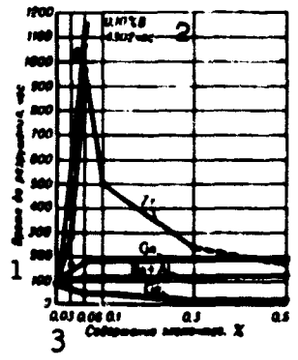

Fig. 2. Effect of small amounts of boron, calcium, barium with aluminum, germanium, and zirconium on time to failure of the EI694 alloy at 600° and a stress of 28 kg/mm^2. 1) Time to failure, hours; 2) hours; 3) element content, %.

TABLE 1

Chemical Composition of Wrought High-Temperature Stainless Steels With Carbide and Intermetallide Strengthening

Марка по ГОСТ 5632-61 1	Заводская марка 2	3 Содержание элемента (%)										4 Другие элементы*
		C	Si	Mn	Cr	Ni	Mo	Ti	W	V	Al	
5 4Kh14N14V2M	6 EI69	0.4–0.5	≤0.8	≤0.7	13–15	13–15	0.25–0.4	–	2–2.75	–	–	–
7 4Kh15N7G7F2MS	EI388	0.35–0.42	0.9–1.4	6–8	14–16	6–9	0.65–0.9	–	–	1.5–1.9	–	–
8 4Kh12N8G8MFB	EI481	0.34–0.4	0.3–0.8	7.5–9.5	11.5–13.5	7–9	1.1–1.4	–	–	1.4–1.55	–	[illegible]
–	EI736	0.34–0.4	0.3–0.8	7–9	11.5–13.5	6.5–8.5	1.1–1.4	–	–	1.4–1.55	–	[illegible]
–	EI696A	≤0.1	≤1	≤1	10–12.5	18–21	–	2.3–2.8	–	–	[illegible]	[illegible]
9 Kh12N20T3R	EI696	≤0.1	≤1	≤1	10–12.5	19–21	–	2.6–3.0	–	–	≤0.6	[illegible]
10 Kh12N22T3MR	11 EI696M и EP33	≤0.1	≤0.6	≤0.6	10–12.5	21–23	1–1.6	2.6–3.0	–	–	≤0.6	[illegible]
12 KhN35VTYu	EI787	≤0.08	≤0.6	≤0.6	12–16	33–37	–	2.1–3.2	2–4	–	0.1–1.7	2.1
13 KhN35VMTR	EI692	≤0.12	≤0.6	≤1	14–16	32–36	2–3	1.1–1.5	2.1–3.2	–	–	[illegible]
KhN35VT	EI612	≤0.12	≤0.6	1–2	14–16	34–38	–	1.1–1.5	2.4–3.2	–	–	[illegible]
14 KhN35VTR	EI725	≤0.1	≤0.6	≤1	14–16	35–38	–	1.1–1.5	2–3	–	–	[illegible]
15 –	EI703	≤0.1	≤0.6	≤0.6	12–15	33–37	3–3.6	2–2.6	–	–	2.4–3.2	[illegible]
	16											17

*Boron introduced into alloys in theoretical amount.

1) Grade per GOST 5632-61; 2) factory designation; 3) element content, %; 4) other elements*; 5) 4Kh14N14V2M; 6) EI; 7) 4Kh15N7G7F2MS; 8) 4Kh12N8G8MFB; 9) Kh12N20T3R; 10) Kh12N22T3MR; 11) EI696M and EP33; 12) KhN35VTYu; 13) KhN35VMTR; 14) KhN35VT; 15) KhN35VTR; 16) EP; 17) [illegible] to.

Usually the heat treatment of the wrought high-temperature stainless steels consists of quenching from high-temperatures with the formation of a solid solution (austenitic quench) and subsequent aging at moderate temperatures. The purpose of the quench is conversion into the solid solution of the carbides and intermetallides which have precipitated or which have been fractionated during hot working and homogenization of the alloy. The creation of a certain degree od supersaturation in the solid solution is necessary for subsequent strengthening of the alloys as a result of dispersion hardening, which takes place at elevated temperatures. Dispersion hardening is of great importance in the high-strength-at-high-temperature alloys which are used for blades and discs of the modern gas turbines.

Aging temperature and duration are selected as a function of the steel alloying and operating conditions of the part. In certain cases, EI481 for example, aging to the maximal hardness is dangerous, since this causes the steel to be very notch sensitive as a result of severe embrittlement; a slight increase of the aging temperature aids in softening the steel as a result of coagulation of the dispresed particles. More complex heat treatment also is used, consisting of single or double quench, single or double aging. For example, double aging for the EI481 steel and double quenching for the EI787 steel.

Operational life of gas turbine engine components depends to a considerable degree on the grain size or the diversity of grain size of the wrought high-temperature stainless steel (Fig. 3). Usually the diversity of grain size is created during heat treatment of parts which have been hot pressure worked in the zone of critical degrees of deformation. In this case, during heat treatment, along with the formation of a fine-grained structure, in the severely deformed portions of the part there appears a coarse-grained structure in the zones which

have received a critical degree of deformation. The diverse-grained structure most often is formed in those portions of the part in which plastic deformation was hindered as a result of reduction of the metal temperature during forging, stamping, or as a result of design peculiarities of the part which hinder metal flow in the die during deformation. When parts with diverse-grained structure are subjected to the action of stresses at high temperature, the portions with fine-grained structure, having greater plasticity, are easily deformed under the action of the stresses. As a result of this, a greater load is exterted on the portions with the coarse-grained structure which has lower plasticity, which leads to premature cracking of the steel along the grain boundaries. During operation of parts with diverse-grained structure, cracks appear first of all at the junction of the larger grains.

To increase the operational life of parts made from the wrought high-temperature stainless steels, it is very important to avoid the formation of strain hardening during mechanical working. The presence of work hardening on the surface of the parts increases the diffusional mobility and facilitates increase of grain coarseness and embrittlement of the material even at low temperatures. The work hardened layer should be removed by electro-chemical etching.

In addition to the chrome stainless steels, in machine design use is made of austenitic high-temperature steel: with carbide strengthening, for example 4Kh14N14V2M (EI69), 4Kh15N7G7F2MS (EI388), 4Kh12N8G8MFB (EI481) (foreign designations G-18B, S-590), with intermetallide strengthening, for example Kh12N0T3R (EI696), Kh12N2T3MR (EI696M), KhN35VT (EI612), KhN35VTYu (EI787), EP105 (foreign designations A-286, Incoloy 901, Incoloy 979).

The chemical composition of the wrought high-temperature stainless steel is shown in Table 1, and the mechanical properties and heat

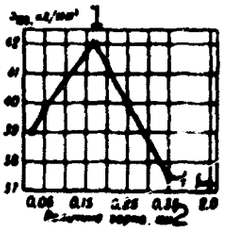

Fig. 3. Effect of grain size on 100-hour stress-rupture strength of 4Kh12N8G8MFB steel at 650°. 1) σ_{100} kg/mm^2; 2) grain size, mm.

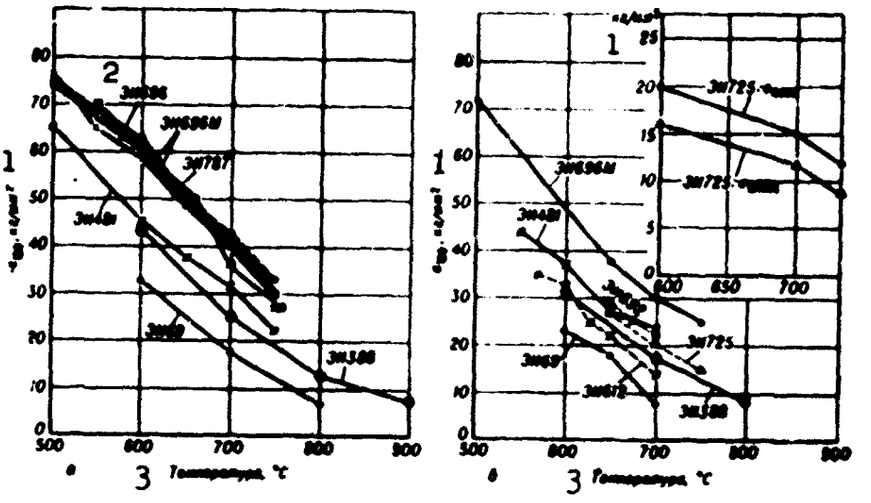

Fig. 4. Variation of stress rupture strength with temperature increase: a) After 100 hours; b) after 1000 hours. 1) σ_{100} kg/mm^2; 2) EI; 3) temperature, °C.

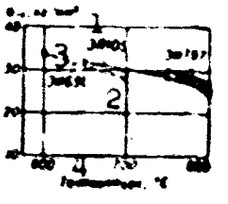

Fig. 5. Variation of fatigue limit with temperature increase. 1) σ_{-1} kg/mm^2; 2) EI; 3) EP; 4) temperature, °C.

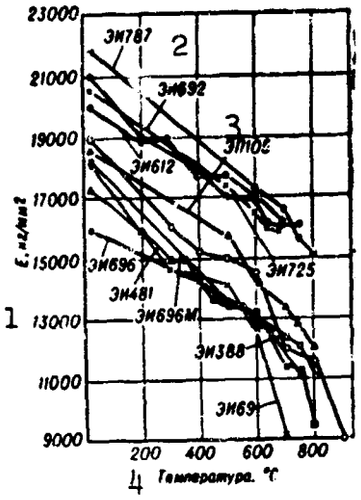

Fig. 6. Variation of elastic modulus with temperature increase.

1) E, kg/mm^2; 2) EI; 3) EP; 4) temperature °C.

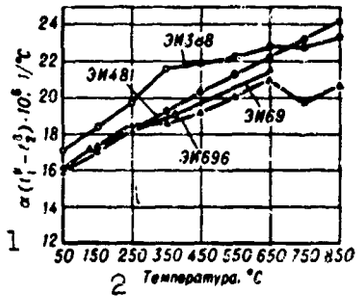

Fig. 7. Variation of coefficient of linear expansion with temperature increase. 1) EI; 2) temperature, °C.

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TABLE 2

Mechanical Properties and Heat Treatment Regimes of Wrought High-Temperature Stainless Steels

Марка по ГОСТ 5632-61	Заводская марка	Термическая обработка	НВ ($d_{отп}$, мм)	$\sigma_в$ (кг/мм²)	$\sigma_{0,2}$ (кг/мм²)	δ (%)	ψ (%)	$a_н$ (кгм/см²)	K (кг/мм²)
1	2	3	4	5				5'	6
6) 4Х14Н14В2М	7) ЭИ69	8) Отжиг при 820°	4,3—3,6	72	32	20	35	5	—
9) 4Х15Н7Г7Ф2МС	ЭИ3ия	10) Закалка с 1170—1190°, выдержка 30—45 мин., охлаждение в воде или на воздухе, старение при 800±20° в течение 8—10 ч.	3,8—3,3	90—100	62	≥15	≥15	≥3	18 950
4Х12Н8Г8МФБ 11	ЭИ481	12) Закалка с 1140±10°, выдержка 1 ч. 45 мин., 2 ч. 30 мин., охлаждение в воде, старение двухступенчатое: при 660±10° в течение 16 ч., затем при 790° в течение 14—16 ч., охлаждение на воздухе	3,65—3,45	≥90	≥60	≥16	≥36	4,5—6	17 600
	ЭИ734	13) Закалка с 1150°, выдержка 1 ч. 45 мин., охлаждение в воде, старение двухступенчатое: при 670° в течение 14 ч., затем при 800° в течение 16 ч., охлаждение на воздухе	3,6	≥100	60	8,20	≥25	≥3,5	16 900
	ЭИ696А	14) Заготовка со стороной квадрата до 100 мм; закалка с 1170—1190°, выдержка 2 ч., охлаждение на воздухе или в воде, старение при 750—775° в течение 25—16 ч., охлаждение на воздухе*	3,9—3,5	≥80	≥45	≥15	≥15	≥3	—
15) Х12Н20Т3Р	ЭИ696	16) То же	3,8—3,5	≥90	≥60	8,25	≥30	8—12	17 200—17 500
17) Х12Н22Т3МР 18)	ЭИ696М и ЭИ33	19) Прутки, закалка с 1170—1200°, выдержка 2—8 ч., охлаждение на воздухе, старение при 750—800° в течение 16—25 ч., охлаждение на воздухе*	3,7—3,4	≥90	≥60	≥8	≥10	≥3	—
20) ХН35ВТЮ	ЭИ787	21) Кованый пруток и диски (сторона квадрата 90 мм), закалка с 1150—1160°, выдержка 6—10 ч., охлаждение на воздухе, 2-я закалка с 1050°, выдержка 4 ч., охлаждение на воздухе, старение при 830° в течение 16 ч., охлаждение на воздухе	3,6—3,35	105—120	60—80	11,5—22	15—29	3,5—7	—
		22) Лопатки компрессора; нагрев до 1120°, выдержка 1 ч., штамповка с охлаждением на воздухе, старение при 750° в течение 16 ч., охлаждение на воздухе	3,2—3,05	≥135	95—100	20—25	36—45	7—8,6	—
23) ХН35ВМТР	ЭИ892	24) Закалка с 1140—1160° на воздухе, старение при 750° в течение 24 ч.	—	85—95	50—75	24—27	26—30	6—10	20 700
25) ХН35ВТ	ЭИ612	26) Закалка с 1180°, выдержка 1 ч., охлаждение в воде, старение при 780° в течение 8—10 ч. и при 830° в течение 25 ч.	—	80—87	55—65	18—30	36—50	11—18	20 200
ХН35ВТР	ЭИ725	28) Закалка с 1120—1150° на воздухе, старение при 750° в течение 24 ч.	—	80—90	45—50	20—30	30—36	10—16	21 000
27	ЭИ1035	30) Прутки, закалка с 1120—1150°, выдержка 2—3 ч., охлаждение в масле, старение при 775—800° в течение 16 ч. и дополнит. старение при 630—650° в течение 10—16 ч., охлаждение на воздухе	—	90—120	70—75	10—15	12—20	3—6	18 600
	29								

*Used only for material inspection at producing plant. Parts are subjected to different heat treatment depending on use conditions (see text).

1) Grade per GOST 5632-61; 2) plant designation; 3) heat treatment; 4) HB ($d_{отп}$, mm); 5) (kg/mm²); 5') $a_н$ (kgm/cm²); 6) 4Kh14N14V2M; 7) EI; 8) anneal at 820°; 9) 4Kh15N7G7F2MS; 10) quench from 1170-1190°, hold for 30-45 min, cool in air or water, aging at 800 + 20° for 8-10 hours; 11) 4Kh12N8G8MFB; 12) quench from 1140 ± 10°, hold for 1 hr 45 min, 2 hr 30 min, cool in water, two-step aging; at 660 ± 10° for 16 hours, then at 790° for 14-16 hours, air cooling; 13) quench from 1150° hold for 1 hr 45 min, cool in water, two-steep aging; at 670° for 14 hours, then at 800° for 16 hours, cool in air; 14) blank with square side up to 100 mm; quench from 1170-1190°, hold for 2 hours, air or water cooling, aging at 750-775° for 16-25 hours, air cooling*; 15) Kh12N20T3R; 16) same; 17) Kh12N22T3MR; 18) EI696M and EP33; 19) rods, quench from 1170-1200°, hold for 2-8 hours, cool in air, aging at 750-800° for 16-25 hours, air cool*; 20) KhN35VTYu; 21) forged rod and discs (square side 90 mm); quench from 1150-1160°, hold for 6-10 hours, air cool, second quench from 1050°, hold for 4 hours, air cool, aging at 830° for 16 hours, air cool; 22) compressor blades; heat to 1120°, hold for 1 hour, stamping with air cooling, aging at 750° for 16 hours, air cool; 23) KhN35VMTR; 24) quench from 1140-1160° in air, aging at 750° for 24 hours; 25) KhN35VT; 26) quench from 1180°, hold for 1

hour, water cool, aging at 780° for 8-10 hours and at 830° for 25 hours; 27) KhN35VTR; 28) quench from 1120-1150° in air, aging at 750° for 24 hours; 29) EP; 30) rods; quench from 1120-1150°, hold for 2-3 hours, oil cool, aging at 775-800° for 16 hours and additional aging at 630-650° for 10-16 hours, air cool.

treatment regime are presented in Table 2. Figures 4-6 show the variation of the stress-rupture strength, fatigue, limits and the elastic modulus of wrought high-temperature stainless steel at various temperatures. The variation of the physical properties with temperature increase is shown in Figs. 7-8.

The 4Kh14N14V2M (EI69) chrome-nickel-tungsten steel is used primarily for exhaust valves of internal combustion engines (see Valve Steel) and as a fastener material in gas turbine construction. In the latrer case it is successfully replaced by the more economical EI388 steel. The variation of the properties of the 4Kh14N14V2M steel as a function of temperature is shown in Fig. 9.

For valves, the steel is used in the condition after hot working pressure with well refined grain and after annealing for 5 hours at 820°.

The 4Kh15N7G7F2MS (EI388) chrome-manganese-nickel steel is the most economical, is used for various detail parts of gas turbine installations which operate under relatively low loads (turbine locomotives, stationary gas turbine installations). The mechanical, high-temperature strength, and physical properties of the steel are presented in Figs. 4, 6, 7, 8, 10. At working temperatures to 700° it is used without protection from oxidation, at higher temperatures parts are subjected to aluminizing or electrolytic nickel plating. The steel is used successfully for fastener details after quenching from 1180°, 8-hour aging at 800°, and 10-15 minute heating at 900° in a salt bath consisting of 50% $NaNO_3$ and 50% KNO_3.

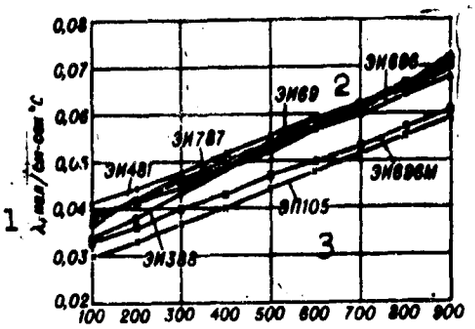

Fig. 8. Variation of coefficient of thermal conductivity with temperture increase. 1) λ, cal/cm-sec-°C; 2) EI; 3) EP.

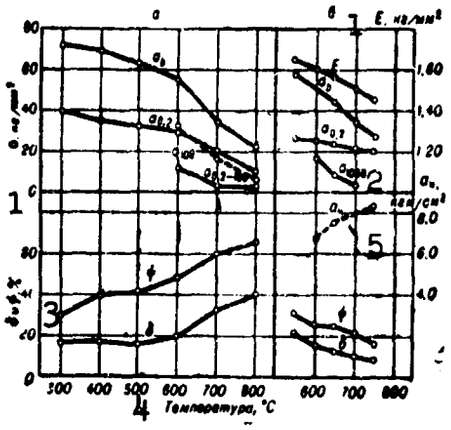

Fig. 9. Variation of mechanical properties of 4Kh14N14V2M steel with temperature increase: a) Stamping and 5-hour soak at 820°; b) quench from 1175° in water and 5-hour aging at 750°. 1) σ, kg/mm^2; 2) $a_н$, kgm/cm^2; 3) σ and ψ; 4) temperature, °C; 5) an.

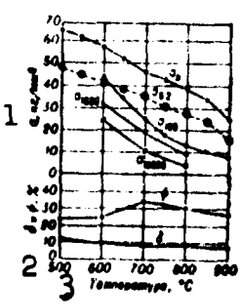

Fig. 10. Variation of mechanical properties of 4Kh15N7G7F2MS steel with temperature increase. Quench from 1180°, hold for 45 min, water cool, aging at 800° for 8 hours 1) σ kg/mm^2; 2) δ and ψ; 3) temperature, °C.

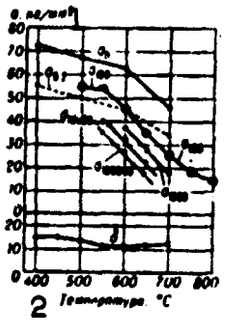

Fig. 11. Variation of mechanical properties of 4Kh12N8G8MFB steel with temperature increase. Heat treatment to HB (d_{otp} = 3.6 mm). 1) σ, kg/mm^2; 2) temperature, °C.

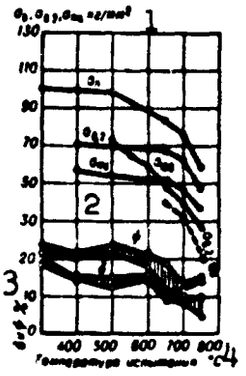

Fig. 12. Variation of mechanical properties of Kh12N20T3R steel with temperature increase. Quench from 1180° in air, 16-hour aging at 750°. 1) σ_b, $\sigma_{0.2}$, σ_{pts}, kg/mm^2; 2) σ_{pts}; 3) δ and ψ; 4) test temperature, °C.

The 4Kh12N8G8MFB (EI481) chrome-manganese-nickel steel is used to fabricate turbine discs weighing from 50 to 500 kg and diameter up to 1 meter, and also for shroud rings used to join discs, screens, labyrinth seals and fastener details. The complex technological operation of half-hot work hardening is not required for discs, since the required strengthening is obtained by means of a heat treatment consisting of a water quench and double aging. Figure 11 shows the variation of the steel mechanical properties as a function of temperature. Steel with high hardness, obtained as a result of aging at 650-700°, has high strength but low and unstable high-temperature strength as a result of heightened notch sensitivity at operating temperatures of the

order of 650°. To reduce the notch sensitivity, the steel is subjected to double aging (first at 670° for 16 hours, second at 780-800° for 14-16 hours). This results in good high-temperature strength of the steel and stable operation of the discs. Only the disc rim should be subjected to the second aging to provide further softening of the rim. The more economical EI734 steel has been developed to economize the nickel in the steel of this type and to eliminate niobium from the chemical composition. This steel has the same properties as the EI481 steel and is recommended for numerous detail parts operating at high temperatures (rings, bolts, pins and discs).

The Kh12N20T3R (EI696) steel is used for fabricating turbine discs, structural parts of trubine housings, couplings, shafts, nozzle cone parts. Afterburner chambers fabricated from sheet material operate quite satisfactorily to 800°. With regard to high-temperature strength properties, this steel is close to the nickel alloy KhN77TYuR (EI437B), is equivalent to the nickel alloy KhN77TYu (EI437A), and is the most economical steel of the iron-base wrought high-temperature stainless steels. Figure 12 shows the variation of the high-temperature strength properties of the Kh12N20T3R steel with temperature change. High strength properties at high temperatures are obtained as a result of the use of heat treatment consisting of an austenite quench from 1100-1180° and subsequent dispersion hardening at 750-775°. In order to eliminate shrinkage, the quench should be performed in oil at a temperature of about 1100° and double aging should be used: 10 hours at 750-800° and 10-20 hours at 600-650°, air cool. For small sections the cooling during quenching should be done in air, for large sections, in oil.

The following thermal and mechanical treatment is used for fasteners and other high-strength detail parts used at 500-600°: heating

to 1120°, deformation in the hot condition with a reduction of 20%; double aging: 16 hours at 700-750° and 10-20 hours at 600-650°, air cool (σ_b = 100 kg/mm^2, $\sigma_{0.2}$ = 70 kg/mm^2, δ = 15%, ψ = 20%). Minimal strength and hardness of the steel at room temperatures are obtained with an austenitic quench from 1000-1150°. The steel is easily stamped in this condition. The greatest changeof the steel hardness takes place with aging in the range 650-750°.

The EI696A steel is a modification of the EI696 steel and is used for detail parts fabricated from sheet by welding and operating at a temperature not over 800°. The parts weld best in the austenite-quench condition (quench from 1000°). Higher electrode pressure is required in spot and seam welding, and constant conditions are necessary in argon-arc welding to avoid the appearance of cracks. EI696A steel with 2.4-2.7% Ti and 0.008% B and with lower aluminum content welds better than the steel with high aluminum content. To improve the strength, welded details are subjected to aging at 700-750° for 5-16 hours.

The Kh12N22T3MR (EI696M and EP33) steel is also dispersion hardening with intermetallide strengthening. It is used for fabricating highly loaded detail parts for gas turbine engines operating at temperatures to 750° (turbine discs, compressor discs, deflectors, rings, turbine and compressor blades). Tempering of parts operating up to 600° is performed at 950-1050° in oil, double aging for 16 hours at 720-750° and for 16 hours at 600-650°. For detail parts operating at 650-750°, it is advisable to perform the quench from 1100-1130° with air cooling, aging for 16-25 hours at 750-785° and 10-16 hours at 600-650°. For detail parts operating under conditions of concentrated loads (discs, turbine blades) at these same temperatures, quench from 1120° in oil is recommended with double aging: for 2-5 hours at 830-850° and 16-25 hours at 700°. With respect to stress rupture strength, the

EI696M steel is close to the nickel alloy EI437B and can replace it at 700 and 750°. The mechanical properties of the steel are shown in Fig. 13. The EI696M steel differs from EI696 (as a result of molybdenum addition) in having less tendency to loss of strength with air cooling during heat treatment, which is very important for the fabrication of discs and other parts of large dimensions and sections. Processing plasticity is similar to that of the EI696 steel (Fig. 14).

The KhN35VTYu (EI787) steel is used for detail parts of gas turbine engines operating from 500 to 750°. For parts operating at 500-650° and with high stresses, the thermal and mechanical treatment consists of heating the blanks to 1150°, deformation in the hot condition with large degree of reduction, and subsequent aging for 16 hours at 750°. Double quenching is used for parts operating 650-750°: air from 1150° (6 hour soak) and air from 1050° (4 hour soak), and then 8-hour aging at 830° with air cooling. The variation of steel properties with temperature increase is shown in Fig. 15. This steel welds very poorly.

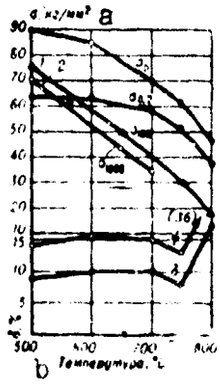

Fig. 13. Variation of mechanical properties of Kh12N22T3MR steel with temperature increase: 1) oil quench from 1120° plus 16 hours at 730° plus 16 hours at 630°; 2) oil quench from 1120° plus 16 hours at 780°. a) σ, kg/mm^2; b) temperature. °C.

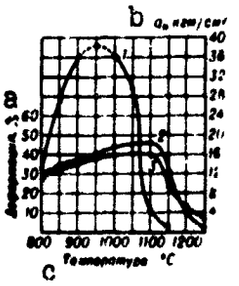

Fig. 14. Diagram of Kh12N22T3MR steel plasticity as a function of temperature; 1) Impact strength; 2) reduction on press prior to appearance of cracks; 3) reduction under hammer prior to appearance of cracks. a) deformatin, %; b) a_n, kgm/cm^2; c) temperature, °C.

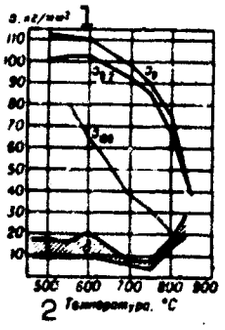

Fig. 15. Variation of mechanical properties of KhN35VTYu steel with temperature increase. 1) σ, kg/mm^2; 2) temperature, °C.

The KhN35VMTR (EI692) chrome-nickel-titanium steel belongs to the mildly dispersion hardening steels which are used in turbine construction for fabricating blades and fastener details operating at 650-700° with service life of the order of 10,000 hours. The steel has satisfactory plasticity under stress-rupture conditions at 650-700° and is scale resistant to 850°. The mechanical properties are given in Figs. 4, 6.

The KhN35VT (EI612) chrome-nickel steel belongs to the steels which are strengthened by means of dispersion hardening and tungsten alloying. The steel is intended for turbine blades, discs and rotors operating for long periods at 650-680°. The mechanical properties are shown in Figs. 4, 6, 16. Under stress rupture conditions, the steel has adequately high plasticity, therefore working deformation of the order of 0.5-1% is permitted. The steel is scale resistant to 800°.

The steel welds satisfactorily with the use of electrodes covered with the KTI-7 coating and which contain niobium in addition to the other alloying elements of the steel. Welding is performed both in the condition after austenitic quench and after quench and double aging. The parts should be subjected to double tempering after welding.

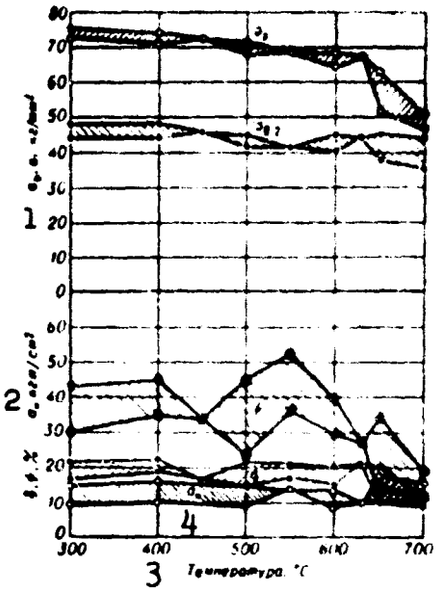

Fig. 16. Variation of mechanical properties of KhN35VT steel with change of test temperature; 1) σ_b, σ_s kg/mm^2; 2) a_n, kgm/cm^2; 3) temperature, °C; 4) an.

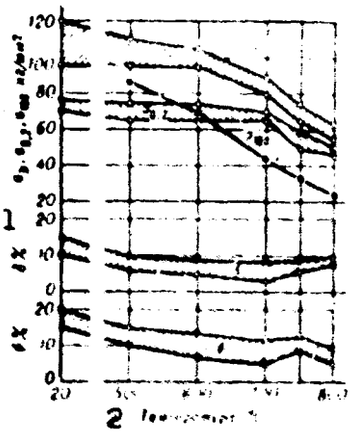

Fig. 17. Variation of mechanical properties of EP105 steel with temperature increase. 1) σ_b, $\sigma_{0.2}$, σ_{100} kg/mm^2; 2) temperature, °C.

TABLE 3

Stress Rupture Strength of EP105 Steel

Температура (°С) 1	Предел 100-часовой длит. прочности (кг/мм²) 2		Относит. удлинение после длит. испытания на образцах без надрезов 3
	образцы без надрезов 4	образцы с надрезом 5	
500	87	—	—
600	70	70	—
700	45	45	1.5—3.5
750	35	35	2.5—6
800	25	25	5—7

1) Temperature, °C; 2) 100-hr stress rupture strength limit (kg/mm^2); 3) relative elongation after long-term testing on unnotched specimens; 4) smooth specimens; 5) notched specimens.

The KhN35VTR (EI725) steel is intended for fabricating turbine cases, guide vanes operating at 750°. The steel belongs to the dispersion hardening group and has high strength at high temperature. The mechanical properties are shown in Figs. 4, 6. It may be used in designs fabricated from sheet by welding. It is scale resistant to 800-850°.

The EP105 chrome-nickel-titanium-aluminum steel is dispersion hardening with intermetallide strengthening. In addition to the intermetallide γ'-phase, in the steel structure there are present titanium carbide TiC, titanium nitride TiN, and the boride "Y" phase in which there is a small amount of chromium and iron. The steel has high strength at high temperature, particularly at 750-800° (Fig. 17). It is used for gas turbine discs and blades operating to 800° in place of the nickel alloys EI437A, EI437B.

This steel deforms satisfactorily in the 1100-900° range and machines satisfactorily. It is recommended for turbine blades and discs operating to 800° and as a replacement for the EI437A and EI437B alloys.

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F.F. Khimushin

WROUGHT MAGNESIUM ALLOYS are magnesium alloys which are subjected to rolling, pressing, forging and stamping. These alloys are used for production of extruded rods, strip, profiles and tubes, rolled plates and sheet, forgings and stampings. Industrial use is made of the wrought magnesium alloys alloyed with aluminum, zinc, manganese, zirconium, the rare-earth elements, thorium and certain other metals. For the chemical compositions see Magnesium Alloys. Details and components of various structures made from the wrought mill products are fabricated by mechanical working, welding and riveting, three-dimensional and sheet stamping. Depending on the basic properties and purpose, the wrought magnesium alloys can be divided into four groups: 1) alloys with high plasticity, corrosion resistance, weldability andlow strength (σ_b = 17 – 23 kg/mm^2); 2) alloys of medium strength (σ_b = 23 – 26 kg/mm^2) with good plasticity and weldability; 3) high strength alloys (σ_b = 26 – 40 kg/mm^2) with medium and low plasticity; 4) high strength alloys intended for use at elevated temperatures.

The first group includes the MA1 alloy of the Mg-Mn system which is noted for the highest corrosion resistance, best weldability and high plasticity (see Low-Strength Wrought Magnesium Alloys); the second group includes the low-alloy MA8 alloys of the Mg-Mn system with the addition of 0.2% Ce, the MA9 alloy of the same system with additions of 0.5% Al and 0.2% Ca and the medium-alloy MA2 alloy of the system Mg – Al – Zn – Mn. The alloys of the second group have processing plasticity which is sufficient for the rolling of sheet, satisfactory weldability and corrosion resistance and higher mechanical properties in comparison

with the MA1 alloy (see Medium-Strength Wrought Magnesium Alloys). The third group includes the alloys MA2-1, MA3 and MA5 of the Mg – Al – Zn – Mn system, the VM65-1 alloy of the Mg – Zn – Zr system, and the MA10 alloy of the Mg – Al – Cd – Ag – Mn system. The alloys of this group, except for MA3, are strengthened by heat treatment and (with the exception of VM65-1) have a tendency to stress corrosion which increases from the MA3 alloy to the MA10 alloy (see High-Strength Wrought Magnesium Alloys). The fourth group includes the alloys alloyed with the rare-earth elements – VM17 of the Mg – Ce – Mn system and MA11 of the Mg – Nd – Mn – Ni system, and also the alloys with thorium MA13 and VMD1 of the Mg – Th – Mn system. The alloys of this group have good plasticity in pressure working and can be welded using argon-arc welding. The corrosion resistance of the alloys with thorium is no lower than that of the MA8 alloy and is somewhat better than that of the MA11 alloy. The alloys of the fourth group are not subject to stress corrosion. The MA11 and MA13 alloys can be heat treated. The VM17 alloy is intended for long-time operation ($\geq$ 100 hours) at temperatures to 200°. the MA11 alloy is for temperatures to 250°, and the MA13 and VMD1 alloys are good to 350°. For short time operations ($\leq$ 5 hours) the VM17 alloy can be used at temperatures to 250°, the MA11 alloy to 300°, and the MA13 and VMD1 alloys to 400° (see High-Temperature Wrought Magnesium Alloys).

The hexagonal structure of the crystal lattice of magnesium and its alloys gives rise to certain peculiarities of the deformation process and the properties of the resulting mill products. At room temperature, slippage in the crystal lattice of magnesium takes place only along one base plane of the hexagonal prism, which explains the low plasticity of the alloys at this temperature. Therefore, all the pressure working operations are performed in the hot condition. In the process of deformation at temperatures above 200-225°, there appear addi-

tional slippage planes and the plasticity of magnesium and its alloys increases sharply. With sheet stamping, bending and straightening, the blanks are heated (depending on the degree of deformation and the type of alloy) to 250-400° and the tool is heated to 150-300°. Because of the limited number of slippage planes of the hexagonal lattice of magnesium and the low speed of the diffusion processes which take place in the magnesium, the plasticity of magnesium and its alloys to a considerable degree depends on the deformation rate. Therefore, pressure working (rolling and pressing) of the majority of the alloys is performed with low rates, while for forging and stamping use is made of hydraulic or manual presses rather than hammers. In the deformation process the base plane of the crystal lattice of magnesium and its alloys is located at a small angle to the direction of deformation. This explains the definite orientation of the crystal structure of the wrought mill products and the anisotropy of the mechanical properties. The degree and nature of the anisotropy depend on the temperature and the technology of the production of the mill products. The table presents typical variations of the mechanical properties with the direction of cut of the specimens with respect to the direction of deformation.

Table of Comparative Mechanical Properties Along and Across the Direction of Deformation of Certain Wrought Magnesium Alloys

1 Сплав	2 Вид полуфабриката	3 Состояние материала	4 $\sigma_{0,2}$ (кг/мм²)		4 σ_b (кг/мм²)		δ (%)	
			5 Направление вырезки образцов					
			6 вдоль	7 поперек	6 вдоль	7 поперек	6 вдоль	7 поперек
МА1	8 Листы толщиной 0,8—3 мм	9 Отожженные	10	12	21	26	7	10
МА8			20	18	27	25	11	20
10 ВМ65-1	11 Полоса сечением 34×455 мм (прессованная)	Искусственно 12 состаренная	28	20	33	28	10	14

1) Alloy; 2) form of mill product; 3) material condition; 4) (kg/mm^2); 5) specimen cut direction; 6) along; 7) across; 8) sheets of thickness; 9) annealed; 10) VM ; 11) strip of section 34 x 455 mm (extruded); 12) artificially aged.

In the use of the wrought mill products made from the magnesium al-

loys it is necessary to take measures to protect them from corrosion. Certain of the high strength alloys (MA3, MA5 and MA10) have a tendency to stress corrosion and can be used under the condition of limitation of the long-time tensile stresses to values not exceeding 50-60% of the values of their tensile yield strength. In the design it is necessary to provide detail shapes such that water cannot remain in the various cavities, pockets and gaps. In connecting details made from the magnesium alloys with details made from the other materials, it is necessary to take account of the possibility of contact corrosion (see Corrosion of the Magnesium Alloys, Protection of the Magnesium Alloys).

The condition (form of heat treatment) of the mill products made from the wrought magnesium alloys is designated by corresponding codes. After hot working the mill products are marked with the alloy type without additional code; those delivered in the heat treated conditon are marked with the type of alloy and an additional symbol designating the form of heat treatment; M – annealed: H -- strain hardened with subsequent partial anneal; T4 – solution treated; T1 – artificially aged; T6 – solution treated plus artificial aging; T8 – solution treated plus cold working plus artificial aging.

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A.A. Kazakov

WROUGHT SCALE-RESISTANT STAINLESS STEEL is steel with high resistance to oxidation at high temperatures (700-1200°).

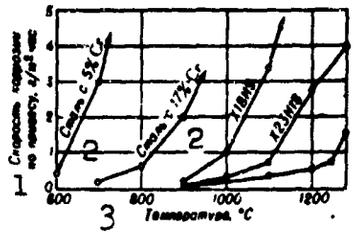

Fig. 1. Scale resistance of chrome and chrome-nickel steel (heated in air atmosphere). Curve at lower right is for Kh20N80T alloy. 1) Corrosion rate from weight increase, g/m^2-hr; 2) steel; 3) temperature, °C.

TABLE 1

Chemical Composition of Wrought Scale-Resistant Stainless Steels

Марка по ГОСТ 1	Заводская марка 2	Содержание элементов (%) 3					
		C	Si	Mn	Cr	Ni 4	др. элементы
5 1Х18Н9Т	6 ЭЯ1Т	≤0,12	≤0,8	1—2	17—19	9—11	0,5—0,7 Ti
7 Х23Н18	8 ЭИ417	≤0,2	≤1	≤2	22—25	17—20	
9 Х25Н25ТР	ЭИ813	0,07—0,12	≤0,8	1—2	23—26	24—27	1,1—1,6 Ti; B ≤0,01
10 Х25Н20С2	ЭИ283	≤0,2	2—3	0,2—0,7	24—27	18—21	
11 Х25Н16Г7АР	ЭИ835	≤0,12	≤1	5—7	23—26	15 18	0,3—0,45 N; B ≤0,02
12 ХН38ВТ	ЭИ703	0,06—0,12	≤0,8	≤0,7	20—23	35—39	0,7—1,2 Ti; Al ≤0,5 2,8—3,5 W
	ЭП126 (ВЖ100) 13	0,1	0,6	1,5	19—22	25—30	4,8—6 W; 2,8—3,5 Mo; 0,15—0,3 N$_2$; 0,7—1,3 Nb; 0,005 B

1) Grade per GOST; 2) plant designation; 3) element content (%); 4) other elements; 5) 1Kh18N9T; 6) EYa1T; 7) Kh23N18; 8) EI417; 9) Kh25N-25TR; 10) Kh25N20S2; 11) Kh25N16G7AR; 12) KhN38VT; 13) EP126 (VZh100).

The resistance of the wrought scale-resistant stainless steels to oxidation is higher, the higher the chrome and silicon content. Nickel also contributes to the scale resistance (Fig. 1). The chemical composition of scale-resistant chrome-nickel steel with austenitic and aus-

tenitic-ferritic structure is shown in Table 1, and the mechanical properties are given in Table 2. As a rule, the carbon content in the wrought scale-resistant stainless steels does not exceed 0.2%. The carbon content in cast steel is in the range of 0.2-0.5%. After an austenitic quench, the wrought scale-resistant stainless steels have moderate strength and high plasticity; the higher the quenching temperature, the higher the plastic properties at room temperatures and the lower they

TABLE 2

Mechanical Properties and Heat Treatment Regimes for Wrought Scale-Resistant Stainless Steels

Сталь по ГОСТ 1	2 Завод-ская марка	3 Термич. обработка	HB	$\sigma_в$	$\sigma_{0,2}$	δ	ψ	5 $a_н$ (кгм/см²)	6 E (кг/мм²)
			4 (кг/мм²)			(%)			
7 1Х18Н9Т	8 ЭЯ1Т	9 Закалка с 1050—1100° на воздухе или в воде	140—170	>55	>20	>40	>55	>25	>20300
10 Х23Н18	11 ЭИ417	Закалка с 1100—1150° в воде или на воздухе	140—180	>58	>30	>35	>50	>20	20400
12 Х25Н25ТР	ЭИ813	13 Закалка с 1150—1200°, выдержка 5—10 мин, охлаждение на воздухе	130—160	>55—65	30—35	35—45	60—65	>25	19850
14 Х25Н16Г7АР	ЭИ835	Закалка с 1150° на воздухе	190—200	80—94	—	45—57	—	37—38	19315
16 ХН38ВТ	ЭИ703	15 Закалка с 1100—1140° на воздухе	—	>74	—	>35	—	—	20320
Х25Н20С2 17	ЭИ283	Закалка с 1050—1100° на воздухе	153	>55	—	>23	>30	>10	—
	ЭП126 (ВЖ100)	Закалка с 1000—1120° на воздухе	—	>80	>37	>50	—	—	20100

1) Steel per GOST; 2) plant designation; 3) heat treatment; 4) (kg/mm^2); 5) a_n (kgm/cm^2); 6) E (kg/mm^2); 7) 1Kh18N9T; 8) EYa1T; 9) quench from — in air or water; 10) Kh23N18; 11) EI; 12) Kh25N25TR; 13) quench from —, hold for 5-10 minutes, air cool; 14) Kh25N16G7AR; 15) quench from — in air; 16) KhN38VT; 17) Kh25N20S2; 18) EP126 (VZh100).

are at high temperatures. Long-term soak of the wrought scale-resistant stainless steels at moderate temperatures may alter the properties determined at room temperatutres, lowering the impact strength and the plasticity (Fig. 2). Increase of the carbon content in the type 25-20 chrome-nickel steel increases its tendency to dispersion hardening after quency at high temperatures and subsequent aging at moderate temperatures. These changes take place with the austenitic structure as a result of formation of carbide phases and the hard intermetallide σ-

phase, and with the austenitic-ferritic structure they take place as a result of the decomposition of the austenite or ferrite and the separation of the σ-phase in the δ-ferrite.

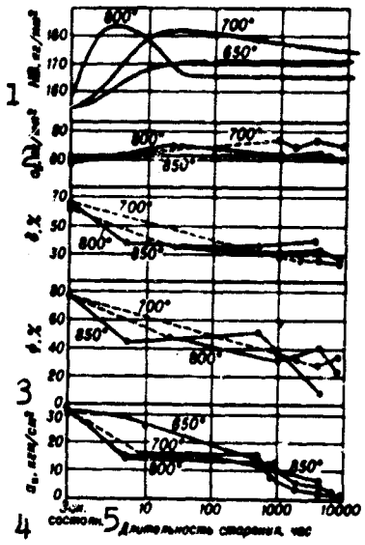

Fig. 2. Effect of long-term heating during aging on the variation of the mechanical properties of the Kh23N18 alloy after water quency from 1180°. 1) HB, kg/mm^2; 2) σ_b, kg/mm^2; 3) a_n, kgm/cm^2; 4) quenched condition; 5) aging duration, hours.

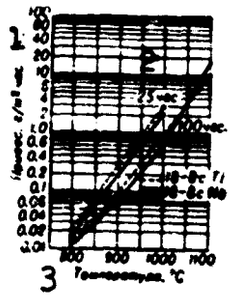

Fig. 3. Scale-resistance of type 18-8 chrome-nickel steel with temperature increase in an air atmosphere. 1) Weight increase, g/m^2-hr; 2) hours; 3) temperature, °C.

The type 18-8 chrome-nickel steel with titanium 1Kh18N9T has scale-resistance to 850-900° and is used widely in the fabrication of exhaust stacks for aircraft engines, detail parts for furnace equipment in boiler construction, etc., has some tendency to dispersion hardening, which shows up after long-term heating in the temperature range

500-800°. From the data of TsNIITMASh, the use of a stabilizing anneal at 700° for 20 hours somewhat improves the stress-rupture strength at 550°. The relative elongation after tests for stress rupture and plasticity was reduced, but after a 15,000-hour stress rupture test it remained adequate and amounted to 3-6%. Aging duration to 5000 hours slightly reduces the impact strength and the relative elongation, but the yield limit is somewhat increased. In this case no tendency to intercrystalline corrosion was observed. Figure 3 shows the scale resistance of the steel.

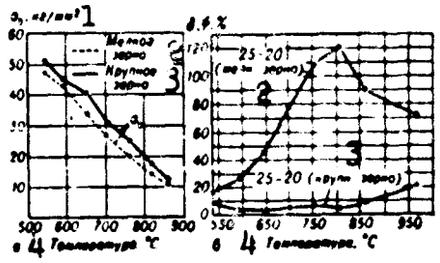

Fig. 4. Effect of grain size on variation of strength (a) and plasticity (b) of the Kh23N18 steel. 1) σ_b, kg/mm^2; 2) fine grain; 3) coarse grain; 4) temperature, °C.

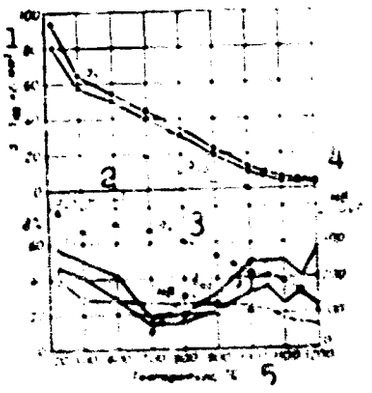

Fig. 5. Variation of mechanical properties of the Kh25N16G7AR steel with temperature increase. 1) σ_b, σ_{100}, kg/mm^2; 2) a_n, kgm/cm^2: 3) a_n; 4) HB, kg/mm^2; 5) temperature, °C.

The type 25-20 chrome-nickel steel (Kh23N18) combines adequately high oxidation resistance at high temperatures with good strength at

high temperature. It is somewhat more difficult to weld than the 18-8 type chrome-nickel steel. The high temperature strength properties of the steel depend to a considerable degree on the grain size and the heat treatment regime. Coarse grain gives the steel greater strength

TABLE 3

Strength of Weld Joints of Kh25N16G7AR Steel

Темп-ра (°C) 1	Точечная сварка 2	Роликовая сварка 3	Аргонодуговая сварка 4
	Разрушающее усилие на точку (кг) 5	σ_b (кг/мм²) 6	
20	1080—1150	79—86	88—89
800	460—480	22—27	26—27
900	340—380	16—20	20—21

1) Temperature, °C; 2) spot welding; 3) seam welding; 4) argon-arc welding; 5) fracture force on spot (kg); 6) σ_b (kg/mm^2).

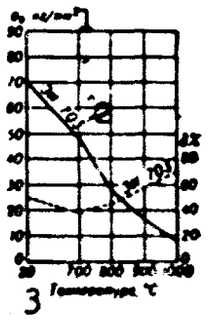

Fig. 6. Variation of mechanical properties of KhN38VT steel (EI703) with temperature increase. 1) σ_b, kg/mm^2; 2) KI; 3) temperature, °C.

at high temperatures and lower plasticity. Long-term heating of the steel in the temperature range which leads to the formation of the σ-phase reduces the plasticity and the toughness properties somewhat, which, however, has little effect on the operational life. Coarse grained steel containing more than 0.05% carbon acquires a tendency to intergranular corrosion after heating at 600-800° and decomposes under the action of highly aggressive media. Heating at higher temperatures does not cause this phenomenon. An austenitic quench of the steel fr

TABLE 4

Strength of Welded Joints of KhN38VT Steel (sheet thickness 1.5 mm)

Temp-ra (°C) 1	2 Точечная сварка	3 Роликовая сварка	4 Аргонно-дуговая сварка
	5 Разрушающее усилие на точку (кг)	6 σ_b (кг/мм²)	6 σ_b (кг/мм²)
20	1050	68—72	67—70
900	480	14—17	14—17

1) Temperature, °C; 2) spot welding; 3) seam welding; 4) argon-arc welding; 5) failure load on spot (kg); 6) σ_b (kg/mm^2).

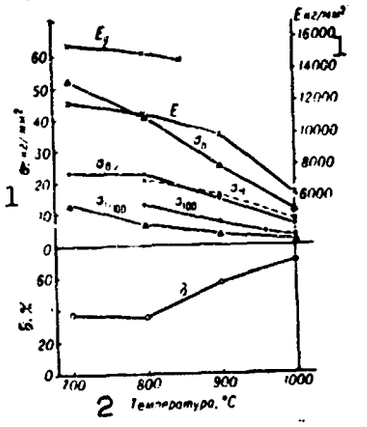

Fig. 7. Variation of mechanical properties of EP126 steel with temperature increase. 1) – kg/mm^2; 2) temperature, °C.

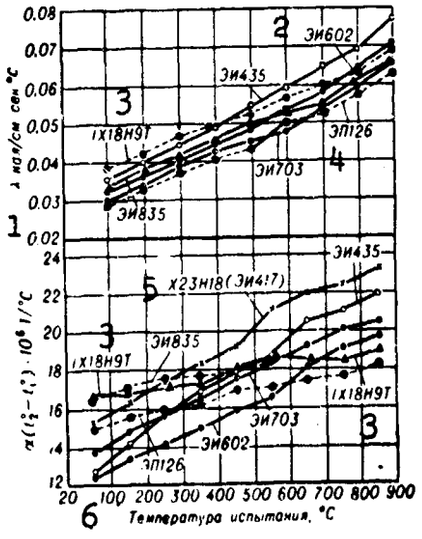

Fig. 8. Variation of physical properties of wrought scale-resistant stainless steel with temperature increase. 1) – cal/cm-sec-°C; 2) EI; 3) 1Kh18N9T; 4) EP; 5) Kh23N18 (EI417); 6) test temperature, °C.

high temperatures (1175°) gives the 25-20 steel greater tensile strength and greater resistance to stress-rupture failure at 600-1000°, than after normalization or quenching from 900-1000°, but reduces its plasticity. The effect of grain size on the variation of the mechanical properties of the Kh23N18 steel is shown in Fig. 4.

The type 25-20 fine-grained chrome-nickel steel has better resistance for operation under conditions of the action of high heat transfer (gas turbine nozzle vanes) than coarse-grained steel. The type 25-20 chrome-nickel steel with high silicon content Kh25N20S2 has better resistance to oxidation at high temperatures, and particularly in an atmosphere of the products of combustion of a fuel with high sulfur content, than steel without silicon. In reducing media this steel is more resistant to carburizing in comparison with the usual chrome-nickel steel.

However, the addition of silicon increases the tendency to formation of the σ-phase during long-term heating, which somewhat reduces the steel plasticity. Reheating to the σ-phase solution temperature eliminates this brittleness. The type 25-20 chrome-nickel steel with 1.8% silicon has higher strength at high temperatures and is used abroad widely for fabricating furnace equipment, and also for detail parts of gas turbines (combustion flame tubes, nozzle tail cones).

The Kh20N14S2 (EN211) chrome-nickel steel has high resistance to gaseous corrosion in furnace gases and is used to fabricate detail parts for furnace equipment. With regard to strength properties at high temperatures, it is close to the type 18-8 steels, but has lower plasticity.

The Kh25N16G7AR (EI835) chrome-nickel-manganese steel with nitrogen has high strength at high temperature and high scale resistance in comprsison with the type 18-8 chrome-nickel steel with Ti and Nb and is

recommended for use as sheet material. The variation of the mechanical properties with temperature increase is shown in Fig. 5.

Extended heating at 600-850° for 100 hours does not cause variations of the strength characteristics, but has some effect in reducing the plasticity. In comparison with the initial condition (quench from 1150° into water), in which the material has good plastic properties δ and ψ and 8-10 bending cycles, the material aged at 650-850° has less plasticity (δ and ψ are reduced to 35-40%, and the number of bend cycles to 2-3). This steel deforms well in cold pressure working, is amenable to spot, seam, and argon-arc welding. The strength of the weld joints made using spot, seam, and argon-arc welding is shown in Table 3. The steel acquires a tendency to intercrystalline corrosion after heating in the critical temperature range (500-750°). Therefore its use for equipment operating in strongly aggressive media must be monitored for intercrystalline corrosion in the weld joints by means of testing using the AM method (GOST 6032-58). The KhN38VT (EI703) chrome-nickel steel has high strength at high temperature as a result of the addition of tungsten and titanium of niobium. In the austenitic-quench condition the steel has good formability. The variation of the mechanical properties of the steel with change of temperature is shown in Fig. 6. The steel welds well using argon-arc, arc and resistance (spot and seam) welding.

The EP126 (VZh100) steel which contains, in addition to 20% Cr and 25% Ni, the high-melting elements (5% W, 3% Mo), has high strength at temperatures above 800° (Fig. 7). This steel is amenable to deep drawing, welds well using argon-arc, spot and seal welding. It is recommended for fabricating structural elements operating at 700-1000°. Its resistance to short-term (up to 1 hour) creep may be improved by strain hardening.

With respect to its characteristics, the chrome-nickel scale-resistant steel in many cases is not inferior to the nichrome alloys EI-435 and EI602 which are widely used as high-temperature, high-strength materials for gas turbine engines. The variation of the physical properties of the wrought scale-resistant stainless steels with temperature is shown in Fig. 8.

References: Khimushin, F.F., Zharoprochnyye gazoturbinnyye stali i splavy [High-Temperature Gas Turbine Steels and Alloys] in book: Sovremennyye splavy i ikh termicheskaya obrabotka [Modern Alloys and Their Heat Treatment], Moscow, 1958; Liberman, L.Ya. and Peysikhis, M.I., Spravochnik po svoystvam staley, primenyayemykh v kotloturbostroyenii [Handbook on Properties of Steels Used in Boiler and Turbine Construction], 2nd edition, Moscow-Leningrad, 1958; Spravochnik po mashinostroitel'nym materialam [Handbook on Machine Construction Materials], Vol. 1, Moscow, 1959; Khimushin, F.F., Nerzhaveyushchiye stali [Stainless Steels], Moscow, 1963; Fedortsov-Lutikov, G.P., et al., in book: Voprosy metallovedeniya kotloturbinnykh materialov [Questions of Metal Science of Boiler and Turbine Materials], Moscow, 1955 (TsNIITMASh, Book 7); Clark, C.L., High-Temperature Alloys, N.Y., 1953; Symposium on the Nature, Occurrence and Effects of Sigma Phase, Phil., 1951 (ASTM. Special Technical Publ., No. 110); Freeman, J.W., Comstock, G.F. and White, A.E., "Trans. ASME," 1952, Vol. 74, No. 5, page 793.

F.F. Khimushin

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[Transliterated Symbols]

4544 ЦНИИТМАШ - TsNIITMASh = Tsentral'nyy nauchno-issledovatel'skiy institut tekhnologii i mashinostroyeniya = Central Scientific Research Institute for Technology and Machinery

XEROGRAPHIC X-RAY AND GAMMA DEFECTOSCOPY is the method of x-ray and gamma radioscopy which provides for recording of the x-ray and gamma-ray images on a layer of photoconductor to which there is communicated an electrostatic charge. Most often the photoconductor is a thin layer of selenium (50-200 microns) applied on an aluminum substrate of thickness 0.8-1.0 mm. The xerographic plate thus obtained has sensitivity to visible light, x-rays and gamma rays. The complete cycle for obtaining the images consists of the following operations: communication of the electrostatic charge to the plate, exposure, development of the latent electrostatic image. To communicate the electrostatic charge, the xerographic plate, mounted in a holder (sensitive layer turned toward the top of the holder) is placed in the field of a corona discharge (10-15 kv). The charging duration is 1-10 seconds. The charge is retained in the closed holder for a period of 1-5 hours. During exposure the details to be examined are placed on the plate which is in the closed holder. When using Co^{60} gamma rays the exposure time is about the same as that needed with the use of x-ray film, and when using x-rays for the illumination the exposure time is less by a factor of 2-6 times than for x-ray film. During irradiation of the details the surface charge of individual portions of the sensitive layer changes its magnitude as a function of the intensity of the radiation passed, which in turn depends on the thickness of the details and the presence of defects in them. As a result of the exposure there appears on the surface of the sensitive layer the so-called latent electrostatic image. The development of the latent electrostatic image is accomplished without

access to light by means of sprinkling extremely fine powder on the sensitive layer of the plate located in the holder. During this dusting the powder particles are charged either by a separate generator or as the result of the use of the triboelectric effect. The development-dusting process requires 10-15 seconds, after which the plate can be removed from the holder for inspection and analysis of the pattern. After inspection of the picture the image formed by the powder is erased using a soft cloth and the plate can be reused (up to 600 times). For retention of the image use is made of either photography of the plate or, if the powder is made from a low-melting resin, the image can be transferred to white paper and fixed by heating. The entire process of transfer and fixing of the image requires 20-30 seconds.

The advantages of xerographic x-ray and gamma-ray defectoscopy are: small time interval (up to 1 min) between termination of exposure and obtaining the image; low cost of the materials used (cost of a single plate is about 25 times less than the cost of the film for an equivalent number of exposures); possibility of multiple usage of the plate; shorter exposure duration with defect detectability equal to that of x-ray film; no requirement for special dark room, use of water and chemicals.

The deficiencies of the xerographic x-ray and gamma-ray defectoscopy are: complex technology for preparation of the xerographic plates; weak mechanical strength of the sensitive layer which prohibits bending of the plate; gradual alteration of the plate properties with storage as a result of conversion of the amorphous selenium into the crystalline state.

References: Kornishin K.I., Kserograficheskiy metod polucheniya izobrazheniy pri rentgenovskoy defektoskopii [Xerographic Method of Obtaining Images in X-Ray Defectoscopy], M., 1959; Dyuran R.L., Industri-

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al Xerography, in book: Industrial Radiography, transl. from Eng., M., 1960.

K.I. Kornishin

X-RAY DEFECTOSCOPY – checking of components and materials with the aid of x-rays. The x-ray image can be detected and recorded by various x-ray-recording devices focused on the object to be fluoroscoped. In the simple diagram of fluoroscopy given below (Fig. 1) the outline of the x-ray image, which is not visible to the eye, is shown by cross-hatching. The x-ray source can be an x-ray apparatus or Betatron, which consists of an x-ray or betatron tube, its power supply, and a control unit. X-rays are high-frequency electromagnetic oscillations produced in an x-ray tube or betatron on the sudden retardation of high-speed electrons at the anode (target). In an x-ray tube the electrons are accelerated by the linear electrostatic field between the cathode and the anode, while in a betatron tube they are accelerated by the vortical electric field set up by the alternating magnetic flux.

Fig. 1. Diagram of fluoroscopy of an object: 1) X-ray source; 2) working x-ray beam; 3) object to be fluoroscoped; 4) internal defect; 5) x-ray image of object (not visible to eye); 6) x-ray recording system.

It is best to use soft (long-wave) x-rays for checking plastics and light alloys. This is done with tubes having a beryllium window, which readily passes the soft components of the retarded-radiation spectrum. Pulse tubes are used in investigating rapid processes, as in

recording a bullet in flight or shrapnel from an exploding shell. Such tubes reduce the exposure time to the order of a μsec. High-voltage sectional x-ray tubes or betatrons are used for fluoroscoping thick-walled components of steel and other heavy alloys. Soviet sectional tubes are rated at 400 kv, while equivalent American tubes are rated at 100 and 200 kv.

Fig. 2. RUP-200-5-1 apparatus: 1) Portable rack; 2) box for accessories; 3) control panel; 4) transformer unit and x-ray tube.

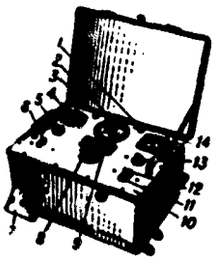

Fig. 3. Control panel (with lid open): 1) Red indicator light; 2) 15-min time relay; 3) green indicator light; 4) milliameter; 5) control knob for tube plate current; 6) circuit switch; 7) protective cover; 8) high-voltage control knob; 9) ruled chart; 10) upper control panel; 11,12) "start" and "stop" buttons; 13) line switch; 14) voltmeter.

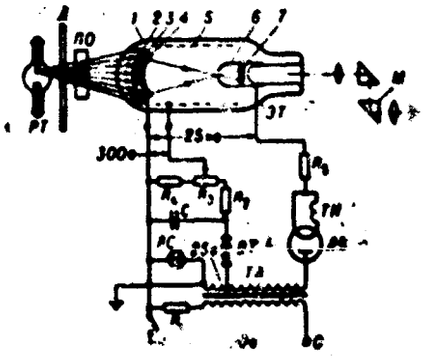

Fig. 4. Diagram of electro-optical converter and its power supply: RT) x-ray tube; D) diaphragm; PO) object to be fluoroscoped; VT) solid-state rectifier; LV) rectifier tube; LS) indicator light; ET) vacuum tube; TA) plate transformer; M) monocular; TN) filament transformer.

1) Glass bulb; 2) aluminum plate; 3) fluorescent screen; 4) photocathode; 5) electrically conductive layer; 6) plate (aluminum cone); 7) fluorescent output screen. a) RT; b) D; c) PO; d) ET; e) kv; f) v; g) TN; h) LV; i) VT; j) LS.

X-ray devices are rated for different plate voltages and each is consequently suitable for a definite range of thicknesses and a certain material; for example, the RUP-200-5-1 apparatus is suitable principally for checking steel components under laboratory, shop, and field conditions (Figs. 2 and 3). The optimum fluoroscopy regimes for these devices are given by the exposure charts, which are determined experimentally. The betatron is used for checking very thick components (e.g., steel more than 100 mm thick).

There are four methods of recording x-rays suitable for defectoscopy: photographic (using a photographic emulsion), fluoroscopic or visual (using a fluorescent screen, electrooptical converter, scintillating monocrystals, etc.), xerographic or electrographic (using a charged semiconductor layer with a conductive underlayer), and ionization (using an ionization chamber, Geiger-Muller counter, or scintillation counter). The first three methods make it possible to obtain a visible image of the object in the recorder plane; the ionization method records the rays in a certain volume of space, giving no visible image. The most common industrial technique is the photographic method, which is based on the ability of x-rays to produce a physicochemical reaction in silver bromide, so that a latent image of the contours of the object and the defects in it is formed in the emulsion layer of the photographic film. Development makes the latent image visible and, after the film has been fixed, the picture (roentgenogram) can be examined in transmitted light with a viewer.

The fluoroscopic method is based on the ability of certain sub-

stances (cadmium, zinc, and tungsten salts, monocrystals of cesium iodate, calcium, and sodium, etc.) to fluoresce under the action of x-rays. The brightness of the light emitted by these substances is proportional to the intensity of the x-rays acting on them. As a result of this property, an invisible x-ray image can be made visible by a screen manufactured from such substances. The fluoroscopic method is less sensitive with respect to detection of defects, but is more efficient than the photographic method. The low sensitivity of this technique results from an imperfection of the human eye, which begins to perceive the light emitted by the screen only when it reaches a definite brightness; the eye is capable of distinguishing two adjacent fields on the luminescing screen only if their brightness ratio is no less than 1.15. In addition, the fluoroscent screen itself (if it consists of polycrystals of thefluorescent substance) has a granularity that limits its resolving power.

The brightness of an x-ray screen is quite restricted, usually not exceeding 1-2 apostilbs. An image hundreds of times as bright is furnished by the electrooptical converter (EOP), i.e., an electron-beam tube in which the x-ray image of the object is subjected to four-fold conversion: into light on the fluorescent input screen, into an electronic image on the photocathode, into an accelerated electronic image on the plate, and again into light (of greater brightness) on the output screen of the EOP. The high brightness of the output screen of the EOP permits its use for x-ray checking of thicker components than is possible with an ordinary fluorescent screen, giving better visibility of certain defects at lower radiation-source powers. The principal drawback of the EOP is its low resolving power (2-3 min/mm, as against an average of 60-70 min/mm for x-ray films). This limits its usefulness in the x-ray inspection of critical welded components, since

fine cracks, unfused areas, and small pores cannot be detected with the EOP; this device is used principally for x-ray defectoscopy of castings. Figure 4 is a diagram of the EOP and its power supply and shows the positioning of the apparatus for fluoroscopy of an object. The ionization method is used principally for defectoscopy of products with plain-parallel surfaces and for checking deviations in the thickness of materials (see Ionization method for x-ray and gamma-defectoscopy). Other techniques for detecting defects are being perfected (see Xerographic x-ray and gamma-defectoscopy). Defects detected fluoroscopically are classified according to character, size, number, and location in the product. The permissibility of given defects in the product is determined by its technical specifications, comparing the article under inspection with a standard article (see Defects in metals).

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S.V. Chernobrovov

YIELD POINT – a sharp (sudden) transition from elastic into plastic deformation expressed on the load-extension diagram (and sometimes of torsion and even compression diagrams) of low-carbon steels, certain brasses, bronzes, light alloys, etc., as a rapid fall of the stress or as a yield plateau (i.e., retention of a constant load along a given section of the diagram). The yield point is characteristic also for certain plastics and nonmetallic crystals. The causes for the yield point are examined by the theory of dislocations.

Ya. B. Fridman

YIELD TEMPERATURE T_f – characterizes the transition of linear polymers from the hyperelastic state to the viscous flow state under small stresses. Starting with a temperature T_f the lower, the smaller the specific gravity, linear polymers begin to yield. The yield temperature is arbitrary, since it depends on the methods and conditions of its determination. For low-molecular amorphic substances T_f practically coincides with the vitraification temperature T_g.

G.M. Bartenev

YOUNG'S MODULUS – see Modulus of Elasticity.

ZEFRAN – is a synthetic fiber from a mixture of polyacrylonitrile with modified polyacrylonitrile or with a copolymer of acrylonitrile and vinyl acetate with a low quantity (14% by weight) of the graft polyvinyl - pyrrolidone copolymer. The physicochemical and mechanical properties of zefran are: white color; inflammable; specific gravity 1.19; moisture content at standard conditions 2.5%, rising to 4.7% at a relative moisture of 95%; softening temperature 254°; 2% shrinkage in boiling water within 10 hrs; almost no difference to the fiber from not-modified polyacrylonitrile with regard to the resistance to light and weather, to chemical reagents and solvents; high elasticity, resistance to wear, increased hydrophilic nature and lowered electrifiableness (in textile treatment) than other polyacryl fibers, good colorability (the color being stable to light and washing) by vat, anthraquinone, sulfur and naphthol dyes. The breaking length of zefran is 32.5 km in a dry state, 27.9 km in a wet state, and 12.6 km in a loop; the breaking elongation is 33%; the initial modulus of elasticity is 396 kg/mm^2 (at a breaking length of 30.6 km and a 30% elongation). Zefran is used in pure state and mixed with viscose rayon staple fiber or wool mainly for consumer goods which must be stable in shape and fashion, not-crushing and not-felting.

L.M. Musichenko-Vasil'yeva

ZINCITE – is zinc oxide (ZnO). The chemical composition of an ideally pure zincite is 80.3% Zn; 19.7% O; the impurities are: 0.01% FeO; 0.27% MnO, and 0.08% SiO_2. The color is pale yellow, orange-yellow or dark brown. The cleavability along the {1010} is mediocre. The specific gravity is 5.66.

The mineral crystallizes in the hexagonal system. The crystal is optically biaxial, and positive. Zincite has the following refraction indices in the range of wavelengths from 405 to 671 millimicrons (see Table).

Показатели преломления 1	2 Длина волны (ммк)									
	405	436	460	492	497	546	578	589	610	671
N_m	2,239	2,137	2,097	2,064	2,059	2,075	2,011	2,009	2,001	1,984
N_g	2,48	2,151	2,115	2,081	2,076	2,041	2,028	2,024	2,017	2,001

1) Refraction indices; 2) wavelength (millimicrons).

The specific electric resistance of the natural zincite crystal is 28 ohm•cm, that of a synthetic zincite is 10^6 at 20°, 22 at 650° and 0.4 ohm•cm at 650° in a hydrogen atmosphere. The electrical resistance of the powder is 10^{17} ohm•cm. The electrical conductivity of the pressed powder varies between 10^{-4} and 10 $ohm^{-1}•cm^{-1}$ depending on the extent of the crystallization of the aggregate. The electrical conductivity of the powder in a vacuum (10^{-6} mm mercury column) changes from 10^{-5} to 1 $ohm^{-1}•cm^{-1}$, respectively, in the temperature range from –183° to 300°. The surface conductivity (at 25°) is $1.5•10^{-4}$ $ohm^{-1}•cm^2$. The dielectric constant is as follows: 10.4 at 0.1-10 Mcps, and 9.8 at 25 Mcps for a fine-disperse powder (0.085-0.845 microns), and 40 in the

frequency interval 0.1-10 Mcps for acicular crystals. The zincite single-crystal possesses poor piezoelectric, detector, and photoelectric properties. The latter appear in both constant and pulse illumination, increasing with rising temperature and rising dispersity of the substance. A bright-green luminescence appears under illumination by a light of the wavelength of 365 millimicrons. The melting point of the synthetic zincite is 1975 ± 25°. The specific heat (c_p; joules/g) is 0.48 at 0°; 0.58 at 200°, 0.615 at 400°, 0.66 at 800°, and 0.69 at 1200°. The heat conductivity (cal/cm·sec·°C) is 0.0409 at 200°; 0.0268 at 400°; 0.0167 at 600°, and 0.01305 at 800°. Considerably large zincite segregations are rare in nature. Therefore, synthetic zincite obtained from zinc and a number of its salts are used almost exclusively in industry.

The application of zincite in semiconductor engineering (as a powderlike semiconductor) is of the greatest interest. Mixed with TiO_2 (10-25%), it is used in the manufacture of nonlinear resistors (10^2-10^6 ohm·cm), high- and low-resistance nonlinear elements. A single-mineral zincite aggregate in the form of a powder pressed at 250 atm and fired at 1000-1500° is used as a detector. The luminescent properties of the zincite may be utilized for the manufacture of crystal phosphors used to detect and to measure radioactive radiation, and also for the manufacture of the screens of electron-ray devices. Zincite is used in electrical engineering in the manufacture of electric contacts; in the chemical industry as a catalyst for the synthesis of acetone, and in the separation of low-boiling aromatic hydrocarbons from the petroleum; in the rubber industry it is used in the vulcanization of diverse rubber types to intensify the process and to increase the stability of the objects; in the paint and varnish industry, as a prime coat for steel or wood and in the preparation of special paints. Zincite is also

a component of certain heatproof paints. Insecticides are prepared from a mixture of zincite and arsenic. Zincite is used also for the preparation of adhesive plasters, adhesive tapes and zinc ointments. Only chemically pure zincite is used in the radio engineering, pharmaceutical and chemical industries.

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V.V. Nasedkin

ZIRCON – is a mineral, zirconium orthosilicate, $ZrSiO_4$; it contains 67.7% ZrO (49.5% Zr), and 32.9% SiO_2. Hafnium (up to 16% HfO_2) is always, yttrium, cerium, thorium, and uranium are frequently, and niobium, tantalum and phosphorus are sometimes present as impurities. The mineral crystallizes in the tegragonal system and occurs generally in the form of well developed crystals. The cleavability is incomplete. The structure of the zircon is of the insular type: the $(SiO_4)^{4-}$ tetrahedrons are insulated from each other and bound in the lattice by the Zr^{4+} ions which are surrounded by 8 oxygen ions. The mineral is colorless, but frequently stained yellow, orange, or brown, more rarely green. The luster is adamantine. The specific gravity is 4.2-4.7. The Mohs hardness is 7.5. The refraction indices are: N_0 = 1.92-1.96, N_e = = 1.96-2.02. The mineral luminesces lemon-yellow in cathode rays, green in x-rays, and orange in ultraviolet rays. Zircon resists acids (excluding hydrofluoric acid), borosilicates, metaphosphates, Na_2SO_4, the fusing agent NaCl + $ZnCl_2$, and $K_2S_2O_7$; it is not wettable by most of the molten metals. Molten fluorides, cryolites, $Na_4P_2O_7$, $BaCl_2$, lead bronze (2% Pb), metal oxides, and all strongly basic substances have a destructive effect. The melting point is 2200-2500°. The thermal expansion coefficient of the zircon is $4.5 \cdot 10^{-6}$; it is smaller than that of the Mullite ($5.4 \cdot 10^{-6}$). The heat conductivity of a polycrystalline aggregate of synthetic zircon (5 microns great particles) is 0.011 at 200°; 0.010 at 400°; 0.0090 at 600°; 0.0083 at 800°; 0.0079 at 1000°; 0.0076 at 1200°, and 0.0074 cal/sec·cm·°C at 1400°. The specific heat is 0.61 joules/g at 60°. The mineral is a dielectric. The appliance of

zircon bases on its refractoriness, the chemical stability, and the physical properties: a high specific gravity, dielectric properties, low thermal expansion coefficient, non-wettability by molten metals, low heat conductivity, etc. Zircon is used in engineering in the manufacture of refractories (refractory bricks and cement) resistant to thermal shocks, abrasion and acid blast-furnace slags. Zircon refractories are used in glass-melting furnaces, in aluminum electrometallurgy, in the rammed lining of steel-casting ladles, in furnaces producing calcium phosphate, in the smelting of rare metals, platinum, platinum-rhodium alloys and palladium, in roasting ovens for the catalysis of hydrocarbons, etc.; in the ceramics industry, circon porcelain with a high mechanical strength, a low thermal expansion coefficient and low heat conductivity, good dielectric properties and a high chemical stability is produced from zircon. The zircon porcelain is used in electron-ray tubes, in internal combustion engines (sparkplug insulator), in the production of high-voltage insulators (especially, when working at high temperatures) and of milling balls for mills in the ceramic and glass industries. The refractoriness of the zircon and its nonwettability by molten metal are utilized in foundry work. Zircon is used as a molding material in high-precision casting, in the preparation of molding paints and linings of molds, which reduce significantly the pickup of steel and certain types of nonferrous cast materials (aluminum, magnesium, phosphor bronze, nickel alloys); it is also used in the manufacture of very stable ceramic paints and of white (opacifying) enamels; in the production of zirconium dioxide, metallic zirconium and hafnium; in the manufacture of zirconium alloys in ferrous and nonferrous metallurgy; as an abrasive in sandblasting devices for cleaning ceramics after biscuit firing, for frosting and finishing of glass, for cleaning the metal surface before enameling, etc. (aside from the in-

crease in the quality and speed of these operations, the application of zircon instead of quartz sand considerably reduces the cases of silicosis of the workers); as an addition to quartz sand (up to 2.5%) which serves for fireproof and acidproof laboratory vessels having a high elasticity; as a powder for the heat insulation of high-temperature devices and establishments; as a chemically inert substance in devices working at high temperatures and in chemically active media; as a stabilizing filler in silicon rubbers; a number of special objects is formed by casting or drawing zircon (gas-turbine blades, for example); as a technical stone for the bearings of precision instruments; transparent and finely colored zircon varieties (hyacinth) are used as jewels. Zircon concentrates obtained mainly by enrichment of zircon-containing sands and composed mainly (by 90% and more) from zircon, are used in industry. The requirements of industry on the zircon concentrates vary strongly according to the purposes. Especially high requirements are made on concentrates which are used without chemical treatment (refractories, ceramics, molding mixtures, etc.). Zircon concentrate containing not more than 2% iron ixides and 0.5% alkalis, substances which reduce the refractoriness, is used for the manufacture of refractories. Quartz, forming with zircon (when present in a quantity of 5%) an eutectic with the melting point at 1675°, is a harmful impurity in concentrates used in casting or in the manufacture of refractories. The percentage of iron, rare earths (cerium) and other coloring components must not surpass 0.1%, and that of titanium not 1% in concentrates used in the preparation of enamels, porcelain, and glazes. Alaklis, quartz and kaolin are useful impurities in this case. Concentrates with a minimum content of hafnium are required for the preparation of a zirconium appliable in nuclear engineering, where hafnium is a harmful impurity. Zircon concentrates used for the production of

ferroalloys (ferrozirconium, ferrosilicozirconium, etc.) must not contain more than 0.05-0.08% phosphorus because the latter is a harmful impurity in alloys.

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