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FOREIGN TECHNOLOGY DIVISION

(PART II)

ENCYCLOPEDIA OF CONTEMPORARY ENGINEEPING.
STRUCTURAL MATERIALS.

corrosion fatigue thru hastelloy

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UNEDITED ROUGH DRAFT TRANSLATION

(PART TWO OF FIVE PARTS)

ENCYCLOPEDIA OF CONTEMPORARY ENGINEERING.
STRUCTURAL MATERIALS.

English pages: 915 - 1822

SOURCE: Entsiklopediya Sovremennoy Tekhniki. Konstruktsionnyye Materialy. Volumes I, II, III, Gosudarstvennoye Nauchno Izdatel'stvo "Sovetskaya Entsiklopediya", Moskva, 1965, Vol. I, pp. 1-416, Vol. II, pp. 1-408, and Vol. III, pp. 1-527.

Translated under: Contract AF 33(657)-14184, SA2

TM7500368

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CORROSION FATIGUE – failure under the combined effect of multiple loads and an aggressive medium. Under corrosion fatigue, as under fatigue, the cracks originate at the surface of the body and gradually extend into the depth, resulting in reducing the carrying cross sec-

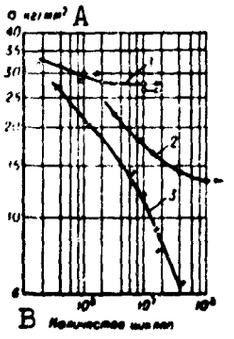

Fig. 1. Fatigue curves for specimens from 35 steel as a function of the medium. 1) Air; 2) potable water; 3) 3% solution of NaCl. A) Kg/mm^2; B) number of cycles.

tion. The process terminates in a rapid failure of the remaining cross section due to mechanical stresses. Usually 2 main zones are discernible in a corrosion fatigue fracture: fatigue (with participation of corrosion) and postfracture zones (see Fatigue Fracture). The main differences between corrosion and ordinary fatigue are: a large number of cracks and absence of an endurance limit (of a horizontal section on Veler's curve, which is characteristic of ferrous metals at room and low temperatures, see Fig. 1). Hence corrosion fatigue cannot be characterized only by the value of stresses without specifying the number of cycles. Corrosion fatigue depends to a large extent on the corrosion resistance of materials under the given conditions. In steels the reduction in strength is retarded after 50 million cycles while for alu-

minum and magnesium alloys the strength reduction continues even at a large number of cycles and the corrosion fatigue strength can drop to 1 kg/mm^2. Corrosion fatigue failure is brought about by the simultaneous effect of corrosion and stresses. Successive effect of these factors is less dangerous. A major role in corrosion fatigue is played by the creation of a substantial electrochemical inhomogeneity. The most stressed and deformed microvolumes have their electrode potential and corrosion resistance reduced, which facilitates the subsequent crack formation and development. The corrosion fatigue strength after 20-50 million cycles (for carbon and low-alloy steels, practically independent of their composition and processing it is from 10 to 16 kg/mm^2 in

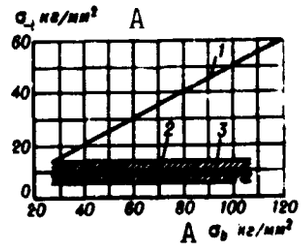

Fig. 2. The fatigue limit as a function of the ultimate strength for various steels in various media. 1) Air; 2) potable water; 3) sea water. A) Kg/mm^2.

potable water and from 4 to 10 kg/mm^2 in sea water) is usually substantially lower than the endurance limit in air (from 15 to 95 kg/mm^2 for the same steels). An increase in the endurance limit in air or in the ultimate strength or hardness usually does not result in increasing the corrosion fatigue resistance (Fig. 2). Cast irons and structural steels differ little with respect to corrosion fatigue resistance, despite the substantial difference in other mechanical properties. An increase in the corrosion resistance of a material substantially increases the corrosion fatigue resistance. The reduction in the fatigue strength of the 1Kh18N9T stainless forged steel when tests in air are replaced by tests

in sea water is less than 10% (for carbon, low and medium alloy steels it is reduced by a factor of 3-10, in many titanium alloys such a reduction does not exist). From all the engineering materials titanium alloys have the highest corrosion fatigue strength in sea water. Stainless cast alloys with an inhomogeneous structure undergo a substantial (by a factor of 2 and more) reduction in the fatigue strength upon changing from air to sea water. The fatigue strength of copper alloys changes very weakly upon changing from air to potable water and it changes slightly more upon changing to sea water, however, even in the latter case the corrosion fatigue strength of copper alloys exceeds by approximately a factor of two the fatigue strength of carbon, low and medium alloy steels. The corrosion fatigue strength of aluminum alloys in sea water is low, even for the more corrosion resistant alloys such as AV, AMg5V and MAg6 the fatigue corrosion strength for 20 million cycles is about 3 kg/mm^2. With a reduction in the cycle frequency the corrosion fatigue strength is reduced (the endurance at the given stress amplitude is decreased). The endurance of carbon and low-alloy steels upon changing from a frequency of 1000-3000 to a frequency of 100 cycles per minute for a stress amplitude of ± 10 kg/mm^2 is reduced by a factor of 10; for the more corrosion-resistant copper alloys the effect of frequency is much weaker. The notch sensitivity in corrosion fatigue depends on the stress amplitude, aggressive medium, shape of notch and the metal; for noncorrosion-resistant materials it is smaller than under ordinary fatigue. For standard structural steels under relatively high stresses (up to 10^6 cycles) corrosion fatigue calculations in sea water should be based on the fatigue strength of notched specimens tested in air; under low stresses and a large number of cycles the main effect is exerted by corrosion. Hence for corrosion fatigue with a large number of cycles the effect of notches must be taken into account.

For stainless steels, which in sea water are susceptible to crevice corrosion, the presence of stress raisers (narrow slits, notches, gaps, contact zones in press fitting, etc.) can be found to be more dangerous than in air. An increase in the absolute dimensions of a component from structural steels (see Scale Effect) under high stresses (and, consequently, a small number of cycles) reduces the corrosion fatigue strength, under lower stresses it somewhat increases this strength. The corrosion fatigue strength of brasses and stainless steels is reduced with an increase in the component's dimensions. The main means for increasing the corrosion fatigue strength are increasing the corrosion resistance in the given medium by application of metallic and nonmetallic coatings, theremodiffusion coatings, which are created by casehardening the component's surface, electrochemical protection by zinc or magnesium protective agents or by applying an external current. In the

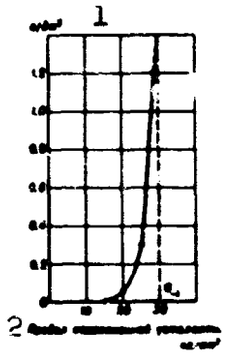

Fig. 3. Effect of the cathode current on the corrosion fatigue strength of specimens from 35 steel when tested in a 3% solution of NaCl. 1) Amps/decimeter^2; 2) corrosion fatigue limit, kg/mm^2.

latter case the reduction in strength due to corrosion can be entirely eliminated by increasing the density of the applied current (Fig. 3). Nonmetallic coatings lose their protective properties with time, are easily damaged by mechanical effects, which can result in a sharp reduction in the corrosion fatigue resistance. Anode coatings (i.e., those that have a more negative electrode potential than the metal be-

Methods for Protecting from Reducing the Fatigue Strength upon Simultaneous Corrosion Attack

Form of protection	Medium	Degree of protection C(%)	
		Potable water	Sea (salt) water
Nonmetallic coatings	Bakelite varnish	–	100
	Ethynol varnish with aluminum powder	–	80
	Iron medium-based ethnol varnish	–	80
	Rubber coating	–	93
	Polyethylene	–	78
	Enamel paint	–	50
	Asbovinyl	–	23
	Bituminous coatings	–	0
Anodic	Galvanizing	90-100	85-95
	Zinc metallizing	–	90-95
	Hot zinc coating	60	95
	Aluminum metallizing	–	80
	Electrolitic cadmium plating	20-75	40-70
Cathodic	Metallizing brass coating	–	25
	Metallizing coating by the 1Kh18N9T stainless steel	–	0
	Bright chromizing without tempering	16	15
Metallic coatings	Bright chromizing with tempering at 650°	–	5
	Satin chromizing with and without tempering	–	25
	Satin chromizing with a nickel-copper sublayer	–	25

Methods for Protecting from Reducing the Fatigue Strength upon Simultaneous Corrosion Attack (Continued)

Form of Protection	Medium	Degree of protection C(%)	
		Potable water	Sea (salt) water
Metallic coatings (continued)	Bright chromizing with tempering at 650° and "cooking through" in oil	-	70
	Electrolitic copper coating	-72	-32
	Electrolitic tin coating	45	14
	Electrolitic nickel coating	34	5
	Electrolitic chromium coating with a nickel sublayer	50	25
Casehardening	Thermodiffusion zinc coating	-	100
	Anticorrosion nitriding	80-200	60
	Siliconizing	15	-
	Cyanizing	2	-
Electrochemical protection	Sacrificial protection with zinc	80	60
	Sacrificial protection with magnesium	-	80
	Cathodic protection with an external current	-	100
Treating the medium	Addition of corrosion retarding agents	90-100	40-67
	Addition of up to 1% of oil to the medium	50-70	-
Combined protection methods	Electrolitic zinc coating preceded by surface hardening by high-frequency currents	-	200
	Sacrificial protection with zinc and shot peening	-	106

Methods for Protecting from Reducing the Fatigue Strength upon Simultaneous Corrosion Attack (Continued)

Form of Protection	Medium	Degree of protection C(%)	
		Potable water	Sea (salt) water
Combined protection methods (Continued)	Sacrificial protection with zinc with surface hardening by high-frequency currents	–	210
	Sacrificial protection with magnesium with shot peening	–	113
	Enamel paint after aluminum metallizing	–	98
	Metallizing by the 1Kh18N9T stainless steel after hardening burnishing of the main steel product (shaft).	–	40-60

ing protected) are most reliable from among mechanical coatings, since the protective electrochemical effect does not cease even due to occasional mechanical damage (appearance of discontinuities). Electrodeposited cathodic (i.e., with an electrode potential which is more positive than the base metal) coatings for steels, i.e., chromium, nickel, copper, tin, are unreliable attendant to submerging in potable and the more so sea water. The degree of protection from corrosion fatigue can be estimated by the coefficient C for different protection methods.

The corrosion fatigue strength is substantially increased even when compressive residual stresses are created in the surface areas of the body with simultaneous surface hardening. Combined methods, which make use of a combination of various kinds of surface hardening (mechanical, heat treatment, and casehardening) with various corrosion

protection measures (nonmetallic and anodic metallic coatings, sacrificial coatings, cathodic polarization by external current, etc.).

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Ya.B. Fridman

CORROSION INHIBITORS – see Phenolic Molding Powders.

CORROSION OF ALUMINUM ALLOYS. Aluminum is a very electronegative metal of the more active class, due to its position in the electromotive series. The corrosion resistance of aluminum increases significantly as a result of the formation of a tight oxide film on its surface. An oxide film (Al_2O_3) with a thickness of up to 50-200 A is formed on the surface of aluminum even at room temperature. Each damage to the surface of this film results in a reduction of the corrosion resistance; this reduction occurs in the aluminum alloys upon whose surface wuch a continuous, tight and homogeneous film as that of aluminum cannot form, owing to the heterogeneous structure of the alloys. Thus, the effect of the diverse corrosive media depends primarily on the behavior of the oxide film in this medium and on the type of the chemical reactions which occurs in this medium in the case of corrosion.

The main types of a corrosive destruction of aluminum alloys are subdivided into uniform and nonuniform corrosion. Nonuniform corrosion, in turn, is subdivided into pit corrosion (saucer-shaped pit, point and pit corrosion) and intergranular corrosion which sometimes occurs in the form of a laminating corrosion. Mixed tvpes of corrosion, a pit corrosion combined with an intergranular one, for example, etc., occur frequently.

The decrease of the mechanical properties largely depends on the type of the corrosive destruction, i.e., on the nature of its propagation on the surface or into the body of the corroded metal (alloy). The relation between the individual types of corrosion and the mechanical properties is shown in Fig. 1 for the D16 alloy, as an example. The

lowest decrease of the mechanical properties corresponds to the uniform corrosion, and the highest one to the intergranular corrosion, with the same loss in weight, i.e., with a similar material effect of the corrosion.

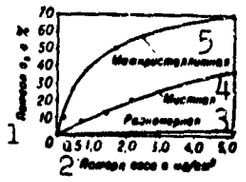

Fig. 1. Effect of the various types of corrosive destruction on the loss in strength of the nonplated D16 alloy (a 0.7 mm thick sheet). 1) Loss in σ_B, %; 2) loss in weight, mg/cm^2; 3) uniform; 4) pitting; 5) intergranular.

The aluminum alloys are subdivided, according to their method of production, into malleable and casting alloys, and sintered aluminum powders (SAP) or sintered aluminum alloys (SAS).

Corrosion resistance of the malleable aluminum alloys. It is expedient to subdivide the malleable aluminum alloys into two large groups with regard to their corrosion resistance: 1) alloys with a relatively high corrosion resistance; all alloys with a low and medium strength which do not contain copper, and the plated alloys of the systems Al-Cu-Mg and Al-Zn-Mg-Cu belong to this group; 2) copper containing alloys with a low corrosion resistance. All nonplated alloys of the Duralumin type Al-Cu-Mg, belong to this group; 2) copper containing alloys with a low corrosion resistance. All nonplated alloys of the Duralumin type Al-Cu-Mg, the high-strength alloys of the Al-Zn-Mg-Cu system, the forging alloys of the Al-Cu-Mg-Si system, and the heatproof alloys of the Al-Cu-Mn and Al-Cu-Mg-Fe-Ni systems belong to this group.

The corrosion resistance of alloys not containing copper (of low or mean strength). All alloys of low and medium strength possess a relatively high corrosion resistance and are suitable for severe severe working conditions (sea, tropics). The alloys with a low strength, pure

aluminum, AMts, and AMg, and the AMg3 alloy with a medium strength are easily welded by all welding methods; their corrosion resistance does not depend on the state of the material (tempered, cold hardened) nor on the heatings during production or in service. The corrosion resistances of the welded and nonwelded joints are similar. The high corrosion resistances of the welded and nonwelded joints are similar. The high corrosion resistance of the alloys AMg5 and AMg6 of the Al-Mg system is a result of their structure and stability after subsequent heatings (within 60-200°, during production and in service). It is well-known that the homogeneous state of the Al-Mg alloys containing 5% and more magnesium has the highest corrosion resistance. This homogeneous state, however, is unstable, and a decomposition of the oversaturated solid solution, resulting in an adverse segregation of the β-phase on the grain boundaries, occurs even at a minimal increase of temperature (60-70°) when maintained for an appropriate time; the alloy becomes susceptible to stress- and intergranular corrosions. The tendency of the supersaturated solid Al(Mg) solution to decompose increases even further when cold deformation has preceded the heating. A stable state of the material, resistant to cold hardening and heating, can be obtained only when certain working conditions are strictly observed, i.e., tempering at 325-350° before the cold rolling, and final tempering in the 310-335° range. The corrosion resistance of the welded joints of the ANg5 and ANg6 alloys is similar to that of the nonwelded joint. It is reduced when the material is heated above 100° after the welding, owing to the proneness to corrode intergranularly in the transition zone. Objects welded from AMg5 and AMg6 alloys do not undergo a cracking corrosion under stresses.

The corrosion resistance of the AD31, AD33, AD35 and AV alloys of the Al-Mg-Si system depends essentially on the ratio of magnesium to

silicon in the alloy. Hence, the AV alloy possesses a lower corrosion resistance in the naturally and, especially, in the artificially aged state than the AD31 and AD33 alloys. The corrosion resistance of the naturally aged AV alloy is higher than that of the artificially aged one, owing to the presence of copper, even in very small quantities, in the alloy. An increasing loss of the mechanical characteristics, especially of the elongation, during the corrosion process can be observed when the copper content is increased, owing to the intense development of intergranular corrosion (Fig. 2). Hence, the copper content in the AV alloy must be limited at 0.1% for use under severe service conditions. The corrosion resistance of the AD35 alloy is somewhat higher than that of the AV alloy because the former does not contain copper. The AD31 and AD35 alloys possess a higher corrosion resistance in the naturally and artificially aged state. The AD31 alloy is characterized by a better workability; it is more easily polished and has a better decorative appearance. The joints of AD31, AD33, and AD35 alloys welded by fusion-welding, possess a corrosion resistance nearly equal to that of the nonwelded joints. Welded joints of the AV alloy show a higher loss in strength than the nonwelded joints.

All alloys of the Al-Mg-Si system, in both the welded and nonwelded state, do not incline to a corrosive cracking under stresses. Their corrosion resistance does not change after heating, during production or in service.

The V92 alloys of the Al-Zn-Mg system possesses the highest mechanical properties of all the alloys of a medium strength, but its corrosion resistance is lower. The resistance to stress corrosion of the V92 alloy and of its welded joints depends primarily on the heat treatment, the cold hardening and the supplementary heatings (during production or in service). The V92 alloy and its welded joints have a

high stress-corrosion resistance in the naturally aged state. A supplementary cold hardening after tempering and artificial aging significantly reduces its resistance to stress corrosion. Supplementary heatings at 70° for 1000 hours and also at higher temperatures have also an adverse effect (Fig. 3).

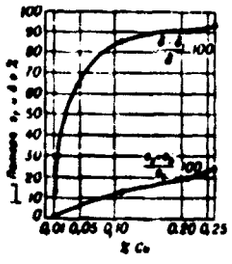

Fig. 2. Drop in the σ_b and δ of the AV alloy during 6 monts of corrosion by spraying with a 3% NaCl solution. 1) Losses in σ_b and δ, %.

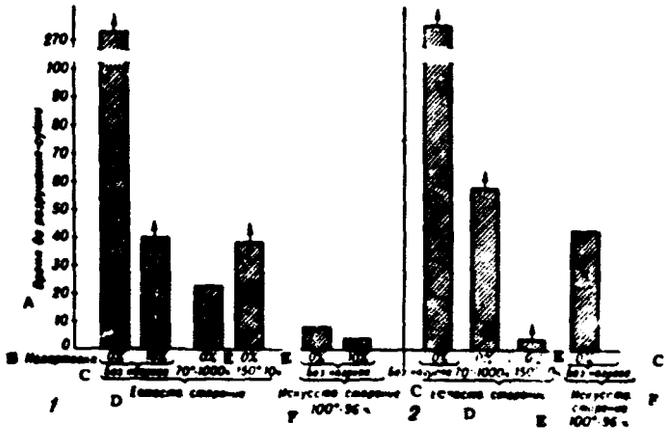

Fig. 3. Stress-corrosion resistance of the V92 alloy (a 2 mm thick sheet) in a 3% NaCl solution under alternating loads: 1) Welded; 2) nonwelded. A) Destruction time in days; B) cold hardening; C) without heating; D) natural aging; E) hours; F) artificial aging.

The corrosion resistance of copper containing alloys. All alloys of this group, except plated sheets of the Al-Cu-Mg and Al-Zn-Mg-Cu systems, possess a reduced corrosion resistance and require a protection against corrosion. It is not recommended that they be used under maritime conditions.

The alloys D1, D18, V65, D16, D6, D19, M40, and VD17 belong to the Al-Cu-Mg system. The D1, D16, D19, and M40 alloys are deliverable in

sheets. Pure aluminum is used for the plating layer. The sheets have plating layers of various thicknesses: the thickness of the plating layer on each side is about 4% of the sheet thickness for sheets with a thickness up to 2.5 mm inclusively; it is about 2% on sheets which are thicker than 2.5 mm (the absolute thickness of the plating layer is less on thin than on thick sheets). The diffusion of the copper from the core of the sheet into the plating layer during heat treatment is one of the major factors adversely effecting the corrosion resistance of the plated sheets. Therefore, the sheets with a thickness of 0.3-0.7 mm have, as a rule, a reduced corrosion resistance owing to the thorough diffusion of the copper from the core into the plating layer. Sheets of the D16 alloy with a thickness of from 0.5 to 4 mm and an increased corrosion resistance (the thickness of the plating layer is 8% on each side) are produced according to a special TU. Plated sheets of the D1, D16, D19, and M40 alloy have an almost equal corrosive resistance. Besides its mechanical protection, aluminum plating also provides a chemical portection against corrosion in all these alloys. The type and conditions of the heat treatment is an important factor influencing the corrosion resistance of alloys which are hardened by heat treatment.

The alloys of the Al-Cu-Mg system show the best corrosion resistance in hardened and in naturally aged state. Corrosion resistance is reduced owing to a proneness to corrode intergranularly and to crack under stress, when these materials are heated higher than 100°. The proneness to corrode intergranularly after alloys of the Duralumin type have been heated depends on their phase composition.

The alloys V65, D18, D6 and D16 with the phase composition (α + $CuAl_2$ of α + $CuAl_2$ + S) possess a greater proneness to corrode intergranularly than the alloys D19, VD17, and M40 with the phase composi-

tion (α + S). Objects having a large cross section, pressed from D16, undergo (especially in the middle part of the cross section) an intergranular corrosion and cracking stress-corrosion in the hardened and artificially aged state owing to the delayed cooling during the hardening process. The loss in strength caused by corrosion of specimens of D16 alloy cut out from different cross sections (the scheme of the cuts is shown in Fig. 5) is given in Fig. 4. The quoted data prove that the specimens taken from the extremity, i.e., from the thinnest part of the profile, show a minimum loss of strength. Specimens taken from the massive part of the profile (cross section 2) have a significantly higher loss of strength. The microscopic investigation revealed a different type of corrosive destruction: a strong intergranular corrosion in the cross section 2, and the absence of intergranular corrosion in the extremity. The same semifinished products, made from M40 and D19 alloys, do not undergo an intergranular and stress-corrosion in the massive part of the profile. The corrosion resistance of specimens of the M40 and D19 alloys, taken from the massive part of the profile, is similar to the corrosion resistance of specimens of the D16 alloy taken from the thin part of the profile. Heating at 150° for 40-60 minutes results in an increased proneness of the V65, D18, D1, and D16 alloys to corrode intergranularly, but does not incline the alloys D19 and M40 to corrode in such a manner. Microphotographs of tests for the tendency to corrode intergranularly of rivets made from V65, D18, D16, and D19 alloys after heating at 150° for 45 minutes are shown in Fig. 6.

The alloys D16, D19, M40, and VD17 of the Al-Cu-Mg system are used as heat-resistant alloys. The D16 alloy must be utilized in the artificially aged state for service in parts having working temperatures of 150° and above. The employment of the D16 alloy in the artificially aged state is necessitated by the fact that artificial aging prevents nearly

all the reduction of corrosion resistance, caused by heatings during service, and prevents also the recovery phenomenon (see Aging of Aluminum Alloys) which occurs when D16 is used in its naturally aged state.

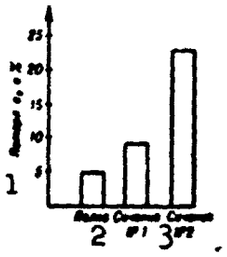

Fig. 4. Loss in ultimate strength of D16 specimens after corrosion in a 3% NaCl + 0.1% H_2O_2 solution for 10 days. 1) Loss in σ_b, %; 2) bordering; 3) cross section no.

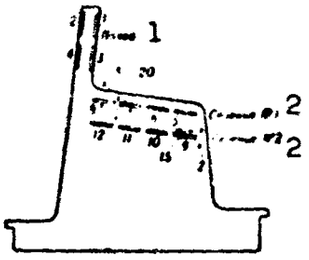

Fig. 5. Scheme of the cutting out of the specimens. 1) Extremity; 2) cross section no.

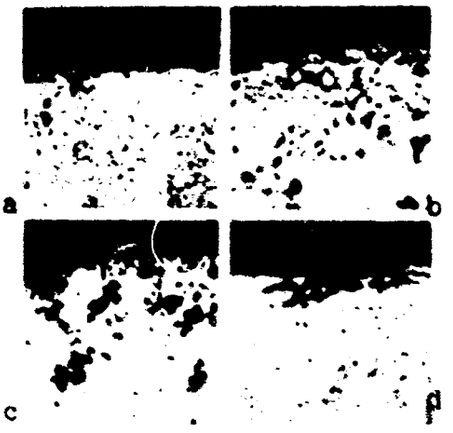

Fig. 6. Microphotographs of rivets from the alloys V65 (a); D18 (b); D16 (c), and D19 (d) heated at 150° for 45 minutes and tested for the tendency to corrode intergranularly in a 3% NaCl solution + 1% HCl for 48 hours. (The microsections are not pickled; magnification by 100 times.)

Artificial aging of sheet material at 190° for 11-13 hours, and that of pressed material at 190° for 6-8 hrs ensures a corrosion resistance nearly equal to that of the naturally aged state and also a stable corrosion resistance after heating in service (Table 1).

TABLE 1

Corrosion Resistance of a Pressed Angle Profile (2 mm thick bordering) from the D16 Alloy*

1 Режим старения	2 Темп-ра и длительность нагрева	3 Потеря об (г/м²)
4 Естественное старение	5 Без нагрева	17.5
	150°-5 час	28.8
	150°-30 час	58.3
Искусственное старение при 190°-6 час. 7	Без нагрева	13.9
	150°-5 час	17.3
	150°-30 час	20.8

* Tested in a 3% NaCl + 0.1% H_2O_2 solution for 2 months.

1) Aging conditions; 2) temperature and time of heating; 3) loss; 4) natural aging; 5) without heating; 6) hours; 7) artificial aging at 190° for 6 hours.

The alloys D19 and M40 may be employed after both natural and artificial aging for service in designs working at elevated temperatures. The corrosion resistance does not change after heating in those states. Table 2 gives the corrosion resistance of the D19 alloy in the naturally and artificially aged state as a result of the duration and temperature of the heating. In the form of pressed and stamped pieces, the VD17 alloy can be employed only in the artificial aged state. Its corrosion resistance is higher than those of the AK3 and AK4-1 alloys.

The heat-resistant alloys VAD1 and M40 can be readily welded by fusion and are also used in the welded state. The corrosion resistance of the welded joints and of the transition zone of these alloys is reduced owing to the tendency to corrode intergranularly. Heat treatment (hardening and aging) after welding almost entirely counteracts the

tendency of the welded joints to undergo intergranular corrosion. Welded objects (made by fusion welding) from VAD1 and M40 alloys require a reliable protection against corrosion owing to their reduced corrosion resistance; it is not recommended that they be used under martime conditions.

The high-strength alloys V95, V96, V93, and V94 of the Al-Zn-Mg-Cu system have, in contrast to the alloys of the Duralumin type, a low corrosion resistance (laminating corrosion) and a very low resistance to stress corrosion. All alloys of this system, therefore, are used only in the artificially aged state under conditions which ensure an adequate high resistance to stress corrosion. The V95 alloy, a typical representative of this group, is widely used in the form of sheets, and of pressed and forged objects. The sheets are plated with an aluminum alloy containing 1% zinc to increase corrosion resistance. The plating also protects the core of the V95 alloy against cracking corrosion after artificial aging at 120° for 24 hours, which also ensures optimum mechanical properties. The corrosion resistance of plated sheets of the V95 alloy is similar to that of the plated D16 sheets. Pressed semifinished products of the V95 alloy are used after artificial aging under conditions which ensure an optimum corrosion resistance (140° for 16 hrs, or in a step-by-step method). Pressed semifinished products of the V95 alloy have the same corrosion resistance in the stressed and nonstressed state as the semifinished products of the D16 alloy. The processing conditions have a decisive influence on the stress-corrosion resistance of pressed and forged semifinished V95 products with large cross sections. An increased degree of the total deformation (obtained by forging or pressing the blank) results in an increased stress-corrosion resistance. Large forged pieces have a reduced stress-corrosion resistance in transverse direction (to the height of the forged piece).

The forging alloy V93 has a somewhat higher stress-corrosion resistance in large cross sections than the V95 alloy, when aged artificially by a step-by-step method. The V95 alloy is used in the form of pressed and stamped semifinished products. It has an increased proneness to undergo stress corrosion in comparison to the V95 alloy, owing to the higher zinc content. This fact limits its application. The riveting alloy V94 has the same corrosion resistance as the V65 alloy, supplementary heating at 120-150° does not cause a tendency to corrode intergranularly.

The alloys AK6 and AK8 of the Al-Cu-Mg-Si system are widely used in the production of forged and stamped pieces; they are employed in the artificially aged state under conditions which ensure maximum mechanical properties. In this state, the alloys incline to undergo intergranular corrosion or cracking stress-corrosion; they must, therefore, be adequately protected against corrosion. The corrosion resistance of the AK6 and AK8 alloys in the naturally aged state is somewhat higher and comparable to that of the D16 alloy.

The heat-resistant alloys D20, D21, and VAD23 of the Al-Cu-Mn system are characterized by a high copper content (5-6%), and this fact explains their reduced corrosion resistance. Sheets and pressed semifinished products are made from the D20 and VAD23 alloys. The sheets are plated with pure aluminum to increase corrosion resistance. The corrosion resistance of the plated D20 and VAD23 sheets is lower than that of plated sheets of the duralumin-type alloys owing to the more intense diffusion of the copper from the core into the plating layer. These alloys are used – after having been artificially aged – under conditions which ensure an optimum corrosion resistance. The D20 alloy, aged artificially under conditions which ensure the optimum mechanical properties, is prone to undergo intergranular corrosion and cracking stress-corrosion. The D20 alloy is weldable by argon-arc welding. The corro-

sion resistance of the welded joints and of the transition zone is low as they are prone to corrode intergranularly. The proneness of the transition zone of welded products from D20 to undergo intergranular corrosion is somewhat greater than that of the heat-resistant and weldable VAD1 and M40 alloys. It is not recommended that alloys of the V1-Vu-Mn system be used under maritime conditions.

The corrosion resistance of the heat-resistant alloys AK2, AK4, and AK4-1 of the Al-Cu-Mg-Fe-Ni system is by far lower than that of the copper-containing aluminum alloys, owing to the addition of nickel and iron to the alloys. These alloys are used in the artificially aged state under conditions which ensure the optimum mechanical properties; this results, however, in a proneness to undergo stress-corrosion. These alloys must be adequately protected against corrosion during their service. As a rule, all malleable aluminum alloys are anodized (see Anodized Aluminum Alloys) or chemically oxidized (see Chemical Oxidation of Aluminum Alloys) in order to protect them against corrosion, and, depending on the service conditions, they receive supplementary protection by a number of paint and varnish coatings.

The corrosion resistance of casting aluminum alloys. Among the standardized casting aluminum alloys, the alloy AL8 of the Al-Mg system possesses the highest corrosion resistance against air and salt water. The alloys AL13, AL23 of the Al-Mg-Si system, and the VL15 alloy of the Al-Mg-Zn system also belong to the corrosion-resistant alloys. Silumin, both eutectoid (Al2 alloy) and hypoeutectoid, is characterized by an adequately high corrosion resistance when it does not contain copper (AL4 and AL9 alloys), but its corrosion resistance is inferior to that of the alloys of the Al-Mg system. All these alloys may be used under severe service conditions. The copper-containing casting aluminum alloys AL5, AL7, AL19, etc., possess a relatively low corrosion resistance.

The zinc-containing Silumin AL11 also has a reduced corrosion resistance. The corrosion resistance of casting aluminum alloys depends on the chemical composition and on the compactness of the ingot. Porous ingots are markedly less resistant to corrosion. An appropriate protection is selected, depending upon the degree of porosity of the ingots. The casting aluminum alloys are protected against corrosion by anodizing or by chemical oxidation and by paint and varnish coatings.

The corrosion resistance of the SAP and SAS. There exist two grades of SAP: SAP-1 and SAP-2, which differ in their alumina content. The corrosion resistance of SAP-1 and SAP-2 is high, it does not depend on the alumina content (up to 17%) and is comparable with the corrosion resistance of pure aluminum. These materials are not prone to undergo intergranular and stress corrosion. The SAS-1 material contains 30% Si and 7% Ni; its corrosion resistance is significantly lower than that of the AK4 alloy. In the junction of parts from different metals and alloys in a design, it must be taken into account that a contact with a more electropositive metal promotes the development of the corrosion of aluminum alloys. A contact with copper or its alloys, with nickel, nickel coatings, and also with silver involves a maximum increase of the corrosion of aluminum alloys in natural atmosphere. Contacts with structural steels, cadmium, zinc, chromium, lead, titanium, magnesium, and stainless steel are permissible in natural atmosphere. Contacts with copper and its alloys, stainless steel, titanium and its alloys, nickel and nickel coatings, tin and tin coatings, lead, silver, magnesium and its alloys are not permissible for aluminum alloys used under salt or fresh water. A contact of aluminum alloys with zinc and zinc coatings, cadmium and cadmium coatings, and with pure aluminum is harmless. A contact between aluminum alloys of different chemical composition is also permissible. An anodic film does not curb the harmful

effect of cathodic contacts on the corrosion of aluminum alloys.

The intergranular corrosion of aluminum alloys spreads along the boundaries of the crystallites (grains) of the metal (alloy), resulting in a loosening of the connection between the grains and in the destruction of the metal (alloy). The intergranular corrosion is a dangerous type of corrosive destruction. It causes an essential reduction of the mechanical properties, of the plasticity at first. A material prone to corrode intergranularly is also prone to undergo cracking stress-corrosion. Clear traces of corrosion are not always visible on the surface; therefore, the destruction of a design may occur quite suddenly. The intergranular corrosion is detectable under the microscope on microsections cut from the corroded object (or semifinished product) or on a polished section of the surface of the piece itself. The boundaries of the crystallites are clearly distinguishable under the microscope on the nonpickled polished section when intergranular corrosion is present. A typical microphotogram of the intergranular corrosion is shown in Fig. 7. Many of the aluminum alloys suffer an intergranular type of corrosion. This is most characteristic for the copper-containing alloys (the alloys D1, D16, D18, D20, V65, AK8, AK6, etc., for example), and also for alloys of the Al-Mg system containing 5% or more magnesium (AMg5 and AMg6). The proneness of these alloys to corrode intergranularly is caused by the decomposition of the supersaturated solid solution principally along the boundaries of the grains, and also by the type of the distribution of the decomposition products. The decomposition of the solid solution may be caused by heating (artificial aging, heating during production and service) or by a delayed cooling during the hardening process. The delayed cooling in hardening of alloys containing copper (of the Duralumin type) may occur under working conditions when the semifinished products or the objects are kept in

the open air before the immersion into the quenching medium, or when the quenching water has an elevated temperature, or when special quenching media are used, and also when the object or semifinished product is large (has a great cross section).

It is assumed that the intergranular corrosion is caused principally by the decomposition of the precipitated phase along the grain boundaries, or by the destruction or the narrow peripheral zone of the grain adjacent to the boundary. The development rate of intergranular corrosion depends primarily upon the degree of the discontinuity in the decomposition of the supersaturated solid solution, on the type of the distribution of the segregated phase, on the degree of dispersity and on other factors. The higher the rate of intergranular corrosion, the higher the loss of the mechanical properties. The nature and degree of the decomposition of the supersaturated solid solution depend considerably upon the conditions of the heat treatment (Table 3). The data of Table 3 prove that hardening in air (delayed cooling) instead of hardening in cold water results in the appearance of intergranular corrosion and lowers the strength by 6 times.

Fig. 7. Typical intergranular corrosion. [Nonplated sheet of the D16 alloy in artificially aged state (150° for 5 hours)]. Conditions of the corrosion: 5 days in a 3% NaCl + 0.1 H_2O_2 solution (the microsection is not pickled. Magnification by 100 times).

Cracking corrosion is a dangerous type of corrosion of structural materials. This type of corrosive destruction is characteristic for

many of metallic alloys (copper, lead, magnesium, aluminum alloys and also steel). The alloys of the systems Al-Zn-Mg and Al-Zn-Mg-Cu (the alloys V92, V93, V95, and V96) among the aluminum alloys are especially

TABLE 2

Corrosion Resistance of Non-Plated Sheets (1.2 mm thick) of the D19 Alloy*

Режим старения 1	Темп-ра и длительность нагрева 2	Потеря σ_b (%) 3
4 Естественное старение	5 Без нагрева	7,0
6 То же	150° – 50 час.	12,1
"	200° – 1 час 7	8,0
"	250° – 1 час 7	10,6
8 Искусственное старение при 190° в течение 12 час.		
6 То же	Без нагрева	12,4
"	150° – 50 час	13,8
"	200° – 1 час 7	9,6
"	250° – 1 час 7	3,3

* Test in a 3% NaCl + 0.1% H_2O_2 solution for 5 days.

1) Aging conditions; 2) heating temperature and time; 3) loss; 4) natural aging; 5) without heating; 6) the same; 7) hours; 8) artificial aging.

TABLE 3

Effect of the Heat Treatment on the Corrosion of the Non-Plated D16 Alloy (a 0.6 mm thick sheet)*

1 Термич обработка	Потеря прочности в % от 2 исходной	Тип коррозии 3
Закалка в холодной воде 4	11,0	Местная 5
Закалка в воде при 80° 6	20,0	Межкристаллитная 7
Закалка в воды при 100° 6	30,0	То же
Закалка в масле 9	32,0	"
Закалка с задержкой на воздухе 30 сек 10	42,0	8 "
Закалка на воздухе 11	46,0	"
Закалка + возврат 12	55,0	"
Закалка + старение при 13 160° в течение 8 час	52,0	"
Закалка + старение при 160° в течение 30 час 13	13,2	Межкристаллитная + местная 14
Закалка + старение при 190° в течение 12 час 13	12,0	То же 8

1) Heat treatment; 2) loss in strength in % of the initial strength; 3)

type of corrosion; 4) quenching in cold water; 5) pit; 6) cooling in water at ...; 7) intergranular; 8) the same; 9) cooling in oil; 10) cooling with a delay of 20 seconds in air; 11) cooling in air; 12) cooling + return; 13) cooling + aging at ... for ...; 14) intergranular + pit corrosion.

threatened by cracking corrosion. Alloys of the systems Al-Cu-Mg and Al-Cu-Mg-Si (D16, AK8, etc.) and the alloys of the Al-Mg system containing 5% and more magnesium (AMg5, AMg6, AL8) are less liable to cracking corrosion. The proneness to undergo cracking corrosion of the alloys of the Al-Cu-Mg and Al-Mg systems appears, as a rule, jointly with the tendency to corrode intergranularly. The chemical composition of the alloy and its structure, the magnitude of the stress and the nature of the corrosive medium are the main factors which determine the proneness of the alloys to undergo cracking corrosion. Corresponding with this fact, the casting method, the magnitude and type of deformation, the mode of the heat treatment, the state of the surface, the type of the stressed state and the operation conditions substantailly effect the proneness to undergo cracking corrosion.

There is no uniform point of view with regard to the mechanism of the cracking corrosion. Among the assumptions expressed by the different investigators, it can be considered as certain that the cracking corrosion is connected with the process of the partial decomposition of the supersaturated solid solution, the distribution of the decomposition products along the grain boundaries and a preferentail destruction of them in the given corrosive medium. Hence, the corrosion has not only a selective but also a local character, and cracking corrosion is also an intergranular one: the cracks develops along the grain boundaries. A sufficient high (external or internal) tensile stress is necessary to start the cracking corrosion. Compression stresses do not encourage cracking corrosion. Compression stresses do not encourage cracking cor-

rosion, to the contrary, they inhibit it. The length of time before the cracking begins is shortened by increasing the tensile stresses; this relation has, as a rule, a hyperbolic character. The appearance of cracking corrosion and the rate of its development depend on the nature of the corrosive medium. Special methods, besides the usual, common methods of preservation, are used to prevent cracking corrosion: 1) Increase of the stress-corrosion resistance of the alloy itself. This is attainable in the case of alloys of the Al-Zn-Mg and Al-Zn-Mg-Cu systems by a correct combination of the basic alloying elements, by the introduction of special additions (manganese and chromium for V95), and also by the state in which the alloys are used (V95, for example, only in the artificially aged state, V92, however, in the naturally aged state). Alloys of the Al-Cu-Mg system, the D16 alloy, for example, require that the hardening conditions be strictly observed: the quenching must be carried out quickly in cold water without a delay when the object is transferred from the heating equipment into the quenching bath. Artificial aging under fixed conditions must be carried out when the semifinished products or objects are exposed to a heat of 150° or more during their fabrication or service. A special stabilizing tempering is necessary for the alloys of the Al-Mg system (AMg5, AMg6). 2) Compressing stresses are created in the surface layers by treatment with a blast of metal shot, by rolling or by other methods.

Quick tests of aluminum alloys in order to determine a proneness to undergo cracking corrosion are carried out under the following conditions: a) repeated or continuous immersion into a 3% NaCl solution; b) spraying of a 3% NaCl solution or of fresh water (a 0.001% NaCl solution in distilled water) in a moist chamber; c) in ambient atmosphere (more frequently in an industrial atmosphere). The test with repeated immersion in a 3% NaCl solution is the hardest one. The tests are car-

ried out on special specimens which are exposed to tensile stresses. Some types of specimens are shown in Figs. 8-9.

Fig. 8. A sheet specimen in the form of a loop in the test appliance.

Fig. 9. A ring-shaped specimen (for the test of stress-corrosion in pipes.

Protection of aluminum alloys against corrosion. Aluminum alloys are protected against corrosion by metal coatings (plating, electroplating, metal sputtering), and by nonmetallic coating (oxide films, paint and varnish coatings, greasing). Plating is the most widely used method of metallic coating for the protection against corrosion of semifinished products from high-strength alloys. The plated aluminum alloys are a bimetal having a core from the alloy itself, which has high mechanical properties, Duralumin, for example, covered on both sides with a plating layer, pure aluminum or an alloy with a high corrosion resistance (near to that of pure aluminum). Apart from this, the plating also provides electromechanical protection for the core. Hence, high mechanical properties and a relatively high corrosion resistance are efficiently combined in the plated aluminum alloy. The plating method is widely used in our national industry for sheets of high-strength alloys. Alloys of the Duralumin type are plated by pure aluminum (of the A1 grade), the V95 alloy is plated by the V95K alloy (Al + 1% Zn). Recently, the plating of the inside of pipes has been introduced. Plating is widely used abroad for sheets, pipes, wires and rods. Pure alu-

minum, the alloy 6003 (of the AD33 type) is used for plating, the 7072 alloy (Al + 1% Zn) is also frequently employed.

Electroplating of aluminum alloys is used mainly for preservative and decorative purposes and to increase the wear resistance. Chromium and nickel-chromium coatings (see Chrome Plating of Aluminum Alloys, Nickel Plating of Aluminum Alloys) are used for these purposes. The method of protection by metal sputtering is not widely used at the time. One of the main methods of protecting aluminum alloys is by oxide films. The oxide films are obtained by chemical (see Chemical Oxide Coating of Aluminum Alloys) or by electrochemical methods (see Anodizing of Aluminum Alloys). The oxide films formed by chemical or electrochemical treatment are readily adhesible and are, therefore, widely used as a basis for coatings of paint and varnish. Anodic films filled with special organic or anorganic dyestuffs are used for decoration purposes. Diverse methods of paint and varnish coatings in combination with or without oxide films also belong to the widespread methods of nonmetallic coatings. Protective greases (see Preservation of Aluminum Alloys) are used in the storage and transport of aluminum alloys.

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CORROSION OF BERYLLIUM. The corrosion resistance of beryllium, particularly in aqueous solutions, depends strongly on the purity of the metal, and most of all on the content of carbide and slag inclusions. The metal produced prior to 1940-45 frequently did not have adequate purity. This factor must be considered in examination of data on the corrosion resistance relating to that period. Along with an overall relatively high corrosion resistance, Be has a tendency to local, pitting corrosion. At 30° Be hardly reacts with water, however the reaction accelerates with increase of the temperature. With temperature below 100° and exposure up to a year the rate of corrosion levels off and amounts to 0.0025-0.005 mm/year. Rapid destruction of the metal starts above 300°. The presence of dissolved oxygen in the water considerably reduces both the local and overall corrosion. Chlorine ions accelerate the corrosion, which increases even more with dissolved oxygen in the water. Pitting corrosion of Be increases with presence in the water of chlorine sulfate, copper, iron ions. The corrosion rate does not depend on the velocity of water flow (9 m/sec for flowing water). Application of mechanical loading to Be also has no effect. With contact of Be and pure aluminum preferential corrosion proceeds on the aluminum in static conditions, on the beryllium in dynamic conditions. With contact of Be with stainless steel under both static and dynamic conditions of test there is preferential corrosion of the Be with a rate 3-5 times greater than with noncontacting specimens.

Corrosion of Be in air is slight up to 600°. The thickness of the uniform and almost pore-free film of Be oxide covering a fresh cut of

the metal amounts to $1 \cdot 10^{-5}$ mm. With corrosion there proceeds the formation of the hydroxide of Be (BeO-H_2O). As a result of the slow hydrolysis of the carbide found in Be, there are often encountered on the surface of the metal scaly delaminations and corrosion products. The first noticeable signs of corrosion on the Be surface appear after: 60 hours at 700°, 12 hours at 800° and 1 hour at 900°. Only 0.75% Be nitride is found in the products of Be corrosion in air at 1000°. Be nitride forms at a temperature above 700° in oxygen-free nitrogen. The previously formed film of Be oxide prevents the interaction of Be with nitrogen in the air. Corrosion of Be in dry CO_2 up to 600° is slight after several hours exposure. Above this temperature, particularly in the presence of moisture, the rate of corrosion increases sharply and destruction of the metal is observed.

The corrosion of Be in molten metals proceeds both as a result of the ordinary solution of one metal in another, and as a result of the interaction of Be with the impurities dissolved in the molten metal (oxygen, carbon, nitrogen and the metals). As a result of several factors which are difficult to account for oxygen (content in melts, hydrostatic and thermal peculiarities of the system) we must recommend preliminary corrosion testing on system models.

In static tests Be shows a low corrosion rate in the following molten metals: sodium, gallium and the eutectic alloy of bismuth-tin-lead up to 500°; bismuth, lithium, potassium, sodium-potassium alloy, eutectic alloy of bismuth-lead and mercury up to 600°; magnesium to 800° and lead to 1000°. For example, the corrosion rate for sodium is 40-110 mg/dm^2 per month. Under dynamic donitions with high flow velocity of liquid sodium (oxygen content 0.01%), no reaction with Be is observed in the range of 380-760°. The Be-sodium-inconel system operates well to a temperature of 650°. In the case of application of loads to Be immersed in molten sodium, the corrosion rates does not increase at 540°.

For the protection of Be from corrosion use is made of inorganic inhibitors which primarily reduce local corrosion in water, and then protective layers of corrosion-resistant metals and oxides are applied. Adequately reliable inhibitors are not available, however at 85° the addition of sodium bichromate $Na_2Cr_2O_7$ in the amount of 0.0005% in water with pH = 7.5-8 makes a considerable reduction of Be pitting under both static and dynamic conditions. Addition of sodium nitrate in the amount of 0.0005% to desalted water with pH = 5.5-6.5 also eliminates pitting of Be at 85°. The corrosion resistance improves if the Be is subjected to anodizing in a 1% solution of chromic acid with the use of a graphite or platinum cathode. The creation of a strong corrosion-resistant coating for operation at elevated temperatures is difficult because of the tendency of Be to diffusion and the formation of brittle substitution phases. However, in some operating conditions several coatings are used for protection: electrolytic coating with nickel for protection from corrosion in water vapors below 350°, chrome plating over copper or a zinc sublayer for protection from interaction with molten sodium at 500°.

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CORROSION OF BRASS. The corrosion of brass in an atmosphere which is not contaminated with aggressive gases and other impurities (rural area) is slight, but increases sharply with the presence in the air of a admixtures of sulfur dioxide, ammonia, chlorine, oxides of nitrogen (industrial urban atmosphere). The corrosion of brass in sea water amounts to 0.04-0.06 mm/yr. The most aggressive media for brass are the solutions of the oxidizing acids, ammonia, salts of mercury, copper and trivalent iron. The characteristic forms of brass corrosion are: dezincing and cracking. Dezincing is most frequently observed with exposure of brass to solutions containing chlorine ions. Brasses having less than 20% zinc are not subject to dezincing. Alloying of the brass with several hundredths of a percent of arsenic prevents dezincing. Corrosion cracking of brass was previously termed "seasonal" cracking. This obsolete term arose in connection with the observed preferential cracking of brass in the seasons of high humidity (Fall and Spring for the Moscow climatological conditions, Wintertime in England, see tables 1 and 2).

The term "spontaneous" cracking was also previously used.

Brass is very prone to corrosion cracking in the presence of tensile (residual or externally applied) stresses in the surface layers and with the action of certain specific corrosion-active substances (ammonia, sulfur dioxide, oxides of nitrogen, cyanides) or the metals which dissolve zinc (mercury, low-melting brazes). Ammonia (only in the presence of oxygen and moisture) is the most corrosion-active agent, however the presence of the acidic oxides (even CO_2) significantly re-

tards the corrosion process and can neutralize the action of the ammonia. In the air the ammonia content is usually very low, while the acidic compoents (sulfur dioxide, for example) content is considerably higher (Table 3), therefore in practice the cracking of brass takes place from the action of the SO_2 and not NH_3 (with the exception of localities with the release of large quantities of NH_3 -- ammonia plants, stables, sewage plants

TABLE 1

Duration of Testing to Cracking of Brass Specimens in Open Air (Moscow, 1950)

1 Месяцы	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2 Длительность испытания (сутки) . . .	38	15	5	17	42	36	25	25	7	3	6	21

1) Months; 2) test duration (days)

TABLE 2

Number of Lots of Cracked Brass Rods, from data of O.V. Ellis (England, 1914-18)

1 Месяцы	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2 Количество партий прутков	17	12	16	11	11	3	0	1	5	9	8	13

1) Months; 2) number of lots of rods

TABLE 3

Composition of Urban Air

1 Газ	2 Содержание		1 Газ	2 Содержание	
	3 (объемные %)	4 (мг/м³)		3 (объемные %)	4 (мг/м³)
5 Азот	78	975000	Криптон . . . 12 . . .	0.0001	2.9
6 Кислород	21	300000	Водород . . . 13 . . .	0.00005	0.045
7 Аргон	0.932	16630	Сернистый газ 14 . . .	0.00001	0.3
8 Двуокись углерода . . .	0.03	594	Ксенон . . . 15 . . .	0.000008	0.47
9 Окись углерода	0.0018	23	Аммиак . . . 16 . . .	0.0000026	0.02
10 Неон	0.0018	16	Хлор . . . . . 17 . . .	0.0000008	0.02
11 Гелий	0.0005	0.9	Окислы азота . 18 . . .	0.00000015	0.003

1) Gas; 2) content; 3) (volume %); 4) (mg/m^3); 5) nitrogen; 6) oxygen; 7) argon; 8) carbon dioxide; 9) carbon monoxide; 10) neon; 11) helium; 12) krypton; 13) hydrogen; 14) sulfur dioxide; 15) xenon; 16) ammonia; 17) chlorine; 18) nitrogen oxides

TABLE 4

Duration of Testing To Cracking of Brass Specimens

1 Условия испытания	Л90	Л80	Л75	Л70	Л68	Л62
	2 Длительность испытания					
3 Влажные образцы над 25%-ным NH_3 (минуты)	60	19	19	9	8	9
4 Сухие образцы над 0.3%-ным NH_3 (сутки)	8	4	2	2	2	2
5 В растворе $[Cu(NH_3)_4]OH_2$ (минуты)	61	25	22	17	15	21
6 Над раствором $(NH_4)_2CO_3$ (сутки)	56	50	21	13	12	9
7 В 1%-ном $HgNO_3$ (секунды)	593	28	14	11	10	14
8 Над раствором H_2SO_3 (сутки)	10 Не растрескивались		22	1.6	1.3	0.5
9 В атмосферных условиях (сутки)	11 То же		78	14	3	2

1) Test conditions; 2) test duration; 3) moist specimens over 25% NH_3 (minutes); 4) dry specimens over 0.3% NH_3 (days); 5) in solution of $[Cu(NH_3)_4]OH_2$ (minutes); 6) over a solution of $(NH_4)_2CO_3$ (days); 7) in 1% $HgNO_3$ (seconds); 8) over a solution of H_2SO_3 (days); 9) in atmospheric conditions (days); 10) did not crack; 11) same.

The effect of test conditions for cold-formed specimens with tensile stresses equal to the elastic limit is shown in Table 4.

The danger of cracking is higher, the higher the tensile stresses in the surface layers of the alloy. Therefore we should avoid such operations as tube drawing without mandrels, turning of caps, assembly of brass details with interference fits. With the same values of the stresses the tendency to corrosion cracking is less for the brasses which are work hardened to a greater degree during cold deformation and which have smaller grain size. The tensile stress in the brasses should be relieved by mechanical work: rolling, impact treatment, etc., or by annealing at 250-300°. Brass goods and semimanufactures cannot be stored near sources which release ammonia, sulfur dioxide, nitrogen oxides; to avoid possible condensation of atmospheric moisture it is desirable to store brass in heated rooms. The most reliable methods for prevention of cracking are zinc and cadmium plating. Electroplating with silver, copper, tin does not prevent the formation of cracks. Alloying of brass with silicon reduces the tendency to corrosion cracking.

The tendency of brass products to cracking is evaluated from the

magnitude of the tensile stresses which cause cracking after a definite time, and from the time required for crack formation with exposure of the brass to gaseous or liquid media. Most common are the tests in an ammonia atmosphere (over aqueous solutions of ammonia of 5, 10, 20 or 25% concentration) and in aqueous solutions of the mercury salts (nitrous or chlorous). Testing in an ammonia atmosphere is very severe; in this medium brass cracks even with very low stresses (1 kg/mm^2) or with low zinc content (3-5%). The mercury test causes cracking of brass with tensile stresses of 10 kg/mm^2 or higher. More realistic testing is that in an air atmosphere over diluted solutions of sulfuric acid, since sulfur dioxide is a basic corrosion-active impurity of the atmosphere of inhabited localities.

References: Tomashov N.D., Teoriya korrozii i zashchity metallov (Theory of Corrosion and Protection of Metals), M., 1959; Corrosion of Metals, coll. of articles transl. from English, vols. 1-2, L.-M., 1952; Bobylev A.V., Korrozionnoye rastreskivaniye latuni (Corrosion Cracking of Brass), M., 1956.

A.V. Bobylev

CORROSION OF BRONZE. The corrosion resistance of bronze is quite high as the result of the high thermodynamic stability of copper. The bronzes resist quite well the action of atmospheric air, the gaseous carbon compounds (other than acetylene), organic solvents, alcohols, aldehydes, ketones, fresh and salt water; but they are nonresistant to the action of ammonia and its salts, the acids, particularly nitric, nitrous, picric, hydrofluoric, hydrochloric, chromic, the halogens, sulfide solutions and mercury salts. At high temperatures the bronzes are subject to corrosion under the action of oxygen, sulfur and its oxides, hydrogen sulfide, phosphorus, the halogens. Alloying of copper with aluminum, beryllium or magnesium strongly increases the resistance of the bronzes to gaseous corrosion, while arsenic, chromium and cerium reduce this resistance (table 1).

TABLE 1

Values of the Constant K for Copper Alloys* (equation $W_2 = Kt$, where W is the increase of weight of the oxide film in g/cm^2 and t is time in seconds)

1 Содержание легирующего элемента (%)	2 $K \cdot 10^{10}$ ($g/cm^2 \cdot sec$)	1 Содержание легирующего элемента (%)	2 $K \cdot 10^{10}$ ($g/cm^2 \cdot sec$)	1 Содержание легирующего элемента (%)	2 $K \cdot 10^{10}$ ($g/cm^2 \cdot sec$)
1.0 Al	23.1	0.67 [illegible]	28.0	3.0 Si	14.8
2.5 Al	0.925	0.7 Mg	33.2	2.8 Sn	75.0
3.0 Al	0.231	2.76 Mg	0.231	4.0 Ti	33.2
9.5 Ag	~545	5.0 Mn	59.2	5.0 Zn	45.0
0.38 Be	28.0	1.0 Ni	45.4	40.0 Zn	3.70
1.0 Be	3.80	20.0 Ni	66.5	5.2 Ni+0.38 B	20.8
2.4 Be	0.0578	0.05 P	75.0	7Ni+0.5 B	11.3
1.0 Ca	39.2	0.54 P	~251	6.1 Sn+0.54 P	52.1
5.0 Co	168	2.4 Sb	45.0	Чистая медь	45.4
2.0 Cr	112	0.5 Si	66.9	3	
7.75 Fe	52.1	1.8 Si	14.8		

* Oxidation in air at 800°

1) Content of alloying element (%); 2) $K \cdot 10^{10}$ (g/cm^2-sec); 3) Pure copper.

Alloying of copper with aluminum and beryllium improves the resist-

ance with respect to the action of sulfur and its compounds, while alloying with nickel decreases this resistance. The indices of the corrosion of the copper alloys at 200-220° in vapors from sulfate pulp production containing 17-18% SO_2, are given in table 2.

TABLE 2

Loss of Weight of Copper Alloys Exposed to SO_2

1 Сплав	2 Химич. состав сплава (%)		4 Потеря веса в сутки ($мг/дм^2$)
	Cu	3 другие элементы	
5 Нейзильбер	55	18 Ni; 27 Zn	637.9
5 Нейзильбер	65	18 Ni; 17 Zn	674.2
5 Нейзильбер	75	20 Ni; 5 Zn	355.6
6 Бронза	90	10 Sn	220.3
7 Фосфористая бронза	95.5	4.3 Sn; 0.2 P	285.8
Фосфористая бронза	91.8	8.0 Sn; 0.15 P	396.3
8 Никелевая бронза	88.5	5Ni; 1.5 Si; 5 Sn	704.9
9 Алюминиевая бронза	90	10 Al	264.2
10 Кремнемарганцовистая бронза	94–95	1–1.2 Mn; 3.4 Si	502.3

1) Alloy; 2) chemical composition of alloy (%); 3) other elements; 4) weight loss per day (mg/dm^2); 5) German silver; 6) bronze; 7) phosphor bronze; 8) nickel bronze; 9) aluminum bronze; 10) silicon-manganese bronze.

The weight loss in mg/dm^2 after 5 hours exposure to sulfur at 130° for copper and copper alloys as a function of the alloying elements is:

Cu	2% Zn	5% Zn	7% Zn	9% Zn	2% Mn	5% Mn	15% Mn	33.3% Mn
19.2	10	5.8	4.6	2.2	2.8	1.8	0.74	1.8

The bronzes are stable with respect to hydrogen if they do not contain oxygen in solid solution or in the form of oxides which can be reduced by the hydrogen in the process of its diffusion into the alloy

at elevated temperatures. Alternate exposure to oxygen and hydrogen can lead to brittleness of the bronzes.

The characteristics of bronze corrosion in agitated sulfuric acid of varying concentration are shown in table 3.

TABLE 3

Rate of Corrosion of Bronzes in Sulfuric Acid at 20-80°

1 Легирующие элементы бронзы	2 Концентрация кислоты (%)								
	10			35			55		
	3 Темп-ра (°С)								
	20	40	80	20	40	80	20	40	80
	4 Скорость коррозии (мм/год)								
4% Sn + 3% Zn	0.199	0.305	0.589	0.060	0.144	0.358	0.025	0.049	0.148
9% Al + 6% Ni	0.092	0.211	0.627	0.036	0.050	0.286	0.017	0.032	0.150
10%Al + 3%Fe + 1.5% Mn	0.109	0.168	0.190	0.029	0.048	0.401	0.015	0.024	0.054
5% Al	0.233	—	0.426	0.148	0.351	0.449	0.068	0.110	0.110
4% Si	0.218	0.526	0.579	0.131	0.316	0.345	0.074	0.161	—

1) Alloying element of the bronze; 2) acid concentrations (%); 3) temperature (°C); 4) corrosion rate (mm/year)

The generally high corrosion resistance of the bronzes permits their use in the great majority of cases without protective coatings or other methods of protection against corrosion. Pure copper does not have a tendency toward corrosion cracking; its alloying with elements which are not corrosion resistant can lead to cracking of the alloy in media which have an active reaction with the given element (with the presence of tensile stresses of sufficient magnitude in the surface layers of the alloy). With increase of the degree of alloying the tendency to cracking increases. The aluminum bronzes tend to crack in an ammonia medium and in solutions of the mercury salts; the presence of high tensile stresses leads to the formation of cracks even with an Al content in the alloy of 3%. The alloys of copper with manganese (20% and more) are very prone to cracking under the action of sulfur dioxide, nitrogen oxides and solutions of mercury nitrate, while the tin bronzes tend to crack in solutions of the mercury salts. The pure copper-nickel

alloys have no tendency to corrosion cracking.

References: Tomashov N.D., Teoriya korrozii i zashchity metallov (Theory of Corrosion and Protection of Metals), Moscow, 1959; Klinov I.Ya., Korroziya khimicheskoy apparatury i korrozionnostoykiye materialy (Corrosion of Chemical Apparatus and Corrosion-Resistant Materials), 3rd ed., M., 1960; Corrosion of Metals, collection of articles translated from English, vols. 1-2, L.-M., 1952; Bobylev A.V., TsM, 1959, No. 2, p. 65-70; — Byull. Tsentr. In-ta informatsii tsvetnoy metallurgii (Bulletins of the Central Institute of Information for Nonferrous Metallurgy), 1959, No. 5 (130), p. 35-40.

CORROSION OF CHROMIUM. With heating in air and in oxygen, chromium begins to oxidize at about 400-450°. The variation of chromium oxidation rate with temperature (in $g/m^2/hr$) is: 0.007 (600°), 0.014 (700°), 0.02 (800°), 0.06 (900°), 0.1 (1000°), 1 (1100°), 1.15 (1200°) preliminary passivation of the surface considerably reduces the rate of oxidadation of chromium with subsequent heating even to high temperatures. Diffusion of oxygen into chromium and its alloys is not observed.

Beginning at 600-650° chromium interacts chemically with gaseous nitrogen. The nitrides which are formed embrittle the metal. With increase of the temperature the rate of nitriding of chromium and the depth of the diffusion layer increase. However, above 1500° the chromium nitrides dissociate and the nitriding terminates. The diffusion of nitrogen takes place both frontally and along the boundaries of the grains, particularly in the case of accumulation of impurities on the grains. During the process of heating in air at 1200° the thickness of the nitrided layer increases on the average with a rate of 0.002 mm/ /hour. At 20° the plasticity of chromium can be restored after removal of the nitrided metal layer. The weight increase of chromium during heating in air reflects the progress of two processes - nitration and oxidation (here the rate of nitration predominates). Taking account of the statements above, we can consider that chromium is corrosion resistant in an oxidizing atmosphere above 1200°.

If we heat chromium in an atmosphere containing gaseous compounds of carbon, sulfur, (also oxygen and nitrogen), the metal interacts with these elements. To prevent embrittlement of chromium in the process of

long-term heating in an atmosphere of active gases, use is made of surface protection and alloying. The nature of the interaction of chromium with the active gases is altered by alloying. In the highly alloyed chromium alloys diffusion of nitrogen into the depth of the material is not observed. Depending on the alloying, the alloys are subject to conventional gas corrosion with the formation of oxides on the surface. With regard to corrosion resistance in an oxidizing atmosphere, chromium yields only to the chrome-nickel alloys. The alloy of chromium with 1% yttrium is heat resistant at 1300° (weight gain 0.2 $g/m^2/hr$).

Concentrated nitric acid and its aqueous solutions, formic, citric, tartaric acids do not attack chromium. Many oxidizers: chlorine and bromine water, concentrated nitric, phosphoric, hypochlorous and perchloric acids passivate chromium. Passivation is caused by the formation of a thin oxide film or absorbed oxygen film on the surface of the metal. In the passivated condition chromium does not interact with the dilute mineral acids. Chromium reacts little with dry and moist air at 20°, does not react with sea water or even with sea water spray in the air.

Chromium is not attacked by the molten alkaline carbonates, is slightly attacked by acetic acid, with heating is corroded by the alkaline hydroxyls, is strongly oxidized by molten sodium nitrate and sodium perchlorate. Chromium interacts with silicon tetrachloride at 1200°. Chromium reacts slowly with dilute sulfuric acid, reacts with boiling concentrated sulfuric acid.

On heating to 1600° in an oxidizing atmosphere, chromium interacts with phosphorous. Calcium vapors do not have any noticeable effect on chromium heated to 800°. At high temperatures chromium interacts with carbon, silicon, boron. Beginning at 1000° chromium oxidizes in an at-

mosphere of carbon monoxide, begins to react with sulfur vapors at 700°, and with hydrogen sulfide at 1200°, forming chromium sulfides. Hot nitric acid forms oxides and nitrides with chromium.

Chromium dissolves in aqueous solutions of HF, considerably more slowly in aqueous solutions of hydrochloric acid, hydrogen bromide and hydrogen iodide. Heating of these reagents accelerates the interaction with chromium. A mercuric chloride solution dissolves chromium, forming chromium chloride.

References: Udy M.J., Chromium, v. 2, L., 1956.

I.O. Panasyuk

CORROSION OF COPPER. The chemical activity of copper is low, it cannot be dissolved in acids with the release of hydrogen; dissolution of copper takes place in oxidizing acids (nitric, chromic) or in the presence of the oxidizing salts (ferric chloride, potassium brichrcmate). A characteristic feature of copper is lack of resistance to the combined action of NH_3, O_2 and H_2O as a result of the formation of the complex ion $[Cu(NH_3)_4]^{++}$. Complexing also takes place under the action of hydrochloric acid and the cyanides.

The normal potential of copper has a positive magnitude (+0.35 v on the hydrogen scale in a Cu^{++} ion solution medium) and it can be considered one of the seminoble metals; in ammonia solutions the copper potential is negative.

In nonoxidizing acids (other than the hydrohalics) without access to air, copper is corrosion resistant. With passage of oxygen through these acids the copper corrosion rate per day amounts to the following values in mg/cm^2:

Hydrochloric acid	4% solution	8600
" "	20% solution	13400
Sulfuric acid	6% solution	920
" "	20% solution	840
Citric acid	50% solution	170
Acetic acid	6% solution	143
" "	50% solution	445

The corrosion rate of copper constantly submerged in sea water is 0.02-0.07 mm/year. Copper is nonresistant to the action of sea water

flowing with a velocity of more than 1 m/sec (jet or impact corrosion). In atmospheric conditions copper has considerable resistance as a result of the formation on the surface of a protective layer of basic carbonates; the presence in atmospheric air of the corrosion-active contaminants: SO_2, NH_3 etc., markedly accelerates the corrosion of copper. At elevated temperatures (above 200°) the corrosion of copper is significant (see Table).

TABLE

Values of Constant K for Copper in Air and Oxygen Atmospheres (equation $W_2 = Kt$, where W is the increase of weight of the oxide film in g/cm^2 and t is time in sec.).

1 Температура (°C)	2 Величина K (г см².сек)	
	3 на воздухе	в кислороде 4
600	—	3
700	8	16
800	80	87
900	336	349
1000	1350	1780

1) Temperature; 2) value of K (g/cm^2-sec); 3) in air; 4) in oxygen.

At high temperatures copper reacts also with sulfur, its compounds, the halogens, phosphors and the vapors of certain acids, copper is stable with respect to N_2, CO, CO_2, H_2O. Hydrogen and the gases which evolve it on heating cause "hydrogen disease" of copper if the latter contains oxygen and is heated above 400°. The sharp reduction of plasticity in this case is associated with the reduction of cuprous oxide by the hydrogen and the formation of water vapor by the reaction: $Cu_2O + H_2 = 2Cu + H_2O$.

With the action of acetylene on copper there may be formed explosive copper acetylides.

References: Tomoashov N.D., Teoriya korrozii i zashchity metallov (Theory of Corrosion and Protection of Metals), M., 1959; Corrosion of Metals, collection of articles transl. from Eng., books 1-2, L.-M., 1952.

A.V. Bobylev

CORROSION OF MAGNESIUM ALLOYS. Magnesium and the magnesium alloys have relatively low corrosion resistance because of the high electronegative potential and the inadequate protective properties of the natural oxide film. The standard potential of magnesium is -2.34 v, the irreversible potentials in many neutral electrolytes are in the range from -1.25 to -1.5 v, therefore magnesium is capable of displacing hydrogen from neutral media, for example from water: $Mg+2H_2O \rightarrow Mg(OH)_2+$ $+H_2\uparrow$. In this case two processes take place: the anodic is ionization of the magnesium $Mg+\underline{n}H_2O \rightarrow Mg^{++}\cdot\underline{n}H_2O+2\underline{e}-$, and the cathodic is the assimilation of an electron $2\underline{e}^-+2H^+\cdot\underline{n}H_2O \rightarrow H_2\uparrow+\underline{n}H_2O$. This reaction takes place with hydrogen depolarization; with oxygen depolarization the reaction proceeds in accordance with the equation $4\underline{e}^-+O_2+2H_2O \rightarrow 4OH-$. The processes with predominant oxygen deplarization take place under a thin film of moisture and in atmospheric conditions. In distilled water the oxygen and hydrogen depolarization are of commensurate importance. In solutions of salts and acids, as a rule, the process proceeds with purely hydrogen depolarization.

Magnesium and its alloys do not have adequate stability in the majority of the inorganic media. They are stable in a solution of chromic acid and its salts, in solutions of hydrofluoric acid of definite concentrations and its salts, in alkaline solutions. The low electrode potential and the instability of the protective oxide film in neutral and acidic solutions lead to very high rates of corrosion of magnesium and its alloys in these media. In the alkaline solutions the corrosion rate

diminishes markedly as a result of increased stability of the protective film and simultaneous reduction of the concentration of the hydrogen ions. The corrosion rate increases with temperature rise and depends on the composition and structure of the alloy.

In atmospheric conditions the corrosion of the magnesium alloys depends on the air moisture, the temperature, the gas and salt content in the air atmosphere, the duration of the stay of the moisture film on the surface and the rate of evaporation of this film. The highest corrosion rate is noted in industrial regions, the lowest in rural areas. Coastal regions occupy an intermediate position. The corrosion products formed in the industrial atmosphere have approximately the following composition: 61.5% $MgCO_3 \cdot 3H_2O$; 26.7% $MgSO_4 \cdot 7H_2O$; 6.4% $Mg(OH)_2$; carbonaceous substances about 2.5%. In a pure atmosphere the corrosion products consist basically of magnesium hydroxide. The corrosion resistance of high-purity magnesium is reduced by the great majority of the metallic impurities and alloying additives, which act as cathodes with respect to magnesium. In media in which the corrosion process takes place with primarily hydrogen depolarization, severe reduction of the corrosion resistance is observed under the influence of impurities with a low hydrogen overvoltage: Fe, Ni, Co, Cu. Metals with a high hydrogen overvoltage, for example Zn, Cd, Al are less dangerous. Each impurity has its limiting content, above which the corrosion resistance of magnesium falls sharply (Fig. 1). All the metals reduce the corrosion resistance of magnesium to a considerably smaller degree in media in which the process proceeds with predominance of hydrogen depolarization, for example, in atmospheric conditions. A reduction of iron and nickel impurities in the alloys of the system Mg–Al–Zn–Mn can to a considerable degree improve the corrosion resistance under severe conditions. Thus, the corrosion resistance of the alloy ML5hp (high purity) in a 3%

NaCl solution with an iron impurity content to 0.005 and nickel to 0.0006% is increased by a factor of 12 times.

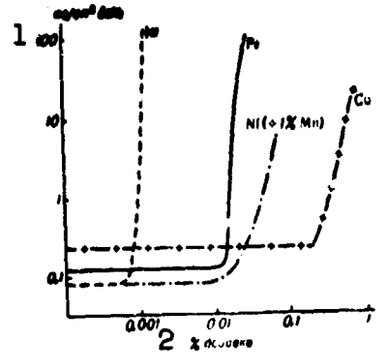

Fig. 1. The effect of impurities on the corrosion resistance of high-purity magnesium (Hanawalt, Nelson, Peloubet). 1) mg/cm^2-day; 2) % impurity.

The reduction of the corrosion resistance of the alloys of the system Mg-Al-Zn-Mn under the influence of an iron impurity is increased with increase of the aluminum content. Heat treatment effects the corrosion resistance of the magnesium alloys. Thus, the ML5 alloy in the cast condition has a higher corrosion resistance than in the tempered condition; aging at 175° after homogenization at 420° for 24 hours somewhat increases the corrosion resistance of the alloy in the tempered condition (Fig. 2).

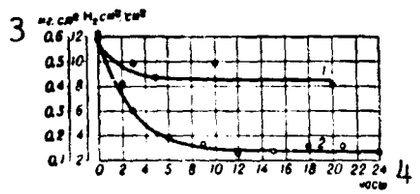

Fig. 2. Effect of long-term aging on corrosion resistance of the ML5 alloy: 1) in atmospheric conditions of an industrial region; 2) in a 0.5% NaCl solution; 3) mg/cm^2; 4) hours.

In the smelting and casting of the magnesium alloys, wide use is made of the chlorides of the alkaline and alkaline-earth metals as refining and protective fluxes. Inclusions of these fluxes may remain in the castings if technological conditions are not observed. On contact with moisture, the flux inclusions form solutions of the salts, which cause active dissolution of the magnesium alloys. In this case intensive destruction of the alloy proceeds only at the locations of the flux inclusions (Fig. 3). Flux corrosion is very dangerous, since it leads to destruction of the metal clear through the part. Preparation of cast details and ingots without flux inclusions is one of the primary methods for improving the corrosion resistance of the mag-

nesium alloys. The corrosion resistance of the various casting magnesium alloys in atmospheric conditions is practically the same. The corrosion resistance of the new casting alloys ML9, ML10, ML11, ML12, BML1, BML2 in the heat treated condition is higher than that of the widely used ML5 alloy (Fig. 4). The comparative corrosion resistance of the wrought alloys is shown in Fig. 5. The MA11, MA10 alloys have low corrosion resistance. The corrosion resistance of the other wrought alloys MA9, MA8, MA3, MA2, VM65-1, VMD1, VM17 is practically the same. However, many high-strength wrought magnesium alloys are prone to a more dangerous form of corrosion - corrosion cracking. Therefore the characteristics presented above for the general corrosion is not an adequate basis for selection of an alloy.

Fig. 3. Flux corrosion on the ML5 alloy.

Corrosion Cracking of the Magnesium Alloys - formation of cracks in the alloys with simultaneous action of a corrosive medium and tensile stresses (external and internal). The primary factors effecting the tendency to corrosion cracking are the composition and structure of the alloys, the magnitude of the tensile stresses and the nature of the corrosive medium. The wrought alloys are, as a rule, prone to corrosion cracking. With respect to the tendency to corrosion cracking under atmospheric conditions, the wrought magnesium alloys are divided into three groups: 1) the alloys which have practically no tendency to corrosion cracking - MA1, MA8, MA11, VMD1, VM17; 2) the alloys which have only a slight tendency to corrosion cracking - MA2, VM65-1, MA2-1; 3) the alloys having a high tendency to corrosion cracking - MA3, MA5 and MA10, particularly the MA10 alloy (Fig. 6). The tendency to corrosion cracking of the alloys of the Mg-Al-Zn-Mn system increases with increase of the aluminum content.

The effect of aluminum on the corrosion cracking of the binary Mg-Al alloy is shown in Fig. 7. Alloys with aluminum content up to 2% (limiting solubility of aluminum at room temperature) are not prone to corrosion cracking in atmospheric conditions, i.e., the tendency to corrosion cracking is manifested only in the alloys which are supersaturated solid solutions. Heat treatment which leads to alteration of the phase composition of the alloy significantly changes the tendency to stress corrosion. Heat treatment of the Mg+8% Al alloy which leads to complete disintegration of the supersaturated solid solution and to the precipitation of the intermetallic compounds in the form of very fine particles which are not bound with one another prevents corrosion cracking. A corrosive environment is one of the conditions which cause corrosion cracking. Insulation of the surface of the stressed specimen, for example, by paint-type coating, lubricant, etc., either markedly delays the time for crack formation or prevents it. Corrosion cracking also does not take place in media in which practically no corrosion occurs, for example, in anhydrous gasoline, kerosene, acetone, etc. Time to cracking for the same alloy varies as a function of the medium from several minutes to several months or to complete stability in the given medium. However, with a high corrosion rate corrosion cracking does not occur. The na-

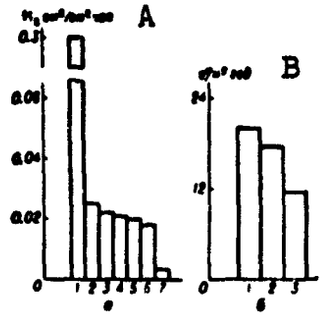

Fig. 4. Comparative corrosion resistance of the magnesium casting alloys (heat treated) in various media: a) 0.5% NaCl solution; b) moist atmosphere (φ – 98%); 1 – ML5; 2 – ML19; 3 – ML10; 4 – ML11; 5 – ML12; 6 – VML1; 7 – VML12. A) $cm^3/cm^2/hr$; B) $g/m^2/yr$.

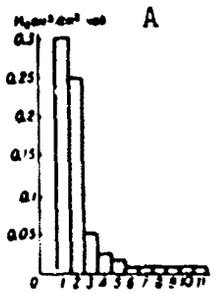

Fig. 5. Comparative corrosion resistance of the wrought magnesium alloys (extruded condition) in a 0.5% solution of NaCl: 1 – MA11; 2 – MA10; 3 – MA5; 4 – MA4; 5 – MA3; 6 – MA2; 7 – MA8; 8 – VM65-1; 9 – VM17; 10 – MA9; 11 – VML1. A) $cm^3/cm^2/hr$.

ture and the thickness of the natural or artificial protective films play a major role in the rate of crack formation. Corrosion cracking can proceed only with the action of tensile stresses, while compressive

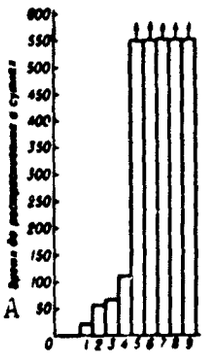

Fig. 6. Stress corrosion of certain wrought magnesium alloys in the extruded condition in atmospheric conditions of an industrial region: 1 – MA10; 2 – MA5; 3 – – MA4; 4 – MA3; 5 – MA8; 6 – MA11; 7 – VML1; 8 – VM17; 9 – MA2. A) Time to cracking, days.

stresses aid in the reduction of the tendency to corrosion cracking. Shot peening, rolling and other processing which creates compressive stresses on the surface of the magnesium alloys significantly improve the resistance of the alloys to corrosion cracking. The corrosion crack always develops perpendicular to the direction of action of the tensile stresses, and the specimen failure is of a brittle nature. The crack, often intermittent, passes both through the body of the grain and along the grain boundaries (Fig. 8). With increase of the tensile stresses, the time to failure diminishes systematically (Fig. 9). There exist, as a rule, critical stresses below which the alloy is practically free of corrosion cracking. Moreover, the higher the tendency of the

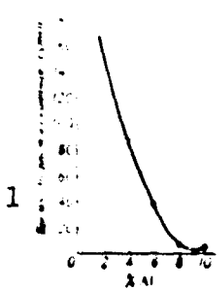

Fig. 7. Effect of aluminum on corrosion cracking of an alloy of the Mg-Al system in a 0.001% NaCl solution medium with alternate immersion. 1) Time to cracking in days

alloy to corrosion cracking, the lower the value of the critical stress. The value of the critical stress depends to a considerable degree on the magnitude of the residual stresses. With high values of the residual tensile stresses the limiting value of the applied tensile stress becomes very small. Such a material may be subject to cracking without the application of external stresses. Annealing which leads to the relief of the internal tensile stresses will significantly increase the stress corrosion resistance. The mechanism of the corrosion cracking process is still a subject of discussion. Studies of recent years have established the electrochemical nature of corrosion cracking of the magnesium alloys. It has been shown that the genesis of the cracks is the result of the activity of submicroscopic elements which causes selective dissolution of one of the atoms in the crystalline lattice. Protection of the magnesium alloys from corrosion cracking can be accomplished in the following ways: 1) increase of the stress corrosion resistance of the alloy by means of heat treatment or variation of the alloy composition which does not lead to a significant reduction of the strength characteristics; 2) use of rational forms of details (for example, elimination of abrupt transitions); 3) creation of compressive stresses in the surface layer; 4) application of coatings. Paint-type coatings cannot provide reliable protection from corrosion cracking in places where the coating is damaged. The metallized coating is more resistant to mechanical damage and, moreover, it provides elec-

Fig. 8. Corrosion crack on MA5 alloy (magnified 200 times).

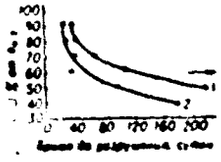

Fig. 9. Effect of increase of tensile stresses on corrosion cracking of magnesium alloys in industrial region atmosphere: 1) MA2-1 (half-hard sheet, 1.2 mm thick); 2) MA10 (extruded); 3) % of $\sigma_{0.2}$; 4) time to failure, days.

trochemical protection for the alloy.

Magnesium alloys are recommended for use primarily in the medium which is least aggressive for them - in atmospheric conditions. All the casting alloys, and also the MA1, MA2, MA2-1 wrought alloys (in the annealed condition), MA8, VM17, VM65-1, VMD1 with suitable protection by inorganic films and paint-type coatings (see Paint-Type Coatings for Magnesium Alloys) can be used with confidence in atmospheric conditions.

For the wrought alloys MA3, MA5, MA10 which have a high tendency to corrosion cracking, it is necessary to restrict the magnitude of the applied tensile stresses in the design and also to use increased protection.

For details used in a marine atmosphere where the contact with sea water is not excluded it is recommended that only the most corrosion resistant ML5hp be used, which can also be used for details in tropical conditions. The magnesium alloys are not recommended for details used with full immersion in sea water.

Protection of the magnesium alloys from corrosion is provided by a whole complex of measures, including reduction of metallic and nonmetallic impurities, absence of flux inclusions, application of inorganic films and paint-type coatings, and in some cases also the use of metallic coatings, the selection of rational design shapes and combinations of contacting materials in the products. Corrosion protection by inorganic films with paint-type coatings provides for reliable operation of details and structures under atmospheric conditions. The inorganic films without paint-type coating do not provide for adequate protection of details operating for long periods under various climatic conditions, but they do improve the protective properties of the paint-type coating and its adhesion to the metal. In addition, the inorganic films are used for the protection of details and semi-manufactures in the process

of production and transportation (see Anodizing of Magnesium Alloys, Oxidizing of Magnesium Alloys, Packaging of Magnesium Alloys). The paint-type coating for the magnesium alloys consists of a priming passivating layer and an outer lacquer-base or enamel-base layer. The metallic coatings (galvanic metallizing, cladding) do not find wide application because of the inadequate effectiveness and the complexity of the technology. Sometimes metallic coatings are used to improve the wear-resistance and the electrical and thermal conductivity of the magnesium alloys. The application of galvanic coatings is difficult because of the oxide film on the surface of the magnesium alloys and the strong electro-negative potential of magnesium, therefore prior to the application of these coatings the surface is processed in special solutions (see Galvanic Coating of the Magnesium Alloys). The galvanic metallic coatings, being cathodic, provide protection only in the absence of pores, therefore it is necessary to use multilayer coatings. Cladding for the protection of the magnesium alloys has not found application in either the Soviet or foreign industry. Effective protection of the MA10 high-strength magnesium alloy from corrosion cracking is provided by a metallic coating using an alloy of magnesium with zinc and lithium.

In a structure, particularly vulnerable regions are the joints where, as a rule, there is contact of differing metals, and the gaps in which moisture accumulates. All the metals which may be in contact with the magnesium alloys (aluminum alloys, steel, zinc plated, cadmium plated, chrome plated alloys, etc.) are cathodes with respect to the magnesium alloys, however, the degree of their influence differs. The method of attachment of the details to one another and the corrosive medium have a major effect on the development of contact corrosion. In atmospheric conditions the most unfavorable contacts are with copper and its

alloys, nickel, steel, the noble metals (silver, gold, platinum). Contact is permissible with the other grades of magnesium alloys, aluminum and its alloys, zinc and the zinc coatings, cadmium and cadmium coatings, parkerized steel (under the condition of oil treatment of the phosphate film), chromed steel (chrome thickness not less than 40 microns), tinned copper alloys and tinned steel, titanium. In conditions of a marine atmosphere and in the tropics contacts are permitted with the other grades of magnesium alloys, aluminum and its alloys which have been anodized with a filler of bichromate anodic film, with cadmium and cadmium coatings, chrome plated steel (coat thickness not less than 60 microns). Of the aluminum alloys the AMg5 alloy causes the least acceleration of the corrosion, therefore it is recommended that rivets from this alloy be used for riveting of sheet material for which contact corrosion is particularly dangerous. As additional protection, use is made of insulation of the contacts with the aid of primers, lubricants, cements, ground coats, sealants, tapes and gaskets. In severe operating conditions (marine atmosphere, tropical conditions) use is made of insulating gaskets (Fig. 10a) or the contacting surfaces are covered with a special protective (from the penetration of moisture) coverings (Figs. 10b, c, d). Materials for the gasct washers are getinaks, ebonite, organic glass and others.

In structures special attention must be turned to contacts with the nonmetallic materials, which must be nonhygroscopic and nonaggressive with respect to the magnesium alloys. Riveted and welded seams require particularly careful protection. To avoid corrosion of the weld joint in gas welding, the use of fluxes containing chlorine salts is categorically forbidden. Welding must be accomplished with the use of fluorine fluxes or by the argon arc method. To improve the corrosion resistance of seams made by spot welding, the welding is done using a

raw primer, the zone of thermal influence is not permitted to reach the surface, electrode copper adhering to the surface is removed.

Care must be taken to provide a form of details and structures

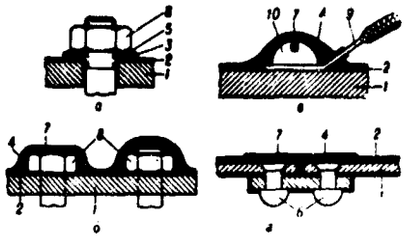

Fig. 10. Protection of magnesium alloy details from contact corrosion: a) Use of insulating gaskets; b, c, d) use of special protective covers; 1) Magnesium alloy detail; 2) paint-type coating; 3) layer of rubber cement 88; 4) layer of cement or P-5 primer; 5) gasket washer; 6) rivet; 7) final enamel coat layer; 8) bolt, nut; 9) grounding terminal; 10) grounding attachment screw

which will eliminate the accumulation of moisture in isolated regions or rapid drainage must be provided. Drain holes must be provided in regions where moisture accumulation cannot be avoided.

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M.A. Timonova

CORROSION OF MOLYBDENUM. Compact molybdenum is relatively stable in the air, although its polished surface dulls after several days. The average rate of corrosion of rolled molybdenum in atmospheric conditions is about 0.0002 mm/yr. With heating in the air molybdenum oxidizes, and at a temperature of about 700° its oxides begin to evaporate intensively. At 1000-1200° the molybdenum loss as a result of vaporization of the oxides from the surface amounts to about 1.5 mm/hr.

Molybdenum does not interact with cold solutions of the alkalis NaOH and KOH, dissolves sparingly in dilute alkalis in the air and dissolves rapidly in the presence of the molten salts KNO_2, KNO_3, $KClO_3$, K_2CO_3 and other oxidizers. Molybdenum is relatively stable to the action of certain molten metals (Table 2). In all the molten metals the presence of oxygen reduces its stability. After a 100-hour test in sodium vapors at 1500° intercrystalline corrosion is observed in specimens of molybdenum at a depth of 0.025 mm. Molybdenum interacts with gallium at 500°, with an aluminum alloy containing 2 at. % uranium at 900°. It has also been established that molybdenum does not interact with UO_2 and BeO in the course of a 100-hour test at 1100°.

Macroetching, the removal of the gas-saturated surface layer from molybdenum semifabricates or the preparation of their surface for welding and brazing is accomplished in various solutions containing nitric acid, while the best results are given by use of a solution of a mixture of concentrated nitric and orthophosphoric acids with a ratio of 1:1 (with specific weight of reagent 1.37-1.38).

For chemical etching of microslides of Mo and Mo-base alloys the

following reagent is recommended: 2 g NaOH + 4 g $K_3Fe(CN)_6$ + 60 cm^3 H_2O.

TABLE 1

Interaction of Molybdenum with Acids and Halogens

1 Реагент	2 Концентрация (% вес.)	3 Взаимодействие с молибденом: 4 при 20°	5 при нагреве
6 Кислоты:			
HCl	37%	Не взаимодействует 12	—
HCl	10%	То же 13	17 Взаимодействует при темп-ре ок. 70°
H_2SO_4	98%	Оч. слабо взаимодействует 14	18 Взаимодействует при 200—250°
H_2SO_4	10%	То же 13	19 Взаимодействует выше 110°
HF	48%	Не взаимодействует 12	20 Не взаимодействует при темп-ре ок. 70°
HNO_3	65%	Взаимодействует 15	16 =
HNO_3	20%	Интенсивно растворяет молибден	=
7 Галлоиды:			
8 Фтор		Не взаимодействует 12	—
9 Хлор		То же 13	17 Взаимодействует при темп-ре ок. 500°
10 Бром		То же 13	17 Взаимодействует при темп-ре ок. 500°
11 Йод		То же 13	21 Не взаимодействует при 500°

1) Reagent; 2) concentration (wt. %); 3) interaction with molybdenum; 4) at 20°; 5) with heating; 6) acids; 7) halogens; 8) fluorine; 9) chlorine; 10) bromine; 11) iodine; 12) does not interact; 13) same; 14) interacts very weakly; 15) interacts; 16) actively dissolves molybdenum; 17) interacts at a temperature about; 18) interacts at 200-250°; 19) interacts above 110°; 20) does not interact with a temperature about 70°; 21) does not interact at 500°.

TABLE 2

Stability of Molybdenum in Liquid Metals

1 Жидкий металл	2 Стойкость к разъеданию: 3 при 300°	3 при 593°	4 Примечание
Na, K или Na — K	6 Хорошая	6 Хорошая	
Cr	6 Хорошая	7 Неудовлетворительная	
5 Bi	6 Хорошая	6 Хорошая	8 После 160 час. при 980° разъедания не обнаружено, после 22 час. при 1095° обнаружено (0,9—2,4)·10⁻² % Mo и Bi
Pb	6 Хорошая	6 Хорошая	9 При 980° в течение 250 час. нет заметного разъедания
Li	6 Хорошая	—	10 При 1000° за 50 час. растворимость в Li менее 10^{-4} вес. %
Mg	—	6 Хорошая	

1) Liquid metal; 2) resistance to pitting; 3) at; 4) remarks; 5) or; 6) good; 7) unsatisfactory; 8) no pitting detected after 160 hours at 980°; detected after 22 hours at 1095° $(0.9\text{-}2.4\%)\cdot10^{-2}$ % Mo and Bi; 9) no pitting noted at 980° in course of 250 hours; 10) solubility in Li less than 10^{-4} wt. % at 1000° after 50 hours.

References: Nuclear Reactors, transl. from Eng., Vol. 3, M., 1956 (Material of US AEC); Zarubin N.M., Koptsik A.N., Proizvodstvo tugoplavkikh metallov (Production of Refractory Metals), M.-L., 1941; Filyand M.A., Semenova Ye.I., Svoystva redkikh elementov (Properties of Rare Elements) (Handbook), M., 1953.

Ye.S. Ovsepyan

CORROSION OF NICKEL ALLOYS. Nickel and the nickel alloys are characterized by high corrosion resistance both under normal atmospheric conditions and in many aggressive media, which to a considerable degree is associated with the comparatively high thermodynamic stabibility of nickel and its alloys in oxidizing media. Among the various nickel-base alloys there is great practical interest in the corrosion-resistant alloys alloyed with copper, chromium, molybdenum, silicon.

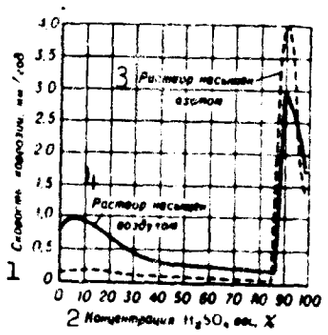

Fig. 1. Effect of sulfuric acid concentration on corrosion rate of the 70% Ni + 30% Cu alloy at 30°. (Mixing velocity 5.2 m/min, test duration 24 hours). 1) Corrosion rate, mm/yr; 2) [illegible] concentration, % by weight, 3) solution saturated by nitrogen; 4) solution saturated by air.

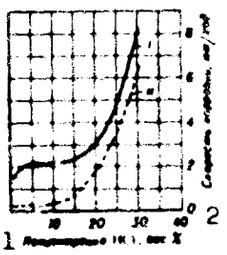

Fig. 2. Effect of hydrochloric acid concentration on the corrosion rate of the 70% Ni + 30% Cu alloy at 30°. I) Solution saturated with air, test duration 24 hours; II) solution saturated with nitrogen, test duration 48 hours; 1) HCl concentration, % by weight; 2) corrosion rate, mm/yr.

Nickel-Copper Alloys. With a Cu concentration of about 30% the alloys of the Ni-Cu system have the highest corrosion resistance. The wrought alloy monel-metal containing 30% Cu, 1.5-2% Fe, 1.5% Mn, remainder nickel is widely used. Monel-metal has considerably higher corrosion resistance than nickel in nonoxidizing acids containing oxygen (aerated solutions). The corrosion resistance of monel-metal in sulfuric and hydrochloric acids at 30° is shown in Figs. 1, 2. Monel-metal is stable in solutions of hydrofluoric acid of all concentrations (including anhydrous hydrofluoric acid) and resists well the action of pure phosphoric acid of all concentrations with limited access to air. With strong aeration or introduction of oxidizers the corrosion rate of monel-metal in hydrofluoric and phosphoric acids increases sharply. Monel-metal decomposes in nitric acid. Monel-metal is stable in sea water, with quiescent conditions, just as for nickel, being less favorable. Monel-metal is characterized by high corrosion stability in solutions of the alkalies and many of the organic acids (with limited access to air). Monel-metal is stable in solutions of many salts, including solutions of the chlorides NaCl, $ZnCl_2$. In acidic solutions of the salts containing ions - the oxidizers 70% Ni+30% Cu, NO_3, monel-metal is unstable. In atmospheric conditions the alloy is sensitive to the sulfur dioxides. With increase of the temperature the corrosion rate of monel-metal increases considerably (Figs. 3, 4) in all media with the exception of solutions of hydrofluoric acid which do not contain an excess of air.

Nickel-Chrome Alloys. We differentiate ferrous and non-ferrous nichromes. The ferrous nichromes contain 60% nickel and 13-15% chromium, remainder Fe. Inconel, containing 73-75% Ni, 13-15% Cr and 5-6% Fe is also a ferrous nichrome. Nonferrous nichrome usually contains about 20% Cr. The ferrous and non-ferrous nichromes have high corrosion resist-

ance in rural and marine atmospheres. In an industrial atmosphere containing sulfur oxides the nichromes are subject to corrosion. The nichromes are very stable in fresh water, and also in moving sea water, stagnant sea water is less favorable. They are also stable in mine waters.

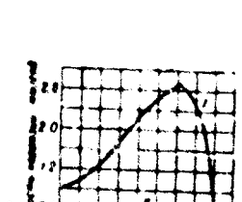

Fig. 3. Effect of temperature on corrosion rate of the alloy 70% Ni+30% Cu in 5-6% solution of sulfuric acid with flow rate of 4.7-5 m/min; I) Solution saturated with air; II) solution saturated with nitrogen. 1) Corrosion rate, mm/yr; 2) temperature, °C.

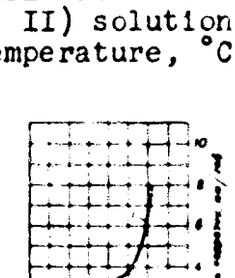

Fig. 4. Effect of temperature on corrosion rate of the 70% Ni + 30% Cu alloy in 5% solution of hydrochloric acid (test duration 24 hours): I) Solution saturated with air; II) solution saturated with nitrogen. 1) Corrosion rate, mm/yr; 2) temperature, °C.

At ordinary temperatures the nichromes are stable in solutions of sulfuric acid (to 5%), solutions of hydrofluoric and phosphoric acids of all concentrations (including anhydrous hydrofluoric acid, and also in solutions of hydrogen sulfide). Alloys with 20% chromium content are particularly corrosion resistant in nitric acid. In highly concentrated nitric acid (over 96%) and other strong oxidizers the nichromes decompose as a result of the overpassivation phenomenon. The higher the chromium content in the nickel alloys, the higher their stability in solutions of nitric acid; here the addition of Fe increases the stabil

ity of the nichromes. In hot solutions of nitric acid the stability of the nichromes is less than that of the chrome-nickel and chrome stainless steels. The nichromes are stable in salt solutions, in acidic solutions of the chlorides, with the exception of $FeCl_3$ and $CuCl_2$ solutions. The nichromes are stable in the organic acids at ordinary temperatures, but their stability is markedly reduced in boiling solutions of acetic and formic acids. The nichromes are stable in alkaline solutions with the exception of those which are highly concentrated (at high temperatures), for example, 90-98% NaOH at 375-475°, in this case the ferruginous nichromes are more stable. The nichromes are also stable in an aqueous solution of ammonia.

Nickel-Molybdenum-Iron and Nickel-Molybdenum-Iron-Chromium Alloys. Alloying of nickel with molybdenum sharply increases its corrosion resistance in solutions of hydrochloric acid. The Ni-Mo alloys have high resistance in solutions of sulfuric acid. Alloys alloyed with iron have found practical application, since in this case it is possible to obtain alloys which can be pressured worked using conventional technology. The Ni-Mo-Fe alloys are additionally alloyed with Cr, W and Si. There are two alloys of the Ni-Mo-Fe type: alloy A (EI460) containing 20% Mo and 20% Fe, alloy B (EI461) with 30% Mo content and 5% Fe. Both alloys are stable in a hydrochloric acid solution. With increase of the temperature the corrosion rate increases, particularly that of alloy A. Alloy B is stable in solutions of hydrochloric acid of all concentrations right up to the boiling point (Fig. 5). The alloys are stable in a sulfuric acid solution to 50% and with temperatures to 70°, however, in the presence of oxidizers their corrosion resistance is sharply reduced both in sulfuric and hydrochloric acids. They also have low corrosion resistance in solutions of nitric acid. In order to ensure high corrosion resistance of the Ni-Mo-Fe alloys in oxidizing conditions,

they are additionally alloyed with chromium to 15% and with tungsten to 5% (alloy C) or only with chromium to 20% (alloy F). With regard to stability in hydrochloric acid containing no oxygen, these alloys are inferior to alloy B, particularly at elevated temperatures. The corrosion resistance of the alloys A and B is markedly reduced in the presence of the ions Fe^{3+}, Cu^{2+}, while under these conditions the alloys C and F are characterized by high corrosion resistance. All these alloys are stable in organic acids, alkali solutions, neutral and alkaline solutions of the salts.

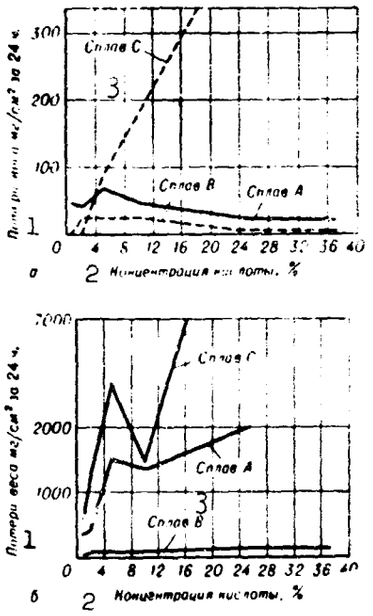

Fig. 5. Corrosion rate of nickel-base alloys of the Ni-Mo-Fe and Mi-Mo-Fe-Cr systems: a) In aerated hydrochloric acid at 70°; b) in boiling hydrochloric acid. 1) Weight loss, mg/cm^2 in 24 hours; 2) acid concentration, %; 3) alloy

Of the nickel-base casting alloys widest application has been found for the alloys D and G (indium). Alloy D contains 10% Si, 3% Cu and is used for operation in hot solutions of sulfuric of all concentrations and in other non-oxidizing acids and salts. In oxidizing acidic media the alloy is characterized by low corrosion resistance. Alloy G has a more complex composition: 22% Cr, 6% Cu, 6% Mo, 6% Fe, sometimes contains up to 2% W and to 1% Al. This alloy is stable in sulfuric, nitric, phosphoric acids and their mixtures, and also in solutions of the salts. The corrosion rate of alloy G increases with higher temperatures. The alloy is characterized by high resistance to corrosion in sea water. Its corrosion resistance is unsatisfactory in solutions of hydrochloric acid and in moist chlorine. Among the casting alloys, use is made of the inconel alloy con-

taining about 2% Si; its corrosion properties are close to those of wrought inconel. Casting variants of the alloys A, B, C, F also are used.

Comparative data on the corrosion resistance of typical nickel alloys at ordinary temperatures are presented in Table 1. The classes of corrosion resistance are shown in accordance with the logarithmic scale of corrosion rate following GOST 5272-50: I) Completely stable, corrosion rate < 0.001 mm/yr; II) very stable, from 0.001 to 0.01 mm/yr; III) stable, from 0.01 to 0.1 mm/yr; IV) less stable, from 0.1 to 1 mm/yr; V) low stability, from 1 to 10 mm/yr; VI) unstable, above 10 mm/yr. The corrosion rate increases considerably with increase of the temperature (Figs. 3-5).

Depending on the magnitude of the stationary potential, the nickel alloys, just as the stainless steels, may be in the active, passive and overpassive states (see Corrosion of Stainless Steels). Figure 6 shows the potentiostatic curves for certain nickel alloys in 1 N HCl. The potentiostatic curve for the alloy F is similar to that for the stainless steels. Alloy C has a comparatively low critical passivation anode current, differing little from the residual current density in the passive condition. With increase of the potential the corrosion rate of the alloy increases somewhat, particularly noticeably in the overpassivation region. The high corrosion resistance of alloys F and C is similar to the corrosion resistance of the stainless steels, which is associated with their high capability for passivation resulting from alloying with chromium. The corrosion resistance of the nichromes also increases with increase of the chromium content, here there is a sharp reduction of the value of the critical passivation anode current density (Fig. 7). The alloys F, C and the nichromes have particularly great advantages for operation in media containing oxidizers, however in strongly oxi-

dizing media with a potential over 1.2 v they are subject to destruction as a result of overpassivation. The high corrosion resistance of alloy B in hydrochloric acid and in other media cannot be explained by passivity in the usual sense used for the stainless steels, since the alloy does not have a sharply defined passivity region (Fig. 6). Only a very narrow portion of the potentiostatic curve in the region of negthode current density increases, the stationary potential of the alloys increases and the corrosion rate increases markedly, while the corrosion rate of the alloys F and C alloyed with chromium diminishes markedly as a result of the passivity. The polarization diagrams which clarify the effect of the nature and rate of the cathodic process on the mechanism of corrosion of alloys B, C, F are shown in Figs. 8 and 9.

This mechanism is well illustrated by the data on the corrosion rate of the nickel alloys in hydrochloric acid (Table 2).

The nickel-base alloys are less sensitive to structural corrosion than the stainless steels, which is apparently associated with the greater corrosion resistance of nickel in the active state in nonoxidizing media in comparison with iron and chromium. However, even the nickel alloys in certain conditions can demonstrate a tendency for intergranular corrosion and stress corrosion. Thus, the alloys of the Ni-Cu system may be subject to corrosion cracking under the action of mercury and mercury compounds, solutions of fluosilicic acid. Concentrated solutions of caustic soda at high temperatures cause corrosion cracking of the Ni-Cu alloys and the nichromes, although the nichromes have

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TABLE 1

Class of Corrosion Resistance of Nickel Alloys at Ordinary Temperatures (20-35°) in Typical Aggressive Media

Агрессивная среда 1	Концентрация (%) 2	Никель 3	Монель-металл 4	Сплавы типа хастелой 5					Нихром типа 80—20 6	Инконель 7
				A	B	C	D	F		
Азотная кислота 8	10	V	IV	—	IV	II	—	II	III	—
	30	VI	VI	—	—	II	—	II	III	III
	50	V	VI	—	IV	III	—	I	III	III
	70	V	VI	—	IV	III	—	II	III	III
	90	VI	VI	—	VI	VI	—	VI	VI	VI
Серная кислота 9	2	III	III	—	III	II	III	II	—	IV
	5	III	—	IV	III	II	III	II	IV	IV
	10	III	—	III	III	II	III	II	—	IV
	50	IV	II	III	II	III	III	II	—	V
	85	—	—	III	II	II—III	III	II	—	—
	96	V	IV	III	II—III	II—I	III	II	—	IV
Соляная кислота 10	1	II	IV	IV	III	II	III	I	—	—
	5	IV	IV	III—IV	III	II	III	IV	—	V—IV
	10	IV	IV	III—IV	III	III	IV	IV	IV	—
	20	IV	—	III	III	III	IV	IV	IV	—
	37	V	V	III	II—III	III	IV	III	IV	—
11 Плавиковая кислота (аэрированная)	5	II	III—IV	—	IV	IV	IV	—	IV	II
	25	IV	II	—	IV	IV	IV	IV	—	II
	45	IV	III—IV	—	III	IV	IV	IV	—	II
12 Едкий натр	5	—	II	I	I	I	I	I	—	I
	25	I	II	I	I	I	I	I	I—II	I
	50	—	II	I	I	I	I	I	—	I
13 Фосфорная кислота	10	V	III—IV	III	II—III	II	III	II	III	—
	30	III	III	III	II—III	I—II	II	II	—	—
	50	III	III	III	II—III	II	II	I	—	III
	85	II	III	III	I—II	I	II	I	—	I—II
14 Морская вода	—	II—III	II—III	—	I	—	—	I	II—III	—
15 Уксусная кислота	10	II	IV	—	II	II	III	II	II	III
	50	IV	IV	—	II—III	II	III	II	—	—
	99	II	IV	—	II	II	II	I—II	—	—
16 Муравьиная кислота	10	IV	—	III	III	II	III	I	III	—
	30	III—IV	IV	III—IV	III	II	III	II	—	—
	60	—	—	—	III	II	IV	I—II	—	—
	90	—	—	IV	II	II	IV	II	—	IV

1) Aggressive medium; 2) concentration (%); 3) nickel; 4) monel-metal; 5) Hastelloy type alloys; 6) nichrome type 80-20; 7) inconel; 8) nitric acid; 9) sulfuric acid; 10) hydrochloric acid; 11) hydrofluoric acid (aerated); 12) caustic soda; 13) phosphoric acid; 14) sea water; 15) acetic acid; 16) formic acid.

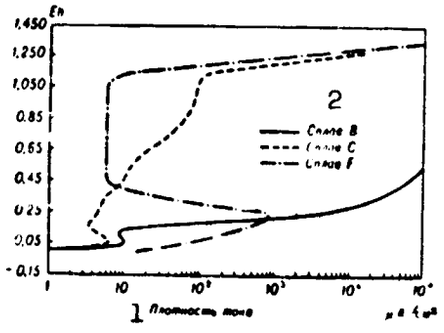

Fig. 6. Anode curves for alloys B, C, F in 1 N HCl at room temperature. 1) current density; 2) alloy.

a higher resistance to this form of failure. The nichrome type alloys have a tendency to pitting corrosion, particularly in stagnant sea water conditions, however, this tendency is considerably less than that of the stainless steels; the pitting formed in this case is broader and less deep. Pit corrosion is manifested particularly strongly in a hypo-

chlorite solution. Alloy D and the alloys containing molybdenum are characterized by high resistance to pitting corrosion.

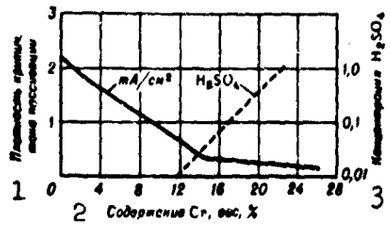

Fig. 7. Effect of chromium content in nickel on critical anode current density for passivation in aerated 0.01 N H_2SO_4 at 25° and on the critical anode current density for passivation in air-saturated sulfuric acid of varying concentration (ma/cm^2). 1) Critical passivation current density; 2) Cr content, % by wt; 3) concentration.

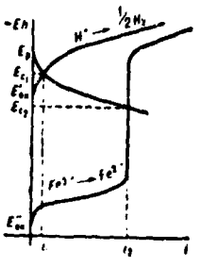

Fig. 8. Polarization diagram clarifying the effect of the nature and rate of the cathodic reaction on corrosion of alloy B (sharp increase of corrosion rate in presence of ions of the oxidizer Fe^{3+}).

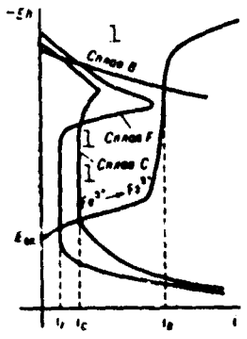

Fig. 9. Polarization diagram clarifying the different corrosion rate of the alloys B, C, F in the presence of oxidizers. 1) Alloy.

After heating in the 500-700° range, the nickel alloys A, B, C, F are prone to intergranular corrosion as a result of the depletion of the grain boundaries of molybdenum and chromium.

Methods of protecting the nickel alloys from corrosion. First of all, provision must be made for the proper selection of the alloys for operation in the particular aggressive media. Alloys containing chromium should not be used in nonoxidizing aggressive media; under these conditions monel-metal and alloys A, B are used at both normal and elevated temperatures. On the contrary,

TABLE 2

Corrosion Rate of Nickel Alloys in 1 N HCl + 1 N $FeCl_3$ at 24-26°.

1 Сплав	B	C	F
Скорость коррозии (мм/год) 2	52	0,06	0,003

1) Alloy; 2) corrosion rate (mm/yr).

the alloys A, B should be used in acidic oxidizing media. Alloy B has the highest stability in hydrochloric acid in high concentrations at high temperatures, and additional alloying with antimony (0.5%) increases the corrosion resistance considerably. In the presence of oxidizers it is advisable to use the alloys alloyed with chromium (C, F), in many cases they can be replaced by the nichromes. Anodic protection can be used for the alloys containing chromium, here the alloys transition from the active to the passive state and this state is maintained with a very small current density. Anealing is used to combat corrosion cracking of the alloys of the Ni – Cu system. The tendency of the alloys Ni – Mo – Fe and Ni – Mo – Fe – Cr to intergranular corrosion after heating in the 500-700° range is reduced by alloying with niobium, which binds the carbon into carbides. However, the effectiveness of niobium alloying is considerably less than with stainless steels. Combined alloying with niobium and tantalum is also used. Alloying with vanadium to 1.5% is effective in reducing the tendency to intergranular corrosion.

Heating to 1000° for 1-2 hours is used to reduce the tendency of alloys A and F to intergranular corrosion; this heat treatment is not effective for alloys B and C (for optimal heat treatment of the nickel alloys see Nickel Alloys – Acid Resistant). In atmospheric conditions the nickel-base alloys are characterized by high corrosion resistance, particularly in the polarized condition.

Nickel is stable with heating in an oxidizing atmosphere to 900°, but its corrosion resistance diminishes in the presence of sulfur oxides. Oxidation of nickel at high temperatures is markedly reduced by chromium, aluminum and silicon, and also by small additions of calcium and cerium (Fig. 10). Most effective is the combined alloying of the nickel alloys with these elements. Wide use is made of the nichromes as

a heat resistant material, while alloys of the nimonic type additionally alloyed with titanium and aluminum are used as heat resistant and high temperature materials. An exceptionally harmful impurity in the nickel alloys is cerium. In the presence of cerium there is formed on the grain boundary the low-melting eutectic Ni-$N_{13}S_2$ ($t°_{pl}$ 625°) which at high temperatures causes a tendency of the alloys to intergranular corrosion. In order to improve the corrosion resistance in oxidizing and reducing atmospheres containing sulfur oxides, the nickel is alloyed with manganese (to 4.5%) or chromium.

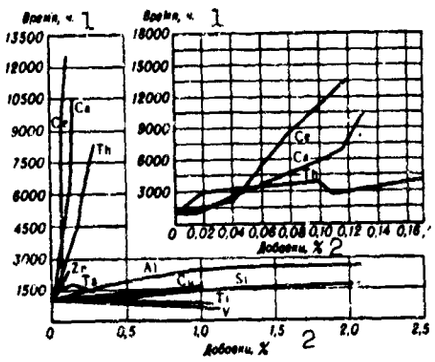

Fig. 10. Effect of alloying additives on life of 0.4-mm-diam. 80-20 nichrome wire at 1050°. 1) Time, hr; 2) additives, %.

Corrosion of the nickel alloys in molten metals and hydroxides. Nickel and its alloys (Hastelloy A, B, C; inconel, nichromes, monel-metal) have high corrosion resistance in molten sodium, potassium and their alloys at temperatures to 650° and temperature differentials of 150°. At higher temperatures their corrosion resistance is reduced. The nickel alloys can have only limited application in molten lithium, in this case the chrome-nickel alloys have higher corrosion resistance, while nickel and monel-metal are lower. Nickel and its alloys decompose rapidly in molten bismuth, lead and their alloys. In molten caustic soda nickel is stable to 675°, at higher temperatures nickel dissolves with transport to the cold portions of the piping. Intense dissolution is noted above 800°. Additions of sodium aluminate and sodium carbonate reduce the corrosion of nickel. The dissolution of nickel is less in a reducing atmosphere (for example, in hydrogen) than in a neutral or oxidizing atmosphere.

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B.P. Batrakov

CORROSION OF NIOBIUM. Niobium is corrosion resistant in many chemical reagents and is widely used in chemical technology. The absence of interaction with the molten alkaline metals to comparatively high temperatures makes niobium very promising for use as a material for heat exchangers of atomic reactors, where its application is desirable because of the small neutron capture cross section.

As a result of interaction with gases (O_2, N_2, H_2) niobium forms interstitial solid solutions with a body-centered cubic lattice, and then forms chemical compounds (oxides, nitrides, hydrides) with properties differing markedly from the properties of pure niobium. Oxygen solubility increases with increase of the temperature from 0.25% (wt) at 500° to 0.72% (wt) at 1915°. Niobium begins to oxidize in the air above 200°. Severe oxidation is observed even at 400°. During oxidation there are formed the oxides NbO and NbO_2, which with increase of the temperature transition to the higher oxide Nb_2O_5. The rate of oxidation of niobium reaches 400 $g/m^2/hr$ at 1100°. The formation of the higher oxide Nb_2O_5 which is accompnaied by a considerable increase of the volume (2.69 times) and the appearance of internal stresses, leads to the destruction of the oxide, which aids in the further oxidation of the metal.

The solubility of nitrogen in niobium increases with increase of the temperature from 0.005% (wt) at 300° to 0.07% (wt) at 1500°. With high nitrogen contents there are formed the nitrides: NbN and Nb_2N. Niobium also interacts actively with hydrogen with the formation of hydrides, where the less impurities the niobium contains the more hydro-

gen it will dissolve. With very high temperatures the solubility of hydrogen in niobium diminishes. While at room temperature and a pres-

Corrosion Resistance of Niobium

Среда 1	Концентрация (вес. %) 2	Темп-ра (°С) 3	Коррозия (мм/год) 4
5 Неорганич. кислоты			
Азотная кислота 6	Концентрированная	25	0
7 Смесь азотной и плавиковой кислот	—	20—100	Быстро растворяется
Перекись водорода	30	21	0.0008
9 Плавиковая кислота 8	40	20—100	Быстро растворяется
Серная кислота 10	20	21	0
	25	21	0
	98	21	0.0004
	То же	50	0.0033 (крупный)
	"	100	0.076 (крупный)
	"	150	0.082 (крупный)
	"	175	5.88 (быстро растворяется)
11 Соляная кислота	20	19—26	0
	Концентрированная	19—26	0.0006
	То же	100	0.0234
12 Смесь соляной и азотной кислот (2:1)	"	19—26	0.0005
		50—60	0.0254
13 Ортофосфорная кислота	85	25	0.0005
	85	150	0.0254
	85	210	0.0132
14 Хлорная кислота	Концентрированная	150	0
15 Щелочные растворы			
16 Аммиак (водный раствор)	25	150	0
17 Едкое кали	5	20	0.1885
	5	100	Хрупкий
	40	100	Быстро растворяется
18 Едкий натр	5	20	0.02815
	5	100	Хрупкий
	40	110	Быстро растворяется
19 Неорганич. соли 20			
Двухромовокислый калий	43 Раствор	0—150	Корродирует 47
21 Хлорид алюминия	Водный насыщ. раствор	0—150	0
	То же	0—150	0
22 Хлорид магния	" 44	0—150	0
23 Хлорид натрия	"	0—150	0
24 Хлорид олова	"	0—150	0
Хлорид цинка 25			
26 Органич. реагенты			
27 Винная кислота	20	22	0
Молочная кислота 28	85	19—26	0
Уксусная кислота ледяная	—	19—26	0
29 Фенол 30	Водный насыщ. раствор	19—26	0
Щавелевая кислота	То же	15—26	0.01405 (крупный)
32 Расплавл. металлы			
33 Висмут	—	300	Хорошая устойчивость 48
34 Висмут+висмут	—	600	Ограниченная устойчивость 49
	55.5% Bi	1000	Растворяется 50
	44.5% Pb	300	Хорошая устойчивость
35 Калий (при низком содержании кислорода)	—	600	То же
Кальций	—	300	Устойчивость ограниченная
	—	600	То же
Литий 54	—	1000	Хорошая устойчивость
Магний 55	—	600	То же
Натрий (при низком содержании кислорода)	—	300	"
	—	600	"
Ртуть	—	300	"

1) Medium; 2) concentration (wt %); 3) temperature (°C); 4) corrosion (mm/yr); 5) inorganic acids; 6) nitric acid; 7) mixture of nitric and hydrofluoric acids; 8) hydrogen peroxide; 9) hydrofluoric acid; 10) sulfuric acid; 11) hydrochloric acid; 12) mixture of hydrochloric and nitric acids (2:1); 13) orthophosphoric acid; 14) perchloric acid; 15) alkaline solutions; 16) ammonia (aqueous solution); 17) caustic potassium; 18) caustic soda; 19) inorganic salts; 20 potassium bichromate; 21) aluminum chloride; 22) magnesium chloride; 23) sodium chloride; 24) tin chloride; 25) zinc chloride;

26) organic reagents; 27) tartaric acid; 28) lactic acid; 29) glacial acetic acid; 30) phenol; 31) oxalic acid; 32) molten metals; 33) bismuth; 34) bismuth-lead; 35) potassium (with minimal oxygen content); 36) calcium; 37) lithium; 38) magnesium; 39) sodium (with minimal oxygen content); 40) mercury; 41) concentrated; 42) same; 43) solution; 44) aqueous saturated solution; 45) dissolves rapidly; 46) brittle; 47) corrodes; 48) good stability; 49) limited stability; 50) dissolves.

sure of 1 atm niobium of 98.5% purity will dissolve 104 cm^3/g, at 900° it will dissolve only 4 cm^3/g. Above 1000° niobium practically does not react with hydrogen. Beyond the limits of solubility, hydrogen forms a niobium hydride which is highly brittle. The niobium hydrides decompose in a vacuum. The presence of gases has a marked effect on the mechanical and physical properties of niobium. Oxygen has a particularly strong effect on the properties of niobium. The metal becomes brittle when saturated with oxygen, loses its capability for being deformed, welded and machined.

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G.V. Kurganov, L.P. Zharova

CORROSION OF STAINLESS STEELS. The high corrosion resistance of the stainless steels is determined by their ability to be easily passivated even in ordinary atmospheric conditions by the oxygen of the air. This property depends on the chromium content - the basic alloying element of the stainless steels. The lowest chromium content which provides the steels a passive conditions is 12%. With increase of the chromium content the corrosion resistance of the stainless steels in oxidizing conditions increases markedly. Nickel also provides passivation for the stainless steels, but to a considerably smaller degree. The corrosion resistance of the stainless steels also depends strongly on the carbon content; as a rule, with increase of the carbon the corrosion resistance of the stainless steels diminishes considerably (Fig. 1). To provide high corrosion resistance the stainless steels are in many cases additionally alloyed with molybdenum, copper, titanium, niobium and other elements.

The corrosion resistance of the stainless steels depends on the structural state.

The solid solutions alloyed with chromium and nickel have the highest corrosion resistance. All the factors which increase the nonhomogeneity of the structure of the stainless steels with the formation of carbides, nitrides and the intermetallides of chromium lead to reduction of the chromium concentration in the solid solution and to the reduction of the corrosion resistance of the stainless steels. The corrosion resistance of the stainless steels is determined by the stability of the passive film and depends on the nature of the aggressive me-

dium. As a rule, in oxidizing media the stainless steels have high corrosion resistance, while in nonoxidizing aqueous media the corrosion rate of the stainless steels is high and increases with increase of the chromium content, since in these conditions the chromium is thermodynamically unstable as a result of the destruction of the passive film (Fig. 2). Thus, the stainless steels are stable in solutions of nitric acid, various neutral and weakly-acid solutions with access to oxygen, and are unstable in hydrochloric, sulfuric and hydrofluoric acids.

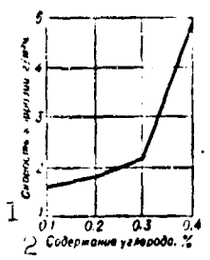

Fig. 1. Effect of carbon content on corrosion rate of Kh13 steel (heat treat: anneal 850°, hold for 1 hour, furnace cool) in a 10% nitric acid at boiling temperature for 50 hours. 1) Corrosion rate, g/m^2-hr; 2) carbon content, %.

It has recently been established that the stainless steels also lose their stability in strongly-ozidizing media (Fig. 3) as a result of the destruction of the passive films with high oxidizing-reducing potential of the medium. This new phenomenon has been termed overpassivation or transpassivation of the stainless steels. This effect shows up in highly concentrated nitric acid, particularly at high temperature, and also in other strongly ozidizing media.

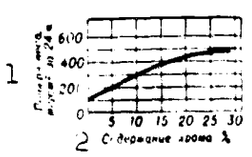

Fig. 2. Effect of chromium content on corrosion stability of stainless steel in cold 10% sulfuric acid (without stirring or aeration).

The comparative corrosion resistance of typical stainless steels in various media at ordinary temperatures are shown in Table 1. The classes or corrosion resistance are shown in accordance with the logarithmic scale of corrosion rate following GOST (Govt. Standard) 5272-50:

I - completely stable, 0.001 mm/yr; II - very stable, from <0.001 to 0.01 mm/yr; III - stable, from 0.01 to 0.1 mm/yr; IV - reduced stability, from 0.1 to 1 mm/yr;

V - low stability, from 1 to 10 mm/yr; VI - unstable, above 10 mm/yr.

With increase of the temperature the corrosion resistance of the stainless steels deteriorates markedly in both nonoxidizing and oxidizing media (Figs. 4, 5). High alloying with nickel, and also with copper

TABLE 1

Classes of Corrosion Resistance of Stainless Steels at Ordinary Temperatures (20-35°) in Typical Aggressive Media

1 Агрессивная среда	2 Концентрация (%)	1Kh13	Kh17	Kh28	1Kh18N9T	Kh18N11B	0Kh23N28M3D3T; 0Kh18N18M3D3T
3 Азотная кислота	1–5	IV	I–II	I	I	I	I
	15–30	III	I–II	I	I	I	I
	70–90	I–II	I–II	I	I	I	I
	99	IV	IV	IV	IV	IV	IV
4 Серная кислота	0,25	V	V	–	I–II	I–II	I–II
	1	VI	V	V	III	III	I–II
	5–10	VI	VI	VI	IV	IV	I–II
	35	VI	VI	VI	VI	V	I–II
	50	VI	VI	VI	VI	VI	III
	80	V	IV	IV	V	VI	III
	96	IV	IV	IV	I–II	I–II	I–II
5 Соляная кислота	0,25	V	V	IV	III	III	I–II
	1	VI	V	V	IV	III	I–II
	5	VI	V	VI	V	IV	IV
	20	VI	VI	VI	VI	V	IV
6 Фосфорная кислота	1	<IV	<IV	<IV	<IV	<IV	–
	10	V	V	<IV	<IV	<IV	–
	25	VI	V	<IV	<IV	<IV	–
	50	V	IV	<IV	<IV	<IV	–
	85	<IV	<IV	<IV	<IV	<IV	–
7 Муравьиная кислота	1	V	IV	IV	<IV	<IV	II
	5–10	V	V	V	<IV	<IV	–
	25	VI	V	V	V	IV	II
	50	VI	V	V	V	V	II
	80	V	V	V	<IV	<IV	–
	100	IV	<IV	<IV	<IV	<IV	–
8 Уксусная кислота	5–10	IV	<IV	<IV	<IV	<IV	I
	30	V	IV	IV	<IV	<IV	I
	50	IV–V	IV	IV	<IV	<IV	II
	80	V	IV	IV	<IV	<IV	–
	100	IV	<IV	<IV	<IV	<IV	II
9 Щавелевая кислота	0,5	IV	<IV	<IV	<IV	IV	II
	5–10	IV	IV	IV	<IV	<IV	II
10 Хромовая кислота	1	I	–	I	I	I	–
	5	II	–	I	I	I	–
	10	II	–	II	II	II	–
	30	II	–	IV	III	II	–
	60	III	–	IV	V	V	–
11 Плавиковая кислота	40	VI	VI	VI	VI	VI	–
12 Морская вода	–	IV	III–IV	III	III	III	–
13 Едкий натр	30	<IV	<IV	<IV	<IV	<IV	–

1) Aggressive medium; 2) concentration (%); 3) nitric acid; 4) sulfuric acid; 5) hydrochloric acid; 6) phosphoric acid; 7) formic acid; 8) acetic acid; 9) oxalic acid; 10) chromic acid; 11) hydrofluoric acid; 12) sea water; 13) caustic soda.

and molybdenum, leads to a sharp improvement in the corrosion resist-

ance of the stainless steels in sulfuric acid.

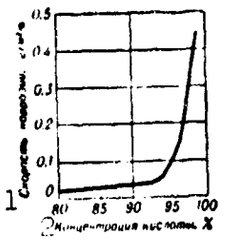

Fig. 3. Corrosion rate of stainless steel Kh18N9T as a function of the concentration of nitric acid at 50°.

Mechanism of electrochemical corrosion, passivity and overpassivity of the stainless steels. Corrosional and electrochemical behavior of the stainless steels is determined not only by the chromium content, but also by the oxidizing properties of the aggressive media (oxidizing-reducing potential and concentration of the oxidizer which is present in the solution).

The passive state of the stainless steels arises with definite potentials and rates of the cathodic reaction. For the genesis of the passive state of any metal, including the stainless steels, it is necessary that the oxidizing-reducing potential of the medium, and consequently the potential of the cathodic reaction, exceed the value of the first critical anodic potential for metal passivation and that the cathode current (rate of the cathodic process) exceed the value of the critical passivation anodic current density. Nonobservance of these conditions leads to an active state, and the stainless steel dissolves rapidly. The conditions for passivity of the stainless steels are provided in oxidizing media, and the conditions for the active state are provided in reducing or weakly oxidizing media, which corresponds to the experimental data on the corrosion resistance of the stainless steels in various media (Table 1). The higher the chromium content, the more negative is the passivation potential and the lower the passivation anodic current density of the stainless

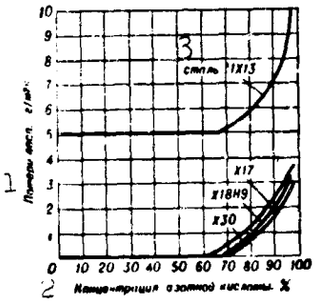

Fig. 4. Corrosion rate of typical stainless steels in boiling solutions of nitric acid of varying concentration. 1) Weight loss, g/m^2-hr.; 2) nitric acid concentration, %; 3) steel.

steels (Table 2). The electrochemical parameters shown characterize the tendency of the stainless steels to passivation.

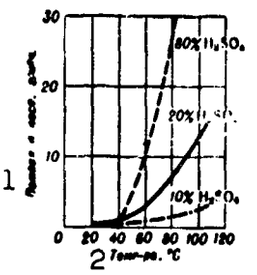

Fig. 5. Effect of temperature on corrosion of Kh18N10M2 steel in sulfuric acid. 1) Weight loss, g/m^2-hr; 2) temperature, °C.

With transition from the active to the passive state, on the steels there can be noted an unstable state in which, depending on the effect of various factors, the metal can reach complete passivation or can again transition into the active state. Complete passivity of the steels is achieved with higher potentials (Table 2), which depend on the steel composition and in many cases on the solution composition (for example, the presence of activators). It has been established that the passive state of the stainless steels can be destroyed by means of anodic polarization with a high potential or by the creation of strongly oxidizing conditions with a high oxidizing-reducing potential of the medium.

TABLE 2

Conditions for Passivity of Steels with Varying Chromium Content at Room Temperature

Состав стали 1	Среда 2	$E'_{кп}$ критич. потенциал пассивации по водородной шкале (в) 3	$i'_{ак}$ плотность критич. анодного тока пассивации (ма/см²) 4	$E'_{к}$ критич. потенциал полной пассивации по водородной шкале (в) 5
Fe	6 1н. H_2SO_4	+0.46	17000	—
Fe	7 10%-ная H_2SO_4	+0.46	1000 *	0.5
Fe+2.8% Cr	8 То же	+0.45	360 *	0.5
Fe+6.7% Cr	»	+0.3	340	0.5
Fe+9.5% Cr	»	+0.2	27	0.48
Fe+12% Cr	»	−0.02	27	0.38
Fe+14% Cr	»	−0.05	19	0.32
Fe+16% Cr	»	−0.08	12	0.2
Fe+18% Cr	»	−0.1	11	0.2
Fe+18% Cr +8% Ni	»	—	2.2	—

* Higher actual current density indicates effect of mechanical passivity

1) Steel composition; 2) medium; 3) E'_{kp} critical passivation potential on hydrogen scale (v); 4) i'_{ak} passivation critical anode current density (ma/cm^2); 5) E'_k critical potential for complete passivation on hydrogen scale (v); 6) 1 N; 7) 10%; 8) same.

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The different states of the stainless steels (active, passive, unstable and overpassivation) can be shown well with the aid of the potentiostatic diagrams of corrosion rate-potential or anode current density-potential, where we have in mind the equivalent corrosion rate current without account for the current expended on the release of hydrogen in the region of the strongly negative potentials or the release of oxygen in the region of the highly positive potentials. A schematic of the potentiostatic diagram for stainless steel is shown in Fig. 6.

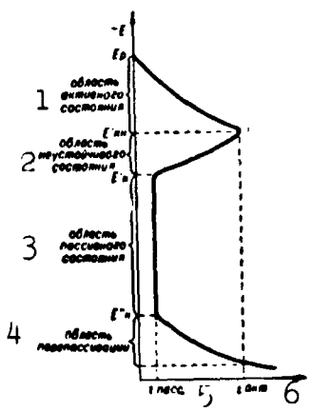

Fig. 6. Potentiostatic diagram for stainless steel which characterizes the active and passive state, the overpassivation state and the unstable state: E_r is the protective or equilibrium potential; E'_{kn} is the critical anode potential for complete passivation; E''_k is the second critical potential - the over-passivation potential; i'_{akt} is the passivation anode critical current; i_{pass} is the residual current in the passive state. 1) Region of the active state; 2) region of the unstable state; 3) region of the passive state; 4) overpassivation region.

In the active region and the overpassivation region the rate of corrosion of the stainless steels increases with increase of the potential in accordance with the law of electrochemical kinetics. In the unstable region, on the other hand, the corrosion rate of the stainless steels diminishes with increase of the potential, which is associated with the passivation of the surface of the stainless steels. On reaching complete passivation, the rate of corrosion of the stainless steels becomes practically independent of the potential.

The corrosional stability of the stainless steels is determined by

the magnitude of the stationary potential and by its position relative to the values of the critical potentials (E_r, E'_{kn}, E'_k, E''_k). The value of the stationary potential corresponds to the point of intersection of the cathode curve with the anode polarization curve. With the aid of the polarization diagram (shown schematically in Fig. 7) we can indicate all three basic states (active, passive, overpassivation) which determine the electrochemical and corrosional behavior of stainless steel. On Fig. 7 the points E_{akt}, E_{pass}, E_{per} mark the values of the stationary potential of stainless steel respectively in the active, passive and overpassive states. From this diagram it follows that, depending on the magnitude of the oxidizing-reducing potential and the rate of the cathode reaction, the stainless steel may be in the active state, i.e., it behaves like an ordinary carbon and low-alloy steel, in the passive state shich is the most characteristic state for stainless steel, and in the overpassivation state where the corrosion of stainless steel again increases.

The corrosion rate depends not only on the steel composition, but also on the value of the pH, the nature and the concentration of the activators, the internal and the externally applied stresses, the temperature, the inhibitors present. Depending on these factors, there are variations of the values of the critical potentials, and also the density of the anode current, the equivalent corrosion rates, i.e., the potentiostatic diagrams may be displaced in the coordinates: corrosion rate-potential. Thus, with increase of the activator concentration and the temperature there is a narrowing of the region of the passive state and an increase of the corrosion rate in the passive state. Increase of the temperature and the concentration of the hydrogen ions also leads to an increase of the corrosion rate of the stainless steels in the active state. The anode inhibitors can alter the corrosion rate in the

passive state and the value of the potentials for complete passivation and overpassivation, and also the passivation current of the stainless steels.

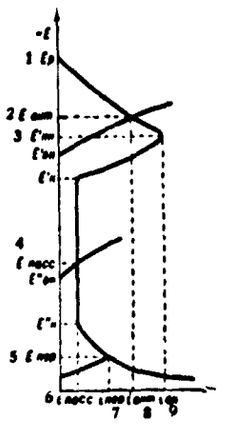

Fig. 7. Polarization diagram characterizing the three basic states of stainless steel (active, passive and overpassive states): E'_k is the critical anode potential for complete passivation; E''_k is the critical anode potential for overpassivation; E_r is the equilibrium or protective potential; E'_{ok}, E''_{ok}, E'''_{ok} (lower curve) are the values of the oxidizing-reducing potentials in the given conditions; i_{ak} is the critical passivation anode current; i_{akt} is the current in the active state; i_{pass} is the residual current in the passive state; i_{per} is the current in the overpassivation state. 1) E_r; 2) E_{akt}; 3) E'_{kn}; 4) E_{pass}; 5) E_{per}; 6) i_{pass}; 7) i_{per}; 8) i_{akt}; 9) i_{ak}.

According to the present concepts, the passive state of the metals is determined by the adsorption or phase film formed on the metal surface. Characteristic for the stainless steels is the formation of phase-adsorption films, here the phase films can be formed both prior to immersion of the stainless steels in the solution ("primary films," arising in the air), and during immersion into the solution, when with deep passivation (time, potential) the adsorption films transition into phase films which are detectable by the electronographic and chemical methods. The forming phase films aid in the deeper passivation of the stainless steels in the film pores and at the locations of destruction of the phase film as a result of the effect of self-polarization, here the given films perform the function of an effective cathode which re-

acts to the oxidizing-reducing properties of the solution. The structure of the passive film formed on the stainless steels is shown schematically in Fig. 8. As a result of the selfpolarization, the oxygen is embedded deeply into the metal. The overpassivation effect of the stainless steels is associated with the formation of soluble compounds or ions of hexavalent chromium, here a stationary potential of 1.36 v (Fig. 9) is established on the steel, corresponding to the reaction according to the equation:

$$2Cr^{+++} + 7H_2O \rightleftarrows Cr_2O_7'' + 14H^+ + 6e^-$$

With the presence of activators and applied stresses there may occur a breakdown of the film at a potential lower than 1.36 v. Increase of the temperature has an effect in this same direction. The considered mechanism for corrosion, passivity and overpassivity of the stainless steels applies to all classes of the stainless steels.

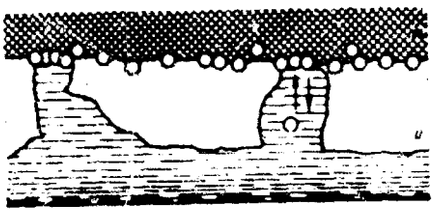

Fig. 8. Schematic representation of passive surface of stainless steel, where M is the metal, P is the phase film, the circles are the adsorption film.

Structural and local corrosion of stainless steels and methods of combating it. In view of the complex structural state and the great difference in the electrochemical and corrosion properties of the structural components, the stainless steels are particularly prone to the manifestation of various local failures (intercrystalline corrosion, stress corrosion, pitting and spalling corrosion). Crevice corrosion is also characteristic for the stainless steels in complex structures having gaps and crevices. The corrosion of local nature is the most dangerous form of failure of the metals in structures.

Intergranula corrosion of the austenitic stainless steels shows up in the weld joints and with improper heat treatment of the stainless

steel (heating in the 500-800° range). The phenomenon of intergranular corrosion is due to the fact that the grains are in a passive state while the boundaries of the grains are in the active state. The conditions for passivation of the grain body and the grain boundary differ sharply as a result of the formation on the grain boundaries of chromium carbides in the form of a continuous chain and the formation of regions depleted of chromium (less than 12% chromium), while the grain body retains in the solid solution a high chromium content (more than 12%) which is capable of supporting the grain in the passive state. Moreover, with the formation of the carbides and intermetallides along the grain boundaries there appear internal stresses which also hinder the passivation of the grain boundaries. The austenitic steels which are not stabilized by titanium or niobium have the highest tendency to intergranular corrosion. In the weld joint the effect of the intergranular corrosion (Fig. 10) shows up in the parent metal, in the heat effected zone at some distance from the weld seam where there are created favorable conditions for the formation of chromium carbides (heating to 450-850°). It has been established that with increase of the carbon content in the steel the sensitivity to intergranular corrosion of the chrome-nickel steels increases markedly; it also depends on the temperature and time of tempering (Fig. 11). The greatest sensitivity of the austenitic chrome-nickel steels to intergranular corrosion is seen after tempering at a temperature of 650°. Grain size is also of significant importance for intergranular corrosion; it has been established that the smaller the grain size, the lower the sensitivity of the stainless steels to intergranu-

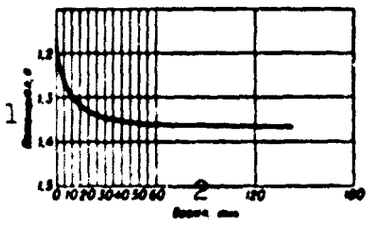

Fig. 9. Time variation of electrode potential of Kh18N9T steel in a 96% solution of nitric acid at room temperature. 1) Potential, v; 2) t me, min.

lar corrosion (Fig. 12). The sensitivity of the ferritic steels to intergranular corrosion also increases with increase of the carbon content. However, the greatest sensitivity is shown, in contrast with the austenitic steels, after quenching or normalization from high temperatures as a result of formation during cooling from the supersaturated solution of nonequilibrium ferruginous carbides and nitrides of chromium. In these cases there is also observed a depletion of the chromium and an increase of the internal stresses of the grain boundaries. With the use of high tempering and in particular with annealing at 780-850°, as a result of diffusion there takes place an equalizing of the concentration of the chromium through the grain and the sensitivity of the steel to intergranular corrosion is eliminated.

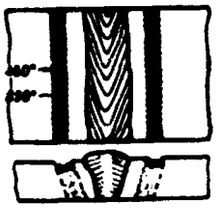

Fig. 10. Intergranular corrosion in parent metal as a result of the action of welding heat.

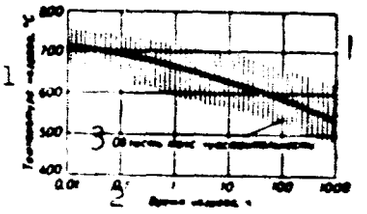

Fig. 11. Maximal sensitivity to intergranular corrosion of chrome-nickel steel (18% Cr, 8% Ni with low carbon content) as a function of temperature and heating time. 1) Heating temperature, °C; 2) heating time, hours; 3) region of maximal sensitivity.

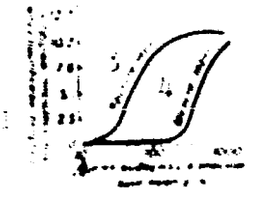

Fig. 12. Effect of grain size on tendency of chrome-nickel steel (18% Cr, 8% Ni) to intergranular corrosion. 1) Depth of intergranular corrosion, mm/100 hours; 2) soak time in dangerous temperature zone, hours; 3) coarse grain; 4) fine grain.

For the determination of the tendency of the stainless steels to intergranular corrosion the most rapid testing can be conducted in solution where the stationary potential of the stainless steel is between the grain passivation potential and the grain boundary passivation potential, which is regulated by the oxidizing-reducing potential of the medium. According to GOST 6032-58 accelerated tests on the intergranular corrosion of the austenitic stainless steels are conducted after a provoking anneal at 650° for 2 hours. Several methods of accelerated testing are used depending on the composition and applications of the steels.

The following effective methods are used to combat intergranular corrosion: 1) Reduction of the carbon content, which leads to a reduction of the carbide formation along the grain boundaries. Usually the stainless austenitic and ferritic steels containing less than 0.03% carbon are insensitive to intergranular corrosion. 2) Use of water quench from a high temperature for the austenitic steels (the same effect is achieved for many steels by normalization from high temperatures). Here the chromium carbides along the grain boundaries go into the solid solution. 3) Use of a stabilizing anneal at 750-900°. As a result of the diffusion process, there takes place an equalization of the chromium concentration both through the grain and along the grain boundaries. This method is particularly effective for the ferritic chrome steels. 4) Alloying of the steel with stabilizing carbide-forming elements - titanium, niobium, tantalum (Fig. 13). Titanium and niobium are more energetic carbide-forming elements than chromium, here the titanium and niobium carbides are formed at higher temperatures than the chromium carbides. In place of the chromium carbides, the carbon is bound into the titanium or niobium carbides, and the chromium concentration in the solid solution is maintained the same not only

through the grain, but also along the grain boundaries. The titanium content in the stainless austenitic steels must be 5 times greater than that of carbon and the niobium content must be 8-10 times greater than the carbon. The addition of titanium also eliminates the intergranular corrosion of the ferritic chrome steels (Fig. 14). 5) The creation of two-phase austenitic-ferritic steels. The opposing governing laws in the behavior of the austenitic and ferritic steels are well combined in the austenitic-ferritic steels, which are insensitive to intergranular corrosion. Depending on the heating regime, the intergranular corrosion is blocked by ferrite grains or by austenite grains. To reduce the tendency to intergranular corrosion of weldments of the austenitic steels, use is made of welding wire made from two-phase austenitic-ferritic steels.

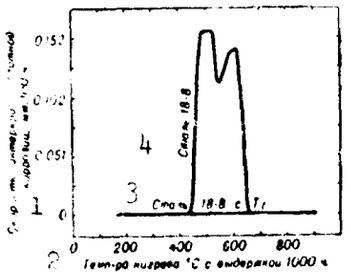

Fig. 13. Effect of titanium on sensitivity of an 18-8 type stainless steel to intergranular corrosion, 1) Rate of intergranular corrosion, mm/100 hours; 2) heating temperature °C with soak of 1000 hours; 3) 18-8 steel with Ti; 4) heat treatment temperature, °C.

In certain media there has been found a new form of intense local corrosion of weld seams of the stainless steels in the zone lying directly adjacent to the weld seam ("knife" corrosion). The steels stabilized by niobium or titanium are also subject to this form of structural corrosion. These phenomena are associated with high heating of the steels during welding (above 1300°) when the titanium or niobium carbides transfer completely into the solid solution. With the subsequent rapid cooling the titanium or niobium carbides do not manage to precipitate out, however favorable conditions are created for the formation of chromium carbides in close proximity to the weld seam, as a result of which there arise zones depleted of chromium; the internal stresses are also increased in these

zones. All this leads to rapid destruction of the steel in the zone directly adjacent to the weld seam as a result of its transition into the active state. "Knife" corrosion also manifests itself in the overpassivated state in strongly oxidizing media (Fig. 15). The nature of the mechanism of "knife" corrosion is analogous to intergranular corrosion.

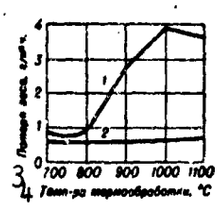

Fig. 14. Effect of titanium addition on corrosion of weld joint of Kh17 steel in 60% nitric acid: 1) Kh17 steel; 2) Kh17 steel with titanium addition; 3) weight loss, g/m^2-hr; 4) heat treatment temperature, °C.

The primary methods of combating "knife" corrosion are: reduction of the carbon content in the steel, stabilizing anneal, increase of the titanium or niobium content above the theoretical value, use of two-phase austenitic-ferritic steels, use of welding regime with elimination of the action of critical temperatures in the heat-effected region.

Fig. 15. Form of "knife" corrosion of welded specimens of Kh18N9T steel.

Most prone to stress corrosion are the high-strength martensitic stainless steels, and also (in some media) the austenitic stainless steels, although they do have high plasticity. Alloying with titanium or niobium does not eliminate the tendency of the austenitic steels to stress corrosion. Stress corrosion of the stainless steels is associated with the formation of notches as a result of the selective dissolution of the grain boundaries, formation of block structures and other nonhomogeneous regions of the steel in which the stresses are concentrated and the anode polarizability is sharply reduced. Here there arises a large differential in the rates of solution

of the basic metal, which is in the passive state, and of the metal in the notches, which is in the active state. On termination of the so-called incubation period, as a result of the intense rectilinear corrosion in the notches there is a reduction of the working section of the detail. Then the strength of the metal becomes less than the applied stress so that there occurs spontaneous development of a crack and destruction of the detail. The sensitivity of the stainless steels to stress corrosion is determined in a boiling 42% solution of magnesium chloride in which the failure of many steels may take place under the influence of the internal stresses. It has been established that stress corrosion of the austenitic stainless steels depends strongly on the nickel content. The highest sensitivity to stress corrosion is shown with a nickel content of 9-14% in the steel, with further increase of the nickel the sensitivity to stress corrosion diminishes and with a nickel content over 40% the steel becomes resistant to stress corrosion. Reduction of the nickel content (less than 9-14%) also leads to a sharp increase of the resistance to corrosion cracking, which must be associated with the formation of two-phase austenitic-ferritic steels which are marked by a high resistance to stress corrosion. Activators (chlorine ions, etc.) present in the solution particularly stimulate stress corrosion.

The primary methods of combating stress corrosion are: reduction of the applied external stresses, increase of the nickel content in the steel to create a stable austenite, the creation of a two-phase austenitic-ferritic steel by means of reducing the nickel or alloying with ferrite-forming elements, use of heat treatment (high-temperature tempering for the martensitic steels or stabilizing anneal for the austenitic steels), creation of compressive stresses on the surface of the steel, for example, by shot-peening, reduction of the activator con-

centration.

Spot and pitting corrosion of the stainless steels is often encountered with operation sea water. In many cases it may be of a perforating nature (for plates and straps). The mechanism of spot and pitting corrosion is associated with the adsorption of chlorine ions onto certain portions of the steel surface, as a result of which localization of the corrosion takes place. Here the main surface of the steel is in the passive state, while the portion with the adsorbed chlorine ions is in the active state; the corrosion products causes this situation. Spot corrosion in the presence of chlorine ions can be caused by breakdown of the passive film under a high potential. Spot and pit corrosion can also develop as a result of the appearance of various surface defects (inclusions, intermetallides, film damage, etc.). The tendency of the various stainless steels to spot and pit corrosion in sea water is shown in Table 3.

TABLE 3

Rate of Spot Corrosion of Various Stainless Steels in Sea Water

Сталь 1	Скорость коррозии (г/м² в сутки) 2	Наибольшая глубина точечной коррозии (мм/год) 3	Время испытания (сутки) 4
IX13	1,66	1,78	388
X17	1	1,75	568
X18H9	0,55	1,75	685
X18H12M2	0,039	0,18	1923
X25H20	0,072	0,18	988

1) Steel; 2) corrosion rate ($g/m^2/day$); 3) greatest depth of spot corrosion (mm/yr); 4) test time (days).

The resistance to spot corrosion of all the stainless steels increases sharply with agitation of the sea water.

Alloying with molybdenum permits a sharp increase of the breakdown potential of the passive film in the presence of the chlorine ions and

thereby expands the region of passivity of the stainless steels in the presence of the chlorine ions. Nickel also reduces the sensitivity of the stainless steels to spot corrosion.

For stainless steel details of complex structure which have crevices, gaps, pockets, the characteristic form of corrosion is crevice corrosion. The mechanism of crevice corrosion is associated with the restriction of the diffusion of oxygen or other oxidizers (as depolarizers) or anodic corrosion retarders (inhibitors) into the inaccessible regions of the structure, as a result of which there is a sharp reduction of the anodic depolarization on these regions, the steel potential is reduced and the stainless steel transitions into the active state.

The methods of combating crevice corrosion reduce first of all to structural techniques - elimination of gaps, crevices, pockets, contacts of the steel with nonmetallic materials. Increase of the content of oxidizer or anodic retardants is also very effective if they are present in the solution.

Methods of improving corrosion resistance. The corrosion resistance of the stainless steels can be to a considerable degree improved by the methods of alloying, use of optimal heat treatment regimes, suitable mechanical, chemical and electrochemical treatment, the use of anodic protection. The increase of the chromium content is most effective. With increase of the chromium there is an expansion of the region of the passive state of the stainless steels, since the passivation potential and current are reduced so considerably (Table 2). With a high chromium content the stainless steels are stable even in weakly acidic media. The corrosion stability of the stainless steels increases markedly with reduction of the carbon content, which is particularly important for combating structural corrosion and improvement of the corrosion resistance of steel after high-temperature tempering. Introduction

of nickel, molybednum and copper (Figs. 16-18) considerably improves the corrosion resistance of the stainless steels, particularly in weakly oxidizing media. Here, on the one hand, there is an increase of the thermodynamic stability of the steels, and on the other there is an increase of the passivity and the protective properties of the passive films. Particularly effective is the influence of titanium, nibium, tantalum as carbide-formers for combating intergranular corrosion.

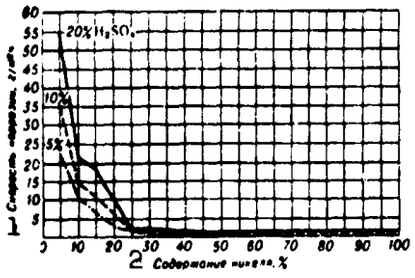

Fig. 16. Effect of nickel on corrosion rate of stainless iron-nickel alloys in sulfuric acid of varying concentration. 1) Corrosion rate, g/m^2/hr; 2) nickel content, %

Recent studies have established the favorable influence of alloying of the stainless austenitic and ferritic steels with a small quantity of the noble metals (palladium, platinum) in weakly oxidizing media at high temperatures, when the stainless steels are in the active state (Fig. 19).

As a result of the reduction of the hydrogen overvoltage, the potential of the steels when alloyed with the noble metals is displaced into the passive region, as a result of which the passivity of the type 18-8 stainless steels is increased and their corrosion resistance improves sharply.

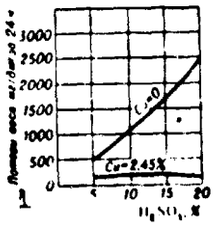

Fig. 17. Effect of copper on corrosion resistance of type 18-8 austenitic steels in sulfuric acid at 40°. 1) Weight loss, mg/dm^2 in 24 hours.

Under conditions of overpassivation the alloying of the stainless steels with the noble metals is not effective and may reduce their corrosion resistance.

The corrosion resistance of the stainless steels of the martensitic and austenitic classes diminishes sharply after high-temperature tempering. The steels of the martensitic, martensitic-ferritic,

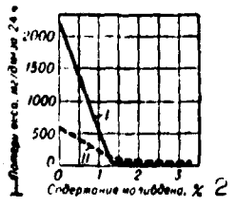

Fig. 18. Effect of molybdenum on corrosion resistance of type 18-8 stainless steel in boilinh 80% (I) and 96% (II) acetic acid. 1) Weight loss, mg/dm^2 in 24 hours; 2) molybdenum content, %.

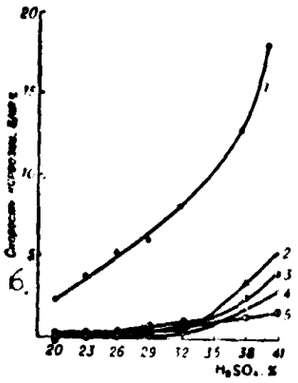

Fig. 19. Corrosion rate of chrom-nickel stainless steel (18% Cr, 8% Ni) in sulfuric acid: 1) Without additional alloying; 2 – 18 Cr + 8 Ni + 0.1 Pd; 3 – 18 Cr + 8Ni + 1.24 Cu; 4 – 18 Cr + 8Ni + 0.1 Pt; 5 – 18 Cr + 8Ni + 0.93 Pd. (Test duration 360 hours at 20°). 6) Corrosion rate, g/m^2/hr.

and martensitic-carbide classes achieve the greatest corrosion resistance after hardening and low-temperature tempering, while the steels of the austenitic and austenitic-ferritic class have the highest resistance after water quench. With heating there takes place dissociation of the α and γ solid solution with the formation of chromium carbides in the austenitic steels and a series of intermediate structures in the martensitic steels (troostite, sorbite, perlite). If the tempered austenitic and martensitic steels are subjected to a stabilizing anneal at 780-900° their corrosion rate decreases. The dependence of corrosion rate on the heat treatment regime is shown in Fig. 20 for the martensitic steel. Even for the austenitic steels stabilized by niobium, after quenching from high temperatures the maximum of the corrosion rate is shifted as a function of the temperature and the duration of the tempering. The ferritic steels have the highest corrosion resistance after annelaing in the range of 760-850°. The corrosion resistance of the stainless steels is determined by the protective properties of the passive surface film, which depend strongly on the steel composition and the surface finish quality. As a rule, the stainless steels with roughly finished surface are characterized by a low corrosion resistance. The highest corrosion resistance in atmospheric conditions is achieved in the poloshed condition. In order to improve the protective properties of the surface film, after mechanical working, including mechanical polishing, the stainless steels are subjected to chemical passivation. In this case there is created an improved passive film and the traces of iron picked up during working by the tool (iron traces on the sur-

face of the stainless steels become a corrosion focus) are removed. The passivation is performed in a 20% solution of HNO_3 at 45-55° for 15-30 minutes, or the passivation can be done at room temperature in a 40% HNO_3 solution. Passivation of the martensitic steels is performed in a solution containing 20% HNO_3 and 2% $K_2Cr_2O_7$ at 45-55° for 15-30 minutes. Passivation of the stainless steels can be performed in other solutions which contain oxidizers.

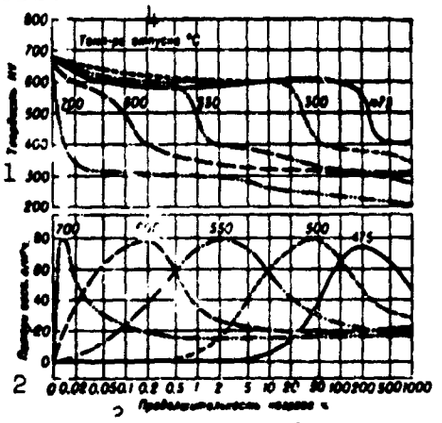

Fig. 20. Corrosion rate in boiling 5% acetic acid and Vickers hardness of 4Kh13 steel as a function of heat treatment (initial state - normalized at 1030°). 1) Hardness HV; 2) weight loss, $g/m^2/hr$; 3) heating duration in hours; 4) tempering temperature, °C.

Electropolishing is used for small details to provide protection. The electropolishing regime and bath composition depend on the composition and the structure of the stairless steels. In this case no additional chemical passivation is performed, since the passive film is formed in the process of the electropolishing.

In accordance with passivity theory, after transition of the metal into the passive state there is required a very slight current to maintain the steel in the passive state. Therefore in many cases, for example, in chemical apparatus, the effect of anodic protection can be used; thus, the Kh18N9 steel, which is subject to corrosion in sulfuric acid, particularly at high temperatures, can be protected by means of anodic polarization. To transfer the stainless steels into the passive state there is first required a considerable current density, however after the steel is brought into the passive state only a few microamps/ $/cm^2$ is required to maintain the passive state.

The effect of anodic protection is shown in Fig. 21. In those

cases when for reasons of strength it is necessary to use steels which are prone to intergranular corrosion, the paint-type coatings are used for their protection in atmospheric conditions (see Paint-Type Steel Coatings).

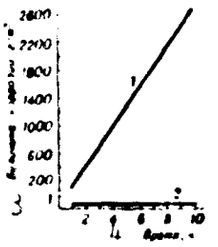

Fig. 21. Effect of anodic polarization on corrosion of the Kh19N9 steel in 50% nitric acid at 50°: 1) Corrosion of steel without polarization; 2) corrosion of steel with anodic polarization with current density 2.5 ua/cm^2; 3) magnitude of corrosion, g/m^2; 4) time, hours.

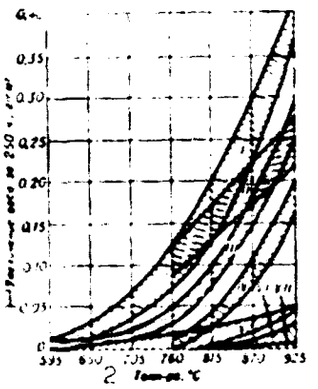

Fig. 22. Thermal stability of various types of steel: I) Carbon; II) low-alloy; III) chrome (6% Cr); IV) chrome (12-17% Cr; V) silchrome (8-1.5 Cr, 2-3% Si); VI) austenitic chrome-nickel; VII) high-chrome (25-30% Cr). 1) Weight increase after 250 hours, g/cm^2; 2) temperature, °C.

Gas corrosion of the stainless steels and methods of combating it. With heating in air or in an oxygen atmosphere, the stainless steels are subject to oxidation with the formation of scale. Their resistance to oxidation improves with increase of the chromium content. Figure 22 shows the rate of oxidation of various steels in air as a function of the composition and temperature. Nickel also improves the resistance to oxidation (Fig. 23).

The rate of oxidation of the stainless steels can be considerably reduced by means of additional alloying with aluminum and silicon (Figs. 24, 25). Addition of tungsten and molybdenum increase the high-temperature strength but reduce the thermal stability of the stainless steels. Additions of cobalt do not reduce the thermal stability. Alloying with chromium improves the corrosion resistance of the steels in hydrogen sulfide considerably.

For protection of the steels from oxidation use is made of the thermodiffusional methods of saturating the steel surface with metals which improve the thermal stability (chromizing, aluminizing, siliconizing). The thermodiffusional saturation is performed in solid powders, by gas saturation and vacuum saturation. Thermodiffusional saturation, particularly chromizing, sharply increases the corrosion resistance of the stainless steels in many aqueous solutions.

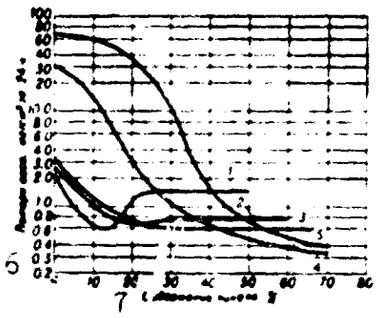

Fig. 23. Effect of nickel content on oxidation of steel at 1000° with various chromium content: 1)- 31% Cr; 2) - 26% Cr; 3)- 21% Cr; 4)- 16% Cr; 5)- 11% Cr; 6) weight loss, mg/cm^2 in 24 hours; 7) nickel content, %.

Corrosion of the stainless steels in molten metals and hydroxides. The nature of the interaction of the liquid metals with the stainless steels does not obey the common laws governing their behavior in aqueous solution. Among the molten metals, liquid sodium, potassium and their alloys are least corrosive. It has been found that the austenitic chrome-nickel steels with low carbon content can be used successfully up to 650° and with a temperature drop of no more than 150°; here the oxygen impurity content must not exceed 0.0[illegible].02%. With a higher oxygen impurity content embrittlement of the austenitic stainless steels will take place even at 350°. In order to prevent erosion it is recommended that the

velocity of movement of the molten sodium, potassium and their alloys not exceed 8 m/sec. High purity of the liquid metal with regard to carbon is also required, otherwise there will be carbonization of the stainless steels as a result of the interaction with the carbide-forming elements found in the steel (chromium, niobium, etc.). Above 650° in liquid sodium, potassium and their alloys, there is observed selective dissolution of the nickel in the stainless steels and its transport to the cold portions of the piping. Molten lithium is more aggressive with regard to the stainless steels, particularly above 760°. Leaching of the nickel in molten lithium takes place far more rapidly, here the surface layer of austenitic steel is transformed into ferrite, therefore the high-chrome ferritic stainless steels are recommended for molten lithium at high temperatures. The molten lithium reacts with the metal carbides. Lithium nitride Li_3N is characterized by particularly aggressive action, in this connection stringent requirements on nitrogen impurities must be applied to molten lithium. The chrome-nickel austenitic stainless steels can be used at lower temperatures and with small temperature differences in molten lithium. Oxygen in the molten metals is combatted by means of the introduction of small quantities of calcium, beryllium, magnesium, zirconium, titanium and other easily oxidized metals which bind the oxygen. It has been established that the austenitic steels are more sensitive to oxy-

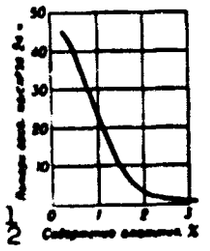

Fig. 24. Effect of aluminum content on resistance to oxidation of steel with 6% Cr. 1) Weight loss, mg/cm^2 in 24 hours; 2) aluminum content, %.

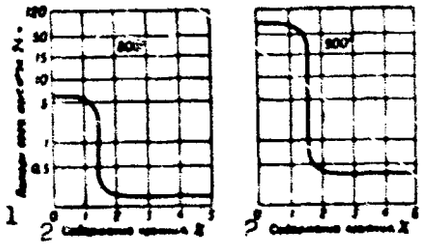

Fig. 25. Effect of silicon content on resistance to oxidation of steel with 6% Cr at 800° and 900°. 1) Weight loss, mg/cm^2 in 24 hours; 2) silicon content, %.

gen impurities than the ferritic stainless steels. Molten bismuth, lead and their alloys, alloys of bismuth with indium and lead are characterized by very aggressive action. The high-chrome ferritic stainless steels are also more resistant in these media. Sodium hydroxide is the most corrosive of the molten hydroxides. The hydroxides of potassium, lithium, strontium, barium are less active in regard to corrosion.

References: Akimov G.V., Osnovy ucheniya o korrozii i zashchite metallov (Fundamentals of the Study of Corrosion and Protection of Metals), M., 1946; -- in collection, Issledovaniya po nerzhaveyushchim stalyam (Studies on the Stainless Steels), M.-L., 1956 (Trans. of Comm. on Combating Corrosion of Metals, No. 2); Akimov G.V., Batrakov V.P., DAN SSSR, 1944, Vol. 45, No. 3, p. 124; Akimov G.V., Gurvich L.Ya., IAN SSSR, Otd. khim. nauk, 1945, No. 5, p. 412; Batrakov V.P., Korroziya konstruktsionnykh materialov v agressivnykh sredakh (Corrosion of Structural Materials in Aggressive Media), Handbook, M., 1952; Korroziya i zashchita metallov (Corrosion and Protection of Metals), collection of articles edited by R.S. Ambartsumyan, M., 1957; Korroziya i zashchita metallov (Corrosion and Protection of Metals), collection of articles edited by V.P. Batrakov, M., 1962; Tomashov N.D., Teoriya korrozii i zashchity metallov (Theory of Corrosion and Protection of Metals), M., 1959; Khimushin F.F., Nerzhaveyushchiye kislotoupornyye i zharoupornyye stali (Noncorrosive, Acid-Resistant, and Heat-Resistant Steels), 2nd ed., M., 1945; Kolomb'ye L. and Gokhman I., Nerzhaveyushchiye i zharoprochnyye stali (Noncorrosive and Heat-resistant Steels), transl. from French, M., 1958; Babanov A.A., Nerzhaveyushchiye stali, (Stainless Steels), M., 1956; Medovar B.I., Svarka khromonikelevykh austenitnykh staley (Welding of Chrome-Nickel Austenitic Steels), 2nd ed., Kiev-M., 1958; Shvarts G.L., Kristal' M.M., Korroziya khimcheskoy

apparatury. Korrozionnoye rastreskivaniye i metody yego predotvrashcheniya (Corrosion of Chemical Apparatus. Corrosion Cracking and Methods of Preventing It), M., 1958; Edeleanu C., "Nature", 1954, v. 173, No. 4407, p. 739; Oliver R., International committee of electrochemical thermodynamics and kinetics. Proceedings of the sixth meeting. 1954, L., 1955; Boimel A. and Carius K., "Arch. Eisenhüttenwesen", 1961, Bd 32, H. 4, S. 237.

V.P. Batrakov

CORROSION OF TANTALUM. Of all the refractory metals tantalum has the highest resistance to corrosion. In its chemical stability tantalum approaches platinum. It is nearly nonreactive with all the organic and

Corrosion Resistance of Tantalum in Various Media

Среда 1	Темп-ра 2 (°С)	Взаимодействие 3
H_2SO_4 (всех концентраций) 4	20—100	Не взаимодействует
HCl (всех концентраций)	20—100	То же
H_3PO_4 (всех концентраций)	20	»
HNO_3 (всех концентраций)	20—100	»
HF (всех концентраций)	20—100	Разрушает быстро
Царская водка 5	20	То же
NaOH (разбавл. раствор) 6	20—100	Разрушает медленно 23
NaOH (концентрир. раствор) 7	20—100	Разрушает быстро 22
Цинк 8	500	Не взаимодействует 20
Натрий 9	1000	То же
Калий 10	1000	» 21
Литий 11	1000	»
Сплав натрия и калия 12	1000	»
13 Свинец	1000	»
Висмут 14	900	»
Галлий	450	»
15 Ртуть 16	600	»
Магний 17	1150	»
Сплавы магния с ураном 18	1150	»
Сплавы магния с плутонием 19	1150	»

1) Medium; 2) temperature (°C); 3) interaction; 4) all concentrations; 5) aqua regia; 6) dilute solution; 7) concentrated solution; 8) zinc; 9) sodium; 10) potassium; 11) lithium; 12) alloy of sodium and potassium; 13) lead; 14) bismuth; 15) gallium; 16) mercury; 17) magnesium; 18) alloys of magnesium with uranium; 19) alloys of magnesium with plutonium; 20) does not interact; 21) same; 22) corrodes rapidly; 23) corrodes slowly.

mineral acids, with the exclusion of HF, mixtures of HF and HNO_3 and aqua regia (Table) and also with the salt solutions which do not give a

strong alkaline reaction. Noticeable corrosion of tantalum is observed in molten alkalies and concentrated alkaline solutions. With corrosion of tantalum in alkaline solutions there is frequently observed embrittlement of the metal as a result of hydrogen adsorption. Tantalum has high resistance in the medium of several of the molten metals. Interaction of tantalum with fluorine is noted at 20°, chlorine at 250°, bromine at 300° and iodine above 1000°.

References: Hampel C.A., "Corrosion", 1958, v. 14, No. 12, p. 29-32.

M.I. Gavrylyuk

CORROSION OF TITANIUM ALLOYS. Titanium and its alloys have high corrosion resistance in atmospheric conditions, fresh and sea water, solutions of the majority of the chlorides, hypochlorites, chlorine dioxide and many salts of the mineral acids at both ordinary and elevated temperatures. Titanium and its alloys also have high corrosion resistance in acidic oxidizing media (nitric and chromic acids, etc.) and in alkaline solutions. In the nonoxidizing acids (sulfuric, hydrochloric) titanium has satisfactory corrosion resistance at ordinary temperatures and with acid concentrations up to 8-10%. With increase of the temperature and concentration of the acids and alkalies, the corrosion rate of titanium increases sharply (Figs. 1, 2). For sulfuric acid two maxima of the corrosion rate are observed, corresponding to 40 and 75% concentration. In 40% sulfuric acid the corrosion process proceeds with liberation of hydrogen, this acid being characterized by the greatest electroconductivity and maximal concentrations of the hydrogen ions. In 75% solution the corrosion process is accompanied by reduction of the sulfuric acid to H_2S and free sulfur, while at high concentrations (80-90%) SO_2 and free sulfur are released. Titanium is relatively more resistant in phosphoric acid and retains high corrosion resistance up to a 30% solution, then with increase of the concentration the corrosion rate rises. Additions of the oxidizers ($K_2Cr_2O_7$; HNO_3; Fe^{+++}; Cu^{++}; O_2; Cl_2 and others) sharply reduce the corrosion rate of titanium and its alloys in hydrochloric and sulfuric acids.

Titanium and its alloys have low corrosion resistance in solutions of hydrofluoric acid; intense corrosion occurs in even a 1% solution of

this acid; additions of oxidizers are ineffective and even increase the corrosion rate. High corrosion resistance of titanium is noted in acetic and formic acids; the majority of foodstuff products do not attack it. Titanium has low corrosion resistance in hot trichloroacetic and oxalic acids, in which titanium forms soluble complex compounds. The classification of the corrosion resistance of titanium in typical corrosive media at ordinary temperatures is shown in Table 1 in accordance with the logarithmic corrosion rate scale following GOST 5272-50: class I - completely stable, corrosion rate < 0.001 mm/yr; class II - very stable - from 0.001 to 0.01 mm/yr; class III - stable - from 0.01 to 0.1 mm/yr; class IV - reduced stability - from 0.1 to 1.0 mm/yr; class V - low stability - from 1 to 10 mm/yr; class VI - unstable - > 10 mm/yr.

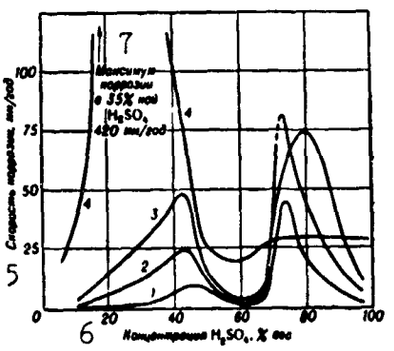

Fig. 1. Variation of titanium corrosion rate with temperature and concentration of sulfuric acid: 1) at 30°; 2) at 40°; 3) at 50°; 4) at 100°; 5) corrosion rate, mm/yr; 6) concentration of H_2SO_4, % by weight; 7) maximum corrosion in 35% H_2SO_4 is 420 mm/yr.

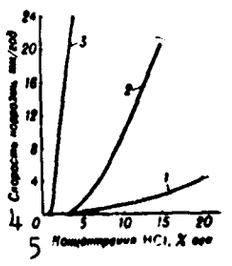

Fig. 2. Variation of titanium corrosion rate with temperature and hydrochloric acid concentration: 1) At 35°; 2) at 60°; 3) at 100°; 4) corrosion rate, mm/yr; 5) HCl concentration, % by weight.

The corrosional behavior of the industrial titanium alloys VT3-1, VT5, VT5-1, VT6, OT4 in HCl and H_2SO_4 solutions, in spite of the difference in alloying, is practically analogous to that of titanium at both ordinary and elevated temperatures.

TABLE 1

Corrosion Resistance of Titanium in Typical Aggressive Media at Ordinary Temperatures

Агрессивная среда 1	Концентрация (%) 2	Класс стойкости 3	Агрессивная среда 1	Концентрация (%) 2	Класс стойкости 3
Соляная к-та 4	5	II	Муравьиная к-та 8	10	II
	10	III–IV		25	II
	15	IV		30	II
	20	IV		90	I
	28	V	Уксусная к-та 9	3	II
Серная к-та 5	10	II		25	I
	50	IV		50	I
	98	V		75	I
Фосфорная к-та 6	1	II		99,5	II
	5	II	Фтористоводородная кислота 10	1	V
	10	II		100	V
	20	II	Едкий натр 11	5	I
	37	IV		10	I
	70	III		40	I–II
Азотная к-та 7	10	II	Морская вода 12	50	II
	20	II		–	I
	30	II			
	40	II			
	50	II			
	60	II			
	64	II			

1) Aggressive medium; 2) concentration (%); 3) stability class; 4) hydrochloric acid; 5) sulfuric acid; 6) phosphoric acid; 7) nitric acid; 8) formic acid; 9) acetic acid; 10) hydrofluoric acid; 11) caustic soda; 12) sea water.

Electrochemical corrosion. The high corrosion resistance of titanium and its alloys in many media is associated with the formation of a surface film which has high chemical stability. The formation of the film in an aqueous solution proceeds by the equation

$$Ti+2H_2O \rightarrow TiO_2(\text{hydrolytic})+4H^+ +4\underline{e}^-.$$

Oxides of more complex composition may also be formed. The natural films on titanium are very thin (12-50A) and compact, they are insoluble in the majority of the electrolytes and are difficult to reduce to the lower oxides. Dissolution of titanium proceeds according to the equation $Ti \rightarrow Ti^{+++}+3\underline{e}^-$. Similar to aluminum, the normal equilibrium potential of titanium is very negative and is equal to –1.23 v. The

stationary potentials of titanium exceed considerably the equilibrium potential. In distilled water and 0.01 N solution of NaCl the electrode potential of titanium becomes more noble with time as a result of passivation, while with cleaning it becomes strongly less noble, however, it quickly returns to the initial values since the protective film is again formed.

Titanium and its alloys obey the general laws for the transition from the active to the passive state and vice-versa which have been established for the other passivating metals (see Corrosion of Stainless Steels). The passive state is achieved by either anodic polarization or addition of oxidizers. The corrosional behavior of titanium and its alloys is determined by the magnitude of the stationary potential and its position with respect to the equilibrium potential, the potential for the beginning of passivation, and the potential for complete passivation (first critical potential). Two typical states must be differentiated for titanium: active and passive. The tendency of titanium to passivation, just as the other metals and alloys, can be characterized by the value of the critical passivation potential, the critical passivation current density, and the value of the critical oxidizer concentration at which titanium and its alloys transition into the passive state.

TABLE 2

Conditions for Transition of Titanium from Active to Passive State in Boiling 5% Na_2SO_4 Solution

Содержание H_2SO_4 (%) 1	Скорость коррозии ($г/м^2 \cdot час$) 2	Критич. плотность тока пассивации ($ма/см^2$) 3	Критич. концентрация γ_{O_2} ... (мг/л) 4
1	18	0.03	0.040
2	37.4	0.2	0.085
3	117.6	0.4	0.185
5	185.8	1.8	0.250

1) H_2SO_4 content (%); 2) corrosion rate ($g/m^2/hr$; 3) cri-

tical passivation current density (ma/cm^2); 4) critical Fe^{+++} concentration (mg/liter).

Table 2 presents the values of the corrosion rate, critical passivation anode current and critical oxidizer concentration which cause passivation of titanium in boiling 5% solution of Na_2SO_4 containing from 1 to 5% H_2SO_4.

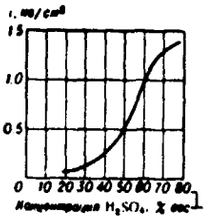

Fig. 3. Variation of minimal current density required for anodic passivity of titanium as a function of sulfuric acid concentration. 1) oncentration, wt. %.

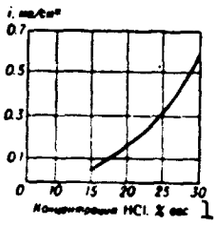

Fig. 4. Variation of minimal current density required for anodic passivation of titanium as a function of hydrochloric acid concentration. 1) concentration, wt. %.

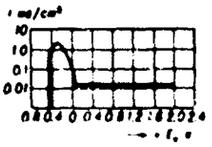

Fig. 5. Potentiostatic curve for titanium in 40% sulfuric acid at 40° in current density-potential coordinates.

The values of the critical current density for passivation of titanium in HCl and H_2SO_4 solutions as a function of the acid concentration are shown in Figs. 3, 4. Low critical passivation current density and critical oxidizer concentration are typical for titanium and its alloys, which confirms their capability for passivation. A typical potentiostatic diagram characterizing

the transition of titanium from the active to passive state in 40% H_2SO_4 at 40° is shown in Fig. 5. It follows from this diagram that the region of the active state corresponds to a potential value from −0.42 to −0.25 v (on the hydrogen scale). In this potential region the titanium corrosion rate increases with increasing potential. The potential of −0.25 v corresponds to the potential for the beginning of passivation. The potential for complete passivation corresponds to +0.052 v and depends on the sulfuric acid concentration. In the potential interval from −0.025 v to +0.052 v there is a transition from the active to passive state (unstable region). The corrosion rate diminishes with increase of the potential. Above a potential of +0.052 v titanium is in the passive state, characterized by high corrosion resistance in various media and practically independent of the potential.

In contrast with chromium and the stainless steels, in solutions of nitric, chromic acids and their mixtures, and also with deep anodic polarization, titanium is not prone to overpassivation. However, in the presence of activators (ions of chlorine, iodine, fluorine) with deep anodic polarization, in the region of high potentials there may appear the breakdown phenomenon associated with destruction of the passive film, which is accompanied by increase of the corrosion rate with increase of the potential and in many cases by localized corrosion of the pitting form. With temperature increase and introduction into the solution of activators, particularly the fluorine ions, the corrosion rate increases sharply even in the passive state (for example, in concentrated nitric acid containing HF). The titanium corrosion rate is reduced in concentrated HF acid. Thus, in 60-70% HF the corrosion rate is less by a factcrof 100 times than in the 40% solution, which is explained by the formation on the titanium of a film of titanium hydrides in accordance with the formula $Ti + 2H^+ + 2\underline{e}^- \rightarrow TiH_2$. Under these con-

ditions the corrosion rate does not depend on the potential, but is determined by the rate of solution of the hydride film according to the formula $TiH_2 + 2H^+ \rightarrow Ti^{++} + 2H_2$, in this case there arises a hydride-passive state. Although the hydride film is porous, concentration polarization is quickly achieved in its pores and the corrosion rate does not progress. In nonoxidizing acids the titanium corrosion rate depends on the hydrogen release overvoltage, which on titanium is reduced in acidic solutions (Fig. 6). It reduces even more with the introduction into the titanium of cathodic additives of the noble metals. Moreover, the hydrogen liberation overvoltage can be increased by means of introduction of certain additives into the solution. Thus, with the introduction of NH_4F there is a considerable reduction of the titanium corrosion rate in a 2 N H_2SO_4 solution as a result of the increase of the hydrogen liberation overvoltage. Thus, depending on the hydrogen overvoltage the rate of dissolution of titanium can very considerably if the corrosion process proceeds with hydrogen depolarization.

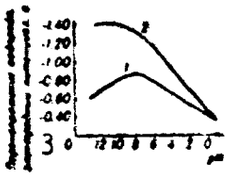

Fig. 6. Curves of variation of hydrogen overvoltage on titanium (1) and the electrode potential with a current density of 10^{-3} a/cm^2 (2) as a function of the solution pH. 3) hydrogen overvoltage, electrode potential, v.

Structural and contact corrosion. A salient feature of titanium and its alloys is the absence of a tendency to intergranular corrosion and stress corrosion in the majority of the corrosive media. Only in highly concentrated fuming (red) nitric acid are titanium and its alloys prone to stress corrosion and intergranular corrosion; in this case there are formed corrosion products which have pyrophoric proper-

ties (i.e., they explode with mechanical impact). The conditions under which this property of titanium and its alloys is manifested are shown in Fig. 7.

In comparison with the other metals, titanium and its alloys are not subject to spot, pitting and crevice corrosion and have high resistance to cavitation and erosion. Figure 8 shows jet erosion of piping made from titanium and certain alloys in sea water, Figure 9 shows tests for cavitation in synthetic sea water on a magnetostriction vibrator at a frequency of 8000 Hz and an amplitude of 0.07 mm.

The fatigue limit of titanium is practically unchanged under the action of many corrosion-active media. The nature of the corrosion behavior of titanium and its alloys is associated with the high capacity for passivation in comparison with the other metals (lower critical passivation potential and lower critical passivation current density in aggressive media).

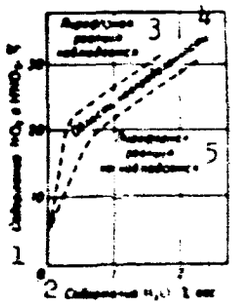

Fig. 7. Effect of nitric acid composition on pyrophoric reaction with titanium. 1) Content of NO_2 in HNO_3, %; 2) H_2O content, %; 3) pyrophoric regime observed; 4) uncertain region; 5) pyrophoric regime not observed.

With respect to their electrochemical behavior in sea water in contact with the other metals, titanium and its alloys are close to the passive austenitic stainless steels. With contact, titanium and its alloys accelerate the corrosion of magnesium, zinc, cadmium, aluminum and their alloys in sea water and have practically no effect on the majori-

ty of the copper alloys, austenitic stainless steels, nickel alloys, silver, since their stationary potentials are very close; contact of titanium with the noble metals (platinum, palladium, gold) is also permissible.

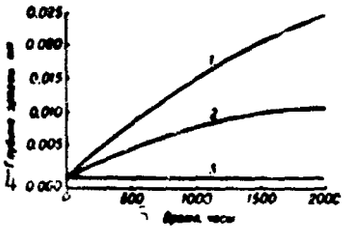

Fig. 8. Test of piping of various metals for jet erosion in sea water containing sand (40 g/liter) with water flow velocity of 1.8 m/sec; 1) Brass 76% Cu, 22% Zn, 2% Al; 2) copper-nickel alloy (70% Cu, 30% Ni with high content of Fe and Mn); 3) titanium; 4) erosion depth, mm; 5) time, hours.

Methods of protection against electrochemical corrosion. In atmospheric conditions, and also in river and sea water, titanium and its alloys do not need corrosion protection if a decorative finish is not required and special demands are not made on the physical properties of the surface (wear-resistance, reflective properties, etc.). In aggressive media (sulfuric, hydrochloric acids, etc.), for protection from corrosion use is made of alloying of the alloys, introduction of oxi-

Fig. 9. Comparative tests on cavitation of titanium and other alloys; 1) Low-carbon steel; 2) LMtsZh55-3-1 brass; 3) 2Kh13 steel; 4) VT1-1 titanium; 5) Kh18N9T stainless steel; 6) IMPl titanium produced by powder metallurgy. 7) cavitation volume loss, mm^3; 8) test duration, hours.

dizers (inhibitors-passivators), anodic protection and various coatings.

Alloying. The corrosion resistance of titanium can be improved by alloying with the elements which reduce the passivation potential and the critical passivation current density. Such elements are chromium, tantalum, zirconium. However, for increasing the corrosion resistance of titanium in sulfuric acid it is necessary to introduce a considerable quantity of zirconium (40-60%); alloying with molybdenum is more effective, its introduction in the amount of 20-30% provides for high corrosion resistance of titanium even in boiling sulfuric acid, but reduces the corrosion resistance in nitric acid. The effect of zirconium and molybdenum on the corrosion resistance of titanium in 40% H_2SO_4 with increase of the temperature is shown in Fig. 10. The marked reduction of the titanium corrosion rate with the introduction of molybdenum is associated with both the retardation of the cathodic process as a result of the increase of the hydrogen overpotential and with the retardation of the anodic reaction. A positive effect of tantalum is noted with more than 8-10% tantalum in the alloy. Small additions of boron (0.005 - 0.7%) are also effective.

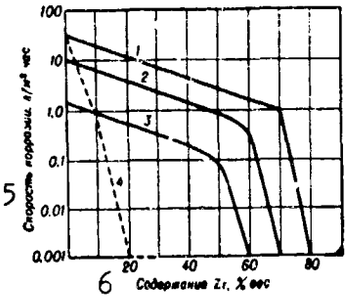

Fig. 10. Effect of zirconium and molybdenum content on titanium corrosion rate in 40% sulfuric acid solution: 1) At 60°; 2) at 40°; 3) at 25°; 4) at 60° and addition of molybdenum; 5) corrosion rate, g/m^2/hr; 6) Zr content, % by wt.

The effect of the alloying elements on the corrosion rate of the titanium alloys in boiling solutions - 10% HCl and 15% H_2SO_4 - are shown in Table 3. For comparison there is shown in the Table the corrosion rate in these conditions of a nickel-base alloy (Hastelloy C).

Alloying with a small amount (0.1-2%) of the noble metals (platinum, palladium) is effective when this is justified from technical and economic considerations. In this case the passive state is achieved as

a result of which there is obtained a shift of the titanium stationary potential into the passive region and the corrosion rate is markedly reduced, particularly in the dilute solution of sulfuric and hydrochloric acids.

TABLE 3

Corrosion Rate (mm/yr) of Titanium and its Alloys in Boiling Hydrochloric and Sulfuric Acids in Comparison with a Nickel-Base Alloy.

Содержание легирующих элементов a	b Агрессивная среда	
	10%-ная HCl	15%-ная H_2SO_4
c Чистый титан	60	95
2—10% Cu	230—>250	130—180
6% Ag, 3% Al	140	180
4% Ag, 6% Al	115	160
2—10% Be	200	>200
1—10% Al	70—150	120—>150
4% Al, 4% V	—	90
6% Al, 4% V	—	70
1—50% Zr	50—5	90—8
1—50% V	85—20	100—15
2—10% Nb	80—200	105—230
2—10% Ta	60—50	95—50
1—10% Cr	90—165	130—215
5% Cr, 3% Al	140	200
20% Mo	0.2	0.2
30% Mo	<0.1	<0.1
2—10% Fe	>200	>200
2—10% Co	230—>300	200—>270
2—10% Ni	170—>200	>290
Хастелой С d	10	1.5

a) Content of alloying elements; b) aggressive medium; c) pure titanium; d) Hastelloy C

TABLE 4

Minimal Concentrations (g/liter) of Oxidizers with which Titanium Transitions into Passive State in Hydrochloric Acid at Normal Temperature

Ионы-окислители a	15%-ная HCl	27%-ная HCl
Fe^{+++}	0,00008	0.00025
Cu^{++}	0,00004	0,0002
Pt^{++++}	0,000002	0.0002

a) Oxidizer ions.

Introduction of oxidizers. The presence in the aggressive media of small quantities of oxidizers shifts the potential of titanium and its alloys in sulfuric and hydrochloric acid solutions into the passive region and the corrosion resistance increases sharply. Table 4 presents the minimal concentrations of the oxidizer ions which put titanium into the passive stage in concentrated solutions of hydrochloric acid. The effect of the ions of the noble metals is particularly great as a result of their precipitation on the titanium.

The titanium corrosion rate in hydrochloric acid solutions will drop sharply in the presence of chlorine (Fig. 11) since in this case chlorine, demonstrating the properties of an oxidizer, has a high oxidation-reduction potential. In HF acid additions of oxidizers is ineffective and even increases the corrosion rate, in the passive state in the oxidizing media additions of fluorine ions also increase the solution rate sharply.

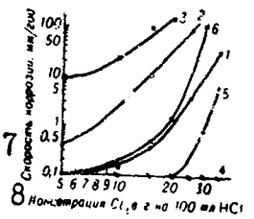

Fig. 11. Effect of chlorine on titanium corrosion in hydrochloric acid (with 200-hr tests): without passage of chlorine ((1) at 20°, 2) at 60°; 3) at 90°; with passage of chlorine (4) at 20°; 5) at 60°; 6) at 90°)); 7) corrosion rate, mm/yr; 8) concentration of Cl_2 in grams per 100 ml HCl.

Anodic protection. As a result of the low passivation current of titanium in hydrochloric and sulfuric acids in comparison with the other metals, it is advisable to use anodic protection in these media. After transition of the titanium into the passive state, with anodic polarization for maintaining the passive state there is required only a very low current density: 0.1-0.2 ua/cm^2 in 40% H_2SO_4, 0.5-1 ua/cm^2 in

78% H_2SO_4, 0.5-1 ua/cm^2 in 15% HCl, 1-2 ua/cm^2 in 25% HCl. Here reliable protection is achieved with potentials of 0.5-1.0 v (on the hydrogen scale). Higher values of the potential can lead to breakdown of the passive film in the presence of Cl^-. The effect of anodic protection of titanium in sulfuric and hydrochloric acids is shown in Figs. 12, 13.

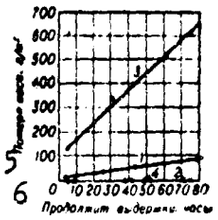

Fig. 12. Corrosion of titanium in sulfuric acid solutions of varying concentration without and with anodic protection: 1) n 40% solution without protection; 2) in 40% solution with anodic protection; 3) in 78% solution without protection; 4) in 78% solution with anodic protection; 5) weight loss, g/m^2; 6) exposure duration, hours.

Protective coatings (chrome plating, copper plating, nickel plating, carburizing, nitriding, oxidation, etc.) are applied to titanium and its alloys primarily to increase the wear resistance, to reduce scoring, to improve brazing. Anodizing is used for additional protection from corrosion, to improve wear resistance and to reduce scoring.

Fig. 13. Titanium corrosion in hydrochloric acid solutions of varying concentration without protection and with anodic protection: 1) In 15% solution without protection; 2) in 15% solution with anodic protection; 3) in 25% solution without protection; 4) in 25% solution with anodic protection; 5) weight loss, g/m^2; 6) exposure duration, hours.

Anodizing is performed most successfully in an 18% solution of sulfuric acid at a temperature of 80-100° and an anode current density of 0.5-2 a/dm^2. The anodizing period lasts from 2 to 8 hours, where the higher the temperature, the higher the current density and the shorter

the anodizing time. The film thickness reaches 2-3 microns. The anode film which increases the corrosion resistance of titanium in H_2SO_4 and HCl solutions cannot serve as a reliable protection in the course of a long time period. The anode film is destroyed quite rapidly in HF acid. Chemically resistant paint-type coatings are also used for protection from corrosion, particularly during chemical milling of titanium and its alloys (see Paint-type Coatings for the Titanium Alloys).

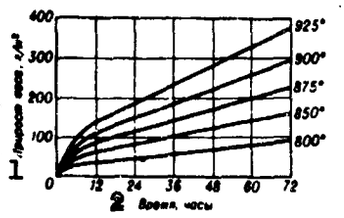

Fig. 14. Isothermal curves for oxidation of titanium at temperatures of 800-925°. 1) Weight loss, g/m^2; 2) time, hours.

Chemical corrosion. Titanium reacts actively with the dry halides: fluorine at 150°, chlorine at 350°, bromine at 360° and iodine at 400°. The titanium corrosion rate diminishes in moist halides (particularly in the interaction with chlorine) as a result of passivation. Titanium interacts actively with the oxygen in the air at temperatures above 700°. With increase of the temperature titanium reduces all the known oxides of the metals. During heating in oxygen or in air, titanium and its alloys are covered with a scale, and under the scale the metal is saturated with oxygen and forms a brittle layer of metal (interstitial solid solution) which is removed by etching in fused salts or acids. The kinetic curves for oxidation of titanium in oxygen are shown in Fig. 14. The distribution of the oxygen between the scale and the solid solution as a result of oxidation in an oxygen stream at 1000° is shown in Fig. 15. With the formation of the Ti-O interstitial solid solution, there is a considerable increase of

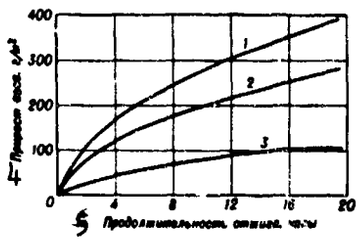

Fig. 15. Oxygen distribution between scale and solid solution in process of oxidation of titanium at 1000°: 1) Overall weight increase; 2) oxides on surface; 3) O_2 dissolved in titanium; 4) weight loss, g/m^2; 5) test duration, hours.

the hardness of the surface layers, from which we can determine the depth of penetration of the oxygen into the metal (Fig. 16). The titanium diffuses through the scale layer to the surface and interacts with the oxygen, where there are continuously formed new layers of TiO_2, including the intermediate layers with a lower degree of oxidation (TiO, Ti_2O_3).

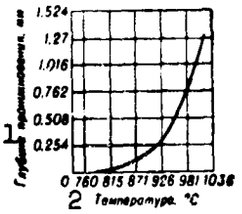

Fig. 16. Depth of oxygen penetration after 10-hour oxidation of titanium at different temperatures (plotted from curves of hardness distribution with respect to layer depth). 1) Penetration depth, mm; 2) temperature, °C.

At 800° the oxidation of titanium is retarded by alloying with up to 1% tungsten, molybdenum, chromium and tantalum, however, high heat resistance of the titanium alloys is not achieved as a result of the alloying. The most effective protection of titanium is provided by application of thermally resistant enamels and combined galvanic coatings (for example, chromium-nickel) with the use of thermodiffusional annealing.

References: Batrakov V.P. Voprosy teorii korrozii i passivnosti metallov v okislitelyakh [Theory of Corrosion and Protection of Metals in Oxidizers], in book: Korroziya i zashchita metallov [Corrosion and Protection of Metals], M., 1957; -- Teoreticheskiye osnovy korrozii i zashchity metallov v agressivnykh sredakh [Theoretical Bases of Corrosion and Protection of Metals in Aggressive Media], in collection: Korroziya i zashchita metallov, M., 1962; Tomashov N.D., Al'tovskiy R.M., Arakelov A.G., Anodnaya zashchita titana v sernoy kislote [Anodic Protection of Titanium in Sulfuric Acd], DAN SSSR, 1958, Vol. 121, No. 5;

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V.P. Batrakov

CORROSION OF TUNGSTEN. Tungsten has exceptional corrosion resistance in alkaline solutions and in practically all the mineral acids. Rapid dissolution of W is observed in a mixture of HF and HNO_3 and in the alkaline solutions containing oxidizers.

Corrosion Resistance of Tungsten in Various Media

[1] Среда	Темп-ра [2] (°C)	Взаимодействие [3]
H_2SO_4 (20—25%-ный раствор)	4 20	8 Не действует
H_2SO_4 (20—25%-ный раствор)	4 100	9 Слабо реагирует
H_2SO_4 (98%-ная концентриров.)	5 20	9 Слабо реагирует
H_2SO_4 (98%-ная концентриров.)	5 110	10 Легко разрушает
HCl (37%-ная концентриров.)	5 20	8 Не действует
HCl (37%-ная концентриров.)	5 100	9 Слабо реагирует
HNO_3 (65%-ная концентриров.)	5 100	11 Медленно разрушает
Царская водка [6]	100	12 Быстро разрушает
HF	100	11 Медленно разрушает
HF+HNO_3	20	12 Быстро разрушает
NaOH (10%-ный раствор) [4]	7 20	8 Не действует
NaOH	Расплавленный	12 Быстро разрушает

1) Medium; 2) temperature (°C); 3) interaction; 4) solution; 5) concentration; 6) aqua regia; 7) molten; 8) no reaction: 9) weak reaction; 10) corrodes easily, 11) corrodes slowly; 12) corrodes rapidly.

Corrosion resistance of tungsten in water and in the air – see Tungsten.

Dissolution of W in a mixture of HF and HNO_3 proceeds unevenly, therefore this solution is not very suitable for polishing and etching. For these purposes the most suitable mixtures are NaOH and $K_3[Fe(CN)_6]$ or NaOH and H_2O_2.

II-3K1

W corrodes in solutions of $CuCl_2$ and $FeCl_3$.

Reacts with fluorine at room temperature, with chlorine at 250°, with bromine and iodine at red-heat temperatures. W does not react with molten mercury to 600°, lithium, sodium, potassium and their alloys to 900°, gallium to 800°, bismuth to 980°, magnesium to 650°.

References: Smithells C.J., Tungsten, transl. from English, M., 1958; Hampel C.A., Corrosion, 1958, Vol. 14, No. 12; Nuclear Reactors, transl. from English, Vol. 3, M., 1956 (Data from US AEC).

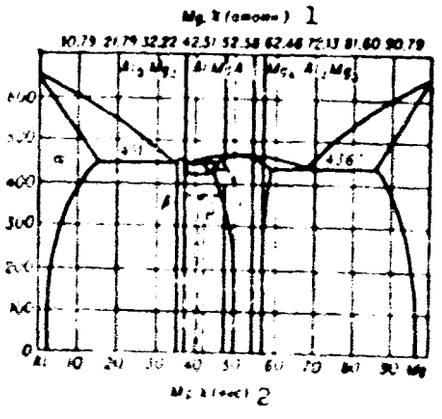
M.I. Gavrilyuk

CORUNDUM is a mineral, aluminum oxide (Al_2O_3). The impurities of other elements in corundum crystals are present in small quantities but cause its coloring. Normally the color is bluish or yellowish gray. Cr gives a red tint, Fe^{2+} gives brown, Ti gives blue, Fe^{2+} and Fe^{3+} give a black coloring. The purest transparent gem variety of corundum are the red ruby and the blue sapphire. Corundum ores normally contain admixtures of the other minerals and when their amount is large the ores are termed emery. In nature corundum is encountered only in the form of α-Al_2O_3 – of triangular form, crystallizing primarily in tapered pyramidal and barrel-like crystals at 500-1500°. The hexagonal β-Al_2O_3 and cubic γ-Al_2O_3 are obtained artificially at 1500-1800°. Corundum is chemically stable, is insoluble in acids and dissolves slowly in borax and/or phosphate, forming a clear glass. The hardness of corundum is 9 on Mohs scale (second hardest mineral after diamond); the ruby and sapphire are somewhat harder than ordinary corundum. Corundum has no cleavage and when split it yields a conchoidal fracture. The specific weight of corundum varies from 3.82 to 4.28 (average is 4.02). The resistance of pure corundum to compression with hydrostatic pressure of kerosene at 2500 kg/cm^2 amounts to 7200 kg/cm^2. Compressibility at 30° and a pressure of 10^7 bar is $\Delta v/v_0 = 3.36$. The coefficient of elasticity of corundum is $5.2 \cdot 10^7$. The mechanical strength of pure corundum increases somewhat at 600-1000°. The primary role in the use of corundum as an abrasive material is played by the abrasive capability, which in corundum is 5 times greater than for quartz, but more than 7 times lower than for diamond. The melting point of pure corundum is

2040°, that of native corundum (depending on the impurities) is 1750-2050°. Depending on the temperature, the specific heat (joules/gram) is: 0.069 (-200°); 0.72 (0°); 1.00 (200°); 1.10 (400°); 1.19 (800°); 1.26 (1200°). According to other data the specific heat at room temperature is 0.1981. The heat content of corundum (cal) as a function of temperature is: 297.89 (1100°); 330.42 (1200°); 395.99 (1400°). Corundum is used primarily as an abrasive material and tc a lesser degree as a raw material for obtaining high-alumina artificial abrasives and refractories. After grinding and classification to a definite grain size, corundum is used: 1) directly in the powder form; 2) in the composition of abrasive suspensions and pastes; 3) in grinding cloths; 4) in abrasive products using a ceramic or organic (predominantly bakelite) binder. The Soviet abrasive industry produces primarily fine corundum powders (micro-powders) with a basic fraction size of 7-30 microns. Corundum has been to a considerable degree replaced by the artificial abrasive materials, but it provides the highest efficiency in grinding glass, particularly optical lenses, and also in the grinding of metal products, particularly ball bearings. Corundum is used in the form of a suspension for the working of facing stones and the preparation of microscopic preparations of rocks and ores (sections, polished sections), and also in the processes of the fine finishing of precision metal details and instruments. In the USSR electro-corundum and alsc synthetic rubies are produced from technical alumina.

References: see under entry Abrasive Materials.

CORROSION-RESISTANT ALUMINUM CASTING ALLOYS – the Al-Mg alloys Al8, AL13, and AL22. Magnesium forms an extensive solid-solution region with aluminum (Fig.); the solubility of magnesium in aluminum is approximately 17% at the eutectic temperature. This homogeneous structure is to a considerable extent responsible for the increased corrosion resistance of Al-Mg-based alloys in salt water and under atmospheric conditions. The corrosion resistance of castings can be increased by reducing the number of gas pores and the content of metallic and nonmetallic impurities (see Corrosion of aluminum alloys).



Phase diagram of Al-Mg system. 1) Mg, % (atomic); 2) Mg, % (by weight).

AL8 alloy is based on a solid solution and consequently has reduced casting characteristics. Its mechanical properties are high and can be improved by using high-purity aluminum and by modification with calcium fluorzirconate. It exhibits high corrosion resistance in salt water. AL8 has good cuttability, is satisfactory for gas and argon-arc welding, and displays reduced hermeticity. AL8 has an increased tendency toward oxidation in the molten state and 0.05–0.07% beryllium should consequently be added to reduce this tendency. An equal quantity of titanium should be added together with the beryllium, in order to break up the grains. A total of 3–5% of boric acid should be added to the casting mixture in order to keep the metal from reacting with the moist mold. The heat-treatment regime (T4)

involves prequenching heating at 430° ± 5° for 10-20 hr and cooling in water at 50-100° or in oil. It is advisable to use quenching media at elevated temperatures (water at 80-90° or oil at 50-60°) in quenching complex castings, in order to avoid cracking. AL8 alloy is used primarily for sand-casting components which will not be subject to high stress but will be exposed to salt water and atmospheric conditions.

TABLE 1

Casting Characteristics of AL8, AL13, and AL22 Alloys

Сплав 1	Ликвидус (°С) 2	Солидус (°С) 3	Линейная усадка (%) 4	Жидкотекучесть (мм) 5
АЛ8 6	608	552	1.3	318
АЛ13 7	650	550	1.0	322
АЛ22 8	—	—	1.2	380

1) Alloy; 2) liquidous (°C); 3) solidus (°C); 4) linear shrinkage (%); 5) flowability (mm); 6) AL8; 7) AL13; 8) AL22.

TABLE 2

Change in Mechanical Properties of AL8 Alloy as a function of Casting Diameter

Диаметр отливки (мм) 1	σ_b (кг/мм²) 2	δ_{10} (%)
15	29	9
30	19	4.5
45	18	4.0
60	17	3.0

1) Casting diameter (mm); 2) kg/mm^2.

TABLE 3

Typical Mechanical Properties of AL8, AL13, and AL22 Alloys (individually cast samples)

Сплав 1	Состояние материала 2	σ_b (кг/мм²) 3	$\sigma_{0.2}$ (кг/мм²)	δ_{10} (%)	HB (кг/мм²)	E (кг/мм²)	G (кг/мм²)	μ	σ_{-1}* (кг/мм²)
АЛ8 4	Литой в песчаную форму, закаленный по режиму Т4 . . . 7	30	17	11	70	7000	2600	0.34	·
АЛ13 5	8 Литой в песчаную форму	17	10	3	65	8700	2500	0.33	—
	Литой в кокиль . . .	20	—	5	70				
АЛ22 6	10 Литой под давлением	25	—	2	100				
	Литой в песчаную форму, закаленный по режиму Т4 . . . 7	24	18	3	95	7000	2600	0.34	—

*Cantilever bending of rotating sample; N = $5 \cdot 10^8$ cycles.

1) Alloy; 2) state of material; 3) kg/mm^2; 4) AL8; 5) AL13; 6) AL22; 7) cast in sand mold, quenched under regime T4; 8) cast in sand mold; 9) cast in chill mold; 10) pressure-cast.

TABLE 4

Physical Properties of AL8, AL13, and AL22 Alloys

Сплав 1	γ (г/см³) 2	α·10⁶ (1/°C) 3 темп-ра 20—200°	20—100°	20—300°	λ при 25° (кал/см·сек·°C) 4	Электропроводность в % к электропроводности меди 5	c (кал/г °C 6
АЛ8 7	2.55	24.5	25.6	28.8	0.20	21.0	0.23
АЛ13 8	2.6	20	24	27	0.[illegible]	21.0	0.23
АЛ22 9	3.5	24.5	25.6	27.8	0.20	21.0	0.22

1) Alloys; 2) g/cm^3; 3) temperature; 4) λ at 25° (cal/cm·sec·°C); 5) electrical conductivity in % of conductivity of copper; 6) cal/g·°C; 7) AL8; 8) AL13; 9) AL22.

AL13 alloy contains a considerable quantity of eutectic and has satisfactory casting characteristics and a high corrosion resistance; its mechanical characteristics are rather low as a result of the fact that it cannot be hardened by heat treatment and is consequently used in the cast state. This alloy has excellent cuttability and satisfactory weldability. It is used for sand-, chill-, and pressure-casting of components which will bear moderate stresses and whose operating conditions require satisfactory corrosion resistance in salt water.

AL22 alloy has satisfactory casting characteristics and a high corrosion resistance. Its mechanical characteristics are lower than those of AL8, but substantially higher than those of AL13. AL22 is intended primarily for pressure-casting of components which must function in salt water. It can be cast in sand or chill molds. It displays satisfactory weldability, good cuttability, and good polishability. The heat-treatment regime (T4) involves prequenching heating at 430 ± 5° for 15–20 hr and cooling in hot water (50–100°).

AL2, AL4 and AL9 also have satisfactory corrosion resistance in salt water, but their primary advantage is their high casting characteristics, as well as the strength and hermeticity of AL4 and AL9. They are consequently considered under High- and medium-strength aluminum

casting alloys.

VAL4 also exhibits a high corrosion resistance in a marine atmosphere (see Self-hardening aluminum casting alloys).

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CORROSION-RESISTANT ALUMINUM SHAPING ALLOYS – are distinguished by high corrosion resistance and, as a rule, low to medium strength (see Medium-strength aluminum shaping alloys); many of them also have good decorative appearance. The term high corrosion resistance covers for the most part high general corrosion resistance and high resistance to corrosion under stress in the atmosphere and in sea water (see Corrosion of aluminum alloys). In occasional cases, e.g., for helicopter rotor blades, corrosion fatigue is of decisive importance. The behavior of corrosion resistant aluminum shaping alloys in special media, such as soils (important for underground pipelines), in strong oxidizing environments, etc., is not considered in the present paper. The corrosion-resistant aluminum shaping alloys include technical aluminum (alloys AD and AD1), alloys of the Al-Mg system with relatively low magnesium contents (AMg1, AMg2, AMg3, AMg4), alloys in the Al-Mg-Si system with relatively low contents of Mg and Si and with a certain ratio between Mg and Si to prevent the appearance of silicon in the structure (alloy AD31), an alloy of Al with Mn (AMts); and SAP-1 (see Sintered aluminum powder).

In addition to these alloys, provided that certain restrictions are observed both in the process of fabricating semifinished products and in using them in structures, alloys of the following systems may also be regarded as corrosion-resistant: Al-Mg (AMg5V and AMg6); Al-Mg-Si (AD33 and AD35) and SAP-2.

Table 1 lists, for orientation purposes, data characterizing the loss of mechanical properties in extruded semifinished products made

TABLE 1

General Corrosion Resistance of Extruded Semifinished Products made from Aluminum Shaping Alloys (test time 3 months)

1 Сплав	2 Потери (в %)	
	Δs_p	$\Delta\sigma$
3 АД; АД1; АМц; АМг1; АМг2; АМг3; АМг4; АМг5В; АМг6; САП-1; САП-2	0–5	0–10
4 АД31; АД33; АД35	0–10	5–30
5 АВ	5–20	30–80
6 М40; Д19; ВАД1; Д16; ВАД23; Д1; Д20; АК4; АК4-1; АК6; АК8; В93; В95; В96	10–40	40–90

1) Alloy; 2) losses (in %); 3) AD, AD1, AMts, AMg1, AMg2, AMg3, AMg4, AMg5V, AMg6, SAP-1, SAP-2; 4) AD31, AD33, AD35; 5) AV; 6) M40, D19, VAD1, D16, VAD23, D1, D20, AK4, AK4-1, AK6, AK8, V93, V95, V96.

from aluminum shaping alloys after testing in an aqueous solution containing 3% NaCl + 0.1% H_2O_2.

The corrosion damage affects elongation to a greater degree than strength.

Despite all the reservations with which the above test results must be taken – they may vary substantially depending on the type of semifinished product, the length of the test, the environment, etc. – they enable us to resolve the corrosion resistant aluminum shaping alloys distinctly into several groups. Pure Al, alloys of Al with Mg and the SAP's possess very high general corrosion resistance. However, alloys AMg5V and AMg6 may be inclined to corrode under stress if the annealing conditions are not properly selected; the corrosion resistance of the SAP's may deteriorate markedly if there are inclusions of iron in them. Alloys AD31, AD33 and AD35 are close to pure Al as regards over-all corrosion resistance and have no tendency to corrosion whatsoever under stress (like alloys D20 and VAD23); the alloy group including types D16, D20, D19, V95 and VAD23 shows considerably poorer general corrosion resistance than aluminum alloy AD31. With suitable

protective measures, however, they perform satisfactorily. Solid semi-finished products made from alloys D16 and AK8 and alloys similar to them may tend to corrode under stress. For alloys V95 and others containing zinc, the corrosion sensitivity under stress is the decisive corrosion characteristic. These alloys can be protected dependably from corrosion cracking by regulating the chemical composition and working procedures, including heat-treatment. Alloy AV occupies an intermediate position between alloys AD31 and D16 and cannot be regarded as a corrosion resistant aluminum shaping alloy.

Technical aluminum is an aluminum alloy with the inevitable iron and silicon inclusions (and sometimes copper, magnesium, titanium, sodium and other elements). The purer the Al, the higher will be its corrosion stability, but the tendency to grain enlargement, which is detrimental to the external appearance of the pieces, becomes even stronger, so that it is necessary to take measures to suppress grain growth. Al is used both in the annealed and in the cold-hardened state; it welds easily but is difficult to cut. Al takes well to color anodizing.

Alloyed with manganese (AMts), Al possesses high strength and is less inclined to grain enlargement than pure Al. As regards weldability, corrosion resistance and machinability, the alloy AMts resembles Al very closely; it is grayish in color. Alloys of Al with magnesium (magnals) are used widely in various branches of engineering. During recent years, the compositions of domestic versions of these alloys have been revised and new types have been created. It has been proposed that a series of magnal-type alloys be created with the magnesium content varying from 0.5-1.8% in alloy AMg1 to 5.8-6.8% in alloy AMg6.

In alloys AMg5V and AMg6, major complications arise as a result of inclusions of intermetallic compounds of complex composition (com-

pounds of Al with Mn, Tk, Cr, V, Fe and Zr, depending on which of these elements are present in the alloys). Intermetallides act in the same way as sharp notches, to the detriment of corrosion resistance and the decorative appearance of the material. Dark laminations running parallel to the rolling plane, generally in the middle of the sheet thickness, are sometimes encountered in magnal sheets and plates. They form at the positions of slag inclusions resulting from the smelting and casting conditions. In welding, these laminations cause buckling. Magnals to be used in critical parts must be inspected to detect lamination of this kind.

The solubility of Mg in Al diminishes with decreasing temperature (from 15-17% at 455° to 2% at 150-200°), but decay of the supersaturated solid solution proceeds extremely slowly in this system. As a result, alloy AMg6 (for example) tempered from 400-430° in water or cooled slowly in air possesses practically the same properties both immediately after cooling and after prolonged holding. The alloys undergo practically no work-hardening during tempering and under normal aging conditions; nor do they soften on annealing. This peculiarity of the magnals is a major advantage for use in welded-up structures; the alloys soften only slightly during welding and the welding strength-loss coefficient is close to unity. As regards mechanical properties, the magnals are peculiar in certain respects. Since they are not hardened by heat-treatment and are used in the annealed state, they are characterized by high elongations, a low yield point and not particularly high strength (the ultimate strengths and yield points according to the TU for the strongest alloy, AMg6, are 32 kg/mm^2 and 16 kg/mm^2, respectively). The strength of magnal sheets can be increased further to a considerable degree by cold-hardening the material (see Table 2).

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TABLE 2

Properties of Work-Hardened Sheets of AMg6 Alloy

Нагартовка A (%)	σ_b B ($кг/мм^2$)	$\sigma_{0.2}$ B ($кг/мм^2$)	δ (%)
0.8	32	17	24
5	35	27.5	19
10	37	29.5	13
15	39	32	10
20	40	34	9
30	42	36	7

A) Cold-hardening (%); B) (kg/mm^2).

The strength loss in the region of the weld seam is compensated by local thickening of the seam zone when cold-hardened material is used. The supersaturated solid solution of Mg in Al is only relatively stable and decays progressively in the course of time with separation of minute inclusions of the β-phase (Al_3Mg_2). Decay is the more rapid the higher the content of Mg in the Al and the higher the holding temperature. Alloys AMg1, AMg2, AMg3 and AMg4 show no tendency to solid solution decay. The structures of alloys AMg5V and AMg6 undergo practically no change at 20-30°, but when the temperature is raised to 60-70° (for example, as a result of solar heating) and held there for hundreds and thousands of hours, decay of the supersaturated solid solution advances rather rapidly. At 150-200°, decay takes place within a few hours. In the temperature range from 60-70° on up to 150-200°, decay results in the formation of continuous beaded chains of the β-phase along the grain boundaries and acceleration of corrosion processes. The strength and plasticity of the material then drop rapidly.

Alloys of the Al-Mg-Si type are acquiring very great importance as structural and decorative materials. They differ sharply from the magnals in a number of properties. These differences result basically from the fact that Al-Mg-Si-type alloys stiffen up considerably during heat treatment, particularly after artificial aging. In the artificially aged state, they show higher $\sigma_{0.2}$ and lower elongation (in alloy AD33, σ_b = 32 kg/mm^2, $\sigma_{0.2}$ = 27 kg/mm^2, δ = 10%; the corresponding figures for AMg6 alloy are 34, 18 and 18). In the annealed state, alloys AD31, AD33 and AD35 show higher plasticity and permit considerably greater deformations than do the magnals. The effect of heat treatment is re-

duced in welding, and the same zone is found to have lost strength. Hence alloys AD31, AD33 and AD35 are conveniently used for riveted or bonded structures of complex shape, as well as for structures requiring higher-than-average yield points (as compared with the yield-point values of the magnals). Alloys AD31 and AD33 permit of extrusion into complex-shaped products, such as complex hollow profiles. Alloys AMg5V and AMg6 are unsuitable for this purpose. The dark laminations and intermetallide inclusions that make work with the magnals very difficult appear less often in alloys AD31 and AD33. Nevertheless, UZ inspection of critical profiled shapes, such as the spars of helicopter rotor blades made from these alloys, is mandatory, since even small slag inclusions and other metallurgical defects sharply reduce the fatigue strength of the products. The corrosion resistance of Al-Mg-Si alloys depends heavily on the silicon concentration and the ratio of the Mg and Si contents. Those alloys in which this proportion is such that all of the silicon is used in formation of the compound Mg_2Si possess good corrosion resistance. As soon as excess silicon appears in the structure, the corrosion resistance of the alloys drops sharply.

The introduction of copper into Al-Mg-Si alloys causes their corrosion behavior to deteriorate even further. It is also necessary to note that the corrosion foci give rise to an extremely sharp drop in the fatigue strength of the alloys. At a given stress level, the number of cycles to failure may be reduced to a fraction by apparently relatively minor corrosion damage.

Technological factors including heat-treatment conditions strongly influence the corrosion resistance of alloys AD33, AD35 and AV, and, in particular, their tendency to intergranular corrosion. When new products made from these alloys are being adapted to production, it is necessary to make a periodic check to detect any tendency to intergranu-

lar corrosion. Storage and shipping conditions that eliminate the possibility of shopwearing, embedding of grit, pitting, etc., all of which are detrimental to the decorative appearance and operational durability of the products, should also be provided for the metal.

At the present time, alloy AD35 is under assimilation; its composition is Mg 0.8-1.4%; Si 0.8-1.2%; Mn 0.6-1.0%. The increased content of Mn in this alloy inhibits grain enlargement; at the same time, the alloy shows higher-than-average strength and good corrosion stability, and is, on the whole, a promising material.

The most decorative alloys are found among those of aluminum with Mg (AMg1, AMg2, AMg4) and alloy AD31. In this case, however, they must be prepared from aluminum of high purity; specifically, alloys AMg1, AMg2, AMg4 and AMg5 must contain no more than 0.05% chromium. Alloy AMg3, which contains Si (to improve its weldability), is least decorative in appearance; one proposal calls for production of alloy AMg3, which contains no Si, for decorative purposes (concurrently with the Si-containing alloy AMg3). In using AD31 in the manufacture of decorative products with particularly highly polished surfaces (e.g., gold-anodized watch cases), it is advisable to refine the composition of this alloy as follows: Mg 0.55-0.9%; Si 0.4-0.5%; Cu $\leq$ 0.05%, Fe $\leq$ $\leq$ 0.12%. To fabricate extruded semifinished products from AD31, for example, for glasswork, it is desirable to hold the Fe content in the range from 0.25 to 0.35% and the Ti content between 0.04 and 0.05%; this is necessary to refine the grain. Alloys of the American 6101 type, which contains Si 0.3-0.7%; Mg 0.35-0.8%; Fe below 0.5%; Cu below 0.1%; Mn below 0.03%; Cr below 0.03%; Zn below 0.03%, are used for electrical purposes.

When the production process is not rigidly adhered to, a tendency to grain enlargement (detrimental to the external appearance of the

pieces) appears in alloys AMg1, AMg2, AD31, AD33. As a rule, alloys AD35, AMg5V, AMg6 show a fine granular structure.

The mechanical properties of AD, AD1, AMts, AMg1, AMg2, AMg3, AMg4, AD31, AD33, AD35 alloy semifinished products are listed in Tables 3-12 and 16. The results of tests on sheets and extruded semifinished products of alloys AD31, AD33, AD35 and AV to determine over-all corrosion resistance will be found in Tables 12 and 13. Alloy AD31 also behaves quite satisfactorily under test conditions in an industrial region whose atmosphere is distinguished by high corrosiveness (Table 14).

In tests of corrosion under stress, all specimens of alloys AD31 and AD33 (sheets and extruded rods) survived without damage for one year. These were tests with alternate immersion in a 3% solution of NaCl (specimens in the form of a loop of sheet metal 1.5 mm thick and a 7.5 x 80-mm fork cut crossgrain from an extruded strip).

Technological data. Alloys AD, AD1, AMts, AMg1, AMg2, AMg3, AMg4, AMg5V, and AMg6 are not strengthened by heat treatment. In addition to alloying, sheets and plates are cold-hardened during rolling. The stronger the alloy and the thicker the sheet or plate, the more difficult it is to accomplish cold-hardening. Alloys AD, AD1, AMts, AMg1, AMg2, AMg3 are highly plastic in the annealed state and show medium plasticity in the half-cold-hardened state and low plasticity in the cold-hardened state. Alloys AD, AD1, AMts, AMg1, AMg2 are annealed at temperatures of 350-410° and cooled in air. Alloy AMg3 is annealed at 270-280° and cooled in air; the forging and stamping temperature is 450-480°.

The plasticity of alloys AMg5V and AMg6 in the annealed state is good, but they have a tendency to rapid hardening and loss of plasticity during deformation. The plasticity is low in the cold-hardened state. If difficulties arise in flanging for welding, it is recommended

TABLE 3

Typical Mechanical Properties of Corrosion-Resistant Alloys at 20°*

Сплав A	B Состояние материала	$\sigma_{0,2}$	σ_b	δ_{10}	ψ	D $\tau_{ср}$	НВ	σ_{-1}
		C (кг/мм²)		(%)		E (кг/мм²)		
F АДН, АД1Н	Нагартованный	10	15	6	60	—	32	4,2—6,3 *
H АДМ, АД1М	Отожженный	3	6	35	80	5,5	25	3,5 *
J АМцН	Нагартованный	18	22	5	50	11	55	7,0 *
K АМцП	Полунагартованный	13	17	10	55	10	40	6,5 *
M АМцМ	Отожженный	5	13	23	70	8	30	5,0 *
N АМг1	То же	5	12	27	—	—	—	6 *
АМг2	Полунагартованный	21	25	6	—	15	60	12,5 *
АМг2	Отожженный	8	19	23	64	12,5	45	12 *
АМг3	То же	10	24	20	—	—	—	—
АМг4	»	13	28	17	—	—	—	—
АМг5В	»	16	30	17	25	—	—	13 *
АМг6	»	17	34	15	25	21	—	12 *
Q АД31Т1	Закаленный и искусственно состаренный	21	24	10	50	—	80	9 *
S АД31Т	Закаленный и естественно состаренный	8	17	20	—	—	—	—
U АД31М	Отожженный	5	9	25	—	—	—	—
V АД33Т1	Закаленный и искусственно состаренный	27	32	10	25	19	—	11 *
W АД33Т	Закаленный и естественно состаренный	13	23	20	—	—	—	—
X АД33М	Отожженный	5	13	23	—	—	—	—
Y АД35Т1	Закаленный и искусственно состаренный	30	36	9	—	—	—	—

[1] For all alloys, E = 7000-7200 kg/mm^2; G = 2700 kg/mm^2.

[2] The endurance limit was determined in bending of a rotating specimen, N = 5 × 10^8 cycles. In the case of a cold-hardened material, σ_{-1} depends on the degree of cold-hardening.

[3] Base 2 × 10^7 cycles.

A) Alloy; B) state of material; C) (kg/mm^2); D) τ_{sr}; E) (kg/mm^2); F) ADN, AD1N; G) cold-hardened; H) ADM, AD1M; I) annealed; J) AMtsN; K) AMtsP; L) half-cold-hardened; M) AMtsM; N) AMg1; O) same; P) half-cold-hardened; Q) AD31T1; R) tempered and artificially aged; S) AD31T; T) tempered and naturally aged; U) AD31M; V) AD33T1; W) AD33T; X) AD33M; Y) AD35T1.

TABLE 4

Influence of Temperature on the Mechanical Properties of Annealed AMtsM Alloy Sheets

A Температура испытания (°C)	Свойства после 30-минутной выдержки B	
	C σ_b (кг/мм²)	δ_{10} (%)
−196	17,5	54
20	12,0	31
100	9,5	36
150	8,5	39
175	7,5	41
200	7,0	41
250	5,5	43
300	4,5	45

A) Test temperature (°C); B) properties after 30 minutes' holding; C) σ_b (kg/mm²).

TABLE 5

Mechanical Properties in Tension of Annealed AMg1 Alloy Sheets, Including Welded Joints

Свойства A	B Температура испытания (°C)							
	−196	−70	+20	+100	+150	+200	+250	+300
σ_b (кг/мм²) C	20–25	11–16	9–13	8–13	7–13	6–10	4–8	3–6
δ (%)	45–50	35–40	25–30	25–30	30–32	40–45	55–60	65
σ_b сварного соединения (кг/мм²) D	–	–	8,0	8,0	7,0	6,0	4,0	–

A) Property; B) test temperature; C) σ_b (kg/mm²); D) σ_b of welded joint (kg/mm²).

TABLE 6

Mechanical Properties of AMg2 Alloy Sheet at Low and Elevated Temperatures (δ = 2 mm)

Свойства A	B Температура испытания (°C)							
	−196	−70	20	100	150	200	250	300
σ_b (кг/мм²) C	31	20	19	17	15	13	11	7
$\sigma_{0,2}$ (кг/мм²)	–	–	8	8	7	6	–	–
δ (l=11,3 $\sqrt{F}$) (%)	30	38	23	26	35	51	62	75

A) Properties; B) test temperature (°C); C) (kg/mm²).

TABLE 7

Mechanical Properties in Tension of AMg3 Alloy Sheets, Including Welded Joints

Свойства A	B Температура испытания (°C)									
	−193	−7[illegible]	−50	+20	+10[illegible]	+150	+200	+250	+300	+350
$\sigma_{0,2}$ (кг/мм²) C	10,0	9,[illegible]	9,5	16,0	16,0	10,0	9,0	7,0	6,0	3,5
σ_b (кг/мм²) C	53,0	23,0	22,5	23,5	23,0	19,5	14,0	8,0	6,5	4,0
δ_4 (%)	43,0	29,0	25,0	22,0	22,5	44,0	52,0	73,0	89,0	102,0
σ_b сварного соединения (средняя) (кг/мм²) D	29,0	24,0 (−100°)	23,0	22,5	22,0	–	13,5	–	6,5	1,9

A) Property; B) test temperature (°C); C) (kg/mm²); D) δ_b of welded joint (average) (kg/mm²).

TABLE 8

Mechanical Properties of 2.0-mm AMg5V Alloy Sheets, Including Welded Joints, at Low and High Temperatures

Свойства A	B Температура испытания (°C)							
	−193	−100	−50	+20	+100	+200	+300	+400
$\sigma_{0,2}$ (кг/мм²)	17.0	16.0	15.0	15.0	13.5	12.0	7.5	2.0
σ_b (кг/мм²) C	42.0	31.0	31.0	31.0	29.5	16.5	8.0	2.5
δ_5(%)	41.5	35.0	31.0	27.5	42.5	62.5	100	100
σ_b сварного соединения (кг/мм²) D	39.0	29.3	28.5	28.0	28.0	18.0	8.7	3.6

A) Property; B) test temperature (°C); C) (kg/mm^2); D) σ_b of welded joint (kg/mm^2).

TABLE 9

Mechanical Properties of AMg6 Alloy Semifinished Products at Elevated Temperature

Свойства A	B Материал	C Температура испытания (°C)					
		20	100	150	200	250	300
σ_b (кг/мм²) D	Лист E	32	30	25	19	16	13
	Профиль F	35	31	—	20	17	—
$\sigma_{0,2}$ (кг/мм²) D	Лист	17	15	13	12	10	8
	Профиль	18	16	—	14	12	—
δ_{10}(%)	Лист	24	31	37	45	45	48
	Профиль	18	20	—	30	35	—
E (кг/мм²) D	Лист	6800	6200	5800	5550	5200	4600
	Профиль	7000	6100	—	5700	5500	—

A) Property; B) material; C) test temperature (°C); D) (kg/mm^2); E) sheet; F) profile.

TABLE 10

Mechanical Properties of AD31T1 Alloy Extruded Rods and Rolled Sheet (tempered and Artificially Aged) at Various Temperatures

Температура испытания (°C) A	$\sigma_{0,2}$	σ_b	δ_{10}
	(кг/мм²) B		(%)
−70	—	25	11
100	13	19	13
150	14	17	15
200	13	15	12
250	9	11	8

A) Test temperature (°C); B) (kg/mm^2).

TABLE 11

Mechanical Properties of AD33 Alloy Sheets and Profiles (Tempered and Artificially Aged) at Various Temperatures

A Температура испытания (°C)	B Время выдержки при температуре испытания (часы)	$\sigma_{0,2}$		σ_b		δ_{10}		ψ
		Профиль C	Лист D	Профиль C	Лист D	Профиль C	Лист D	Профиль C
		(кг/мм²) E				(%)		
−70	—	—	—	35	30	14	22	30
100	0.5	—	21	—	26	—	14	—
	100	—	21	—	26	—	15	—
150	0.5	20	16	24	21	11	15	50
	100	20	—	24	21	11	17	50
200	0.5	15	17	20	19	11	17	35
	100	15	16	18	18	11	15	37
250	0.5	—	12.5	—	14	—	18	—
	100	—	8	—	9.5	—	—	—
300	0.5	8	7	9	8	8	11	70
	100	4.5	—	6	5.5	25	60	80

A) Test temperature (°C); B) Holding time at test temperature (hours); C) profile; D) sheet; E) (kg/mm^2).

that this operation be carried out with backing block or heater. Finished and semifinished products of alloys AMg5V and AMg6 takes place at temperatures between 310 and 335° with cooling in air. Annealing at temperatures above 350° increases the tendency of these alloys to corrode under stress and is severely detrimental to the corrosion resistance after supplementary heating cycles (in manufacture or operation, including solar heating in southern latitudes) in the temperature range from 60-200°. After annealing at a temperature of 310-335°, the material is not sensitive to corrosion under stress. The heating temperature for forging and stamping is 460°. In forging, it is necessary to cool the surface of the blank to a temperature of 400-420° and then to forge with a small reduction.

Alloys AD31, AD33 and AD35 are hardened by heat treatment. They are quenched from 520° ± 5°, cooled in water at room temperature and aged naturally at room temperature (AD31T, AD33T) or artificially at 160° for 12 hours (AD31T1) and 16 hours (AD33T1). For the most part, hardening of alloys AD31, AD33 and AD35 in natural aging is complete after the first two days.

TABLE 12

Fatigue and Creep Limits* of AD33 Alloy Profiles and Sheets

A	σ_b	$\sigma_{0.2}$	$\sigma_{0.2/50}$
	B Лист		Прессованный профиль C
125	—	—	21
150	21	15	—
200	15	11	—

*In kg/mm^2.

A) Test temperature (°C); B) sheet; C) extruded profile.

Alloys AD31, AD33 and AD35 show the highest strength characteristics after artificial aging. Concerning weldability, see the article on Weldable aluminum shaping alloys. In the annealed state, alloys AD, AD1, AMts, AMg1, AMg2, AD31, AD33, AD35 machine unsatisfactorily; alloys AD, AD1, AMts, AMg1, AMg2 machine satisfactorily in the cold-hardened state, and alloys AD31, AD33, AD35 in the naturally and artificially aged states. Alloy AMg3 machines satisfactorily; alloys AMg5V

TABLE 13

Corrosion Resistance of AD31, AD33, AD35 and AV Alloy Extruded Semifinished Products*

Сплав 1	Состояние материала 2	3 Механические свойства до коррозии 4		6 после коррозии		Потери механич. свойств в результате коррозии 7	
		σ_b (кг/мм²) 5	δ (%)	σ_b (кг/мм²) 5	δ	$\Delta\sigma_b$	Δδ
					(%)		
АД31 8	9 Естественно состаренный	16,3	16,5	16,3	16,5	0	0
	10 Искусственно состаренный	23,6	12,5	23,6	12,5	0	0
АД33 11	9 Естественно состаренный	26,2	25,3	26,2	25,5	0	1,1
	10 Искусственно состаренный	30,4	17,3	30,1	16,8	0,9	2,3
АВ 12	9 Естественно состаренный	22,7	28,9	25,16	27,3	0	5,5
	10 Искусственно состаренный	32,3	14,4	29,7	5,7	8,02	60,5
АД35 13	9 Естественно состаренный	32,2	18,9	34,1	17,9	0	4,5
	10 Искусственно состаренный	40,7	13,3	40,4	11,3	0,7	15,0

*The medium was a 3% aqueous solution of NaCl + + 0.1% H_2O_2; the test lasted 3 months with complete immersion.

1) Alloy; 2) state of material; 3) mechanical properties; 4) before corrosion; 5) (kg/mm^2); 6) after corrosion; 7) loss of mechanical properties due to corrosion; 8) AD31; 9) naturally aged; 10) artificially aged; 11) AD33; 12) AV; 13) AD35.

TABLE 14

Results of One-Year Test of AD31 Alloy in the Atmosphere of an Industrial District

1 Вид полуфабриката 3	До коррозии 2		4 После коррозии		Потери механич. 5 св-в	
	σ_b (кг/мм²)	δ (%) 3	σ_b (кг/мм²)	δ	$\Delta\sigma_b$	Δδ
				(%)		
6 Листы	26,6	14,7	26,5	13,6	0,3	7,4
7 Профиль	24,4	17,6	24,6	16,5	0	6,2

1) Form of semifinished product; 2) before corrosion; 3) (kg/mm^2); 4) after corrosion; 5) loss of mechanical properties; 6) sheet; 7) profile.

TABLE 15

Physical Properties

Сплав	γ (г/см³)	ρ (20°) (ом·мм²/м)	λ (кал/см·сек·°С)	α·10⁶ (1/°С)	c (кал/г·°С)
АД1, АД	2,71	59% (АМ)* 57% (АН)** (уд. электропроводность в % от электропроводности меди)	0,52 (20°) АН** 0,54 (20°) АМ*	22 (от −50 до +20°) 25,6 (20–300°)	–
АМц	2,73	40% (АМцН) 41% (АМцП) 50% (АМцМ) (уд. электропроводность в % от электропроводности меди)	0,43 (25°) 0,45 (400°) (АМцМ)	21,6 (от −50 до +20°) 25,0 (20–300°)	0,26 (100°) 0,31 (400°)
АМг1	2,7	0,0341	0,44 (25°) 0,45 (400°)	24,3 (20–200°) 26,2 (20–400°)	0,22 (100°) 0,26 (400°)
АМг2	2,68	0,0476	0,37 (25°) 0,40 (400°)	22,2 (от −50 до +20°) 25,8 (20–300°)	0,23 (100°) 0,26 (400°)
АМг3	2,67	0,0496	0,35 (25°) 0,38 (400°)	23,5 (20–100°) 26,1 (20–400°)	0,21 (100°) 0,25 (400°)
АМг5В	2,65	0,0640	0,29 (25°) 0,35 (400°)	–	0,22 (100°) 0,26 (400°)
АМг6	2,64	0,0710	0,28 (25°) 0,33 (400°)	24,7 (20–200°) 26,5 (20–400°)	0,22 (100°) 0,26 (400°)
АД31	2,71	0,0344	0,45 (25°) 0,45 (400°)	24,3 (20–200°) 26,7 (20–400°)	0,22 (100°) 0,25 (400°)
АД33	2,71	0,0438	0,34 (25°) 0,41 (300°)	24,1 (20–200°) 25,0 (20–300°)	0,225 (100°) 0,25 (300°)
АД35	2,69	0,038	0,44 (25°)	24 (20–200°)	0,21 (100°)

*AM – soft aluminum.
**AN – cold-hardened aluminum.

1) Alloy; 2) γ (g/cm^3); 3) ρ (20°) (ohms•mm^2/m); 4) λ (cal/cm•sec•°C); 5) c (cal/g°C); 6) AD1, AD; 7) (conductivity in % of conductivity of copper); 8) 22 (from −50 to +20°); 9) AMts; 10) (AMtsN); 11) (AMtsP); 12) (AMtsM); 13) AMg1; 14) AMg2; 15) AMg3; 16) AMg5V; 17) AMg6; 18) AD31; 19) AD33; 20) AD35.

TABLE 16

Influence of Pause Between Tempering and Artificial Aging on Mechanical Properties of Alloys AD31 and AD33

Продолжительность перерыва (часы)	σ_b (кг/мм²)			$\sigma_{0,2}$ (кг/мм²)			δ (%)		
	АД31	АД33	АД35	АД31	АД33	АД35	АД31	АД33	АД35
0,25	27,5	31,2	41,0	24,8	28,0	38,9	10,7	11,6	12,0
0,5	27,6	31,0	—	25,1	28,0	—	12,0	11,9	—
1	27,2	30,7	—	24,6	27,5	—	10,0	11,6	—
2	26,9	30,8	38,4	23,9	27,5	34,9	11,5	12,9	13,8
4	25,4	30,1	37,8	21,9	27,0	33,8	11,6	13,1	13,7
8	24,5	29,2	37,3	20,0	26,1	33,5	12,6	13,1	13,8
48	25,1	27,5	37,2	20,7	23,2	32,9	13,1	15,1	14,0
240	24,5	27,7	37,0	20,5	23,0	33,0	13,3	15,0	14,0

A) Duration of pause (hours); B) (kg/mm^2); C) AD31.

and AMg6 machine well.

Alloys AD31, AMg1 and AMg2 take a particularly good polish and are excellent decorative materials.

Note. Alloys AD, and AD1 (technical aluminum) are used in structural elements that do not carry loads and require a material with high plastic properties, good weldability, high corrosion resistance and high thermal and electrical conductivity. Alloys AMg1, AMg2, AD31, AMg4 are distinguished by high corrosion resistance, good decorative appearance, and excellent polish; they are used in lightly and medium-loaded welded and riveted structures (including those requiring deep drawing of the material). These alloys, as well as AD and AD1, are used to make pipes for various purposes, grillwork, interior partitions, electrical conductors, doors, window frames, watch cases, jewelry items, deck superstructures on seagoing and river vessels, siding, bezels, tanks, etc. Alloys AMts and AMg3 are used for lightly stressed welded-up structures (including those requiring deep drawing of the material), when they must show high corrosion resistance (for example, in tanks for storage of gasoline and kerosene); alloys AMg5V and AMg6 are used in medium-loaded welded and riveted structures requiring high corrosion

resistance of the material; alloys AD33 and AD35 are found in medium-loaded, usually riveted or bonded structures requiring higher yield points and high resistance to corrosion and corrosion fatigue.

Thus, alloy AD33 is used to make helicopter blades; alloys AD33, AD35, AMg5V and AMg6 are used for the frames and passenger compartments of railroad cars, welded tanks, suspended load-bearing ceilings, interior partitions in buildings and bulkheads in ships, utility poles, pipelines, excavator booms, elevators, certain assemblies in cranes and drilling derricks, hulls and masts of ships, etc.

References: Voronov, S.M. Izbrannyye trudy po legkim splavam [Selected Works on Light Alloys], Moscow, 1957; ——, Protsessy uprocheniya splavov alyuminiy – magniy – kremniy i ikh novyye promyshlennyye komtsozitsiy [Hardening Processes of Aluminum-Magnesium-Silicon Alloys and Their New Industrial Compositions], Moscow, 1946. Edel'man, N.M., Alyuminiyevyye splavy v grazhdanskom stroitel'stve [Aluminum Alloys in Civil Engineering], in book entitled: Stroitel'nyye konstruktsii iz alyuminiyevykh splavov [Aluminum Alloy Structures], edited by S.V. Taranovskiy, Moscow, 1962; Fridlyander, I.N., Sovremennyye alyuminiyevyye splavy [Modern Aluminum Alloys], ibid., Legkiye splavy. Metallovedeniye termicheskaya obrabotka, lit'ye i obrabotka davleniyem [Light Alloys. Physical Metallurgy, Heat Treatment, Casting and Mechanical Working], collection of articles, Moscow, 1958; Deformiruyemyye alyuminiyevyye splavy [Aluminum Shaping Alloys], collection of articles edited by I.N. Fridlyander [et al.], Moscow, 1961.

I.N. Fridlyander

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[Transliterated Symbols]

1043 САП = SAP = spechennaya alyuminiyevaya pudra = sintered aluminum powder

1046 ТУ = TU = tekhnicheskiye usloviya = technical specifications

1048 УЗ = UZ = ul'trazvukovoy = ultrasonic

1051 ср = sr = srez = shear

1056 АМ = AM = alyuminiy myagkiy = soft aluminum

АН = AN = alyuminiy nagartovannyy = coldhardened aluminum

CORROSION-RESISTANT CAST IRON – is a cast iron with a high chemical resistance to aggressive media, such as acids, alkalis, and other active fluids. Corrosion-resistant iron belongs to the group of alloyed irons; the latter are alloyed with elements which are capable of forming solid solutions or chemical compounds with a high electrode potential, which enter into the iron-base; with elements which are capable of forming a compact corrosion-resistant (passivating) film on the surface of the object; or with elements which improve the precipitation of the carbon in the iron structure in a bound state, i.e., as carbides. The corrosion resistant iron may be a low-alloy one, such as white and gray iron with lamellar graphite, or a high-alloy gray iron with lamellar or spheroidal graphite.

The corrosion-resistant iron grades F15 and F17 do not resist hydrochloric and hot hydrofluoric acids, hot concentrated alkali hydroides, Na_2CO_3 solutions and boiling $Na_2S_2O_3$ solution; the cast iron grades Kh28L and Kh34L do not resist hydrochloric and sulfuric acids of low and medium concentration, hydrochloric and sulfuric acids of low and medium concentration, hydrofluoric acid, highly concentrated alkali hydroxides at high temperatures, nor iron chloride. The corrosion-resistant grades F15 and F17 resist sulfuric and nitric acids up to the boiling point of the latter, and other mineral acids. These iron grades are also resistant to moist chlorine, carbon sulfide, hydrocyanic acid, solutions of ammonium chloride, aldehydes and other aggressive media. They are irreplaceable by other materials in the case of contact with hydrogen.

Castings of gray corrosion resistant iron with spheroidal graphite are less resistant to alkalis than castings of low-alloy iron of the SChSh-1 and SChSh-2 grades due to the tendency of the former to form intercrystalline cracks.

High-nickel-alloy corrosion-resistant iron with austenitic structure of the Ni-Resist type is characterized by a high corrosion resistance, heat resistance and scale resistance. The castings are made of gray Ni-Resist iron with lamellar or spheroidal graphite.

Corrosion-resistant iron of the ZhChNDKh15-7-2 is used for parts of chemical equipment working in solutions and fluids heated up to 400°; the Ni-Resist of type 2 is used for parts working under conditions at which a contamination by copper must be avoided (for parts of chemical equipment in alkaline medium or in ammonia solutions, equipment of food industry, aggregates for the production of synthetic fibers and plastics); the Ni-Resist of the type 3 is used for parts working under greatly varying temperatures.

Gray high-nickel corrosion-resistant iron with spheroidal graphite of the types 2 and 3 is used for parts exposed to the action of corrosion, erosion, cavitation and wear in the media of moist steam, aggressive water and fluids containing aggressive components and suspended abrasive particles; type 3 is used in the case of exhibition to corrosion and wear; type 4 is used for parts with an increased resistance to corrosion, erosion and oxidation.

TABLE 1

Chemical Composition of Corrosion-Resistant White and Gray Iron with Lamellar Graphite

1	2	3	4						6
			C	Si	Mn	S	P	Cr	Ni	
7 8 9						5				
10	Ф15	15								
	Ф18									
11	МФ15	16								
12	Х25Т	17								19
	Х18Л									
	Чугаль	18								

1) Corrosion medium; 2) cast iron; 3) GOST; 4) percentage of elements; 5) not more than; 6) other elements: 7) alkalis; 8) the same; 9) acids, especially hydrochloric acid (10%), 10) sulfuric acid; 11) hydrochloric acid; 12) nitric acid; 13) nitric acid and sea water; 15) F..; 16) MF..; 17) Kh..L; 18) Chugal'; 19) up to.

TABLE 2

Mechanical Properties of Corrosion-Resistant White and Gray Iron with Lamellar Graphite

1	2	3	4	5
Чугун				
Ф15				
Ф18	5			
МФ15				
Х25Т	16			
Х18Л	17			
Чугаль				

Chugal' see Aluminum cast iron.

*Diameter of the specimen = 30 mm.

1) Cast iron; 2) (kg/mm^2); 3) f_{600}*(mm); 4) without notch (kgm/cm^2); 5) F..; 6) MF..; 7) Kh..L.

TABLE 3

Physical Properties of Corrosion-Resistant White and Gray Iron with Lamellar Graphite

Чугун 1	Линейная усадка (%) 2	α·10⁶ при 20–200° (1/°C) 3	γ (г/см³) 4
Ф15 5	1,7–2,3	11–12	6,85–6,95
Ф17 5	1,7–2,3	11–12	6,8–6,9
МФ15 6	2,0	11–12	6,9–7,0
Х[illegible]Л 6	1,5–1,8	2,4–10	7,4
Х[illegible]Л 7	1,4–1,8	13–14	6,4–6,7
Чугаль 8			

1) Cast iron; 2) linear shrinkage; 3) $\alpha \cdot 10^6$ at 20-200° (1/°C); 4) (g/cm^3); 5) F..; 6) MF..; 7) Kh..L; 8) Chugal'.

TABLE 4

Chemical Composition of Corrosion-Resistant Gray Iron of the Ni-Resist Type with Lamellar Graphite

Чугун 1	Содержание элементов (%) 2					
	C	Si	Mn	Ni	Cu	Cr
3 ЖЧНДХ15-7-2 (ГОСТ 7769–55)	2,5–3,0	1,5–3,0	0,5–1,2	14–17	6–8,5	1,5–2,5
2 (США) 4	до 3,0	1,0–2,5	0,8–1,5	18–22	до 0,5	1,75–2,5
3 (США) 4	до 2,6	5,5–6,5	0,4–0,8	29–32 5	до 0,5	4,5–5,5

1) Cast iron; 2) percentage of elements; 3) ZhChNDKh15-7-2 (GOST 7769-55); 4) (U.S.).

TABLE 5

Mechanical Properties of Corrosion-Resistant Gray Iron of the Ni-Resist Type with Lamellar Graphite

Чугун 1	$\sigma_в$	σ_{-1}	НВ	σ_{-1}
	2 (кг/мм²)			
3 ЖЧНДХ 15-7-2	21–27	–	130–150	–
2 (США) 4	17,6–21,1	70,3–84,4	130–160	8,4
3 (США) 4	17,6–24,6	56,1	150–180	6,3

1) Cast iron; 2) (kg/mm^2); 3) ZhChNDKh15-7-2; 4) (U.S.).

TABLE 6

Chemical Composition of Corrosion-Resistant Gray Iron of the Ni-Resist Type with Spheroidal Graphite

Чугун 1	C 3 (макс.)	Содержание элементов* (%) 2 Si	Mn	Ni	Cr
2(США)	3.0	1.75–3.0	0.7–1.0	18–22	1.75–2.5
3(США)	2.6	1.5–2.0	до 0.5	29–32	1.0–1.5
4(США)	2.6	5–6	до 0.5	29–32	4.5–5.5

*The copper content must not surpass 3% (which promotes the formation of spheroidal graphite).

1) Cast iron; 2) percentage of the elements*; 3) maks; 4) (U.S.).

TABLE 7

Mechanical Properties of Corrosion-Resistant Gray Iron of the Ni-Resist Type with Spheroidal Graphite

Чугун 1	σ_b	$\sigma_{0,2}$	HB	δ_{10} (%)
	2 (кг/мм²)			
2 (США)	38–48	22–25	140–200	8–20
3 (США)	38–45	22–27	13–18	140–200
4 (США)	42–50	26–30	130–190	1.5–4

3

1) Cast iron; 2) (kg/mm^2); 3) (U.S.).

TABLE 8

Physical Properties of Corrosion-Resistant Gray Iron of the Ni-Resist Type with Spheroidal Graphite

Чугун 1	α·10⁶ 20–200° (1 °C)	γ (г/см³) 2	λ кал/см·сек·°C 3	ρ (ом·мм²/м)	μ (при H = 10–300 э) 4 5
2 (США)	18.7	7.41	0.032	102	1.02–1.64
3 (США)	12.6	7.45	—	—	40.0
4 (США)	14.4	7.45	—	—	1.10

6

1) Cast iron; 2) (g/cm^3); 3) cal/cm·sec·°C; 4) microohms/cm; 5) (at H = 10-300 oersted); 6) (U.S.).

References: Girshovich, N.G., Sostav i svoystva chuguna [Composition and Properties of Cast Iron], in the book: Spravochnik po chugunnomu lit'yu [Handbook on Iron Casting], 2nd Edition, Moscow-Leningrad, 1960; "Foundry Trade J.," 1960, Vol. 108, No. 2251, pages 103-106; Hall, A.M., Nikel' v chugune i stali [Nickel in Cast Iron and Steel], translated from English, Moscow, 1959; Everest, A.B. and Nickel, O., "Foundry Trade J.," Vol. 108, No. 2265, pages 515-522; Grilliat J. and Poirot, R., "Fonderie," 1960, No. 178, pages 449-461.

A.A. Simkin

CORROSION RESISTANT WROUGHT BRASS is brass containing 60-91% Cu and one or more alloying components. These brasses have higher corrosion resistance than the simple (binary) brasses and are easily pressure worked (see Special Brass). The additives which improve the corrosion resistance of the brasses are: aluminum, manganese, silicon, nickel, tin and arsenic.

Aluminum (see Aluminum Brass) improves the corrosion resistance of the brasses in atmospheric conditions, sea and fresh water. The addition of nickel and iron to the aluminum-bearing corrosion resistant brasses improves their corrosion resistance and strength. The following types of aluminum-bearing corrosion resistant brasses are produced: LA85-0.5, LA77-2, LAZh60-1-1, LAN59-3-2. The ultimate strengths of these brasses in the annealed condition are 38-50 kg/mm^2 and in the work hardened condition (50%) are 58-70 kg/mm^2, the relative elongations are 40-55 and 8-12% respectively. The type LA85-0.5 corrosion resistant brasses with high copper content are used for the fabrication of signs, furniture and artistic products; LA77-2 is used for condenser tubes. LAZh60-1-1 is used for the fabrication of tubes and rods for high-strength details operating in sea water. LAN59-3-2 has very high strength and corrosion resistance and is used for corrosion-resistant, high-strength details used in ocean-going ship construction, electrical machinery construction and chemical apparatus.

Manganese (see Manganese Brass) improves the resistance of the brasses to the action of sea water, chlorides and super-heated steam. In combination with aluminum and iron, manganese also improves the

strength of the brasses. The mechanical properties of the types LZhMts59-1-1, LMts58-2 and LMtsA57-3-1 corrosion-resistant wrought brasses containing manganese are: ultimate strength 45-60 kg/mm^2, relative elongation 40-60% (GOST 1019-47). The LZhMts59-1-1, LMts58-2 and LMtsA57-3-1 brasses are used for the fabrication of tubes, sheet, strip and rods. The nonstandard LNMtsZhA60-1-2-1-1 brass containing (58-62% Cu, 0.5-1.5% Ni, 1.5-2.5% Mn, 0.5-1.1% Fe and 0.5-1% Al), which is characterized by high corrosion resistance in fresh and sea water is also produced. This brass replaces the bronzes and brasses with high copper content and can be produced from the secondary copper alloys; it is used for the fabrication of details in ocean vessel construction.

Silicon (see Silicon Brass) improves the corrosion resistance of the brasses in sea water and atmospheric conditions and also increases the resistance to corrosion cracking. The standard LK80-3 and nonstandard LKS65-1.3-3 (63.5-66.5% Cu, 1-2% Si, 2.5-3.5 Pb) silicon corrosion-resistant wrought brasses are produced. The latter is easily pressure worked and has high antifriction properties. The LK80-3 brass is used primarily for the fabrication of forged and stamped details. The mechanical properties of the LK80-3 brass are: ultimate strength 30-50 kg/mm^2, relative elongation 15-40%.

Nickel (see Nickel Brass) improves the corrosion-resistance of the brasses in atmospheric conditions and in sea water and somewhat improves the resistance to dezincification. The standard brass LN65-5 is produced which has high corrosion-resistance and high mechanical properties (ultimate strength 38-70 kg/mm^2 and relative elongation 4-60%). It is used for the production of sheet, strip, ribbon, tubes, rods and shapes. It is used for condenser tubes, manometer tubes and sieves for paper making machines.

Tin improves the corrosion resistance of the brasses in sea and

fresh water, as the result of which they have received the name of naval brasses. Four grades of these brasses containing tin are produced in accordance with GOST 1019-47; L090-1, L070-1, L062-1 and L060-1. The mechanical properties of the tin brasses (see Naval Brass), depending on the zinc content, are: ultimate strength in the annealed condition from 28 to 35 kg/mm^2 and in the work hardened condition from 45 to 65 kg/mm^2, while the relative elongations are 40-60% and 8-12%, respectively. The L090-1 brass is used for the fabrication of strip and ribbon used for antifriction details which require good corrosion-resistance. The L070-1 brass is intended primarily for the fabrication of condenser tubes, thermal engineering apparatus, etc. The L062-1 brass is delivered in the form of sheet, strip and rods and is intended for all types of details used in ocean vessel construction. The L060-1 brass is used in the form of wire and thin rods for welding various structures in ship construction.

Arsenic in amounts up to 0.05% increase by several fold the resistance to dezincification of the brasses having high zinc content (over 20%).

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

Ye.S. Shpichinetskiy

CORUNDUM MICROLITE – is sintered corundum of microcrystalline structure with high physico-chemical properties. The method of production was developed in the USSR in 1950. Characteristics of corundum microlite technology are: 1) grinding the α-modification of technical alumina to an average grain size of 0.5-0.75 microns; 2) introduction of a modifier (0.6-1% magnesium oxide) into the ground alumina with subsequent plasticizing of the mixture and formation of the parts; 3) sintering of the products at 1750° and brief anneal with soak for 5-10 minutes in the region of the temperature maximum. Properties of sintered corundum of various types are given in Table 1. Table 2 presents a comparison of the properties of corundum microlite and other tool materials.

TABLE 1

1 Тип материала	2 Содержание Al_2O_3 (%)	3 Размер кристаллов (мк)	4 Объемный вес ($г/см^3$)	5 Предел прочности ($кг/мм^2$) при 6 изгибе	при 7 сжатии
8 Зинтеркорунд	99.6	—	3.7	12	50
9 То же	99.6	20–50	—	—	—
•	99.5	12–25	3.6–3.9	30	300
10 Термокорунд	99.0	10–30	3.75	20	150
11 Микролит	92.2	1–3	3.92–3.96	45–55	350 – 500

1) Material type; 2) content of Al_2O_3 (%); 3) crystal size (microns); 4) volumetric weight (g/cm^3); 5) ultimate strength (kg/mm^2); 6) in bending; 7) in compression; 8) Zintecorundum; 9) same; 10) Thermocorundum; 11) microlite.

TABLE 2

1 Материал	2 Твердость по Роквеллу (шкала А)	3 Прочность при изгибе	4 Прочность при сжатии	5 Красностойкость (°С)	6 Теплопроводность (кал/см·сек·°С)	Коэф. линейного расширения α·10⁷ (20–800°)
		4 (кг/мм²)				
8 Микролит	92–93	45–55	350–500	1200	0,042	85
9 Твердый сплав:						
ВК8	88	130	330	850	0,14	60
Т15К6	90	110	400	850	0,065	50
Т60К6	91	90	400	900	--	—
10 Быстрорежущая сталь Р-18	83	170	380	600	0,05	110

1) Material; 2) rockwell A hardness; 3) bending strength; 4) compression strength; 4') kg/mm^2); 5) red hardness (°C); 6) thermal conductivity (cal/cm-sec-°C); 7) coefficient of linear expansion $\alpha \cdot 10^7$ (20-800°); 8) microlite; 9) hard alloy; 10) high-speed steel R-18.

TABLE 3

1 Материал	2 Твердость по Роквеллу (шкала А) при температуре (°С)						3 Снижение твердости (%) при 1000°
	20	400	600	800	900	1000	
4 Микролит	92	87,5	85,5	84	83	82	10,8
5 ВК2	90	85,5	83,5	81	78	75	16,6
ВК3	87,5	83	79	73	67	62	29,1
Т15К6	90	83,5	81	76	73	70	22,1
Т30К4	92	85	81,5	79	75	73	20,6

1) Material; 2) rockwell A hardness at temperature (°C); 3) reduction of hardness (%) at 1000°; 4) microlite; 5) VK.

TABLE 4

Инструментальный материал 1	2 Относительная режущая способность (%) при стойкости		
	15 мин. 3	30 мин 3	60 мин. 3
Т15К6	100	100	100
Т60К6	160	155	150
4 Микролит	190	185	175

1) Tool material; 2) relative cutting capability (%) with durability; 3) 30 minutes; 4) microlite.

TABLE 5

Деталь 1	2 Операция	Количество деталей, обрабатываемых за 8 часов 3	
		твердым сплавом 4	микролитом 5
6 Червяк	7 Черновая обработка поковки по верху	9	18
8 Шпиндель	9 Черновая обработка	17	22—25
10 Вал	Проточка после закалки ($RC = 45-50$)	6	18—20
12 Ось	13 То же	10	35
14 Шкив	15 Торцовая проточка и прорезка канавок	22	40

1) Part; 2) operation; 3) number of parts machined in 8 hours; 4) by hard alloy; 5) by microlite; 6) worm; 7) rough surface machining of forgining blanks; 8) spindle; 9) rough machining; 10) shaft; 11) turning after tempering (RC = 45-50); 12) axle; 13) same; 14) pulley; 15) facing and groove cutting.

TABLE 6

1 Материал вставки	2 Продолжительность службы	
	3 часы	%
4 Для стальных канатов		
5 Сталь У8	93	100
6 Микролит	2782	3000
7 Для пеньковых канатов		
5 Сталь У8	140	100
6 Микролит	3600	2500

1) Insert material; 2) service life; 3) hours; 4) for steel cable; 5) steel U8; 6) microlite; 7) for hemp cable.

TABLE 7

1 Характеристика скважины	2 Диаметр отверстия вставки (мм)	3 Срок службы штуцеров (часы)	
		стальных 4	микролитовых 5
6 Сильно песчаная	7	0.4	20.0
7 То же	12	1.5	45.0
8 Слабо песчаная	12	3.0	115.3

1) Well characteristic; 2) insert opening diameter (mm); 3) insert service life (hours); 4) steel; 5) microlite; 6) very sandy; 7) same; 8) slightly sandy.

Microlite surpasses the hard alloys in ability to retain its properties at elevated temperature (Table 3).

Under conditions of semi-finish turning of 30KhGSA steel with ultimate tensile strength σ_b = 70 kg/mm^2 and a cutoff section of 1.5·0.15 mm^2, the cutting capability of microlite cutters is higher than that of the other tool materials (Table 4).

Corundum microlite was developed for cutting metals and has been applied to the fabrication of cutting tools (cuttirs). Microlite cutters are used in the machining of constructional and alloy steels with strengths up to 160-180 kg/mm^2 and with hardness to RC = 60, and also for various irons and nonferrous metals. Best results are obtained in machining the less ductile materials. In addition to the operations of finish and semi-finish turning, roughing operations have been developed, for example machining of a worm shaft made from 40Kh steel and produced by free forging. In this case the cutting depth is 6-12 mm, feed 0.3-1.2 mm/rev, cutting speed 212-263 rpm. The use of microlite cutters improves machining productivity (Table 5).

Corundum microlite is also used to produce wear-resistant and highly refractory parts for equipment, machines and instrumetns (for example, draw plates, nozzles, fittings, lining plates, balls for mills, thread guides, insulators, gauges). Good results are obtained with use of corundum microlite to protect machines from abrasion in the production of steel and hemp cables. Table 6 gives the comparative service life of microlite and steel inserts.

Microlite sleeves (nozzles) for sandblasting and shot blasting equipment have found wide application in machine construction since their service life is 15-25 times greater than that of the steel sleeves. Thus, the average hourly wear of steel nozzles is 0.5-1.2 mm, while the figure for microlite nozzles is 0.4-0.005 mm. The service life of mi-

crolite fittings for well equipment in the oil fields is 30 times greater than that of steel fittings (Table 7).

In gauges finished with microlite the serice life of the measuring instrument is 80-100 times greater than in gauges made from carbon and alloy steels.

References: Kitaygorodskiy I.I., in book: Peredovaya tekhnologiya mashinostroyeniya (Advanced Technology in Machine Design), M., 1955, page 552; Pavlushkin N.M., Spechennyy korund (Sintered Corundum), M., 1961.

N.M. Pavlushkin

COVAR -- see Alloys for Soldering of Glass.

CREEP – residual deformation increasing with time or length of static loading. Creep may occur at a very slow rate (for example, one one hundred thousandth of a percent per hour) and can continue for months or years. For the most part, creep is studied at constant elevated temperature and constant loading (which for small strains corresponds approximately to constant stress). At nearly constant stress, creep is intimately associated with stress relaxation, and thus in certain cases these processes are interconvertible. The mathematical treatment and calculations for creep require a knowledge for the given material of the relationships connecting the stress σ, temperature $t°$ (T), strain ε_p, rate v_p, and time τ. The frequently employed relationships are: Rabotnov, $\varepsilon_p^n \dot{\varepsilon}_p = A_{(\alpha)} e^{(k\sigma - \beta/T)}$, where A, α, k, β are const; Baily $v_p = A\sigma^n$, where A and n are temperature functions; Kachanov, $v_p = B(\tau)\sigma^n$, where n is const; Malir'n $\dot{\varepsilon}_p = \psi\sigma$, where $\psi = \int_0^\tau B(\tau_1)\sigma^{n-1}(\tau_1)d\tau_1$, n is const; Nadai $v_p = A\sinh\alpha\sigma$ where and α are const. In certain cases, the hyperbolic-sine relationship may lead to an exponential relationship.

In tension, (or compression) without bending, the resultant ε = equals $\varepsilon = \sigma/E + \varepsilon_m + \varepsilon_p + \alpha t$. The first term on the right side corresponds to elastic strain and the second to rapid (nearly instantaneous) plastic deformation at the instant of load application; the third term corresponds to creep deformation, which increases with time; the fourth corresponds to thermal deformation (α is the coefficient of linear expansion, and g the temperature difference). The quantities ε_{p0} and ε_p are determined by different physical processes, and thus must be demarcated. Under conditions of steady creep, σ, t, ε_{p0}, do not depend on time so

that $d\varepsilon/d\tau = d\varepsilon_p/d\tau$, i.e., only ε_p changes with time. Calculations for creep make it possible to determine the stresses, strains, and working time under creep conditions on the basis of the properties of the given material, specified either graphically as a creep curve or by certain creep-resistance characteristics. Such calculations are usually carried out for the steady-creep stage on the assumption that $\varepsilon_p \gg \sigma/E$. Creep calculations have been made for thin-walled and thick-walled tubes and plates, rotating disks, turbine blades and diaphragms, flanges, shells, springs, shafts, etc. Creep plays a very important role for materials in steam lines, steam boilers, turbine blades, atomic-reactor components, parts of rocket and similar components subject to long periods of mechanical and thermal loading and heating. Since in most cases there is no relationship between brief ("static") tests and creep tests, evaluation of high-temperature alloys is carried out, in considerable measure, on the basis of their creep resistance.

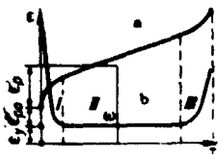

Fig. 1. Creep curves: a) Typical creep curve; b) creep rate obtained by differentiating curve a.

Creep is a strong function of temperature and stress (as these two quantities increase, the creep increases roughly exponentially), of the structure and composition of the material, and sometimes the nature of the surrounding medium. A change in temperature by 100-200° may change the creep rate by a factor of hundreds or even thousands. The basic characteristic for this process is the creep curve, which gives the experimental graphical relationship between the elongation ε (for the most part in tension) and time τ under constant load. Three stages are usual-

ly distinguished on the creep curve (Fig. 1): a first or unsteady stage where the creep rate (determined by the tangent of the slope of the curve) gradually decreases owing to strain-hardening processes; a second or steady stage of creep where the creep rate is constant (within specified limits, this stage is acceptable in operation); a third stage, accelerated creep, where the creep rate progressively increases up to complete failure of the specimen. Under service conditions, this stage generally is not acceptable. For machines with short operating lives (dozens of hours or less) working under moderate stresses, the unsteady stage plays an important role, while where service life is measured in thousands of hours or more, this stage may usually be neglected, with the principal position being occupied by the steady-creep stage, to which most calculations performed pertain. The existence of an absolute creep limit (i.e., stresses below which there is no creep for an arbitrary loading duration) has not been demonstrated. Thus the creep limit is based on acceptance of creep not exceeding a given value. At a given temperature (and sometimes for a given load duration) the creep limit is taken as the constant stress that causes deformation of a given amount (for example, 1% in 100,000 hr) or a definite deformation rate (for example, 10^{-5} % per hour). Rapid methods of determining the creep limit are usually not reliable in virtue of the varying physical-chemical and structural processes for short-term and extended loading. Many of the laws given for variation in creep resistance and ordinary mechanical properties as a function of internal and external factors differ and, on occasion, are contradictory. The creep mechanism is determined not only by displacements as in the case of any plastic deformation, but also by processes of diffusion and selfdiffusion both within grains and on grain boundaries. For certain materials (for example, titanium), creep may also be observed at room temperatures. In creep at elcvated

(oscillation). The high-temperature strength of alloys containing chemical compounds is limited, therefore, to below the eutectic temperature; above this temperature, local fluctuations in composition cause local zones of liquid phase to appear. This leads to a sharp decrease in creep resistance. The better the high-temperature properties of the alloys, the lower the limiting solubility of impurities in the base metal and the lower the peritectic temperature, the greater the decrease in high-temperature strength and creep resistance. The negative influence of impurities may be eliminated (as with the elimination of red-shortness) by the following methods: 1) purification of the metal to remove harmful impurities by vacuum and electroslag melting, electron-beam melting, and other refining processes; 2) by introduction of additives that cause the harmful impurities to associated into high-melting and strong compounds (additives of alkali and alkali-earth metals, zirconium, etc., to form strong oxides, sulfides, phosphides); 3) by a homogenizing annealing to coalesce low-melting interlayers at the boundaries into larger globules and to transfer them within a grain. The best results are yielded by a combination of these methods, for example, the excellent plasticity of chromium, molybdenum, tungsten, and niobium is attained by a combination of vacuum melting with a consummable electrode or electron beam and addition of small amounts of cerium or yttrium to remove harmful impurities. In contrast to short-term strength, creep resistance in many cases decreases as a result of deformation. Thus cold deformation by more than 3-5% reduces the high-temperature strength of types VD17, AK4-1 and other aluminum alloys. The surrounding medium may strongly affect creep; in certain cases, intergranular oxidation, leading to tears speeds up creep, while in other cases an oxidizing medium may prove favorable. As an example, for alloys containing 80% Ni + 20% Cr, at 800-1000°, a change from testing in pure

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argon to testing in air (where the creep curves coincide to the first intercrystalline cracks) may lead to a 10-fold increase in time to failure and to a 2-3-fold increase in plasticity. This fact is explained by oxidation and absorption of nitrogen by the crack surface with formation of chromium oxides, which retard or stop the crack. Increased creep resistance is very important in research on high-temperature alloys. This includes: creation in high-temperature alloys of structural components with high resistance to coagulation and dissolution, with retarded diffusion processes. This is associated with high-temperature melting and recrystallization, for example, for carbides in steels, and for aluminum oxides in SAP aluminum alloys. In cermets and similar materials, the softening processes are shifted toward higher temperatures, and good creep resistance is generally achieved at the price of poor plasticity (the impact resistance is close to zero). Mechanical and heat treatment with favorable orientation of structure (polygonization) may result in a 10-fold or better increase in service life and an increase of the order of 10% in rupture strength. Owing to creep, rods, plates, and shells, may lose stability after a certain period of time. Here in place of the critical load (the stability), the basic characteristic is the critical time or critical strain. For most products, creep conditions are not constant; allowance for this is made by creep testing at varying temperatures and stresses (so-called cyclic creep). Addition of a pulsating load to the constant load will change the creep rate.

In regions of softening (for example, at high temperatures) nonstationarity of loading will generally reduce the "service life" of the material, while in the strengthening region, the rupture strength will change little, occasionally increasing. In service, creep is accompanied by a change in structure, oxidation, consolidation of alloying ele-

ments, recovery, recrystallization, and in many cases tears near grain boundaries. These processes are particularly intensified in surface layers, and have an essential influence on lifetime and reliability of products. As an example, outside layers of nickel-chrome steel turbine blades show formations of oxides of these metals and oxidation along grain boundaries to a depth of tens of microns. Removal of the damaged surface layer considerably increases lifetime (by a factor of 2, for example, following electropolishing). For the most part, temperatures of structural elements will differ owing to intense cooling of hot portions or the temperature gradients required for heat transfer. Thus it is necessary to consider creep under conditions of nonuniform temperature, where stresses due to external loads will be subject to considerable redistribution with time: in hot zones where the creep rate is large, stresses fall, while in cooler zones they will rise, so that the nonuniform stress distribution compensates for the difference in creep rates produced by nonuniform heating. Temperature stresses, being internally compensated, decrease throughout the volume of the body and with time tend to vanish completely (Fig. 2). In creep calculations under conditions of nonuniform heating (B.F. Shorr) the following quantity is used as the fundamental creep-rate parameter: $v_p = \frac{d\varepsilon_p}{dt}$.

Then $\varepsilon_p = \int_0^t v_p(\tau_1)d\tau_1$ depends essentially not only on the values of σ and t° at a given time, but also on the "history" of variation in σ and t° with time, as reflected by the strengthening function: a) in the absence of strengthening, v_p will depend solely on the instantaneous values of σ and t°; at t° = const and σ = const, we have steady creep; b) for unlimited strengthening, v_p will drop, tending toward zero; c) with limited strengthening, terminating after some value of strain accumulation has been reached, the magnitude of accumulated creep deformation p is

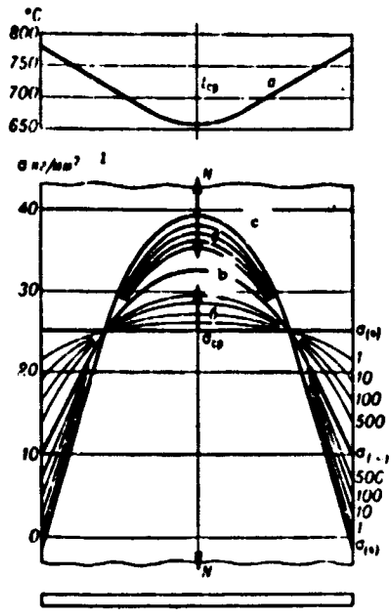

Fig. 2. Distribution of temperature (a) and stresses (b and c) over a thickness of nonuniformly heated rod in tension for various creep times: b) neglecting thermal stresses; c) with allowance for thermal stresses; the numbers on the right indicate the time in hours (B.F. Shorr).
1) σ kg/mm^2.

calculated, regardless of the sign of the creep rate, from the formula

$p = \int_0^{t_1} |v_p(t)|\,dt$, where the vertical bars indicate the absolute value of $v_p(t_1)$. Thus p always increases with time and is the fundamental characteristic of the loading "history." If the sign of v_p does not change with time, then $|\varepsilon_p| = p$.

References: Kachanov, L.M., Teoriya polzuchesti [Theory of Creep], Moscow, 1960; Kishchkin, S.T., Polyak, E.V., in the book, Issledovaniya po zharoprochnym splavam [Investigations of High-Temperature Alloys], Vol. 7, Moscow, 1961; Odnig, I.A. et al., Teoriya polzuchesti i dlitel'noy prochnosti metallov [Theory of Creep and Rupture Strength of Metals] Moscow, 1959; Zharoprochnyye splavy pri izmenyayushchikhsya temperaturakh i napryazheniyakh [High-Temperature Alloys Under Varying Temperatures and Stresses], collection of articles, Moscow-Leningrad, 1960;

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Shorr, B.F., in the book: Prochnost' i deformatsiya v neravnomernykh temperaturnykh polyakh [Strength and Deformation in Nonuniform Temperature Fields], Sb. nauchnykh rabot [Collection of Scientific Papers], Moscow, 1962.

Ya.B. Fridman

CREEPING TEST – is the test of preponderantly heatproof metals and alloys at high temperatures, in which the specimen is exposed to the action of a constant load at constant high temperature for a certain time. The monoaxial stretching is the main method of loading in the creeping test. Other kinds of load (bending, torsion) are rarely used. The deformation of the specimen is recorded (with an accuracy of not less than 0.002 mm) during the creeping test. The results of the tests of a series of specimens at a given temperature and at diverse stresses are designed in the form of so-called primary creeping curves in "time v.s. relative elongation" coordinates, after which the conditional creep limit, i.e., the stress is determined which causes a fixed (summary or residual) elongation of the specimen or a fixed creeping rate $\frac{d\varepsilon}{dt}$ on the linear section (ab in Fig. 1) of the creeping curve within a fixed test time and at the given temperature. The creeping limit is denoted by the character σ with numerals ($\sigma^{800}_{0.2/100}$, for example, is the creep limit with an allowance for a 0.2% deformation within a 100 hrs test at 800°; $\sigma^{600}_{2\cdot10^{-5}}$ is the creep limit at a creep rate of $2\cdot10^{-5}$ %/hr at 600°). Graphs of the elongation (or the mean creeping rate) as a function of the stress are designed (usually in logarithmic coordinates) on the base of the primary curves in order to determine the creep limit. The unknown creep limit is found from these graphs by means of interpolation. The methods of the creep test and also the principal requirements of the device are standardized by GOST 3248-60. Creeping tests are generally very laborious and protracted (up to 5000-10,000 hrs) and are carried out on tens or hundreds of simultaneously acting devices.

The scheme of one section of a four-section device of the IP-4 type (a construction of the TsNIITMASh) for creep tests is shown in Fig. 2. The constant stress in the specimen is established by the weight of interchangeable loads suspended on a lever. The machine is provided with an electric furnace and a dilatometric temperature controller. The temperature of the specimen is controlled by thermocouples and continuously recorded by recorders. The deformation is measured (with an exactness up to 0.002 mm) by a strain-gauge lever-apparatus with two indicators. Cathetometers are used for the measure-

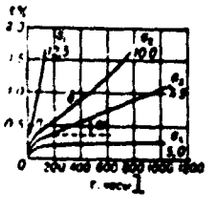


Fig. 1. Creep curves. 1) hours.

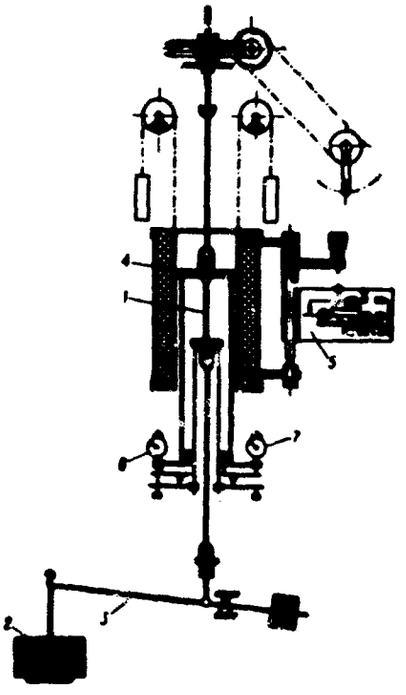


Fig. 2. Device for the creeping test: 1) Specimen to be tested; 2) interchangeable weights; 3) lever; 4) electric furnace; 5) temperature controller; 6) and 7) indicators.

ment of the deformations when tests are carried out at temperatures higher than 1000-1100°. The creep during some seconds or minutes is of special importance in certain cases of the practice. Current-heating or direct heating of the specimen or of the muffle which contains the spec-

imen is usually used in these cases to obtain the creep curve. Devices are used which permit the simultaneous creep (or long-life) test of a number of specimens placed in the working space of one furnace. The "relaxation" method of the creep test, in which the deformation of the specimen remains constant and the stress decreases (relaxes) is also used. The creep of the material is evaluated in this case by the degree of the stress relaxation.

References: Borzdyka A.M., Metody goryachikh mekhanicheskikh ispytaniy metallov [The Methods of Hot Mechanical Tests of Metals], Moscow, 1955.

I.V. Kudryavtsev, D.M. Shur

In this entry, read "long-term" for "creep."

CREEP STRENGTH – resistance to failure due to prolonged effect of a static load and high temperature. It is usually characterized by the ultimate creep strength, i.e., the stress which produces failure of the specimen for the given time under load. It is denoted by the letter σ_{τ}^{t} with two indices, the superscript indicating the test temperature, and the subscript the test duration. Depending on the service life of the component, the ultimate creep strength may be determined by a time from several seconds and minutes (certain types of rockets) to tens and even hundreds of thousands of hours (stationary thermal power installations, civil aviation, etc.). The creep strength tests are usually tensile. Their results are used to construct a creep strength diagram in the coordinates (σ, $\lg\tau$) (Fig. 1) or ($\lg\sigma$, $\lg\tau$).

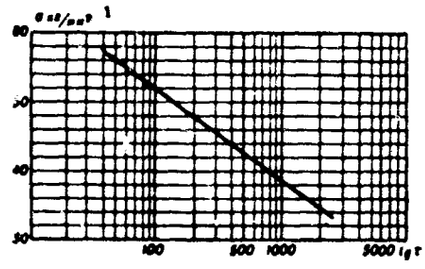


Fig. 1. Creep strength curve of the ZhS6-K alloy at 800°. 1) σ, kg/mm^2.

The creep strengh of a material depends highly on the temperature and on the load duration. The time dependence of the strength is peculiar of all materials, but it is exhibited at different temperatures. For example, the time dependence of the creep strength of structural steels is observed primarily at elevated temperatures, while for phosphorus bronze and aluminum it was established experimentally that the

breakdown stress is reduced with an increase in the time during which the load acts even at 20°.

The reduction in the creep strength with time is regarded as a process of formation and gradual development of cracks, which is based on various physical phenomena: a) thermal motion of atoms or molecules of the solid body; b) stress concentration at the junction of grains which is brought about by relaxation of the tangential stresses along that grain boundary where plastic slip took place; c) the formation of vacancies and their subsequent coagulation, which is due to the dislocation motion; d) structural changes (coagulation or dissolution of phases, oxidation, etc.). As the temperature is increased, the harmful effect of oxidation, particularly along the grain boundaries is made more strongly apparent. The reduction in therupture strength at high temperature with an increased loading duration is not uniquelly related to the time-related variation in the resistance characteristics of plastic deformation, i.e., the ultimate strength or hardness; the latter can increase monotonically if the test temperature is appreciably below the aging temperature; can decrease continuously if the test temperature is higher than the aging temperature; first increase and then decrease, if the test temperature differs little from the aging temperature (Fig. 2).

The relationship between the creep strength and the time to failure is quite well described by the relationship $\tau = A/\sigma^{\alpha}$ where A and α are constants of the material at the given test temperature. In many cases the time dependence of the creep strength in the (σ, $\lg\tau$) coordinates is a straight line. Sometimes, particularly for materials which undergo phase transformations at the operating temperature, the shape of the creep strength curve differs substantially from a straight line. The deviation from rectilinearity for a given material depends on the test

temperature, duration of load application, presence of stress raisers, etc. Hence graphical extrapolation of creep strength curves for loads applied over a long period of time should be used with extreme care. This is particularly true with respect to the creep strength in the ($\lg\sigma$, $\lg\tau$) coordinates, where an inflection in the curve is observed more frequently. Several approximate equations were proposed for estimating the temperature dependence of creep strength. The Stanyukovich equation $\lg\sigma = B + K(1)/(T)$, where B and K are constants of the material for the given test duration, the Larson-Miller equation: $T_1(C + \lg\tau_2)$, where C is a constant coefficient equal, according to Larson, 20, etc. Experimental checks have revealed that the constant coefficients of the suggested equations are a function of the temperature, stress level and the kind of material. Hence they can be used only with a degree of caution, primarily for interpolation within a previously studied temperature interval and also for a close interpolation with respect to temperature (for steelsby 50-100°) and to time.

Of decisive significance in the determination of theoretical ultimate creep strength is the lower boundary of the scattering region, which is obtained in testing specimens of metal from different heats. The extreme values of the scattering region can differ perceptibly from the average curve, e.g., by 10-15% in prolonged testing for 100 hours for aluminum alloys, by 20-25% for prolonged testing of structural steel for 5-10 thousand hours.

Failure due to prolonged application of a static load and high temperature can propagate along grain boundaries, along the grain body as well as be mixed. The character of failure depends on the test temperature, stress level and kind of the stressed state. The higher the test temperature and the lower the stress which is acting, the higher the probability of failure along grain boundaries. Of great importance

for increasing the creep strength is the stability of the solid solutions and the strengthening phases, which ensures slow progress of diffusion processes at high temperatures. In nickel alloys molybdenum, tungsten, cobalt and chrome have a positive effect on the solid solution, boron in small amounts (0.01-0.02%) retards the diffusion along grain boundaries; the strengthening phases usually are Ni_3Al or $Ni_3(Al, Ti)$. Under intergranular failure conditions it is very important that strengthening phases, which interfere with the propagation of the crack, be situated at grain boundaries. Cast alloys have a certain advantage with respect to creep strength, since usually many carbides and intermetallides are contained at their grain boundaries, which is not permissible in shaping alloys due to difficulties which arise in pressworking. The creep strength depends on the grain size, usually being lower for coarsely-grained structures; the optimum grain size for nickel alloys is size 2-3 grain on the standard scale. Variability in the grain structure reduces the creep strength.

The effect of workhardening on the creep strength depends on the degree of workhardening, test temperature and the stress level. The detrimental effect of workhardening is due to the fact that it makes easier diffusion processes which result in embrittlement of the alloy, brings about reset and recrystallization phenomena and makes the structure unstable. Hence workhardening can be found useful only at temperatures which are moderate for the given alloy, and at high temperatures it is beneficial only for loads of short duration. It has been established that a positive influence is had by moderate (2-5%) degrees of compression in the quenched state on the 100-hour creep strength of sheets from the D16 alloy at 175-200°, at 250° workhardening no longer results in increasing the creep strength, and at 300° it reduces it perceptibly. Workhardening by elongation of up to 10% of the quenched

and aged KhN77TYuR (EI437B) alloy reduces the ultimate 100-hour creep strength at a temperature of 700° by a factor of 2. Data are available according to which moderate (10-20%) compression on cold rolling (after quanching) of the No.25 cobalt-base heat resistant Haynes alloy increases substantially its service life at temperatures of 815-980°.

The creep strength can be improved by combined mechanical and heat treatment. Combination of stamping and air quenching (stamping from the quenching temperature) with subsequent aging increases the creep strength by 10-15% (Table 1).

The creep strength depends on the kind of the stressed state. It is known from experience that in order to retain a high creep strength

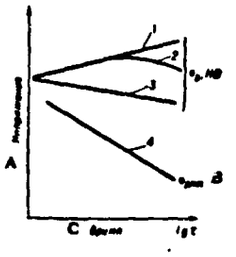


Fig. 2. Change in hardness or strength at 200° after prolonged aging at a high temperature (1, 2, 3) and of the ultimate creep strength (4) at the same temperature). A) Stress; B) creep; C) time.

TABLE 1

Effect of Combined Heat and Mechanical Treatment on the Creep Strength of Certain Alloys

1 Темп-ра (°C)	2 Вид обработки	Пределы длительной прочности σ_{100} (кг/мм²) 3		
		4ЭИ437	5ЭИ787	4ЭИ696
550	Стандартная термическая обработка 5	82	80	67
	Терчо-механическая обработка 6	91	90	78
650	Стандартная термическая обработка 5	55	51	—
	Термо-механическая обработка 6	62.5	60	—

1) Temperature (°C); 2) kind of processing; 3) ultimate creep strength σ_{100}; 4) EI; 5) standard heat treatment; 6) combined mechanical and heat treatment.

in the two-dimensional stressed state (for example, gas turbine disks) the safety factor for the material's plasticity should be higher than for operation under a one-dimensional stressed state.

The notch sensitivity for prolonged static loads at high temperatures is evaluated by the notch sensitivity index (KDN), which is equal to the ratio of the ultimate creep strength of the notched specimen to the ultimate creep strength of a smooth specimen. It depends on the structure of the alloy, the notch shape, test temperature and duration of load application. The EI437 alloy, steels 4Kh12N8G8MFB (EI481), 20Kh3MVF (EI415) with a Brinell hardness of d_{otp} = 3.5-3.7 mm are not sensitive to notching under a prolonged (100 hours) load at 600-700°, and when their hardness is higher (d_{otp} = 3.2-3.3 mm) they exhibit a perceptible notch sensitivity at these temperatures (KDN ≃ 0.75). Usually notch sensitivity is manifested in those cases when the alloy becomes embrittled in prolonged testing. It was established that heat resistant shaping alloys, as a rule, are notch sensitive with attendant prolonged plasticity (which is evaluated on the basis of reduction in the cross sectional area of a specimen which failed after a 100 hour test) of $\psi_{100} < 5\%$, while cast alloys are notch sensitive at $\psi_{100} <$ < 2%. In the absence of embrittling processes, even a quite substantial stress concentration (α_k = 3.5-4.0), does not produce a reduction in the creep strength (Table 2). The method by which the notch is made is of importance, e.g., a notch (α = 3.75) made by a grinding wheel on a thread-grinding machine does not reduce the creep strength of KhN70VMTYu (EI617) and KhN77TYuR alloys at 700; under similar conditions, when the notch is made by a shaping cutter, KDN = 0.7-0.75, which, apparently is due to workhardening of the surface layer in the notch.

The creep strength depends highly on the state of the surface. It is sharply reduced in the presence of grinding cracks and burn-ons, af-

TABLE 2

Ultimate Creep Strengths (for 100 hours) of Specimens of Heat Resistant Alloys

1 Сплав	Темп-ра (°C) 2	σ_{100} (кг/мм²) 3: образцы гладкие 5	образцы с надрезом 6	α_k	КДН 4
7 Деформируемые сплавы					
8 ЭИ826	700	56	54	3.7	0.96
	900	15	19	3.7	1.26
8 ЭИ867	700	75	75	2.4	1.0
	800	45	45	2.4	1.0
	900	20	27	2.4	1.35
	950	12	17	2.4	1.42
9 ХН70ВМТЮ (ЭИ617)	700	56	54	2.4	0.96
	800	32	42	2.4	1.3
	900	20	28	2.4	1.4
10 ХН77ТЮР (ЭИ437Б)	600	80	100	2.4	1.25
	700	48	52	2.4	1.21
	800	22	27	2.4	1.20
11 Литые сплавы					
12 АНВ-300	700	71	72	3.7	1.01
	800	45	45	3.7	1.0
	900	25	26	3.7	1.04
13 ЖС6	700	76	76	3.7	1.0
	800	50	50	3.7	1.0
	900	28	34	3.7	1.24
	1030	10	15	3.7	1.5
ЖС6-К 14	700	78	78	3.7	1.0
	800	52	52	3.7	1.0
	900	32	37	3.7	1.15
Молибден с термодиффуз. покрытием 15	1150	18	15	2.4	0.83

1) Alloy; 2) temperature (°C); 3) σ_{100} (kg/mm^2); 4) KDN; 5) smooth specimens; 6) notched specimens; 7) shaping alloys; 12) ANB-300; 13) ZhS6; 14) ZhS6-K; 15) molybdenum with a thermodiffusion coating.

TABLE 3

Creep Strength at 800° of the KhN70VMtYu (EI617) and ZhS6-K Alloys

1 Сплав	2 Действующее напряжение σ_1 (кг/мм²)	Время до разрушения (в часах) при равных режимах нагружения 3: $\sigma = \sigma_1 = const$	$\sigma = \sigma_1 - 10$ мин. $\sigma = 0 - 10$ мин 4
5 ХН70ВМТЮ (ЭИ617)	54	55	28
6 ЖС6-К	56	50	75

1) Alloy; 2) acting stress, σ_1(kg/mm^2); 3) time to failure (in hours) for various loading regimes:; 4) min; 5) KhN70VMTYu (ei617); 6) ZhS6-K.

ter such machining regimes under which substantial residual tensile stresses arise at the surface (for example, in blades for unfavorable machining conditions they can be as high as 50-60 kg/mm^2).

The creep strength depends on the medium. On contact with low-melting-temperature metals and alloys such as sodium, bismuth, lead-bismuth, lead-tin, etc., the creep strength is sharply reduced; for example, the 100-hour creep strength of the KhN77TYu (EI437A) alloy at 700° is reduced from 40 kg/mm^2 in an air atmosphere to 7 kg/mm^2 on contact with a liquid lead-bismuth eutectic alloy.

Under conditions of nonstationary heating and loading the creep strength of alloys changes; here the character of the change depends on the features of the alloy, the level of the acting temperatures and stresses, and the load duration, so that in the general case a periodically varying load (temperature) cannot be replaced by an average constant load (temperature). Nonstationary loading or heating conditions can also change the relative estimate of the creep strength of materials (Table 3). Approximate formulas are available for estimating the time to failure under nonstationary stress and temperature regimes, which are based on the principle of adding the relative service times and contain various parameters which estimate the deviation from the simple linear summation law.

References: Kishkin, S.T., "DAN SSSR," Vol. 54, No. 4, 1954; Oding, I.A. [et. al.], Teoriya polzuchesti i dlitel'noy prochnosti metallov [Theory of Creep and Creep Strength of Metals], Moscow, 1959; Umanskiy, Ya.S. [et al.], Fizicheskiye osnovy metallovedeniya [Physical Principles of Metal Science], 2nd Edition, Moscow, 1955; Zharoprochnyye splavy pri izmenyayushchikhsya temperaturakh i napryzheniyakh [Heat Resistant Alloys Under Variable Temperatures and Stresses], Collection of articles, Moscow-Leningrad, 1960.

S.I. Kishkina-Ratner

Manuscript Page No.	[Transliterated Symbols]
1092	КДН = KDN = koeffitsient deystviya nadreza = notch sensitivity index
1092	отп = otp = otpechatka = impression

CRITICAL BRITTLENESS TEMPERATURE is the test temperature below which the cold-short materials: Fe-α, Cr, Mo, W, Nb and many alloys based on them transition from the plastic into the brittle condition. In view of the fact that this transition in many cases takes place gradually, the critical brittleness temperature is often determined arbitrarily (for example, as the test temperature at which the impact strength is reduced to 50% of the initial value, or at which more than 50% of the area of the entire fracture becomes crystalline). The critical brittleness temperature is most often determined under dynamic or static bending, however, it is possible to determine it in tension, torsion, etc. The critical brittleness temperature usually increases (i.e., the brittleness increases) with an increase of the ratio of the tensile stresses to the shearing stresses, for example, with transition from torsion to bending, with the presence of hard and brittle surface layers, with increase of the absolute dimensions of the specimen, with increase of the test rate, with increase of the notch sharpness, with enlargement of the grain, as a result of corrosion, etc.

Ya.B. Fridman

CRITICAL STRESS is the ratio of the critical force P_k at which a compressed column loses the stability of its rectilinear form to the cross-sectional area of the column. It is denoted by σ_k. For a compressed column with pin restrained ends, the critical stress is defined by the Euler formula: $\sigma_k = \pi E/\lambda$, where E is the normal modulus of elasticity, λ is the flexibility. The magnitude of the critical stress depends on the column end fixity conditions: for a column with both ends clamped it will be four times greater, and for a column with one end clamped and the other end free it will be four times less than for the column with pinned ends. The Euler formula can be used to determine the critical stress if it is not greater than the proportional limit of the material, i.e., for relatively large values of λ. The critical stress at failure of short compressed columns $\lambda < 30-40$ is approximately equal to the compression yield limit.

Reference: Belyayev N.M., Soprotivleniye materialov [Resistance of Materials], 12th ed., M., 1959.

S.I. Kishkina-Ratner

CROMANSIL – is a medium-alloy structural steel containing chromium, manganese, silicon (about 1% of each element). Depending on the carbon content, Cromansil is produced in the grades 25KhGS, 30KgGS, and 35KhGS (see Heat-treatable medium-alloy structural steel). A castable variety also exists, the 35KgGSA steel. The 25KhG and 30KhGS steels are widely used in different machine-building industries for the manufacture of various weldable and machinable parts. Rods, strips, forged pieces, profiles, hot- and cold-rolled sheets, hot-rolled and cold-drawn pipes, and wires are made from 30KhGSA steel. The ultimate strength of the 25KhGSA and 30KhGSA steels is 110-130 kg/mm^2. This strength is attainable by hardening and tempering. A series of new Cromansil-base steel grades, including the widely used high-strength steel 30KhGSNA was developed additional alloying (see High-strength structural steel).

Ya.M. Potak

CRUMPLING TEST – is a test for the evaluation of the strength under conditions in which the load is transmitted from the one part of the other through the surface on which these parts touch each other, through the contact surface of a rivet hole and a rivet, a lug and a bolt, for example. The crumpling strength depends not only on the properties of the material but also on the size and shape of the mounting, on the ratio d/y (Fig. 1) in a bolt or rivet joint, for example, on the thickness of the connecting pieces, on the number of bolts (or rivets) placed along the direction of the force. The lug has a constant strength in its cross section at $\underline{y} \geq 3\text{-}3.5d$, and $\underline{x} \geq 1.5\text{-}2d$. The size of the specimens for the crumpling test is selected taking into account these relationships.

The crumpling stresses are not uniformly distributed in bolt and rivet joints owing to the presence of holes and of the action of the bolt or the rivet. This nonuniformity is not taken into account when such crumpling characteristics as the nominal values of the modulus of elasticity, the proportional and yield limits, and the crumpling strength are to be determined.

The crumpling stress is calculated according to the formula $\sigma_{см} = \frac{P_{см}}{F_{см}}$ kg/mm^2, where P_{sm} is the crumpling load in kg corresponding to a given degree of deformation or the destruction; F_{sm} is the projection of the crumpling area, in mm^2. $F = d \cdot a$ is valid for bolt or rivet joints, where $\underline{d}$ is the diameter of the hole to be crumpled, and $\underline{a}$ is the thickness of the sheet, the plate or the lug.

One of the most widespread devices for the crumpling test (Fig. 2)

consists in two jaws, hardened up to 55-60 RC, with two holes placed along the axis in each. Interchangeable spacers of a thickness, chosen in accordance to the thickness of the material tc be tested, are placed between the jaws. Polished rolls (RC = 55-60) are set into the holes of the jaws to transmit the force to the surface of two specimens tested simultaneously. A certain gap is provided by means of adjusting spacers in order to avoid friction between the jaws and the specimens; the spacers are removed after an insignificant preliminary load is given. Strain-gauges are used to determine the modulus of elasticity and the proportional and yields limits; the strain-gauge is placed as shown in Fig. 2, when the sum of the both hole diameters, in which the crumpling occurs, is taken as a gauge basis. An average crumpling strength is determined in this case, it is important, therefore, to assort specimens which differ unimportantly in their dimensions (d, a, y, x). The determination of the nominal modulus of elasticity, and of the proportional and yield limits is carried out in the crumpling test in the same manner as in the tensile test according to GOST 1497-61. Industrial standards exist for the crumpling test. The nominal moduli of elasticity amount generally to 0.3-0.4 of the modulus of elasticity of the tensile test (Table). The yield limit is for the most metals higher in crumpling than in stretching, it is lower than in stretching for magnesium alloys, but higher than in compression.

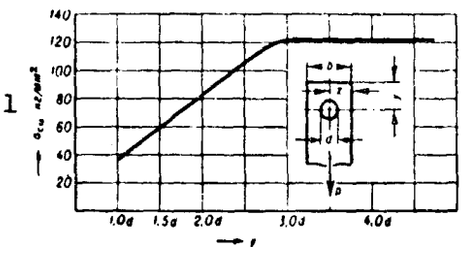


Fig. 1. Effect of the d/y ratio on the magnitude of the ultimate stress in crumpling. 1) σ_{sm}, kg/mm^2.
in

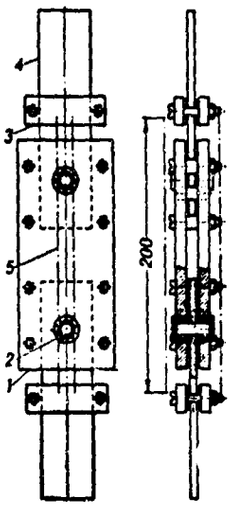


Fig. 2. Device for the crumpling test: 1) Jaw; 2) roll; 3) cover plate; 4) specimen; 5) base of the strain-gauge.

TABLE

Comparison of the Moduli of Elasticity and the Yield Limits of Sheet Materials in Crumpling, Stretching, and Compression

1 Сплав	2 Модули упругости E (кг/мм²) при:			3 Пределы текучести $\sigma_{0,2}$ (кг/мм²) при:		
	4 смятии	растяжении 5	6 сжатии	6 смятии	растяжении 5	6 сжатии
7 Д16АТ	2900	6 900	7 150	35	31	32
8 В95АТ	2850	6 700	6 900	54	48	47
9 МА8	1550	4 100	4 200	14	16	11
10 ВТ5-1	3650	10 500	10 600	95	69	75

1) Alloy; 2) modulus of elasticity E (kg/mm^2) at:; 3) yield limit $\sigma_{0.2}$ (kg/mm^2) at:; 4) crumpling; 5) stretching; 6) compression; 7) D16AT; 8) V95AT; 9) MA8; 10) VT5-1.

Anisotropic materials are tested by crumpling in diverse directions. In glass-textolites, for example, the crumpling strength is lower (especially at raised temperature) at an angle of 45° to the symmetry axis of the elasticity, than along the filling and the warp.

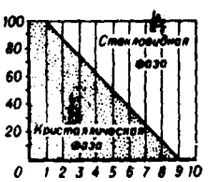
References: Danilov Yu.S., Galimurza A.G., "Zavodskaya laboratoriya," 1954, Vol. 20, No. 5.

S.I. Kishkina-Ratner

CRUSHER GAGE is a plastic dynamically compressible small cylinder for the measurement of impact forces from the value of the upset. The crusher gage is first calibrated (preferably by impact loads of gradually increasing intensity rather than by static loads) to establish the relation between the forces and the upset. In spite of the approximate nature, the crusher gage method, in view of its simplicity with impact rates which are not too high, finds application along with the more precise and modern methods.

Ya.B. Fridman

CRYSTALLINE CERAMICS are synthetic engineering stones obtained by the synthesis of the crystalline and vitriform phases. In accordance with their purpose, the crystalline ceramics are marked by differentiated physical properties which are determined by the selection, preparation and quantitative relations of the crystalline and vitriform phases (figure) and also by the regime of their synthesis. Crystalloceramics as a method of obtaining new ceramic materials has been developed in the Soviet Union by I.I. Kitaygorodskiy since 1943.



Relationship of phases in ceramic materials: 1) Microlite; 2) high refractory; 3) refractory; 4) glazed pottery; 5) porcelain; 6) bone porcelain; 7) bone glass; 8) opal glass; 9) milk glass; 10) glass. A) Vitriform phase; b) crystalline phase.

Characteristics of the crystalline ceramics are: 1) constancy of the phase composition of the material, i.e., unchanged qualitative and quantitative relationships of the crystalline and vitriform phases; 2) minimal content in the material of the vitriform phase, which performs a cementing function. The crystalline phase can be pure oxides, synthetic silicates, aluminosilicates and other salts, rock and non-ore minerals, carbides, nitrides, slags from metallugical production and other materials. To obtain the vitriform phase use is made of glasses of varying composition or certain oxides which from their properties must correspond to the purpose of the crystalline ceramic being prepared, can

serve as a good cementing component for the crystalline phase, and also will have an effect in the synthesis process on the grain size, the grain habit, and the surface properties of the individual crystallites, i.e., on the structure, and consequently on the quality of the material. From the same crystalline phase we can obtain crystalline ceramics with varied properties by using different quantities of glass cements of differing composition for by using different amounts of the same glass cement. Tables 1 and 2 show the variation of the ultimate bending strength of crystalline ceramic calcined at 1620° as a function of the nature of the glass and its quantity (crystalline phase calcined at 1450° and ground by alumina).

Table 3 presents the effect of glass on the chemical resistance of a corundum material.

TABLE 1

Стекло, вводимое в массу (в количестве 1%) 1	Предел прочности при изгибе (кг/мм²) 2
Высокоглиноземистое 3	39.0
Основное 4	37.4
Нейтральное 5	31.0
3С-5К 6	30.2
БД-1 7	28.5

1) Glass introduced into the mass (in amount of 1%); 2) high alumina; 3) bending ultimate strength (kg/mm^2); 4) basic; 5) neutral; 6) 3S-5K; 7) BD-1

TABLE 2

Количество введенного стекла БД-1 (%) 1	Предел прочности при изгибе (кг/мм²) 2
1	28.5
2	31.3
3	31.2
5	27.3
10	23.2

1) Quantity of BD-1 glass introduced (%); 2) bending ultimate strength (kg/mm^2)

TABLE 3

Реагент 1	Химич. устойчивость, % потери веса при содержании стекла (вес. %)			
	0,0	0,5	1,0	2,0
HCl	0,01	0,013	0,015	0,023
HF	0,008	0,14	0,16	0,19
NaOH 3	0,006	0,01	0,011	0,018
$PbO+B_2O_3$ — расплав	0,002	0,021	0,096	0,17
Na_2CO_3 — расплав	0,23	0,25	0,3	0,35
$Na_2SO_4+CaSO_4$ — расплав	0,76	0,81	0,9	0,91

1) Reagent; 2) chemical stability, % weight loss with glass content (%); 3) melt.

The quantity of the vitriform phase in the crystalline ceramic varies from fractions of a percent (microlite) to 40% (electronic materials and glass bonded grinding wheels). Crystalline ceramic materials and glass bonded grinding wheels). Crystalline ceramic materials of three classes have been obtained: 1) Crystalline ceramics in which the quantity of the vitriform phase amounts to 5-15% and in certain cases reaches 40%. This class includes the electrovacuum and high frequency ceramics, aircraft spark plug insulators, domestic refractory equipment, and also abrasive wheels and tools; 2) mineral-ceramic in which the amount of the vitriform phase does not exceed 1% (ceramic cutters, nozzles, draw plates, thread guides, various wear-resistant details); 3) mineral-metal-ceramics in which the crystalline phase consists of oxide compounds and metals. These materials are used for the fabrication of turbine blades, drilling cutters, protective metal coatings.

References: Kitaygorodskiy I.I., DAN SSSR, 1944, Vol. 42, No. 9, p. 407; -, ibid, 1952, Vol. 90, No. 2, p. 225; -, KhNiP, 1958, Vol. 3, No. 1, p. 35.

Ts.N. Gurevich

II-27k

CRYSTALLIZATION OF ALUMINUM ALLOYS IN AN AUTOCLAVE is a method of combating gaseous porosity in molded castings developed by A.A. Bochvar and A.G. Spasskiy. It is based on the fact that an increase of the surrounding pressure reduces sharply the rate of growth of gas bubbles in the crystallizing casting. Castings produced using this method are characterized by high density and mechanical properties. The casting form prepared for pouring is introduced into a horizontally positioned autoclave. After this the autoclave is hermetically sealed with a cover. Special ports are provided in the autoclave above the pouring funnels for pouring the metal into the form. After pouring the metal into the form these ports are quickly closed and the autoclave is filled with compressed air to a pressure of 4-5 atm. The metal is held in the autoclave until completion of the crystallization of the casting and until some cooling has occurred (30-40 min). Then the form is taken out of the autoclave. The crystallization of the aluminum alloys in an autoclave is a very effective method of combating gas porosity in molded castings. It is widely used for the casting of large-size details, particularly when using the alloys based on the Al-Si system.

References: Spasskiy A.G., Osnovy liteynogo proizvodstva [Fundamentals of Casting Production], M., 1950.

M.B. Al'tman

CUNIAL is an alloy of copper with nickel and aluminum. Two grades of Cunial are produced in accordance with GOST 492-52; MNA13-3 (Cunial-A) containing 12.0-15.0% Ni+Co, 2.3-3.0% Al balance copper, up to 1.9% impurities permitted, of that no more than 1.0% Fe, 0.50% Mn, 0.002% Pb. MNA6-1.5 (Cunial-B), containing 5.5-6.5% Ni+Co, 1.2-1.8% Al balance copper, up to 1.1% impurities permitted, of that no more than 0.5% Fe, 0.20% Mn and 0.002% Pb.

Cunial works well in the cold and hot conditions, is capable of dispersion hardening with tempering at 500-600° after hardening and quenching from 900-1000°.

Physical-Chemical and Engineering Properties of Cunial

Сплав 1	γ (г/см³) 2	σв (кг/мм²) 3	δ (%) 3	Темп-ра плавления (°С, ликвидус) 5	Темп-ра литья (°С) 6	Темп-ра горячей обработки (°С) 7	Вид полуфабриката 8
		мягкое состояние 4					
9 МНА13-3 (куниаль-А)	8.5	36	13	1145	1250—1300	900—1000	11 Прутки
10 МНА6-1.5 (куниаль-Б)	8.7	36	28	1120	1200—1250	850—900	12 Полосы

1) Alloy; 2) g/cm^2; 3) kg/mm^2; 4) soft condition; 5) melting point (°C, liquidus); 6) casting temperature (°C); 7) hot working temperature (°C); 8) form of semifabricate; 9) MNA13-3 (Cunial-A); 10) MNA6-1.5 (Cunial-B); 11) rods; 12) strips

In accordance with TsMTY (Ferrous Metal Spec.) 3443-53 Cunial-A is fabricated in the form of extruded rods of 60-95 mm diameter for products of high strength (ultimate strength not less than 70 kg/mm^2, relative elongation no less than 7%). In accordance with TsMTU 4146-53 Cunial-B is fabricated in the form of strips of thickness 0.5-3 mm for springs (ultimate not less than 55 kg/mm^2, elongation not less than 3%).

Cunial has good corrosion resistance. With the presence of tensile stresses in the surface layers it is prone to cracking during annealing and during operation at high temperatures (see Bronze, Wrought Spring).

References: Smiryagin A.P., Promyshlennyye tsvetnyye metally i splavy [Industrial Nonferrous Metals and Alloys], 2nd Edition, Moscow 1956; Butomo D.G. (et al.), Vysokoprochnyy korrozionnostoykiy deformiruyemyy splav [A High-Strength Corrosion-Resistant Shaping Alloy], TsM, 1956, No. 11, p. 70-76; Butomo D.G., Zedin N.I., O treshchinakh na prutkakh iz splava kunial'-A [Cracks in Cunial-A Alloy Rods], ibid, 1953, No. 2, p. 58-62.

A.V. Bobylev

CUNICO - see Permanent Magnet Wrought Alloy.

CUNIFE - see Permanent Magnet Wrought Alloy.

CUPRAMMONIUM – artificial cellulose hydrate fiber from cotton down (lint) or dressed wood pulp. It is formed from a cuprammonium cellulose solution by the wet method. It is produced in the USSR and abroad in the form of a filament thread (general N_m from 110 to 600 and elementary N_m 7500-9000; for special purposes 22,500) under the name kupreza (rayon, FRG), bemberg (rayon, FRG and USA); staple fiber (piece length from 40 to 100 mm) under the name of kupram (staple, GDR and FRG). Cuprammonium fibers have a smooth surface, round cross section, uniform structure along the entire width, which determines uniform and deep dyeing. Cuppramonium fibers are characteristic by chemical resistance to many organic solvents, high thermal conductivity, but low resistance to acids, oxidizers, low resistance to micro-organisms and to atmospheric conditions. The specific weight of the fibers is 1.52-1.54, moisture content under standard conditions 12.5%, at 95% relative air humidity it rises to 27%. The fiber does not melt and burns easily. Cuprammonium fibers have a wide interval of working temperatures: at –40° the strength of the fiber is increased by 72%, the tensile elongation is reduced by 9% (these properties are reversible); cotton and flax under these conditions lose, respectively, 10 and 6% of their strength. When the temperature is raised from 20 to 120° the strength of cuprammonium fibers decreases by 20-25% and the elongation by more than a factor of three. Cuprammonium fibers are soluble in heated dilute and cold concetrated acids. When the fiber is irradiated by ultraviolet rays for six months it loses 60-70% of its strength. Cuprammonium fibers

and products made from them are dyeable by direct, sulfur and vat dyes. The rupture length of standard cuprammonium rayon is 15-23 km (36-45, 14-17) (numbers in parentheses pertain to high-strength rayon and to staple fiber, respectively). Strength losses in the wet state for standard fiber comprise 35-40% (20-44, 30-35), in the loop, respectively, 25-30% (–, 30-40), in a node 25-40% (–, 15). The tensile elongation of dry fiber is 10-17% (8-12, 30-38), of wet fiber 15-30% (–, 40-50). The ultimate tensile strength for standard rayon comprises 23-32 kg/mm^2 (55-69, 21-25); the fiber's elasticity: complete reversibility of deformations takes place for a 1.5-1.7% elongation (–, 1.5-1.7). Cuprammonium is characterized by low wear resistance, particularly in the wet state and high susceptibility to wrinkling. Very fine (N_m elementary 22,500) cuprammonium fibers are used for special purposes and as an organic-solvents-resistant fiber; high-strength cuprammonium fibers (rupture length 36-45 km) is used in the production of cord and cord fabrics; in the pure state and mixed with natural fibers it is used for the manufacture of consumer goods.

Staple fiber 40-45 mm long is used together with cotton, 75-80 mm long fiber is used together with wool and 100 mm long fiber is used in making of carpets.

References: Rogovin, Z.A., Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fibers Production], pages 488-521, 2nd edition, Moscow, 1957; Pashkver, A.B., Tekhnologiya mednoammiachnogo volokna [The Technology of Cuprammonium Fibers], Moscow, 1947; Rayuzov, A.N., Gruzdev, V.A. and Artemenko, M.A., Tekhnologiya iskustvennykh volokon [Technology of Artificial Fibers], pages 404-31, 2nd edition, Moscow, 1952; Moncruiff, R.W., Chemical Fibers, translated from English, pages 164-70, Moscow, 1961; "Textil-Praxis" [Textile Practice], February, 1961.

V.M. Sukhman

CUPROALUMINUM is an alloy of copper with aluminum and other elements. An example of cuproaluminum is aluminum bronze - an alloy of copper with 5, 7, 10 or 12% aluminum.

CUTTING OF HIGH-MELTING ALLOYS.

Tungsten and its alloys are among the most difficult-to-machine materials as a result of the high hardness, increased brittleness, low plasticity, and high abrasiveness of W. The low plasticity of tungsten alloys has a negative influence on their machinability. In this connection an increase in cutting speed reduces machinability, since it does not cause a sufficient increase in heat evolution or a sufficient decrease in strength in the deformed element. Moreover, the reduced plasticity of tungsten alloys causes a sharp decrease in the cutting area in contact with the cutting tool and thus raises the tool pressure required to produce the same cutting force by a factor of 2-4. Sheets of W alloys are laid out with silicon carbide cutting wheels. In order to avoid cracking cold sheets should not be cut with shears, sawn, or die-punched. It is recommended that W-based alloys be laved with tools of R18, R9K5, R9K10, or R9F5 high-speed steel or the hard alloy VK8. A coolant is not employed during lathing, since this reduces the resistance of the tool. Tungsten alloys are milled with high-speed millers of R18, R9K5, R9K10, or R9F5 steel or VK8 alloy. Drilling holes in W alloys presents enormous difficulties associated with the large cutting forces that develop and the low rigidity of standard drills. Holes in W-alloy sheets less than 2 mm thick are first roughed cut by electroerosive or ultrasonic treatment. Drills of R18 and R9F5 high-speed steels with oblique flutes (Fig. 1) are used for drilling to a depth of 1-1.5 d, while high-rigidity drills are employed for holes more than 1.5 d deep. Outside threads are cut with a thread cutter or chaser and

finished with a thread grinder. It is recommended that tungsten alloys be ground with wheels of green carborundum in a ceramic binder having a granularity of 40-60 and a hardness of CM1-CM2. The surface finish produced is of class 7-8 (GOST 2789-51). In order to improve their cutability such alloys are preheated to 370-420°, which raises tool resistance by a factor of 5-6 and reduces the cracking and chipping of the material, thus making it possible to obtain holes less than 5 mm in diameter in both massive and sheet materials. A tungsten sheet heated to 370° can be cut with shears or die-punched.

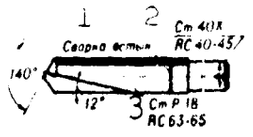


Fig. 1. Drill with oblique flutes for drilling shallow holes in tungsten alloys. 1) Butt weld; 2) 40 Kh steel; 3) R18 steel.

The conditions for cutting molybdenum alloys are similar to those for machining W. In machining molybdenum alloys the cut layer has a tendency to shear off under severe cutting regimes because of its elevated brittleness (as is also the case for W alloys). Detrimental impurities and admixtures substantially reduce machinability. Depending on technological conditions, cooling is carried out with an emulsion, air, or a "mist," i.e., by dispersing an emulsion in a stream of air. Ingots are roughed out with cutters of the hard alloy VK8. The same cutters are also used for finishing.

It is recommended that Mo alloys be face-milled with millers of the hard alloy VK6 or VK8. These alloys are drilled with standard high-rigidity drills of R18 steel.

Thread-cutting requires special care in comparison with lathing, the cutting speed being reduced to 9-12 m/min and a per-pass cutting depth of 0.1-0.15 mm being employed. It is best to cut coarse threads, since fine ones are easily broken. Mo alloys are ground under the same conditions as W alloys. The surface finish produced is of class 7.

Tantalum and niobium alloys have a high viscosity and plasticity

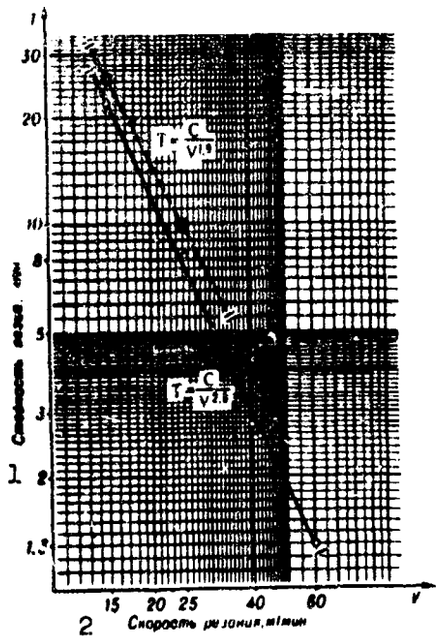


Fig. 2. Influence of cutting rate on cutting resistance during the lathing of niobium alloys. Material to be machined: ——— HB = 160 kg/mm^2, - - - HB = 165 kg/mm^2, cutter of R18 alloy. Machining regime: V = 15-60 m/min, S = 0.2 mm per revolution, t = 0.75 mm. 1) Cutting resistance, min; 2) cutting rate, m/min.

and a comparatively low hardness (HB = = 120-170 kg/mm^2). The difficulty in cutting them lies in their strong tendency to stick to the cutting tool. These alloys are lathed with cutters of R18 or R18F2 steel. Machining with hard-alloy cutters often leads to chipping of the cutter tip and is consequently not recommended. The geometric parameters of the cutters employed are the same as for the machining of tungsten and molybdenum.

The cutting speed of niobium alloys is greatly affected by the stability of R18 cutters (Fig. 2). High cutting speeds produce high temperatures in the cutting zone, which leads to oxidation of the surface being machined Nb and Ta alloys are drilled with R18 drills, using sulfofrezol as a coolant.

Nb and Ta alloys are very difficult to grind. The grinding wheels quickly clog up and require frequent adjustment. The best results are obtained when wheels of electrocorundum in a ceramic binder are used. The grinding regime is the same as for W and Mo. Grinding is accompanied by copious cooling with a 2-3% solution of soda ash. The surface finish obtained is of class 6.

References: Vul'f, B.K., Romadin, K.P., Aviatsionnoye metalovedeniye [Aviation Metalworking], Moscow, 1962; Niobiy i tantal [Niobium and Tantalum], collection of translations, edited by O.P. Kolchina, Moscow, 1954; Machinery (USA), 1960, Vol. 66, No. 10, pages 184-188;

Tool and Manufacturing Engr., 1960, Vol. 45, No. 4, pages 121-122, Metal Industry, 1959, Vol. 94, No. 4-7; Machinery (Engl.), 1953, Vol. 82, No. 2095, pages 72-73.

Ye.P. Bychkov and K.F. Romanov

CYANIDING OF STEEL – is the saturation of the surface of low- and medium-carbon steel (alloy steel being included) with carbon and nitrogen in order to increase the hardness, the resistance to abrasion, and the fatigue strength. In comparison to carburizing, the cyaniding is generally carried out at a lower temperature, and, therefore, the parts are less dangered by warping. The metal obtains a higher abrasion resistance by cyaniding than by carburizing. The cyaniding of small parts is carried out in cyanide baths at 820-850° for 20-40 minutes, and a hard surface layer with a thickness of 0.15-0.25 mm is formed. Then the parts are hardened and tempered at a low temperature, at 180-200°. A deep cyaniding at 930° for 1-5 hours gives a 0.5-1.5 mm thick layer with a hardness of >60 RC. Cyaniding in toxic salts is gradually substituted by gas cyaniding (carbonitriding) carried out in a mixture of 3-10% ammonia and 90-97% carburizing gas (drops of liquid hydrocarbons may substitute the gas). Gas cyaniding is carried out at 850° with subsequent hardening and low tempering; a 0.5-0.7 mm thick layer with a surface hardness of >50 RC is formed on 18KhGM or 25KhGT steel after treatment for 5.5 hours in a continuous muffle-less furnace. Low-temperature cyaniding is utilized to increase the hardness and heat resistance of tools made from high-speed steel. In this case, the process is carried out at 560° for 5-10 minutes in cyanide baths, and for 1-2 hours in gases or in solid packs. The layer obtained by this method has a thickness of 0.01-0.02 mm, and a surface hardness of 1100 HV (the hardness of the core is 850 HV).

References: Metallovedeniye i termicheskaya obrabotka stali [Metal

III-[illegible]

Science and Heat Treatment of Steel, [illegible], Mashgiz, Moscow, 1962.

A.N. Minkevich

CYCLIC STRENGTH – see Endurance.

CYCLIC TOUGHNESS – is the capability of a material to absorb irreversibly deformation energy during alternating loads; it is characterized by the hysteresis loop. Under steady conditions of the alternating loads, the cyclic toughness is characterized by the width Δ of the hysteresis loop. The type and the rate of the change of Δ when the number N of the cycles increases are different for various materials and depend on the frequency and ...e parameters of the stress cycle. The width of the loop (the cyclic toughness) increases steadily up to the point where failure occurs, when maximum cycle stresses surpassing the endurance limit of the material are applied (see the curves 1, 2, and 3 on the Figure). When maximum cycle stresses, equal to the endurance limit, are applied, the Δ of the one metal reaches a certain width and then remains invariable (curve 4); in other metals, the width of the loop passes a maximum (curve 5) before it attains a stable value. Owing to these properties, the cyclic toughness (the width of the hysteresis loop) may serve, beside the endurance limit, as a characteristic of the fatigue strength of material. The cyclic toughness may also serve to indicate the sensitivity of the material to stress concentrations at alternating stresses; the higher the cyclic toughness, the lower, as a rule, is the sensitivity to stress concentrations.

Variation of cyclic toughness under repeated loading. A) Width of hysteresis loop; B) number of cycles.

G.T. Ivanov

DACRON – see Polyester Fiber.

DAMAGE – a decrease in resistance to fatigue or long-term static fracture as a result of repeated or static preliminary loading. The effect of fatigue damage can be most simply measured by Fatigue testing with a single shift from one stress amplitude σ_n (initial) to another σ_k (final). On the fatigue curve the initial amplitude σ_n corresponds to the number of cycles to fracture N_n, while the final amplitude σ_k corresponds to N_k. If the metal is loaded under the initial stress for n_n cycles, if the tests are concluded at the final stress fracture takes place after n_k cycles. The quantity $S = (N_k - n_k)/N_k$ characterizes the degree of damage as a function of the relative duration of the initial loading regime n_n/N_n.

The curve characterizing the relative loss of durability $(N_k - n_k)/N_k$ after a single change in stress amplitude as a function of the relative loading time n_n/N_n is called the damage curve. The shape of this curve depends on the characteristics of the metal and the loading conditions.

For simple linear summation of damage $S = n_n/N_n$, i.e., the damage is proportional to the ratio of the numbers of cycles and $(n_n/N_n) + (n_k/N_k) = 1$. For high-strength and hard steels, cold-worked steels and alloys, and perlitic cast iron $S > 0$ during the initial stages of alternate loading and the decrease in strength is continuously cumulative. The effect of fatigue damage depends to a substantial extent on the level of the alternating stresses and the sequence in which they vary. Damage accumulates more rapidly when stress concentrations are present and does not obey the simple linear-summation law in this case.

On nonstationary alternate loading the cumulative damage is characterized by the formula $\Sigma(n_i/N_i)$, where n_i is the total number of stress cycles at amplitude σ_i and N_i is the number of cycles necessary to cause fracture at this stress, according to the fatigue curve. The cumulative damage depends on the total number of stress cycles and the amplitude spectrum of the alternating load.

In order to characterize the influence of damage on fatigue strength in terms of stresses it is necessary to determine a secondary fatigue curve by testing a series of specimens preliminarily loaded under stresses of amplitude σ_n for N_n cycles.

The ratio of the fracture-stress amplitude for a given number of cycles on the secondary curve to the stress amplitude for the same number of cycles on the primary curve characterizes the change in fatigue strength resulting from damage. Depending on the values selected for σ_n and n_n, the secondary fatigue curve may run above or below the primary curve (see Acclimatization). The position of the damage curve with respect to the fatigue curve depends on the characteristics of the metal and the character of the stressing. One of the most common techniques for determining the damage curve is French's method: after the usual fatigue curve has been obtained several stress levels are selected and a group of specimens is loaded at each of them for different numbers of cycles, keeping the stress below the fracture point in all cases. The specimens are then loaded under stresses equal to their fatigue strength; some of them, having been damaged during the preliminary loading, will fail prematurely. The higher the overload, the lower will be the number of cycles required to cause damage. The line separating the numbers of stress cycles that do not cause a decrease in fatigue strength from the numbers of cycles that do produce such a drop is the fatigue curve, which is bounded on the left by the region of dangerous

overloads. It is sometimes called French's line.

Until a certain point is reached the change in fatigue characteristics due to damage can be eliminated by heat treatment, such as intermediate tempering, which suppresses the effect of the cold-working and other changes caused by cyclic deformation. The number of cycles required to produce damage depends both on the stress amplitude and the character of the loading; under alternate shear cold-working proceeds more rapidly and the region $S < 0$ is more pronounced.

S.V. Serensen

DAMPING OF OSCILLATIONS – is the gradual diminution of the amplitude of free oscillations, caused by the dissipation of energy due to the resistance of the surrounding medium (air, water), and by the resistance in the fastening points of the body (in bearings and points of rest) and the internal friction in the material itself. The part of energy consumed during each cycle of oscillation is measured by the area of the hysteresis loop. The damping of oscillations is connected with a local plastic deformation and depends strongly on the amplitude (magnitude) of the stress; therefore, an ordering of materials in series based on the magnitude of the damping of oscillations becomes sometimes principally changed when the magnitude of the stress is changed at which the damping of oscillations was compared. The damping of oscillations is measured on basis of the decrease in the area of the hysteresis loop or on basis of the diminuation of the amplitudes. The logarithmic decrement of the damping of oscillations is equal to the natural logarithm of the ratio of the foregoing to the following maximum deviation (amplitude) of the oscillation; the determination of the cyclic viscosity (the energy absorbed by the material within 1 period) is also used. This characteristic allows a comparison of the damping of oscillation for one period, which make it possible to compare the damping rates of oscillations having different periods. The ratio of two adjacent amplitudes (and therefore the logarithm of this ratio also, i.e., the logarithmic decrement of the damping of oscillations), however, is not constant in nonlinear systems and becomes, therefore, indefinite. Damping of oscillations rises with rising temperature more strongly than the

majority of the other mechanical characteristics and is the lower, as a rule, the higher the resistance to plastic deformation (damping of oscillations is small in ball-bearing steels, in fine-grained structures, etc.). The purity of the material may strongly affect the damping of oscillation. Thus, the damping of oscillations increases by 250 times when tin with a purity of 99.999% is taken instead of tin with a purity of 99.96%. This difference is determinable only when the measurement of the damping of oscillations is carried out with a very high precision. A minimum of damping of oscillations is desired in tuning forks, strings and gongs; in building materials, on the contrary, a high damping of oscillations is desirable without reducing, however, the other useful properties. The damping of oscillations in constructions overcomes sometimes markedly damping of oscillations in the material.

References: Structural damping. Papers presented ... the A.S.M.E. ... in Atlantic City, N.Y., in Dec., 1959, Oxf., 1960.

Ya.B. Fridman

DARVAN (Darlan) – synthetic carbon chain fiber from a copolymer of vinylidenecyanide and vinyl acetate (1:1), which is used in the textile and knitwear industry. It is produced in the USA in the form of staple fiber (N_m elementary 6000 and 3000, length of sections from 30 to 60 mm), the cross section is elongated in shape. Darvan is distinguished by high thermal resistance, resistance to biological and atmospheric effects; its disadvantage is poor dyeability. Specific weight 1.18, moisture content under standard conditions 2-3%. At temperatures close to the softening temperature (149-168°) Darvan retains 40-50% of its original strength. When held for 195 days at 149° and 8 days at 168° the fiber strength does not change. Darvan held for 2 years (in the state of Florida) in open air has lost 88% of strength. Shrinkage of Darvan when boiled in water for 3 minutes is 1%, it changes little when steamed (1.7 atm), the shrinkage of dry fiber heated to 166° is 5%. Darvan resists the effect of ordinary organic solvents. The rupture length in the dry state 15.75 km, in the wet state it is 13.5 mm. The elongation of the wet fiber comprises 30%. By its resilience Darvan is close to wool. It is used for the making of articles used in the open air (tents), as well as dresses, underwear, curtains, etc.

L.M. Musichenko-Vasil'yeva

DAVIDENKOV'S METHODS – methods for measuring residual stresses. For discs Davidenkov's methods are similar and more accurate than Kalakutskiy's method. Rings are cut from the disc which, after measuring the diameter and width, are slit along the radius. The gradient of residual stresses along the disc radius is determined by the change in the diameter of each ring upon slitting. Usually only tangential residual stresses are determined, without taking into account radial stresses. Davidenkov's methods make it possible, on the basis of data thus obtained, also to calculate the radial stresses. The gradient of residual stresses is determined on the basis of the tangent of the stress diagram slope arc tan α:

$$\operatorname{tg}\alpha = \frac{E}{D}\Delta D_1 \qquad \text{or} \qquad \operatorname{tg}\alpha = \frac{E}{\Delta D}\Delta a$$

where E is the standard modulus of elasticity, D is the diameter of the ring, ΔD_1 is a change in this diameter, and Δa is the change in the distance between markings on both sides as a result of slitting the ring. To determine tangential stresses in thin-walled pipes, rings are cut from them from which external or internal layers are gradually removed (usually by etching). To determine the axial stresses strips are cut from pipes from which layers are also gradually cut. The stresses are calculated on the basis of deformation upon removal of layers, which are measured by using given measuring instruments, or electric strain gages, and on the basis of the elastic characteristics of the material. According to a slightly simplified Davidenkov's method the tangential residual stresses are calculated as a sum of 4 components:

$\sigma=\sigma_1+\sigma_2+\sigma_3+\sigma_4$, where σ_1 is the stress removed in the given layer when the ring is slit along the generatrix, σ_2 is a stress removed in the given layer by removal of the layer proper, σ_3 is a stress produced by an axial tensile or compressive force, which is removed in the given layer upon removal of all the preceding layers, and σ_4 is the stress due to the bending moment which is removed in the given layer upon removal of all the preceding layers. In prismatic bars layers are removed in succession from one side of the bar and the curvature (deflection) change which is thus produced is measured.

References: see at the end of article Residual Stress.

Ya. B. Fridman

DECARBONIZATION OF STEEL – impoverishment of the surface layers of steel in carbon as a result of exposure to hot air or furnace gases at high temperatures.

This process is associated with the fact that oxygen oxidizes carbon in preference to iron. Decarbonization occurs when the diffusion rate of the carbon is higher than the oxidation rate of the iron. A weakly oxidative atmosphere causes intensive decarbonization and only slight scaling; a strongly oxidative atmosphere causes rapid scaling, so that decarbonization is virtually impossible. The degree of decarbonization produced when steel is heated in a hydrogen atmosphere is greatly affected by the humidity: almost no decarbonization takes place in dry hydrogen, while very intensive decarbonization occurs in moist hydrogen. Complete or partial superficial decarbonization of steel may lead to rejection of finished components, so that it is checked in semifinished products in accordance with GOST 1763-42, 5953-51, and 801-47 in metallurgical plants and in finished products in machine-building plants. Decarbonization of steel during heating can be prevented by use of protective atmospheres, vacuum furnaces, and neutral atmospheres (nitrogen and argon freed of water vapor, oxygen, and carbon dioxide). Decarbonization is desirable in rare cases, as in the processing of transformer steel or in order to reduce the sensitivity of high-strength steels to stress concentrators under static loads.

References: Gudremon, E., Spetsial'nyye stali [Special Steels], translated from German, Vol. 1-2, Moscow, 1959-60.

A.N. Minkevich

DECORATIVE ALUMINUM SHAPING ALLOYS – see Corrosion-resistant aluminum shaping alloys.

DECORATIVE BRONZE – an alloy of copper, tin, zinc, and lead used for artistic castings. Decorative bronzes have good casting properties and fill the mold to give a precise impression. The lead present in these alloys makes them readily cuttable. Decorative bronzes are produced from Secondary bronzes and have higher permissible impurity contents, since the finished products need not have high mechanical characteristics. They are manufactured in ingots weighing no more than 42 kg. Depending on the type of alloy (Table), the ingots are marked with the letter "X" in the following colors: BKh1 – white, BKh2 – green, and BKh3 – blue.

References: Smiryagin, A.P., Promyshlennyye tsvetnyye metally i splavy [Commercial Nonferrous Metals and Alloys], 2nd Edition, Moscow, 1956.

O.Ye. Kestner

DECORATIVE LAMINATED PLASTICS – laminated plastic materials which are obtained by hot pressing of multilayer stacks of special grade, synthetic resin impregnated paper. They differ from Getinaks by the presence of an external decorative facing layer. This layer (facing paper) is made from high-strength, bleached, finished sulfite pulp. Colored decorative laminated plastics are made with facing paper with a filler, such as lithopone, using heat and light resistant pigments and vat dyes for coloring. White decorative laminated plastics are obtained from facing paper with a filler consisting of titanium dioxide. Facing paper without a filler is used for making decorative laminated plastics which imitate expensive species of wood and stone (the texture of the wood or stone is printed on the paper which is then colored in an imitating shade). For inside layers of decorative laminated plastics paper from unbleached sulfite pulp (impregnated insulation, kraft wrapping [paper], etc.) is impregnated by a phenolformaldehide resin (bakelite lacquer), which imparts higher impact ductility and water resistance to the decorative laminated plastics. Paper for internal layers is impregnated by colorless transparent carbamide resins; a carbamide melamine-urea-formeldehyde resin (MM-54-U) is used in the USSR. The dry impregnated paper is cut up, assembled into stacks for pressing into a laminated plastic material. In certain cases the external layer of the stack is made from paper impregnated by pure melamine-formaldehyde resin in order to improve the surface hardness and the resistance of the plastic material to the effect of water and aggressive media. Symmetrical placement of layers with resins of identical properties aids in reducing the

warping of the finished products. Each stack consists of three layers: the surface, compensating and inside (with 11 sheets of paper being used per 1 mm of thickness of the plastic material). To obtain decorative laminated plastics thicker than 1 mm, the thickness of the inside layer of the stack is increased. Decorative laminated plastics are produced in the form of sheets with dimensions up to 1.2 × 3 m, and 0.8-5 mm in thickness, less frequently in the form of corrugated sheets, similar to [roofing] slate.

Physicomechanical properties of decorative laminated plastics: specific gravity 1.25-1.45, impact ductility 8-15 kg·cm/cm^2, Brinell hardness 23-25 kg/mm^2, tensile modulus of elasticity 15,000-75,000 kg/cm^2, Martens heat resistance 120-140°, ultimate strength (kg/cm^2) in tension 900-1300, in compression 1400-1600, in static flexure 900-1000, in shear 90-115, resistance to cleavage 180-200 kg, moisture absorption (hygroscopicity) 1.3-2%, water absorption up to 4%, tangent of dielectric losses angle at 50 cps 0.12-0.18, at 10^6 cps it is 0.035-0.039, specific electric volume resistivity $5.5 \cdot 10^{11}$-$9.1 \cdot 10^{11}$ ohm·cm, specific surface resistivity $1.2 \cdot 10^{12}$-1.7^{12} ohms, electric strength 32-33 kv/mm, dielectric permittivity at 50 cps 6.6-10.7 at 10^6 cps it is 9.1-10.0. Decorative laminated plastics are resistant to oils, gasoline, weak organic acids and weak bases, various washing substances in hot water, to short-duration effect of hot objects, can be boiled in water without producing a change in the external appearance and without cleavage for 30 minutes. Decorative laminated plastics are inert to food products.

Advantages of decorative laminated plastics: moderate weight, minimum number of joints at the plastic-finished surface, they are sanitary, light-resistant and ahve no smell at elevated temperatures. The working temperature is from −30 to +80°. They age only insignificantly. By their abrasion resistance decorative laminated plastics are close to granite,

are easily cut. When heated to 100-120° they become temporarily plastic and can be shaped. Decorative laminated plastics are fastened to concrete, timber, metals, etc., by mechanical means, using screws and strips, or by pasting, as well as by a combination of both methods. The linear dimensions of decorative laminated plastics vary substantially when subjected to heat and atmospheric moisture, for which reason compensating gaps are provided when they are fastened mechanically. Decorative laminated plastics are used for facing of walls of premises; for upholstering seagoing vessels, [railroad] cars, aircraft; for facing of tables; to obtain triple-layer decorative structural materials (in particular, with wood shavings and wood fiber panels or honeycomb designs as a base), which are used as wall partitions, etc. Decorative laminated plastics are used for making various indelible indicators, boards, etc., for which purpose the text of the board or the indicator arrow is painted on sulfite pulp paper, and then it is impregnated by melamine-urea-formaldehyde resin, dried, and when the stack is assembled they are placed first, and pressed. Decorative laminated plastics are cheap, strong and are easily replaceable during repairs.

V.N. Gorbunov, V.Z. Mayevskaya, E.G. Gashnikov

DEFICIENCIES OF ELASTICITY (related terms are: elastic imperfections, inelasticity, relaxation phenomena) are deviations of the behavior of materials from the behavior of a perfectly elastic body which would (until exceeding the elastic range) undergo only elastic deformation. Elastic imperfections may be in the form of: 1) appearance of residual (irreversible) deformations after unloading; 2) noncoincidence of the loading and unloading branches, which corresponds to a difference of the loading and unloading work. This difference is measured by the area of the hysteresis loop; 3) microresidual processes which may not be detected from the forementioned characteristics (see Fatigue). The concept of "elastic imperfections" is narrower than that of internal friction, since in the latter case we do not necessarily assume elastic deformation of the body as a whole, for example with macroscopic flow. All real materials are nonuniform to some degree, both with respect to composition and structure (both from grain to grain and within the limits of a grain) and with respect to the loading process (for example, tension and compression are generally accompanied by bending in view of the presence of eccentricity of load application). This nonuniformity leads to the appearance of inelastic irreversible phenomena in individual zones of the body, although the latter as a whole is deformed elastically. See Bauschinger Effect, Hysteresis, Vibration Damping, Elastic Aftereffect, Relaxation.

References: see article on Internal Friction.

Ya.B. Fridman

DEFORMABLE ALUMINUM RIVET ALLOYS – alloys compounded for the fabrication of rivets. The specific requirements set forth for these al-

TABLE 1

Guaranteed Shear Strength of Riveting Wire and Theoretical Shear Strength of Rivets Inserted into Structure

Сплав a	Состояние материала b	ТУ c	$\tau_{ср}$ проволоки ($кг/мм^2$; не менее) d	$\tau_{ср}$ заклепки ($кг/мм^2$; не менее) e
f АД1, АД	Нагартованный g	h АМТУ 333–53	6	1
i АМц	Термически не обработанный j	То же k	7	1
l АМг2	Термически не обработанный m	•	12	12
АМг5П	Отожженный n	•	16	1
p Д18П	Закаленный и естественно состаренный q	•	19	19
r В65	Закаленный и искусственно состаренный s	•	25	27
t Д1П	Закаленный и естественно состаренный u	•	24	22
v Д16П	Закаленный и естественно состаренный w	•	27	25
x Д19П	Закаленный и естественно состаренный y	h АМТУ 377–56	28[3] 27[4]	28[3] 27[4]
z В94	Закаленный и искусственно состаренный aa	h АМТУ 367–56	29	29
bb ВАД23	Закаленный и состаренный cc	–	30[4]	32[4]
dd САП-1	Отожженный ee	–	15	15

[1] Shear resistance of rivets not determined.

[2] For rivets with shank diameter 1.6–6.0 mm.

[3] For rivets with shank diameter of 6.5–8.0 mm.

[4] Average value of shear strength.

a) Alloy; b) state of material; c) TU; d) τ_{sr} of wire (kg/mm^2; not below); e) τ_{sr} of rivet (kg/mm^2; not below); f) AD1, AD1) AD; g) cold-hardened; h) AMTU; i) AMts; j) not heat treated; k) the same; l) AMg2

m) not heat treated; n) AMg5P; o) annealed; p) D18P; q) tempered and naturally aged; r) V65; s) tempered and artificially aged; t) D1P; u) tempered and naturally aged; v) V16P; w) tempered and naturally aged; x) D19P; y) tempered and naturally aged; z) V94; aa) tempered and artificially aged; bb) VAD23; cc) tempered and aged; dd) SAP-1; ee) annealed.

TABLE 2

Heat-treatment Conditions

Сплав 1	2 Термич. обработка заклепок перед постановкой их в конструкцию	3 Термич. обработка заклепок, поставленных в конструкцию
АД1, АД, АМц, АМг2, АМг5П, САП-1 4	Не производится 5	6 Не производится
Д18П 7	Темп-ра нагрева под закалку 495—505°, выдержка 20—30 мин., охлаждение в холодной воде, старение при комнатной темп-ре не менее суток 8	9 То же
10 В65	Темп-ра нагрева под закалку 515—520°, время выдержки 40—50 мин., охлаждение в холодной воде, старение при 75°±5° в течение 24 час. 11	9 То же
12 Д1П	Темп-ра нагрева под закалку 495—510°, охлаждение в воде, старение не более 2 час после закалки 13	Старение не менее 4 суток при комнатной темп-ре 14
15 Д16П	Темп-ра нагрева под закалку 495—505°, охлаждение в воде, старение не более 20 мин. после закалки 16	Старение не менее 4 суток при комнатной темп-ре 17
18 Д19П	Темп-ра нагрева под закалку 503—508°, охлаждение в воде; старение не более 6 час. для заклепок Ø 1,6—5 мм, не более 4 час. для заклепок Ø 5,5—6 мм, не более 2 час. для заклепок Ø 6,5—8 мм, образцы проволоки и заклепок для контроля сопротивления срезу подвергаются старению при темп-ре 100° в течение 3 час 19	Старение не менее 5 суток при комнатной темп-ре 20
21 В94	Темп-ра нагрева под закалку 465°±5°, охлаждение в воде, ступенчатое старение: при 100°—3 часа, при 165°±5°—3 часа 22	Дополнит. термич. обработка не производится 23
24 ВАД23	Закалка с темп-ры 525°±5° в воде, время естеств. старения не ограничено 25	Старение при 170—180° в течение 10—12 час. 26

1) Alloy; 2) heat treatment of rivets before insertion in structure; 3) heat treatment of rivets already inserted in structure; 4) AD1, AD, AMts, AMg2, AMg5P, SAP-1; 5) none; 6) none; 7) D18P; 8) heating temperature for quenching 495-505°, soaking time 20-30 min, cooling in cold water, aging at room temperature for at least one day; 9) same; 10) V65; 11) heating temperature for quenching 515-520°, soaking time 40-50 min, cooling in cold water, aging at 75° + 5° for 24 hours; 12) D1P; 14) heating temperature for quenching 495-510°, cooling in water, aging for no more than 2 hours after tempering; 14) aging for at least 4 days at room temperature; 15) D16P; 16) heating temperature for quenching 495-505°, cooling in water, aging for no more than 20 min after quenching; 17) aging for at least 4 days at room temperature; 18) D19P; 19) heating temperature for quenching 503-508°, cooling in water; aging no more than 6 hours for rivets 1.6-5 mm in diameter, not over 4 hours for

rivets 5.5-6 mm in diameter, not over 2 hours for rivets 6.5-8 mm in diameter; specimens of wire and rivets for shear-strength control are aged for 3 hours at 100°; 20) aging for at least 5 days at room temperature; 21) V94; 22) heating temperature for quenching 465° + 5°, cooling in water; stepwise aging: 3 hours at 100°, 3 hours at 155° ± 5°; 23) no additional heat treatment; 24) VAD23; 25) quenching from 525° ± + 5° in water; no limit on natural aging time; 26) aging at 170-180° for 16-12 hours.

TABLE 3

Typical Mechanical Properties of the Most Important Deformable Rivet Alloys at 20°*

Сплав 1	Состояние материала 2	$\sigma_{0.2}$	σ_b	δ_{10}	ψ	НВ	τ_{sr}
		3 (кг/мм²)		(%)		3 (кг/мм²)	
5 АМг5П	Отожженный . . 6	15	27	23	—	70	19
7 Д18П	Закаленный и естественно состаренный . . . 8	17	36	24	50	70	20
	6 Отожженный	6	16	24	—	38	—
9 В65	10 Закаленный и состаренный	22	40	20	—	—	27
11 Д19П	10 Закаленный и состаренный	28	46	23	42	—	29
12 В94	Закаленный и состаренный 10	44	52	15	45	150	32

*E = 7000-7100 kg/mm², G = 2700 kg/mm², μ = 0.31.

1) Alloy; 2) state of material; 3) kg/mm²; 4) τ_{sr}; 5) AMg5P; 6) annealed; 7) D18P; 8) tempered and naturally aged; 9) V65; 10) tempered and aged; 11) D19P; 12) V94.

TABLE 4

Mechanical Properties of Wire (Φ 8 mm) made from D18P Alloy as Functions of Heating Temperature and Time

1 Темп-ра нагрева (°С)	2 Время нагрева (часы)	3 Испытание при темп-ре нагрева		6 Испытание при 20° после нагрева при данных темп-рах		
		σ_b (кг/мм²) 4	δ_{10} (%)	σ_b (кг/мм²) 4	$\sigma_{0.2}$ / σ_b 4 (кг/мм²)	δ_{10} (%)
100	0.5—100	25—26.0	21—26.0	18	13—15.0	28.5—30
150	0.5—100	23.0	20—26.0	17	11—13.0	26.5—28.5
200	0.5—100	19—21.0	12—26.0	14	10.5—20.0	25.5—27.0

1) Heating temperature (°C); 2) heating time (hours); 3) test at heating temperature; 4) kg/mm²; 5) τ_{sr}.

TABLE 5

Mechanical Properties of Tempered and Aged Wire (⌀ 8 mm) made from V65 Alloy, at Elevated Temperatures

1 Темп-ра испытания (°C)	2 σ_b (кг/мм²)	δ_{10} (%)	3 $\tau_{ср}$ (кг/мм²)	1 Темп-ра испытания (°C)	2 σ_b (кг/мм²)	δ_{10} (%)	3 $\tau_{ср}$ (кг/мм²)
100	36.0	22	25	200	27.0	23	19
150	30.5	22	22	250	24.0	23	13
175	—	—	20	300	15.0	23	9

1) Test temperature (°C); 2) σ_b (kg/mm^2); 3) τ_{sr} (kg/mm^2).

TABLE 6

Typical Mechanical Properties of V65 Alloy Wire (⌀ 8 mm) in Tensile Test as Functions of Heating Temperature and Time

Темп-ра нагрева (°C)	2 Время нагрева (часы)	3 Испытание при темп-ре нагрева			6 Испытание при 20° после нагрева при помян. темп-рах		
		4 σ_b (кг/мм²)	δ_{10} (%)	5 τ_{sr} (кг/мм²)	7 $\sigma_{0,2}$ (кг/мм²)	σ_b (кг/мм²)	δ_{10} (%)
100	0.5	36	22	25	20.5	38.5	24.0
	10.0	—	—	—	22.0	39.0	26.0
	100.0	—	—	—	23.5	40.5	25.0
150	0.5	30.5	22.0	22	20.0	37.5	24.0
	10.0	—	—	—	22.0	40.5	25.0
	100.0	—	—	20	29.0	41.5	17.0
200	0.5	27.0	23.0	19	23.0	39.5	22.5
	10.0	—	16.0	—	28.5	36.0	13.0
	100.0	—	—	—	25.0	35.0	13.5

1) Heating temperature (°C); 2) heating time (hours); 3) test at heating temperature; 4) σ_b (kg/mm^2); 5) τ_{sr} (kg/mm^2); 6) test at 20° after heating to elevated temperatures; 7) kg/mm^2.

TABLE 7

Mechanical Properties of V94 Alloy Wire (⌀ 8 mm) at Low and Elevated Temperatures

A Темп-ра испытания (°C)	B Время нагрева (часы)	C σ_b (кг/мм²)	δ_{10} (%)	D $\tau_{ср}$ (кг/мм²)
−60	0.5	—	—	34
+100	0.5	47.5	16.0	31.0
	100.0	47.5	15.0	30.5
+125	0.5	45.5	17.0	28.0
	10.0	45.5	15.0	25.5
	100.0	36.0	16.0	24.5
+150	0.5	39.0	16.0	27.0
	10.0	35.0	15.0	22.0
	100.0	29.0	18.0	19.0

A) Test temperature (°C); B) heating time (hours); C) σ_b, kg/mm^2; D) τ_{sr}, kg/mm^2.

TABLE 8

Mechanical Properties of D19P Alloy Wire at Elevated Temperatures

Механич. свойства A	Время нагрева (часы) B	C Темп-ра испытания (°C) 100	125	150	175	Время нагрева B (часы)	Темп-ра испытания (°C) 200	250	300
σ_b (кг/мм²) D	0.5	45.5	43.5	41.5	40.5	0.5	37	27	18.0
	100.0	—	—	—	38.5	5.0	37	21	13.5
						10.0	36	21	12.5
						20.0	33	21	12.5
	200.0	43.5	42.5	41.0	38.5	50.0	30	—	—
						100.0	26	—	—
δ_{10} (%)	0.5	22.0	22.0	23.5	22.0	0.5	23	18	18
	100.0	-	-	-	18.0	5.0	15	16	22
						10.0	12	16	22
						20.0	11	16	25
	200.0	20.0	22.0	21.0	15.0	50.0	12	—	—
						100.0	11	—	—
τ_{cp} (кг/мм²) E	0.5	27.5	27.0	27.0	26.0	0.5	25.0	17.0	12.0
	100.0	27.5	27.5	27.0	25.0	5.0	25.0	15.5	10.5
	200.0	27.5	27.5	27.5	23.0	10.0	24.5	13.0	10.5
						20.0	23.0	13.0	10.0
						50.0	18.0	—	—
						100.0	17.0	—	—

A) Mechanical property; B) heating time (hours); C) test temperature (°C); D) σ_b (kg/mm^2); E) τ_{sr} (kg/mm^2).

TABLE 9

Physical Properties of the Most Important Deformable Rivet Alloys

Сплав A	γ (г/см³) B	ρ (20°C) (ом·мм²/м) C	λ (кал/см·сек·°C) D	α·10⁶ (1/°C)	c (кал/г·°C) E
АМг5П F	2.65	0.056(АМг5ПМ) G	0.28(25°) 0.35(400°) АМг5ПМ G	24.1(20–100°) 26.2(20–300°)	0.22(100°) 0.25(400°) G АМг5ПМ
Д18П H	2.76	0.039	0.35(25°) 0.46(400°)	23.0(20–100°) 25.2(20–300°)	0.22(100°) 0.28(400°)
В94 I	2.85	0.044	0.37(25°) 0.63(300°)	21.9(20–100°) 23.8(20–300°)	0.23(100°) 0.29(300°)
В65 J	2.8	0.0501	0.33(25°) 0.46(300°)	-	0.23(100°) 0.29(400°)
Д19 K	2.76	0.041	0.33(25°) 0.41(300°)	-	0.25(100°) 0.28(400°)

A) Alloy; B) γ (g/cm^3); C) ρ (20°C)(ohms·mm^2/m); D) λ (cal/cm·sec·°C); E) c (cal/g·°C); F) AMg5P; H) D18P; I) V94; J) V65; K) D19.

TABLE 10

Corrosion Properties of the Most Important Deformable Rivet Alloys*

Сплав 1	Коррозионные свойства 2
3 АМг5П 4	Сопротивление коррозии высокое
5 Д18П 6	Коррозионная стойкость заклепок неудовлетворительная, при нагреве выше 100° возможна склонность к межкристаллитной коррозии
7 В65 8	Коррозионная стойкость невысокая при нагреве выше 100° возможна склонность к межкристаллитной коррозии
9 В94 10	Коррозионная стойкость удовлетворительная
11 Д19П 12	Коррозионная стойкость невысокая; при нагревах от 125 до 250° склонность к межкристаллитной коррозии меньше, чем у сплава Д16
13 САП-1	Сопротивление коррозии высокое 14
15 ВАД23	Коррозионная стойкость невысокая 16

*The corrosion resistance of rivets made from all aluminum rivet alloys is quite satisfactory in the anodized state.

1) Alloy; 2) Corrosion properties; 3) AMg5P; 4) high corrosion resistance; 5) D18P; 6) corrosion resistance of rivets is moderate; tendency to intergranular corrosion possible on heating above 100°; 7) V65; 8) moderately good corrosion resistance; tendency to intergranular corrosion appears on heating above 100°; 9) V94; 10) satisfactory corrosion resistance; 11) D19P; 12) moderate corrosion resistance; on heating from 125 to 250°, the tendency to intergranular corrosion is not as strong as in D16 alloy; 13) SAP-1; 14) high corrosion resistance; 15) VAD23; 16) moderate corrosion resistance.

loys – rather high shear strength and the ability to withstand considerable cold deformation – stem from the conditions under which the rivets are fabricated and work in the corresponding structures. Rivets made from these alloys – whether or not they have been hardened by heat treatment – are usually headed on automatic presses in an annealed and slightly cold-hardened state (a small amount of cold-hardening is necessary for normal operation of the heading presses). Aluminum rivet alloys hardened by heat treatment may, depending on their composition, may be peened either in the freshly tempered state (within a certain

TABLE 11

Recommended Fields of Application of the Most Important Deformable Rivet Alloys

Сплав 1	2 Область применения
АД1, АД, АМц, АМг2	Слабонагруж. конструкции с повыш. коррозионной стойкостью
АМг5П	Средненагруж. конструкции из алюминиевых сплавов с повыш. коррозионной стойкостью; конструкции из магниевых сплавов
Д18П, В65	Заклепки для нагруж. конструкций, работающих при темп-ре не выше 100°
В94	Заклепки для сильнонагруж. конструкций, работающих при темп-ре до 125°
Д19П	Заклепки для нагруж. конструкций, работающих при темп-ре от 125 до 250°
САП-1	Заклепки для конструкций повыш. коррозионной стойкости, работающих при темп-ре до 500°
ВАД23	Заклепки для сильнонагруж. конструкций, работающих длит. время при темп-ре до 180°

1) Alloy; 2) field of application; 3) AD1, AD, AMts, AMg2; 4) lightly stressed structures with high corrosion resistance; 5) AMg5P; 6) medium-stressed structures of aluminum alloys with high corrosion resistance; magnesium alloy structures; 7) D18P, V65; 8) rivets for stressed structures operating at temperatures not above 100°; 9)V94; 10) rivets for heavily stressed structures operating at temperatures below 125°; 11) D19P; 12) rivets for stressed structures operating at temperatures from 125 to 250°; 13) SAP-1; 14) rivets for structures with elevated corrosion resistance, working at temperatures below 500°; 15) VAD23; 16) rivets for heavily stressed structures operating long-term at temperatures below 180°.

time after tempering) or in the aged state. Difficulties arise in mass production with insertion of rivets in the freshly tempered state because of the necessity of reheating (after the permissible riveting time has expired) or the use of refrigeration to retard aging. Further, riveting in the freshly tempered state interferes with the subsequent aging process and results in a certain lowering of the shear strength of rivets that have been inserted in the structure. For mass-production applications, therefore, it is preferable to use rivets that can be installed in the aged state. The shear strength of installed rivets made from these alloys may be somewhat higher than that of the rivet wire due to cold-hardening of the rivet shank. Rivets made from VAD23

alloy may be inserted only in the tempered or tempered and naturally aged state; however, to obtain the necessary strength after insertion, rivets of this alloy must be given artificial aging (by heating the entire riveted-up unit or each individual rivet). Occasionally, use is made of a riveting technique in which both heads are formed simultaneously when the rivets are inserted into the structure. Rivets made from all aluminum riveting alloys are installed after anodizing in sulfuric acid, with the anodic film chromate-filled; chromic-acid anodizing is also applied.

The basic theoretical characteristic of the riveted joint and the rivets is shear strength; the riveted joint must also withstand shearing vibrational loads satisfactorily. Rivets work in tension to a much lesser degree. Certain characteristics of deformable aluminum rivet alloys are given in Table 1, heat-treatment conditions in Table 2 and the properties of the rivets and their fields of application in Tables 3-11.

Rivets made from alloys D18P and V65 are used most extensively at the present time for stressed structures; for less heavily loaded structures in which elevated corrosion resistance is necessary, alloy AMg5P is employed. Alloy D19P rivets are used in structures that will be subject to heating.

References: Voronov, S.M., Deformiruyemyye alyuminiyevyye splavy [Aluminum Shaping Alloys], Moscow, 1951; Fridlyander, I.N. Vysokoprochnyye deformiruyemyye alyuminiyevyye splavy [High-Strength Aluminum Shaping Alloys], Moscow, 1960; Teploprochnyy material iz spechennoy alyuminiyevoy pudry [Hot-Strength Material made from Sintered Aluminum Powder (SAP)], collection of articles edited by I.N. Fridlyander and B.I. Matveyev, Moscow, 1961; Shilova, Ye.I., Alyuminiyevyy splav V65

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dlya zaklepok [Aluminum Alloy V65 for Rivets], Moscow, 1958.

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Manuscript Page No.	[Transliterated Symbols]
1138	ТУ = TU = tekhnicheskiye usloviya = technical specifications
	ср = sr = srez = shear
	АМТУ = AMTU =
	САП = SAP = spechennaya alyuminiyevaya pudra = sintered aluminum powder

DEFORMATION – change in the relative positions of points in a body under the action of a load, usually accompanied by changes in the body's shape. The characteristic kinds of deformation of materials are: elastic deformation, plastic (residual) deformation and hyperelastic deformation, the latter being specific for nonmetals. Deformation may be homogeneous, if it is identical in any point in the body, or nonhomogeneous, which changes from point to point. Actual bodies (materials) have nonhomogeneous deformation. A distinction is made between linear, two-dimensional, deformation in which deformation takes place parallel to a certain plane (for example, pure shear due to torsion of a cylindrical specimen), and volume [deformation], which takes place in three directions, for example, in hydrostatic compression. In the theory of elasticity any compound deformation is characterized by combination of linear and shear (angular) deformation. Relative deformation (conventional) and true deformation are determined in mechanical tests of materials; in tensile testing of the majority of materials a distinction must be made between uniform deformation (see Uniform Reduction in Area) and concentrated deformation (see Concentrated Reduction in Area).

References: Fridman, Ya. B, Mekhanicheskiye svoystva metallov [Mechanical Properties of Metals], 2nd edition, Moscow, 1952; Nadai, A., Plastichnost' i razrusheniye tverdykh tel [Plasticity and Failure of Solid Bodies]. Translated from English, Moscow, 1954.

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DEFORMATION ENERGY – see Deformation strain.

DEFORMATION RATE — change in deformation per unit time; is usually specified in terms of relative deformation: $V_d = \frac{de}{d\tau}$, where $\underline{e}$ is the relative deformation and τ is the time. The rate of relative deformation depends on the rate of absolute deformation and the specimen's dimensions: $V_d = \frac{1}{l}\frac{dl}{d\tau}$, where $\underline{l}$ is the length of the specimen, and $\frac{dl}{d\tau}$ is the rate of absolute deformation. Sometimes the deformation rate is characterized by the rate of the conventional relative deformation $V_{u.d.} = \frac{d\delta}{d\tau}$, where δ is the conventional elongation; V_d and $V_{u.d.}$ are interrelated by the relationship: $V_d = \frac{V_{u.d.}}{1+\delta}$; V_d can be expressed in terms of the conventional elongation $V_d = \frac{d|\ln(1-\delta)|}{d\tau}$, or in terms of the magnitude of cross-sectional area reduction ψ: $V_d = \frac{d|\ln(1-\psi)|}{d\tau}$.

In rare cases the deformation rate can be specified in terms of the loading rate $V_n = \frac{d\sigma}{d\tau}$, where σ is the stress.

The deformation rate does not affect the elastic properties of the material. The resistance to plastic deformation increases with an increase in the deformation rate. An increase in the deformation rate by an order of several magnitudes results in increasing the resistance to plastic deformation by 20-60%. The effect of the deformation rate is felt stronger in the case of metals with a low melting point, and, as a rule, has a more perceptible effect on the magnitudes of resistance to small elastoplastic deformations (the increase in the yield point upon increasing the deformation rate exceeds the increase in the ultimate strength). The degree by which the deformation rate effects the mechanical properties depends to a large extent on the test temperature, acti-

vity of the surrounding medium and the physicochemical transformations which take place in the process of deformation. The above conditions can have a substantial effect on the quantitative relationships governing standard tests at room temperature. Standard mechanical tests are performed in the interval of [deformation] rates of 10^{-4}-10^{-2} sec^{-1}, which ensure stable values of properties.

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DEGRADATION – destruction of molecules of a substance from which a given material consists. Degradaition produces cuttings of molecules, most frequently free radicals or ions the high activity of which is the cause of many chemical processes which accompany the original act of degradation. Of greatest importance among these processes are chain reactions, a part of which produces further degradation of the material. The destruction of intermolecular bounds is not degradation, since it is reversible. Degradation is of substantial importance for polymeric materials, plastics, rubbers, fibers, etc., particularly in the case when a chain molecule is broken up. This degradation changes substantially the weight of the polymer, the latter being one of the main characteristics which determine the ensemble of its physical properties. Degradation of a polymer with attendant detachment of its side groups but without disturbing the continuity of the chain molecule has a lesser effect on the material's properties (if we compare results of disintegration of equal numbers of chemical bounds). Deep degradation up to the formation of a monomer or of substances close to the monomer, that is, depolymerization, is observed in a number of cases of pyrolysis and radiolysis of polymers. These reactions are characteristic of polymers containing a fourth carbon atom, for example, of polymethylmetacrylate, polystyrene, polyisobutylene, etc. Less extensive degradation usually takes place attendant to mechanical actions on the material, that is, static and dynamic effects (fatigue). Strong actions, for example, ultrasound effects, may also produce deep degradation. Mechanical degradation, which is accompanied by chemical processes such as oxi-

dation, cross linking, is a part of mechanical chemistry. Degradation, alongside with cross linking is the main cause of aging of polymeric materials, since directly and indirectly, by means of transformations which it brings about, it results in changing the molecular structure of the material. It follows from this that resistance to degradation is substantial requirement to the service properties of materials. On the other hand, degradation is used industrially to impart the required properties to materials (for example, plasticization of raw-material rubber in the production of rubber) or to obtain new substances (hydrolysis of timber, pyrolysis of old rubber, etc.). The basic physical agents of degradation are heat, radiant energy and mechanical effects. The first is of general significance while the others are more specific. Each material has its limiting temperature above which degradation starts. The resistance of materials is quite varied. Thus, polyvinylidenechloride is subjected to thermal degradation at temperatures as low as 80°, certain polyaromatic hydrocarbons can withstand temperatures of 1000° and more without degradation. The effect of radiant energy is also determined by the molecular structure of the substance. The most important of chemical degradation agents are oxygen and ozone (degradation of rubbers, plastics, fibers), water (hydrolitic degradation of cellulose, protein fibers, etc.), sulfornating agents, etc. (see Resistance to Atmospheric Effects, Ozone Resistance of Polymeric Materials, Aging of Polymeric Materials). The determination of the degradation temperature, that is, of the temperature limit of the polymer's or polymeric material's resistance, presents certain difficulties, since products of degradation can bring about a chain reaction which appreciably accelerates the degradation proper. The degradation temperature varies from moderate temperatures, for example 80° (polyvinylidene chloride) and 1[illegible]-150° (polyvinyl chloride) to 400° (polyfluoro-

ethylene) and higher (polyphenylenes, etc.). Polyorganosiloxanes and particularly chelate organometallic polymers are distinguished by their high degradation temperatures, which comes close to 800-1000°. The rate of degradation is important in practice; the degradation temperature depends on this rate and on the duration during which the given material is subjected to the high temperature.

References: Grassy, N., Khimiya protsessov destruktsii polymerov [Chemistry of Polymer Degradation Processes]. Translated from English, Moscow, 1959; Bilmeter, F.W., Vvedeniye v khimiyu i tekhnologiyu polimerov [Introduction to the Chemistry and Technology of Polymers]. Translated from English, Moscow, 1959; Kobeko, P.P., Amorfnyye veshchestva [Amorphous Substances], Moscow-Leningrad, 1952; Berlin, A.A., "UKh," Vol. 29, Issue 10, page 1189, 1960; Losev, I.P. and Trostyanskaya, Ye.B., Khimiya sinteticheskikh polimerov [Chemistry of Synthetic Polymers], Moscow, 1960; Andrianov, K.A., in the collection Khimiya i tekhnologiya polimerov. Materialy Mezhdunarodnogo simpoziuma po makromolekulyarnoy khimii [Chemistry and Technology of Polymers. Materials of the Internationa Symposium on Macromolecular Chemistry], No. 7-8, pages 26-41, Moscow, 1960.

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DEGREE OF BLACKNESS – the ratio of the quantity of radiant energy E emitted per unit surface area by a body at a definite temperature T to the quantity of energy E_0 emitted per unit surface area by an absolutely black body at the same temperature (E is the so-called radioactivity and is measured in watts/cm^2 or kcal/m^2-hr).

TABLE 1

Spectral Blackness* (ε_λ) for Metals and Alloys with Unoxidized Surfaces at $\lambda = 0.65\ \mu$

1 Металл или сплав	В твердом состоянии 2	В расплавленном состоянии 3
	ε_λ	
4 Металлы		
6 Бериллий	0.61	0.61
7 Ванадий	0.35	0.32
8 Вольфрам	0.43	—
9 Железо	0.35	0.37
10 Золото	0.14	0.22
11 Индий	0.30	—
12 Иттрий	0.35	0.35
13 Кобальт	0.36	0.37
14 Марганец	0.59	0.59
15 Медь	0.10	0.15
16 Молибден	0.37	0.40
17 Никель	0.36	0.37
18 Ниобий	0.37	0.40
19 Палладий	0.33	0.37
20 Платина	0.30	0.38
21 Родий	0.24	0.30
22 Серебро	0.07	0.07
23 Тантал	0.49	—
24 Титан	0.61	0.65
25 Торий	0.36	0.40
26 Уран	0.34	0.34
27 Хром	0.34	0.39
28 Цирконий	0.32	0.30
5 Сплавы		
29 Алюмель (95% Ni)	0.37	—
30 Константан (55% Cu, 45% Ni)	0.35	—
31 Монель-металл	0.37	—
32 Нихром (80% Ni, 20% Cr)	0.35	—
33 Платинородиевый (90% Pt, 10% Rh)	0.22	—
34 Сталь	0.35	0.37
35 Чугун	0.37	0.40

*These figures are for the high-temperature region.

1) Metal or alloy; 2) in solid state; 3) in molten state; 4) metals; 5) alloys; 6) beryllium; 7) vanadium; 8) tungsten; 9) iron; 10) gold; 11) indium; 12) yttrium; 13) cobalt; 14) manganese; 15) copper; 16)

molybdenum; 17) nickel; 18) niobium; 19) paladium; 20) platinum; 21) rhodium; 22) silver; 23) tantalum; 24) titanium; 25) thorium; 26) uranium; 27) chromium; 28) zirconium; 29) alumel (95% Ni); 30) constantan (55% Cu, 45% Ni); 31) monel metal; 32) nichrome (80% Ni, 20% Cr); 33) platinum-rhodium (90% Pt, 10% Rh); 34) steel; 35) pig iron.

TABLE 2

Blackness of Full Normal Radiation (ε_n) of Certain Materials*

Материал 1	Состояние поверхности 2	Интервал темп-ры, °С 3	ε_n	Материал
Алюминий А00 4	Химически полированный	100—500	0.02—0.04	Олово 35
Алюминиевые сплавы: 5				Платина 36
Д16 6	То же	100—500	0.04—0.05	Ртуть 39
АМг6 7	•	100—500	0.05—0.07	Свинец 40
Д16 8	После анодного оксидирования (толщина слоя 15 мк)	100—500	0.86—0.40	То же
АМг6 29	То же	100—500	0.85—0.40	Серебро 42
Бронза алюминиевая типа БрАЖ9-4 9	Полированная	100—1000	0.02—0.045	Стали: 43 тип Ст.10
Вольфрам 10	То же	20	0.03	44 тип Х18Н9Т
	•	200	0.05	45 тип ЭИ-26
	•	600—1500	0.1—0.24	46 тип ЭИ-259
	•	1800—2200	0.25—0.31	тип ЭИ401
Железо 11	•	100	0.05	Тантал 48
	•	400—1000	0.14—0.38	То же
Железо	Окисленная при 920° в течение 1 часа (воздушная среда)	100—500	0.85—0.80	Титан 49
				Хром (литой)
				Цинк 51
				Асбестовый кар
				Бумага белая
Золото 12	Полированная 31	100—500	0.02—0.03	Вода (слой более 0,1 мм)
Кадмий 13	То же	100—300	0.045—0.065	Графит типа Т
Кобальт 14	•	500	0.13	Кварц плавле
	•	1000	0.23	Кирпич:
Латунь типа Л68 15	•	250—350	0.03	шамотный
То же 16	Окисленная при 600°	200—600	0.61—0.59	огнеупорный вый
Магниевые сплавы: 17	32			огнеупорный литовый
МА8 18	Полированная	100—400	0.03—0.06	
типа МА2 19	Анодированная (толщина слоя 40 мк) 33	100—500	0.92—0.85	
Медь твердая 20	Полированная	100—800	0.02—0.03	Краски масля
Медь расплавленная 21	—	1100—1300	0.16—0.13	дичных цвето
Медь твердая	Окисленная при 600°	50	0.67	Лакокрасочные
Молибден 22	Полированная 34	100—2000	0.03—0.24	тия различны
Никель 23	То же	25—1000	0.04—0.19	Лак бакелитов
Никелевые сплавы: 24	• 37	300—800	0.13—0.19	Сажа с жидки
тип ЭИ435	Окисленная при 1200° в течение 1 часа	100—500	0.92—0.84	Стекло
ЭИ868 25	Окисленная при 1200°	100—500	0.83—0.5	Эмалевые покр
Ниобий 26	Полированная 36	700—2300	0.11—0.2	дикатные тип

С. ч. характеризует как способность т излучать лучистую энергию, так и спос ность поглощать ее. При любой темп поглощательная способность тела тем бо ше, чем больше его испускательная с собность. Для монохроматич. излучен при одной и той же темп-ре С. ч. числен равна коэфф. поглощения: $\varepsilon_\lambda(T) = a_\lambda($ Для полного излучения это положен строго говоря, справедливо только для (ственно серых тел, практически же с вестной степенью приближения $\varepsilon = a$ п нимают для всех тел, приближающихся по свойствам к серым телам

Микроструктура стали стеллита, на-

*For metals and alloys with polished surfaces these values of ε_n correspond to heating in a nonoxidizing medium; linear interpolation can be used to determine the intermediate values of ε_n within the indicated temperature ranges.

1) Material; 2) surface condition; 3) temperature range, °C; 4) A00 aluminum; 5) aluminum alloys; 6) D16; 7) AMg6; 8) D16; 9) BraZh9-4 aluminum bronze; 10) tungsten; 11) iron; 12) gold; 13) cadmium; 14) cobalt; 15) L68 brass; 16) the same; 17) magnesium alloys; 18) Ma8; 19) type MA2; 20) solid copper; 21) molten copper; 22) molybdenum; 23) nickel; 24) nickel alloys; 25) EI435; 26) EI868; 27) niobium; 28) chemically polished; 29) after anodic oxidation (layer 15 μ thick); 30) polished; 31) oxidized at 920° for 1 hr (air atmosphere); 32) oxidized at 600°; 33) anodized (layer 40 μ thick); 34) oxidized at 800°; 35) oxidized at 1200° for 1 hr; 36) oxidized at 1200°; 37) tin; 38) platinum; 39) mercury; 40) lead; 41) silver; 42) steel; 43) type St. 10; 44) type Kh18N9T; 45) type EP26; 46) type EI925; 47) type EI401; 48) tantalum; 49) titanium; 50) chromium (cast); 51) zinc; 52) asbestos board; 53)

white paper; 54) water (layer more than 0.1 mm thick); 55) type GM3 graphite; 56) fused quartz; 57) brick; 58) firebrick; 59) Dinas brick; 60) corundum brick; 61) magnasite brick; 62) oil paints of various colors; 63) lacquers of various colors; 64) bakelite lacquer; 65) soot and molten glass; 66) glass; 67) enamels (silicate, type EV-55); 68) unoxidized; 69) lustrous; 70) oxidized at 200°; 71) rough.

The degree of blackness is often referred to as the relative radiative capacity; it has no dimension and is a measure of the capacity of a given body to emit radiant energy. We can distinguish the blackness of full radiation ε, i.e., that of radiation over the entire wavelength range of the electromagnetic spectrum from $\lambda = 0$ to $\lambda = \infty$, and the blackness of monochromatic radiation over a very narrow range of wavelengths from λ to $\lambda + d\lambda$, which is the so-called spectral blackness and is designated as ε_λ (Table 1). The spectral blackness ε_λ is defined by the equation $\varepsilon_\lambda = E_\lambda / E_0\lambda$, where E_λ and $E_0\lambda$ are the spectral radiativities of the body in question and of an Absolutely black body, respectively.

The blackness of full radiation ε is generally used for solving practical problems in the field of radiative heat exchange. The spectral blackness ε_λ is employed in research on molecular structure and analytic investigations in organic chemistry, for temperature measurements with optical pyrometers, etc. Many real bodies, particularly polished metals, do not obey Lambert's law (see Thermal radiation) and their energy intensity along the perpendicular to the radiating surface differs from that in directions inclined to this surface. It is consequently necessary to distinguish the blackness of full normal radiation ε_n (Table 2), for radiation along the perpendicular to the surface, from the blackness of full hemispheric radiation ε, for hemispheric radiation (radiation in the hemisphere above the radiating surface). In polished metals the blackness of normal radiation is usually

somewhat less than that of hemispheric radiation (this difference is small and is often neglected in practice).

The degree of blackness characterizes a body's ability to emit or absorb radiant energy. At any temperature the absorptive capacity of a body increases with its radiative capacity. The blackness for monochromatic radiation at a given temperature is numerically equal to the absorption factor: $\varepsilon_\lambda = (T) = \alpha_\lambda (T)$. Strictly speaking, this is valid only for absolutely Grey bodies in the case of full radiation; in practice it is assumed, with a certain degree of inexactness, that $\varepsilon = \alpha_\lambda$ for all bodies with characteristics similar to those of grey bodies, i.e., for the majority of structural and heat-insulating materials, oxidized metals, etc. In all other cases, e.g., for polished metals, the absorption factor α also depends on the characteristics and temperature of the radiating body participating in heat exchange.

The blackness of real solids depends on the nature of the body, its temperature, the condition of its surface, the thickness of the radiating layer, etc., the blackness of a body whose surface is in an unspecified state is consequently not a characteristic of the substance composing the body. Carefully polished specimens opaque to thermal radiation are used to determine the blackness of a substance. Unoxidized metals and alloys generally exhibit a low degree of blackness, which is substantially raised by even slight surface oxidation. Heating somewhat increases the ε of metals. oxides, Borides, Carbides, Silicides, etc., exhibit comparatively high values of ε, which decrease on heating in the majority of cases. Solids have minimal blackness when polished, while surface roughness leads to an increase in blackness. The degree of blackness is determined experimentally.

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A.I. Kovalev

DELAYED FRACTURE – fracture of a component at a definite time after initial loading (tightening of bolts or springs, bulbs under constant pressure, welded assembles with internal stresses, etc.) without any increase in the load. Delayed fracture is associated with the "relaxation" of quenched steel (strength and plasticity increase during post-quenching aging at 20°). Strength during delayed fracture is usually less than the short-term strength of the same components, while the fracture itself is more brittle and cracks propagate slowly under low stresses. The culmination of delayed fracture often has an explosive character, as when part of a tightened bolt "shoots off" with a great deal of kinetic energy on completion of fracture. Delayed fracture has been observed in various steels with a martensitic structure (quenched and low-temper), in certain nonferrous metals, and in plastics, silicate glasses, porcelain, etc. This type of fracture is facilitated by nonuniformity of stressing (notches, cracks, warping, etc.) and by structural nonuniformity and heterogeneity (e.g., quenching of steel without subsequent annealing, overheating during quenching, absorption of hydrogen by steel, selective corrosion of glass, etc.). Nonuniformity of stressing and structure causes temporal and quantitative inequalities in the development of plastic deformation in different regions of the body. This leads to deloading of certain zones and to overloading and subsequent cracking in others. Delayed fracture is caused by distortions near the grain boundaries. In many cases this type of fracture is intensified by or develops under the action of corrosive and surface-active media. Delayed fracture is facilitated by any

increase in the elastic energy of the stress system; for example, such fracture occurs for the most part in bolts used to fasten units with low Rigidity, i.e., with a larger store of elastic energy. Conversely, delayed fracture usually does not occur when steel bolts are tighened against a rigid steel plate, since the slight elongation of the bolt leads to considerable deloading. Delayed fracture is reproduced in the laboratory by artificial embrittlement (as by absorption of hydrogen) of the component or by introducing an initial warp with skew washers. In order to reduce the tendency toward delayed fracture it is necessary to increase and maintain uniformity of mechanical state and to reduce stored elastic energy (see Stored elastic energy). In order to do so one must avoid brittle surface layers (resulting from hydrogen, oxygen, or carbon saturation, the superficial action of selective corrosive or adsorptive agents, or extreme superficial cold working) and residual tensile stresses and eliminate and reduce Stress concentrators (notches, bends). Creation of softened surface layers (as by high-frequency local tempering) reduces susceptibility to delayed fracture.

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Ya.B. Fridman

DELTA WOOD – see Laminated Wood Plastics.

DEPTH OF CURVATURE – the linear displacement of points on a shaft or rod in the area of greatest curvature under the action of a bending load; the depth of curvature characterizes the deformation during bending and depends on the magnitude and application mode of the bending load, the distance between supports, the support setup, and the cross-sectional size and shape of the shaft or rod. It can be determined by calculation or experimentally (using dial indicators, cathetometers, etc.).

N.V. Kadobnova, D.M. Shur

DIAMOND (in engineering) – a mineral of the class of natural elements, the cubic modification of carbon, in the varieties: bort, ballas, carbonado. Diamond is encountered in the form of crystals of the octahedral, rhombododecahedral, cubic and tetrahedral habits. Concretions, irregular shapes, compressed and elongated crystals with rounded edges and faces are characteristic. Complex sculptures are frequently observed on the faces. Bort is a fine- or coarse-grained diamond of irregular shape, sometimes with a coarse- or monocrystalline nucleus. We distinguish between ordinary bort, magnetic bort (stewartite), hailstone bort, shotbort and framesite. Ballas is a fine-grained dense diamond of spherical shape, sometimes with radiate-fibrous structure. Carbonado is a very dense aggregate of microscopic diamond grains with rounded and irregular shape, usually dark and opaque, with an enamel-like surface; it is sometimes porous and slag-like.

Diamond always has impurities of Si, Al, Mg, Ca and Fe; sometimes we find Ti, Cr, Cu, Ba, Sr, B, N and others. Diamond leaves an ash on burning; the ash content in colorless diamond is negligible (from traces to 0.02-0.05%); certain varieties of bort (magnetic bort) contain 20% ash. The specific gravity of ridges 3.52; for bort it is 3.40-3.53 and for carbonado 3.016-3.416. The Mohs hardness is 10; the absolute hardness ranges from 5500 to 6950 (for comparison: 2150 for carborundum, 1650 for corundum, 1250 for topaz); the microhardness (Khrushchev) is 10,060 kg/mm^2. The hardness is greatest at the ocathedron [111], intermediate at the rhombododecahedron [110] and minimal on the cube [100]. The coefficient of volume compressibility is 0.16-0.18 $\times 10^{-6}$ kg/cm^2.

The ultimate bending strength is 21-49 kg/mm^2. The tensile strength (theoretical) is 790,000 kg/cm^2. The bulk compression modulus is $5.7-6.3 \cdot 10^6$ kg/cm^2. The elastic modulus parallel to the fourth-order axis (L_4) is $7.4 \cdot 10^6$ kg/cm^2, that on the third order (L_3) is $10.5 \cdot 10^6$ and that for the second order (L_2) is 9.5×10^6. The melting point of diamond is unknown. Diamond burns in air at 850°, in a stream of oxygen at 720°, and it is graphitized in a vacuum at 1500° (heat of transition 454 ± 30 cal). The heat of combustion of diamond in air is 95.505 cal/mole. The thermal conductivity in watts$\cdot cm^{-1} \cdot degree^{-1}$ is 1.210-1.630 at 0° and 1.340-1.720 at 72°. The thermal expansion at 28-105° is $1.45 \cdot 10^{-6}$. The coefficient of linear expansion at 298.6°K is $1.06 \cdot 10^{-6}$; the volumetric expansion coefficient is $2.97 \cdot 10^{-6}$. The atomic specific heat at 27° is 1.4805 cal/g-atom/degree. Diamond may be colorless, white (milk), yellow, brown, cinnamon, pink, violet, green, blue, indigo, gray to black. Synthetic diamonds are colored by exposure to radium rays or bombardment by neutrons and other particles in cyclotrons and reactors; colorless diamonds then become green, pink, red, etc. The refractive index of diamond is 2.4195 (in sodium light). Diamond has a very dispersion of 0.063 (2.465 in violet light and 2.402 in red light).

Two types of diamond are distinguished on the basis of certain physical properties. Diamond of type 1 is opaque to ultraviolet wavelengths shorter than 3000 A, luminesces in ultraviolet light and absorbs frequencies from 4-5 and 8-10 μ in the infrared spectrum; it is a poor conductor of electricity; on bombardment by α-particles, pulse conductivity is excited in it (as is not the case on γ-bombardment); diamond of type 2 is transparent to ultraviolet to 2250 A, does not luminesce in ultraviolet light and absorbs only the 4-5-μ frequencies in the infrared spectrum. It is electrically conductive to varying degrees; on γ-irradiation, an electric current is excited in it, while

bombardment by α-particles excites pulse conductivity only partially (usually in isolated zones of the crystal). Diamond of type 2 may be used in the design of radioactivity counters. The resistivity of diamond at 15° ranges from $3 \cdot 10^{13}$ to $5 \cdot 10^{14}$ ohms·cm. Diamond is paramagnetic; its susceptibility is $49 \cdot 10^{6}$. The dielectric constant is 5.65 for type 1 diamond and 5.70 for type 2 diamond. Diamond is a hydrophobic mineral whose surface is poorly wetted by water, so that it has the ability to adhere to fats – something that is exploited together with x-rays and electroseparation to extract diamond from concentrates. Diamond does not etch in acids; it corrodes in fused soda, NaOH, $KHSO_4$, $NaNO_3$ and other substances.

Synthetic diamond has been produced since 1955 from a carbon compound, which is placed in a chamber and subjected to high temperature (1200–2000°) and a pressure above 80,000 kg/cm^2. The first synthetic diamonds were less than 0.1 carat in size; crystals up to 1 carat have been produced recently.

Industrial uses of diamond are as follows: 1) In the form of whole crystals and grains in crown drills for drilling hard rock (crystals ranging in size from 0.5 to 2 carats, in fine-diamond crown drills, fine crystals down to 150 per 1 carat, shotbort, bort, ballas and carbonado). 2) Ground-off diamonds, 0.5–0.8 carat and over, with sharp cutting edges, in cutting tools for finish machining the surfaces of components made from superhard alloys, as well as aluminum alloys, bronze, babbitt, copper, brass and other metals. Further, diamond cutting tools are used to work on plastics, mica, carbide tools, ceramics, organic glass and the like. Elongate diamond crystals or plates cut out of them specifically for the purpose, in diamond drills for drilling holes in components, optical glasses, technical jewels, and the like. 4) Diamond crystals with sharp artificial or natural edges from 0.15

carat up for machining and truing grinding wheels made from carborundum, corundum and other abrasives. 5) High-quality diamond crystals from 0.16 to 0.60 carat in measuring and precision instruments: step bearings in marine chronometers, profile gauges, hardness gauges (Rockwell cone hardness gauge; Vickers pyramid hardness gauge; Khrushchev and Berkovich microhardness gauges; AB-1 instrument for determining hardness by the elastic recovery method, etc.). 6) High-quality diamond crystals from 0.15 carat on up, in drawing dies for drawing extremely fine wire from tungsten, chrome-nickel steel, copper, brass and other metals. The silk threads of parachute cloth are polished through diamond drawing dies. 7) Fine diamonds, from 0.02 to 0.2 carat in glazier's glass-cutting tools, as well as in engraving styli used for dividing microscopic measuring scales and grids in optical and spectrographic instruments. 8) Fine low-grade crystals ranging in size from 3 to 800 per 1 carat, in various types of diamond pencils for dressing grinding wheels, machining metallic components, etc. 9) Finely divided diamond (powder, dust) for dressing diamond dish saws, the steel punches used to make drawing dies, for grinding metallic components, optical lenses, glass and mirrors; in jewelry for sawing and faceting diamonds and other precious stones (jewels), as well as for machining hard costume jewels (jasper, nephrite, jadeite, agate, etc.). Diamond saws are used to cut optical glass, quartz crystals, corundum, silicon and germanium, which are used as end plates and other components in clockwork mechanisms, radio engineering, ultrasonic generators, in instruments used to measure mechanical forces, and so forth.

The quality requirements for diamonds will be found in the appropriate technical specifications, according to the field of application in question. The number of diamonds mined and the market for them are increasing year by year. Of all the diamonds mined each year, 85-90%

are used in industry. The production and industrial use of synthetic diamonds are also on the rise. Since 1957, synthetic diamonds have been produced on an industrial scale.

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Yu.L. Orlov

DIASPORE – a mineral, natural hydrous aluminum oxide. Diaspore forms thin lamellar and tablet-like crystals; usually it forms foliate and thin scaly aggregates. The color of diaspore is white, yellowish, greenish-gray. Mohs hardness 6-7, brittle. Specific weight 3.3-3.5. Is not soluble in acids and alkalis, it decomposes in H_2SO_4 after intensive calcination. At a temperature of 450-510° (depending on the source) diaspore becomes corundum. Diaspore is encountered in nature primarily in bauxites with a content (in industrially worked deposits) of 46-85%. The chemical composition of calcined concentrate of diaspore of ores of the Ak-Tash deposit (% by weight) is: 70-72 of Al_2O_3, 20 of SiO_2, the total amount of fusing agents is 3-3.5

Diaspore is used as a raw material in the production of silicate-aluminum alloys together with sillimanite, andalusite and kyanite, and also in the production of high-silica refractories, sometimes together with corundum, the refractoriness of which comprises 1800-1850°. After dehydration, as in the case of other varieties of bauxities, diaspore is used as an adsorbent in the removal of sulfur from petroleum, purification of beet sugar (as a replacement for diatomite), etc. The most important forms of diasporite utilization (in bauxites) are: production of metallic aluminum, artificial abrasives (electrical corundum), quick-setting aluminum oxide cements.

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P.P. Smolin

DIATOMITE – loose or dense rock consisting primarily of hollow shells of microscopic (1-10 microns in diameter) organisms (diatoms) of hydrate aluminum oxide (opal) composition; usually contains an admixture of argillaceous and sandy material. Gaize and tripoli are close by composition and utilization to diatomite, differing from it by the absence or small quantity of various remains of organisms and lower degree of hydration of the alumina particles. The color is white, yellowish, gray. Chemical composition (% by weight): 55-95 SiO_2, 0.1-10.5 Al_2O_3, 0.2-10.0 Fe_2O_3, 0.2-4.0 CaO+MgO; calcination (up to 800°) losses 5.8-7.2%.

Use is made of the physical properties of diamomite which are light weight, low thermal conductivity, good adsorption capacity. The specific gravity of opal) and increases with admixture of clay to 2.20, the specific weight is, respectively 0.35-0.95. The porosity may be as high as 92%. The specific gravity of gaize and tripoli is 2.20-2.50, the specific weight 0.50-1.82. Thermal conductivity of piece diatomite (at 50°) is 0.08-0.12 kcal. The adsorption capacity of diatmomite is due to the active alumina which is an acidic substance (alkaline substances are adsorbed better); it increases in proportion to the opal content.

Diatomite serves for thermal insulation primarily at 50-900°; as a ground powder for filling of furnace and dryer domes, etc.; putties from a mixture of diatomite with asbestos (asbozurite), with asbestos and artificial slate production waste (novaasbozurite), with asbestos, artificial slate production wastes and micaceous lamellae (asbestos mica) are most effective up to 200-275°; roasted products such as bricks,

pipeline shells; vulcanite which are sealing (autoclave) products from diatomite, line and asbestos (up to 400°); compositions with organic additives, i.e., sawdust, paper dust, etc., (up to 150°), diatomite-bitumen water-resistant materials (plasters which resist atmospheric effects up to 250°); thermal insulation concrete from diatomite calcined at 800-1100° and mixed with 25% of portland cement (up to 900°). Uses of diatomite: 1) in the building industry, i.e., thermal insulation bricks, concrete ballast, hydraulic additions to cement (particularly for underwater work), hard emulsifier of bitumen pastes for roadbuilding; 2) in the food and petroleum industries for purification of organic substances, particularly in the beet-sugar and soap manufacturing branches, separation of petroleum from water, etc. In the abrasives industry it is used for finishing of metal and marble (by pastes filled with finely ground diatomite); 3) in the chemical industry for obtaining high-silica anti-alkali ultramarine, as a filler – for electric insulation and acid resisting hard rubbers, plastics (battery tanks), insecticides and dynamite.

Requirements put to diatomite are presented in GOST 2694-52 (diatomite bricks), OST 3043, 3053, 3054 (building industry), as well as in a number of departmental TU. The lower limit of the SiO_2 content, the upper limit of the content of Fe_2O_3, Al_2O_3, CaO, MgO, specific weight, content of organic substances, and sometimes also the grain-size distribution, are usually specified.

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P.P. Smolin

DIELECTRIC LOSSES – part of the energy of a variable electric field which is converted into heat in the dielectric. The total energy losses in the dielectric are composed of the conductivity losses, which correspond to the constant strength, and from losses produced by the active component of the displacement current in the dielectric. The latter arises as a result of the fact that in variable fields the dielectric displacement vector D in the dielectric has a phase lag with respect to the field intensity vector E. In practice dielectric losses are frequently characterized by the value of the tangent of the phase shift angle arctan δ between D and E. In the case of a homogeneous field the dielectric losses per 1 cm^3 of the dielectric are

$$p = \omega E^2 \varepsilon \operatorname{tg} \delta$$

where ω is the angular frequency and ε is the dielectric permitivity. The quantity ε arctan δ is called the dielectric losses coefficient. In dielectrics with purely electron polarization (pure nonpolar liquids, nonpolar polymers such as polyethylene, polystyrene, etc.) the dielectric losses are very low (arctan δ 10^{-5}-10^{-4}), are independent of the frequency up to 10^9 cps and are practically independent of the temperature up to the softening temperature. In dielectrics with oriented and elastic ionic polarization (see Dielectric Permittivity) dielectric losses have temperature and frequency maxima. As the frequency is increased, the temperature maximum is displaced in the direction of high temperatures, when the temperature is increased the frequency maximumis displaced in the direction of high frequencies. If the losses are only due to conductivity, then arctan $\delta = \operatorname{tg}\delta = 4\pi\gamma/\omega\varepsilon$ where γ is the specific

conductivity. For hygroscopic dielectrics arctan δ is perceptible dependent on the moisture.

L.S. Priss

DIELECTRIC PERMITTIVITY – one of the main characteristics of a dielectric; the ratio to the force of interaction between point charges in vacuum to their force of interaction in a homogeneous dielectric. Dielectric permittivity is also defined as the ratio of the dielectric displacement (electrostatic induction) D to the intensity E of the average field in the dielectric: $\varepsilon = D/E$.

For isotropic bodies the dielectric permittivity is a scalar, for anisotropic bodies it is a tensor. In the CGS electrostatic system of units the dielectric permittivity ε_m is a dimensionless quantity, in the CGS electromagnetic system of units ε_e has the dimensions sec^2/cm^2. The relationship between the values of the dielectric permittivity in these systems

$$\varepsilon_m = \varepsilon_e (9 \cdot 10^{20})$$

The dielectric permittivity is determined by the ability of the dielectric to be polarized, which can be determined by: 1) deformation of the electron shells of atoms and molecules in the electric field (gas, nonpolar liquid and solid dielectrics), 2) orientation of polar molecules (polar liquids and polymers), and 3) elastic displacement of ionsin crystals and glass. The dielectric permittivity of dielectrics of the last two classes in a unvariable field is highly reduced with an increase in the temperature, while in a variable field it has a temperature maximum and decreases with an increase in frequency at constant temperature. A special class is composed of ferroelectrics (Seignette to salt, barium titanate, etc.), which are substances capable of being in the polarized state in the absence of an electric field. The dielec-

Dielectric Permittivity of Certain Dielectrics at Room Temperature and a Static Field

1 Вещество	ε	1 Вещество	ε
2 Бумага сухая	2—2,5	Фарфор 11	4,4—6,8
3 Кварц кристаллический	4,5	Эбонит 12	2,7—2,9
4 Кварц плавленый	3,5—3,6	Бензол 13	2,29
5 Мрамор	8,3	Вода 14	81
6 Парафиновый воск	2—2,3	Масло вазелиновое 15	1,9
7 Резина	2,1—2,4	16 Масло трансформаторное	2,24
8 Слюда	5,7—7	Спирт метиловый 17	35,4
9 Стекло кронглас	5—7	Спирт этиловый 18	26,8
10 Стекло флинтглас	7—10	Воздух 19	1,000528

1) Substance; 2) dry paper; 3) crystalline quartz; 4) molten quartz; 5) marble; 6) paraffin wax; 7) rubber; 8) mica; 9) crownglass brand glass; 10) flintglass brand glass; 11) porcelain; 12) ebonite; 13) benzol; 14) water; 15) liquid petroleum jelly; 16) transformer oil; 17) methyl alcohol; 18) ethyl alcohol; 19) air.

tric permitivity of ferro electrics has an anomally high value (200-50,000), is highly temperature dependent, passing through a maximum at a temperature which is called the Curie point, and decreases with an increase in the field intensity. The most extensively used methods for determining the dielectric permittivity are based on measuring the capacitance of a capacitor filled by the dielectric under study, since it is directly proportional to the dielectric permittivity.

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L.S. Priss

DIELECTRICS – substances the main electrical property of which is the capacity to become polarized in an electric field and in which prolonged existence of an electrostatic field is possible. The term "dielectrics" was first introduced by Faraday to denote a medium in which a prolonged existence of an electric field is possible. Dielectrics almost have no free electrons or ions, have a negligible conductivity, for which reason many of the dielectrics are used as electrical insulation materials, in which their great practical significance consists. The major characteristics of dielectrics, which determine their quality as electrical insulation materials, are: dielectric permittivity, electrical conductivity, dielectric losses and electric strength. Under the action of an electric field a directed displacement of charges (particles), which is called polarization, takes place. Due to the polarization, the positive charges are found to be displaced in the direction of the field, while the negative charges are found to be oriented opposite to the direction of the field, i.e., a field directed in a direction opposite to the external field is inducted inside the dielectrics. The polarizability of dielectrics is characterized by the dielectric permittivity ε, which is defined as the ratio of the field intensity in the dielectric for the same position of electrodes and the same value of electrode charges. By the nature of particles being displaced in the electric field a distinction is made between electron, ionic and dipole polarization. By the character of particle displacement polarization can be nonhysteresis (elastic), hysteresis (elastic-relaxational) and, in particular, residual. Electron polarization is produced by elastic dis-

placements of electron orbits brought about by the external field. It is nonhysteresis and does not involve energy losses. This kind of polarization is observed in all dielectrics, and is the basic kind for nonpolar dielectrics (polyethylene, polystyrene, transformer oil, etc.). The electron polarization is established almost simultaneously in 10^{-13}-10^{-15} secs, for which reason ε of nonpolar dielectrics is independent of the field's frequency and on the average comprises 1.8-2.3. Ionic nonhysteresis polarization also does not involve energy losses and is produced by elastic displacements of ions under the action of the external field. Ionic polarization is the determining polarization mechanization mechanism for mica, marble, quartz, and other ionic crystals. Since the total polarization of ionic crystals is composed of the electron and ionic polarizations, then the dielectric permittivity for these substances is always greater than for nonpolar substances and comprises 5-15. Dipole polarization is produced by orienting dipoles relative to the direction of the external electric field and differs from the electron and ionic polarizations by the fact that it involves thermal motion of particles and the presence of irreversible energy losses in a varying electric field. Solid, semi-liquid and liquid dielectrics (amino plastics, bakelite, rosin compounds and castor oil) have a primarily dipole polarization. Their dielectric permittivity depends highly on the electromagnetic field frequency and temperature and comprises tens and hundreds of units. A particular kind of polarization is characteristic of ferroelectrics, substance, which in a specified temperature interval have spontaneous polarization in the absence of an external field (see Ferroelectrics). The electrical conductivity of dielectrics is judged about on the basis of the magnitude of the electric resistivity. The comparative evaluation of various electric insulation materials is performed on the basis of the specific volume resistivity ρ_v and the

specific surface resistivity ρ_s. The specific volume resistivity ρ_v is numerically equal to the resistance of a cube of material which a height of 1 cm in which current passes through two opposite faces of the cube; ρ_v is expressed in ohm-cm. The specific surface resistivity ρ_s is numerically equal to the resistance of a surface layer in the form of a square with a side equal to 1 mm, where the current passes through two opposite sides of the square; ρ_s is expressed in ohms. As a rule, the conductivity is related to the displacement of conducting ions, the sources of which in liquid and solid dielectrics are the admixtures. Ionization of gases takes place due to irradiation. Nonpolar liquids have, as a rule, a higher specific electric resistivity, than polar liquids, since it is more difficult to remove electrolite admixtures from the latter. The conductivity of highly polar liquids is relatively high, since they can become ionized under the action of the electric field. Industrially pure nonpolar liquids (gasoline, benzol, transformer oil) with ε 2.0-2.5 have a specific electrical resistivity ρ_v = = 10^{14}-10^{15} ohm-cm, polar liquids (castor oil, etc.) with ε = 4.5 have ρ_v = 10^{11}-10^{13} ohm-cm, highly polar liquids (acetone, water, ethyl alcohol) with ε = 25-85 have a ρ_v = 10^{5}-10^{7} ohm-cm, i.e., by a factor of tens and hundreds of millions lower than the specific electrical resistivity of nonpolar liquids.

The electrial conductivity of solid dielectrics with an atomic or molecular structure is related to the displacement of admixture ions. The electrical resistivity of industrially pure nonpolar dielectrics (polyethylene, polystyrene) may be as high as ρ_v = 10^{17}-10^{20} ohm-cm, while that of polar dielectrics can reach 10^{12}-10^{16} ohm-cm. The electrical resistance depends to a certain extent on the temperature, electric field intensity, material moisture and the time during which the insulation is subjected to the current, i.e., on factors which affect

the concentration of free charges and their mobility. Dielectric losses in dielectrics take place under a steady as well as varying field. In a steady field they are determined by the leakage current and the quality of dielectrics is fully characterized by the value of the electrical resistance. In a varying field the losses are due not only to the presence of a through current, but also to polarization phenomena, for which reason the capacity of dielectrics for energy dissipation is characterized by arctan δ, where δ is the complement of the phase shift angle φ between the current and the voltage. In the case of an ideal dielectric the current vector in the capacitive circuit will lead the voltage vector by 90° and the angle $\delta = 0$. The greater the power dissipated in the dielectric, the saaller the phase shift angle φ and the larger the dielectric losses angle $\delta = 10^{-4}$. Materials with higher values of arctan δ are called low-frequency dielectrics. Very high losses in dielectrics are not permissible, since they can result in an increase in temperature and thermal failure. Phenomena which arise under the action of the electric field and which result in the formation of a high-conductivity channel are called dielectric breakdown. As a result of breakdown in a solid dielectric a fused-through hole is produced and the insulation properties become unsatisfactory. A distinction is made between electrical, thermal and electrochemical breakdown. Electrical breakdown is characterized by a sudden rise in the electric current which takes place due to ionization of the dielectric or as a result of the appearance of conducting electrons in it. In the case of breakdown in solid or liquid dielectrics the conducting electrons appear as a result of their detachment from orbits of molecules or ions of the dielectric, or as a result of their detachment from the metal electrodes. Thermal breakdown is due to the increased generation of heat which is a result of losses, to temperature increases and, as a result, to the

reduction in the electrical resistivity of the dielectric. When the conductivity is increased the current increases, the heat generation is increases, as a result of which the material can melt, crack or become charred. Electrochemical breakdown is produced by electrochemical processes which take place under the prolonged action of voltages, as a result of which the dielectrics are ionized and electrolized. The latter is characteristic of liquid dielectrics, which contain moderate electrolite admixtures. Many gaseous, liquid and solid bodies have dielectric properties. Dielectrics are divided by their structure into organic and inorganic. All gases consisting of neutral molecules are dielectrics. They are distinguished by their high electrical resistivity and low dielectric losses. Thus, for air, which serves as a dielectric in air capacitors, $\rho_v = 10^{18}$ ohm-cm, arctan $\delta = 10^{-9}$ and $\varepsilon =$ $= 1.0006$ at a frequency of $\sim 3 \cdot 10^6$ cops. The shortcoming of gases as dielectrics consists in their low electric strength. The breakdown voltage for air is $E_{pr} = 10$ kv/mm. An electric strength which is higher than that for air is possessed by heavy gases. Thus, in high-voltage apparatus it is possible to use sulfur hexafluoride SF_6 (electric gas), which is a chemically stable gas with a breakdown voltage by a factor of two higher than that for air. Dielectrics are used in transformers, capacitors, high-voltage circuit breakers, in cables, inlets, etc. A valuable property of liquid insulation is the spontaneous and rapid restoration after breakdown. The main liquid dielectrics are petroleum oils (transformer and capacitor) and synthetic liquids: chlorodiphenyls (sovol), chlorodiphenyls with trichlorobenzol (sovtols), organofluoride and organosilicon liquids. Synthetic liquids are easily distinguished from petroleum oils by the absence of oxidation tendency, noncombustibility and higher thermal resistance.

To improve the electrical insulation properties of electrical and

radio devices use is made of compounds which are in a liquid state during pouring, impregnation or coating, and which solidify with time upon heating or cooling. These compounds are used for improving the removal

Indicators of Liquid Dielectrics

Диэлектрики 1	γ (г/см³) 2	ε	ρ_v (ом·см) 3	tgδ при 4 20° и 50 гц	E_пр. 5 (кв/мм)
6 Трансформаторное масло	0,87—0,9	2,2	10^{14}	$2\cdot10^{-4}$	17,5
7 Сопол	1,55	5,2	$7\cdot10^{14}$	$3\cdot10^{-3}$	17,0
8 Совтол	1,52	4,5	10^{13}	$4\cdot10^{-3}$	18—20
9 Фторорганические жидкости	1,8	1,85	10^{16}	$5\cdot10^{-4}$	15—18
10 Кремнийорганические жидкости	0,95	2,5	10^{13}	$2-3\cdot10^{-4}$	12—18

1) Dielectrics; 2) gamma (g/cm^3); 3) ρ_v(ohm-cm); 4) arctan δ at 20° and 50 cps; 5) E_{pr} (kv/mm); 6) transformer oil; 7) sovol; 8) sovtol; 9) organofluoride liquids; 10) organosilicon liquids.

of heat, increasing the mechanical strength of radio units, fastening of coils, etc. Epoxy polyester pour-on compounds (K-168, K-193, etc.) and polyesterstyrene compounds are in extensive use. Organosilocon-based-oil compounds have a working temperature up to 180-200°. From among solid dielectrics plastics and inorganic materials are extensively used. Nonpolar-resin-based plastics (polyethylene, polystyrene, fluoroplast-4) have a high electrical resistivity and very low high-frequency losses: arctan $\delta = (2\text{-}5)\cdot10^{-4}$ at a frequency of 10^{10} cps. These are called high-frequency dielectrics. A high strength σ_b up to 56 kg/mm^2) and operating temperature up to 200-300° are possessed by glass textolites, which are characterized by: $\varepsilon = 3$, arctan $\delta = (100\text{-}400)\cdot10^{-4}$ and $\rho_v = 10^{12}\text{-}10^{14}$ ohm-cm. Mica, glass, electrical porcelain, oxides, etc., are the inorganic dielectrics. Inorganic insultaing materials are distinguished from organic materials by their higher heat resistance. Thus, varieties of mica can be operated at 500-600° (muscovite) and 900-1000° (phlogopite). For operation at higher temperatures use is made of aluminum oxide and beryllium oxide based materials.

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P.T. Kolomytsev

Manuscript Page No.

[Transliterated Symbols]

1181 пр = pr = probivnoye = breakdown

DIFFUSION – in the elementary case it is spontaneous equalization of concentrations in a system; in the general case it is the process of establishing, within phases, of the equilibrium concentration distribution, which arises as a result of random straying of the system's elements. The straying is produced by the thermal motion of atoms or molecules (molecular diffusion) as well as larger particles which are suspended in a gas or liquid (Brownian motion or turbulent diffusion). As a result of diffusion, the chemical potentials of a system equalize at room temperature. In the particular case of a single phase system, in the absence of external forces, diffusion results in the equalization of component concentrations at all sections of the system. If external forces are acting in the system (a gradient of temperature, electric potential, etc.), then as a result of diffusion the gradient of concentrations is established in the system, i.e., the so-called thermodiffusion, electrical transfer, etc. The process of equalization of the isotope composition, as well as the process of shape change of pure solid bodies as a result of diffusion straying of particles is called self-diffusion.

Diffusion in solid bodies has as its cause the thermal motion of particles. However, while in gases the main kind of thermal motion coincides directly with wandering, in solid bodies the main kind of thermal motion which is oscillations about the equilibrium positions, do not coincide with wandering. Gases diffuse in solid bodies in the form of ions or atoms, moving along iterstices of the crystal lattice. Atoms with an ionic radius appreciably smaller than the radius of the solvent

ion (atom) (carbon, boron and possibly also sulfur in transition metals as well as copper in germanium), also move in the lattice.

In crystals in which the atoms of the dissolved substance are located in the replacement positions, diffusion can be brought about by various mechanisms: 1) direct exchange of two neighboring atoms; 2) motion of atoms through interstices; 3) exchanging places with nonoccupied lattice points, i.e., with vacancies; 4) by simultaneous displacement of several atoms along a closed circuit in the process of which one atom moves into the place of another, i.e., ring mechanism. In any diffusion mechanism, performance of the elementary jump requires that activation energy be imparted to the particle. In conjunction with this the temperature relationship of diffusion, according to Boltzmann's law is as follows: $D = D_0 \exp(-E/RT)$, where D_0 is a preexponential multiplier, R is the gas constant and T is the absolute temperature. If E is temperature dependent, then $d\ln D/dT = E/RT^2$. In the case of mechanisms 1) and 2), this energy is used up for deformation of the surrounding lattice, which accompanies the atomic motion. In the case of mechanism 3) the activation energy consists of two parts: the vacancies formation energy and of the work which is needed for overcoming the potential barrier between the diffusing atom and the vacancy. For the system Ag-Zn these quantities comprise 40% and 60% of the total activation energy, respectively. In metals diffusion according to mechanisms 1) and 2) is less probable. Theoretically calculated values of the activation energy of self-diffusion through interstices for copper are 250 kcal/mole, for the vacancy mechanism it is 64 kcal/mole (the experimentally obtained value is about 50 kcal/mole). In face centered and in a number of body centered cubic metals diffusion proceeds primarily by the vacancy mechanism.

In mutual diffusion proceeding by mechanisms 2) and 3) the proba-

ility of the passing of a diffusing atom into a neighboring equilibrium position can be different for components A and B, which makes it necessary to introduce a diffusion coefficient for each of the components, i.e., the partial coefficients D_A and D_B, using the equation $j_i = -D_i \frac{dc_i}{dx}$ where j_i is the flux of particles of the ith kind through a unit surface per second, c is the concentration, x is the coordinate and D is the diffusion coefficient.

If $D_A \neq D_B$, then a resultant flow of the substance in the direction of diffusion of the element with a larger partial diffusion coefficient, and a flow of vacancies in the opposite direction appear. Here the region in which the flow of the substance arrives becomes unstable and macroscopic flow of the substance as a whole starts in the opposite direction with the velocity $v = (D_A - D_B) \frac{dc_A}{dx}$ This phenomenon, which is called the Kirkendall effect, can be detected, if any marks are made on the specimen in the diffusion zone, i.e., nonsoluble admixtures, small wires, foil are introduced, or impressions are made on the surface. Kirkendall's effect take place in a large number of metal pairs with a face-centered and sometimes with body-centered cubic lattices. The total flux, which is brought about by the diffusion proper as well as by the macroscopic flow, is characterized by the so-called heterodiffusion coefficient $D = C_A D_B + C_B D_A$, where C_A and C_B are the molar fractions of the components. In the exchange and ring mechanisms simultaneous displacement of both components takes place with the same velocity, i.e., the partial diffusion coefficient in these cases are equal. Hence the presence of the Kirkendall effect in any given system shows that diffusion proceeds either along the interstices, or by the vacancy mechanism. The resultant flow of atoms in the Kirkendall effect is due to the flow of vacancies in the opposite direction. This flow of vacancies usually coagulates, which results in the formation of a porosity zone to that

side of the diffusion zone toward which the flow of the substance is directed. The nuclei for pore formation are heterogeneous inclusions and dissolved gases, for example, oxygen.

In a number of cases a substantial accelerating effect on diffusion or self-diffusion is exerted by various admixtures or lattice defects (dislocations, vacancies, mosaic structure). Of particular importance are surface diffusion and diffusion along the grain boundaries in metals which are characteristic by their low activation energy. The activation energy of volume diffusion of thorium in tungsten is 116.0 kcal/g-atom, for diffusion along the grain boundaries it is 86.0 and for surface diffusion it is 62.4. These kinds of diffusion play no role at high temperatures, but begin to determine the process of the entire diffusion at lower temperatures, when the volume diffusion practically does not proceed.

The diffusion and self-diffusion rates are substantially affected by stresses and deformations. As a result of plastic deformation slip lines, dislocations take place, blocks are broken down (substructure is developed), etc., i.e., the concentration of lattice defects is increased, which results in an increased diffusion mobility.

A particular case is diffusion accompanied by the formation or disintegration of phases ("reactive diffusion"), which plays an important role in the formation of surface layers, intermediate phases or chemical compounds as a result of casehardening. After holding at high temperatures, these layers may grow or disappear. The displacement of the phase interface (in the case when one phase grows at the expense of the other) or the change in the thickness of the combining layer which forms on the interaction of two components is proportional to $\sqrt{t}$ (t is time) if the kinetics are purely diffusion kinetics.

Diffusion in solid bodies involves different transfer phenomena.

As in the case of electrolite solutions, when the components of an alloy diffuse, a diffusional potential difference arises at the ends of the specimen and, conversely, when current is passed through the alloy, a directed displacement of components, which resultsin establishing a concentration gradient, arises. Study of electrical transfer makes it possible to determine the charges of components in solid solutions and the characteristics of interaction of ions with conducting electrons. These characteristics pertain primarily to ions in the state of transition. Diffusion in solid bodies plays a very important role in metal treatment processes. Due to diffusion, the surface layers of components are saturated by carbon (cementation), nitrogen (nitriding), aluminum (aluminizing), etc. The rate of diffusion determines in many cases the structure of the metal which is obtained after a particular heat treatment or use in service (heat resistant alloys). The knowledge of laws of diffusion makes it possible to obtain alloys with the specified properties.

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Diffuziya v metallakh i splavakh v tverdoy faze [Diffusion in Metals and Alloys in the Solid Phase], Moscow, 1960.

L.K. Belashchenko, A.A. Zhukhovitskiy

DIFFUSION PLASTICITY – residual Plastic deformation in which diffusion processes play a considerable role. The proportion of diffusion plasticity increases with the Similarity temperature and the heating time and this property is consequently especially important for Creep, Relaxation, and long-term static strength and fatigue strength at high temperatures.

Ya.B. Fridman

DILUENTS – mixtures of organic solvents for thinning paints and lacquers to be applied to colorable surfaces. Various diluents are employed, depending on the nature of the film-forming material (see Table).

Diluents (Solvents, Thinners) for Lacquers and Paints

Материалы 1	Разбавители, растворители и разжижители 2	ГОСТ или ТУ 3
Лакокрасочные материалы на глифталевых, пентафталевых и масляно-фенольных смолах; на масляной, маслянно-смоляной, битумной и битумно-масляной основе; меламиноформальдегидные эмали, меламиноформальдегидно-глифталевые эмали (молотковые, ПЭ-29), меламино-алкидные лаки 4	Сольвент каменноугольный 15 Ксилол чистый каменноугольный 16	ГОСТ 1928–50 ГОСТ 9949–62 29
Лакокрасочные материалы на масляной, битумно-масляной и битумной основе 5	Уайт-спирит, уайт-спирит в смеси с ксилолом 1:1 17	ГОСТ 3134–52
Эмали марки «Муар» и эмали на масляной и масляно-смоляной основе 6	Бензин 18	ГОСТ 8505–57
Жаростойкие кремнийорганические лаки и эмали 7	Толуол 19 Ксилол чистый каменноугольный 16	ГОСТ 4809–49 ГОСТ 9949–62
Грунты, лаки и эмали на основе перхлорвиниловых смол и на сополимере хлорвинила и винилиденхлорида (смола СВХ-40) 8	Растворитель Р-4 Разжижитель Р-5 20 21	ГОСТ 7827–55 ТУ МХП 2181-50 30
Грунты, лаки и эмали на основе полиакриловых смол 9	Разжижитель Р-5 Растворитель 648 22	ТУ МХП 2191-50 ГОСТ 4006–48
Нитроцеллюлозные лаки, эмали, шпатлевки, клеи 10	Разбавитель РДВ 23 Растворитель 646 или 648 24	ГОСТ 4399–48 ГОСТ 5630–51
Эпоксидные, нитроэпоксидные молотковые, меламиноформальдегидные и мочевиноформальдегидные лаки 11	Растворитель 646 25	ГОСТ 5630–51
Пентафталевые эмали для наружных покрытий 12	Растворитель РС-2 26	ТУ МХП 1763-52
Синтетические эмали для легковых автомобилей 13	Растворитель 651 27	ТУ МХП 4537-56
Лаки на основе смеси смол поливинилбутираля, меламиноформальдегидной и резиновой (лак АО) 14	Разжижитель Р-6 28	ТУ МХП 4008-53

1) Material; 2) diluents, solvents, and thinners; 3) GOST for TU; 4) lacquers and paints based on glyphthalic pentaphthalic, and butyrophenolic resins and with butylic, butylic-resin, bitumin, and bitumin-bu-

tylic bases; melamine-formaldehyde enamels, melamine-formaldehyde-glyphthalic enamels (malleic enamels, PE-29), melamine-alkyd lacquers; 5) lacquers and paints with butylic, bitumin-butylic, and bitumin bases; 6) enamels of the "Muar" type and with butylic and butylic-resin bases; 7) heat-resistant silico-organic lacquers and enamels; 8) primers, lacquers, and paints based on perchlorovinyl resins and on a copolymer of vinyl chloride and vinylidine chloride (SVKh-40 resin); 9) primers, lacquers, and enamels based on polyacrylic resins; 10) nitrocellulose lacquers, enamels, fillers, and sizing; 11) epoxy, nitroepoxy, moleic, and urea-formaldehyde lacquers; 12) pentaphthalic enamels for exterior use; 13) synthetic enamels for light automobiles; 14) lacquers based on a mixture of polyvinylbutyryl, melamine-formaldehyde, and rubber resins (AK lacquer); 15) coal-tar solvent; 16) pure coal-tar xylol; 17) white spirit, white spirit mixed 1:1 with xylol; 18) gasoline; 19) toluol; 20) solvent R-4; 21) thinner R-5; 22) solvent 648; 23) RDV diluent; 24) solvent 646 or 648; 25) solvent 646; 26) solvent RS-2; 27) solvent 651; 28) thinner R-6; 29) GOST; 30) TU MKhP.

I.I. Denker

DIMENSIONAL ETCHING OF ALUMINUM ALLOYS – a process for etching components over a specified contour to a specified depth. Dimensional etching of aluminum alloys is used in the production of components of intricate shape and variable cross section. Etching produces components

Fig. 1. Aircraft wing skin with a standard camber made from the D16T alloy. The etching is along the T contour.

with identical cross-sectional strength (sheet-metal components with variable cross section, wedge-shaped sheets, monolithic panels, etc.), which makes it possible to substantially reduce the weight of the design. Dimensional etching of aluminum alloys is frequently a more eco-

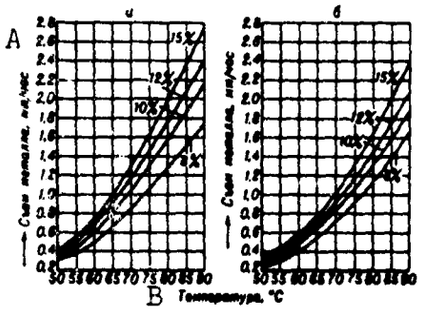

Fig. 2. Temperature dependence of the rate of etching of type D16 (a) and V95 (b) alloys in a sodium hydroxide solution of various concentration (%). A) Metal removal, mm/hour; B) temperature, °C.

nomical process than machining and in many cases it is the only suita-

ble processing method. Figure 1 shows an etched aircraft wing skin made from the D16T alloy.

Dimensional etching of aluminum alloys is usually performed in heated solutions of sodium hydroxide.

Figure 2 shows the effect of temperature on the rate of etching of type D16 and V95 alloys. Increasing the solution temperature from 50 to 90° increases the etching rate by more than a factor of 7, however, the surface finish thus obtained is not as high as the original. Type 95V alloys are etched at a lower rate than type D16 alloys. As the aluminum

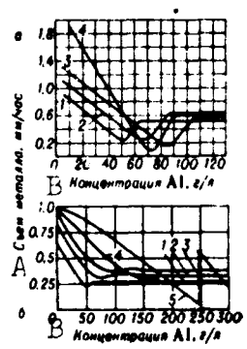

Fig. 3. Dependence of the etching rate of D16 and V95 type alloys on the aluminum content in the NaOH solution for various concentrations and temperatures of the alkali. a) D16. 1) 10% (70°); 2) 12% (70°); 3) 15% (70°); 4) 12% (80°). b) V95 (temperature is 70°). 1) 10%; 2) 15% 3) 20%; 4) 30%; 5) 40%. A) Metal removal, mm/hour; B) Al concentration, g/liter.

begins to accumulate in the etching solution, the etching rate is first reduced, then increases somewhat, after which it remains unchanged for most alkali concentrations (Fig. 3).

As the aluminum content of the solution increases to 25 g/liter, the surface finish of the etched surface is improved (Fig. 4). Surface sections which are not to be etched are usually protected from the effect of the alkaline solution by varnish and paint coatings. In dimensional etching of aluminum alloys the metal is dissolved in the depth as well as sidewise beneath the protective coating.

The process used in dimensional etching of aluminum alloys pro-

vides for degreasing, etching in an alkaline solution to remove surface flaws, electrolytically assisted oxidation in the sulfuric acid solution, filling of the anodic film, application of protective coatings,

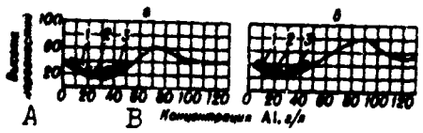

Fig. 4. Dependence of the surface quality of type D16 (a) and V95 (b) alloys on the aluminum content in the NaOH solution. Etching duration: 1) 4 hours; 2) 3 hours; 3) 2 hours. A) Height of irregularities; B) Al concentration, g/liter.

dimensional etching, removal of coatings. The selection of protective coatings is determined by the depth and the etching factor (see the ta-

Protective Paint and Varnish Coatings Used in Dimensional Etching

Лакокрасочное покрытие 1		2 Способ подготовки поверхности	3 Способ нанесения покрытия	4 Толщина покрытия (мкм)	5 Допускаемая глубина травления (мм)		6 Способ образования контура	7 Способ удаления покрытия после травления
наименование 8	марка 9				12%-ным NaOH	40%-ным NaOH		
Перхлорвиниловое 10	Грунт ВГ-2 + лак ХЛ-2 11	Без обработки 12	Распыление	120-160	5	–	Отслаивание 14	Отслаивание 14
Этилцеллюлозное 15	Лак Э-1 16	Анодирование 17	Распыление 13	80-100	4	8	Отслаивание	Отслаивание
Полихлоропреновое 18	Эмаль ХСЭ-101 19	Без обработки	Кистью 20	140-160	5	20	Отслаивание с легкоснимаемым подслоем 21	Смывание 22
Перхлорвиниловое	Эмаль 23 ХВ-16 + лак ХСЛ	Анодирование	Распыление	120-160	3	2	Отслаивание	Отслаивание
Полиамидное 24	Клей ПФЭ 2,10 + лак 548 или 54 25	Анодирование или травление + анодирование 26	Обли или кисть 27	80-100	–	8	Отслаивание	Отслаивание
Смешанная система 28	Эмаль 29 ХСЭ-101 + лак ХСЛ	Без обработки	Распыление	140-160	5	8	Отслаивание	Отслаивание
То же 30	Грунт 31 ВЛ-02 + лак ХСЛ	Без обработки	Распыление	100-120	3	5	Отслаивание с легкоснимаемым подслоем 21	ХСЛ – отслаивание, ВЛ-02 в 30%-ном растворе щелочной э-ты 32

1) Paint and varnish coating; 2) method of preparing the surface; 3) method of coating application; 4) coating thickness (microns); 5) permissible etching depth (mm); 6) method for forming the contour; 7) method of coating removal after etching; 8) name; 9) brand; 10) per-

chlorovinyl; 11) VG-3 primer + VL-2 varnish; 12) without treatment; 13) spraying; 14) peeling off; 15) ethyl cellulose; 16) E-1 varnish; 17) anodizing; 18) polychloroprene; 19) KhSE-101 enamel; 20) by a brush; 21) peeling with an easily removed sublayer; 22) washing off; 23) KhB-16 enamel + KhSL varnish; 24) polyamide; 25) PFE 2/10 glue + 548 or 54 varnishes; 26) anodizing or etching + anodizing; 27) pouring over or brush; 28) mixed system; 29) KhSE-101 enamel + KhSL varnish; 30) same as above; 31) VL-02 primer + KhSL varnish; 32) KhSL – peeling, VL-02 in 30% solution of nitric acid.

ble). Usually dimensional etching of aluminum alloys is performed in solutions containing 120-170 g/liter of sodium hydroxide at 70-90°.

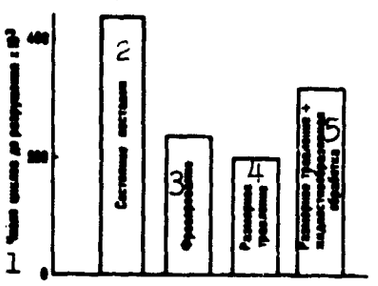

Fig. 5. Effect of various kinds of surface finish on the endurance of the D16 alloy. 1) Cycles to failure × 10^3; 2) as supplied condition; 3) milling; 4) dimensional etching; 5) dimensional etching + fluid abrasive finishing.

The protective coating is usually removed after dimensional etching of aluminum alloys by peeling them off manually, while the VL-02 and VG-2 primers are removed by immersion in 30% nitric acid. The KhSE-101 enamel is removed by washing.

The reduction in the surface finish quality as a result of dimensional etching of aluminum alloys results in approximately the same reduction in the endurance strength of the alloy as milling.

Fluid abrasive finishing following dimensional etching of aluminum alloys, which improves the surface finish, makes it possible to substantially increase the endurance of aluminum alloys (Fig. 5).

Dimensional etching of aluminum alloys is most extensively used in making sheet metal components of aircraft.

References: Golubev, A.I., Naryshkin, A.A. and Padeyskiy, V.N., Razmernoye travleniye detaley iz alyuminiyevykh splavov v seriynom proizvodstve [Dimensional Etching of Aluminum Alloy Components in Mass Production], Moscow, 1959 (Peredovoy nauchno-tekhnicheskiy i proizvodstvenny opyt [Advanced Scientific-Technical and Industrial Experience]. Topic 8. No. M-59-335/7); Golubev, A.I., Protsess formirovaniya anodnykh plenok [Process of Formation of Anodic Films], in the book: Razmernoye travleniye i anodirovaniye alyuminiyevykh splavov [Dimensional Etching and Anodizing of Aluminum Alloys], Moscow, 1959 (Moskovskiy dom nauchnotekhnicheskoy propagandy im Dzerzhinskogo. Ser. "Progressivnaya tekhnologiya mashinostroyeniya" [Moscow F.Z. Dzerzhinski House of Scientific and Technical Propaganda. Series "Progressive Production Processes in Machine Building"], Issue 1). Rozov, M.N., Trainina, T.A., "Zh-PKh," Vol. 29, Issue 6, page 899, 1956; Golovin, I.L., Glubokoye i figurnoye travleniye aluminiyevykh splavov (Khimicheskoye frezerovaniye) [Deep and Contour Etching of Aluminum Alloys (Chemical Milling)] in the book: Legkiye splavy [Light Alloys], [Issue 1], Moscow, 1958; "Ekspress-informatsiya. Korroziya i zashchita metallov" (VINITI) [Express Information Series. Corrosion and Protection of Metals (All-Union Institute of Scientific and Technical Information)], No. 7, report 61, pages 4-6, 1962; USA patent No. 2975041, 14.03.61; Wogeek, W., "Dtsch. Flugtechnik" [German Aircraft Equipment], Vol. 7, No. 7, page 193, 1960; Herrmann, E., "Aluminium," Year of publication 36, No. 8, pages 462-66; "Aircraft Prod.," Vol. 18, No. 5, pages 177-179, 1956.

Ye.M. Zaretskiy

DIMETHYL SILOXANE RUBBER – is the product of the hydrolysis of dimethyl chlorosilanes and the subsequent polymerization of the hydrolysis products in the presence of acid or alkaline catalysts. It is characterized by a heat-resistance of up to 200-250°; its moduli and elacticity remain constant within a wide temperature range. The optimum value of the molecular weight of dimethyl siloxane rubber is 500,000-800,000. A decrease in the molecular weight deteriorates the mechanical properties of dimethyl siloxane rubbers, an increase deteriorates the workability. Benzoyl peroxide and 2.4-dichlorobenzoyl are used for the vulcanization of compounds of dimethyl siloxane rubbers. The dimethyl siloxane rubbers are vulcanized by a two-step method; a previous molding at 25-35 kg/cm2 and 120-150° for 10-30 min, and final vulcanization by heating in air at 200° for 12-24 hours depending on the thickness and shape of the product. It is recommended to vulcanize under the press at a slowly rising temperature up to 125-135°, and to cool the products to 30-40° under pressure in order to avoid the formation of pores. Nonfilled dimethyl siloxane rubbers have a tensile strength of 1.5-2.0 kg/cm^2 at a relative elongation of 150%, and a low tear resistance. An increase in the tensile strength and the tear resistance of dimethyl siloxane rubbers is attainable by addition of active fillers: diverse types of silica, titania, zinc oxide, aluminum oxide, polytetrafluoroethylene, etc. The physicomechanical properties of dimethyl siloxane rubbers filled with silica BS-280 are quoted in Table 1.

The elasticity of dimethyl siloxane rubbers shows almost no change in the temperature range from –40° to +40°, whereas it changes in SKS-

-30 rubbers by 4.5-5 times. A drop of the temperature from 0° to -80° results in a change of the modulus 3-4 kg/cm^2) of dimethyl siloxane

TABLE 1

The Physicomechanical Properties of Dimethyl Siloxane Rubbers

1 Прочность на разрыв (кг/см^2)	2 Относительное удлинение (%)	3 Сопротивление раздиру (кг/см)	4 Свойства после теплового старения при: 200°—20 суток 5		250°—10 суток 5		6 Темп-ра хрупкости (°С)	7 Коэфф. морозостойкости при:		8 Остаточная деформация после сжатия на 20% за 24 часа (%) при:	
			9 Прочность на разрыв (кг/см^2)	10 Относительное удлинение (%)	9 Прочность на разрыв (кг/см^2)	10 Относительное удлинение (%)		-50°	-60°	150°	200°
45	250	8—10	40	115	26	100	-74	0.65	0.06	68	100

1) Tensile strength (kg/cm^2); 2) relative elongation (%); 3) tear resistance (kg/cm); 4) properties after thermal aging at; 5) days; 6) brittleness point (°C); 7) coefficient of the frostproofness; 8) residual deformation after compression by 20% for 24 hours (%) at; 9) tensile strength (kg/cm^2); 10) relative lengthening (%).

rubbers by 1.8-2 times, whereas the modulus does increase by 100 times in natural rubbers when the temperatures drop from +25° to -64°. Dime-

TABLE 2

Resistance of Dimethyl Siloxane Rubbers to the Effect of Solvents, Oils, Acids, and Alkalis

1 Растворители, кислоты, щелочи, масла	2 Темп-ра испытания (°С)	3 Максимальное набухание (%)
4 Бензин «галоша»	25	99
5 Бензол	25	119
CCl_4	25	276
HCl 35%-ная	25	67
HNO_3 65%-ная	25	72
NaOH 40%-ная	25	1.8
Масла: 6		
7 МВП	20	33
7 МВП	150	50
8 МК	20	6
8 МК	150	9
9 Турбинное	150	17
Трансформаторное 10	150	30

1) Solvents, acids, alkalis, oils; 2) test temperature (°C); 3) maximum swelling (%); 4) "galosh" gasoline; 5) benzene; 6) oils; 7) MVP; 8) MK; 9) turbine; 10) transformer.

methyl siloxane rubbers maintain their stability to the effect of oxygen, ozone and ultraviolet rays under diverse atmospherical conditions.

They are waterproof; surfaces coated with them become covered with ice insignificantly. Dimethyl siloxane rubbers possess good dielectrical properties: the breakdown voltage is 6.3-8.1 kv/mm; the dielectric constant is 3.0 (at 1 Mcps), the tangent of the loss angle is 0.09 (at 1 Mcps); the specific volume resistance is $1.1 \cdot 10^{14}$ ohm·cm. The electric insulating properties of dimethyl siloxane rubbers remain constant up to 150-200°, in a moist atmosphere, and also in the case of contact with water. Data for the resistance of dimethyl siloxane rubbers to the effect of diverse chemical reagents are quoted in Table 2.

Dimethyl siloxane rubbers are nontoxic and physiologically inert; they burn and maintain burning. Total destruction thermal aging at 150-200° in the absence of air, resulting in a loss of the mechanical properties, further, loss of the resistance to abrasion and an increased viscosity in the case of a simultaneous effect of temperature and load are the disadvantages of the dimethyl siloxane rubbers.

Dimethyl siloxane rubbers are used in the aircraft industry as heat- and frostproof packings for engines and hydraulic systems, in the electric cable industry, in the food industry, and in medicine.

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F.A. Galil-ogly

DISLOCATIONS in crystals – linear defects of the crystal lattice, which disturb the ordered alternation of atomic planes. Due to the presence of dislocation, actual crystals are capable of plastic deformation and failure under the action of stresses which are by several orders of magnitudes lower than those calculated for ideal crystals. Dislocations affect not only the strength of crystals, but also their electric resistivity, latent heat, optical, semiconductor, magnetic, etc., properties, determine the mosaic structure of real crystals, surface topography and growth character of crystals for low super-saturations.

Geometry of dislocations. The elementary forms of dislocation are edge and screw dislocations (Fig.1). If one of the crystallographic planes is terminated inside the crystal (Fig. 1b), then the edge of this "extra" plane form an edge dislocation. In the case of screw dislocation (Fig. 1c) not a single of the atomic planes terminates inside the crystal, but the planes proper are found to be only approximately parallel and join one another in a manner such that actually the crystal consists of a single atomic plane, bent along a spiral surface. On each traverse about the dislocation line (which coincides with the screw axis) this "plane" either ascends or descends by one lead of the screw which is equal to the inter-plane distance.

Fig. 1. Schematic drawing of the structure of a crystal, depicted in the form of a family of atomic planes. a) Ideal crystal; b) crystal with an edge dislocattion; c) with a screw dislocation.

If a circuit is composed from the lattice translation vectors in such a manner, that it closes in an ideal crystal, then this circuit (Burgers circuit), constructed about the dislocation line in a defective crystal, will be found to be broken (Fig. 2). The vector $\vec{FA} = b$, which must be drawn in order to close the ends of this circuit is call-

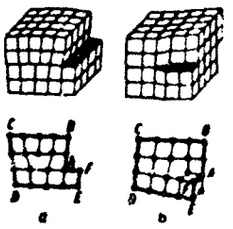

Fig. 2. Position of atoms in a crystal with edge a and screw b dislocations. The atoms are depicted in the form of cubes. Below is shown the construction of a circuit of the ABSDEF type and of the Burgers vector $\vec{FA}$. The lattice points (circles) correspond to centers of cubes of the top drawing.

ed the shear vector or the Burgers vector of the given dislocation. The character of a dislocation is determined by the magnitude and direction of Burgers vector. In the case of edge dislocation the Burgers vector corresponds to the additional interplanar distance which has come about due to the extra plane, and is directed perpendicular to the dislocation line. In the case of screw dislocation the Burgers vector corresponds to the lead of the screw and is directed parallel to the dislocation line. In the general case the dislocation line can be an arbitrary planar or space curve, along which the Burgers vector remains constant. It follows from this that dislocations cannot terminate inside the crystal (or crystalline grain) and must either close on themselves or branch out into other dislocations, or emerge at the surface of the crystal. The branching out of dislocation is governed by a theorem which is analogous to Kirchhoff's theorem for branching out streamlines: if all the dislocations are thought of as moving to

Fig. 3. Schematic diagram of translational slip as a result of dislocation displacement. The dislocation line is denoted by ⊥.

the point of intersection, then the sum of their Burgers vectors should be zero. Branching out and then coming close again, dislocations can form in the crystal planar and space networks which determine the mosaic structure.

Dislocation motion. Plastic deformation of crystals usually involves a collective movement of atoms which can be described as "motion." Here the dislocations may move along slip planes as well as perpendicular to them. Figures 2 and 3 illustrate the "dislocation mechanism" of translational slip. Since the atomic planes are not perfectly rigid, the shear cannot take place simultaneously over the entire slip plane. Successive displacement of atoms creates the dislocation motion. The boundary of the local slip section forms a dislocation which as an edge dislocation if that boundary is perpendicular to the shear direction (Fig. 2a), and screw dislocation if it is parallel to this direction (Fig. 2b). In the general case dislocation can be regarded as the boundary of local shear over a surface supported on the dislocation line. Intersection of a crystal by slip dislocation (Fig. 3) results in displacement by the magnitude of the Burgers vector. Since successive reconnection of bounds, which corresponds to dislocation slip, requires moderate displacements of atoms, then for dislocation displacement in the slip plane it is sufficient to have moderate stresses (in metals they are of the order of 10^{-4} of the shear modulus). This is responsible for the fact that the shear strength of real crystals containing dislocations is found to be by several orders of magnitude lower than

the shear strength of ideal crystals.

The displacement of edge dislocations in a direction perpendicular to the slip plane (creeping over), which corresponds to contraction or growth of "extra" atomic planes, and requiring in conjunction with this diffusional displacement of vacancies or internodal atoms, has another character.

From the point of view of the dislocation theory, various processes which take place on plastic deformation and breakdown of crystals are determined by collective displacements of atoms which involve the creeping over or slip of individual dislocations or entire series of dislocations.

Lattice distortion. Dislocations produce local lattice distortions, which in the approximation of the theory of elasticity can be characterized by the field of stresses σ_{ik} and rotations ω_i of the lattice. In the cylindrical coordinate system with axes r, φ and z, the quantities σ_{ik} and ω_i are expressed, respectively:
for screw dislocation

$$\sigma_{z\varphi}=\frac{Gb}{2\pi r};\quad \omega_r=\frac{b}{4\pi r}$$

for edge dislocation

$$\sigma_{rr}=\sigma_{\varphi\varphi}=\frac{\sigma_{zz}}{2\nu}=-\frac{G}{2\pi(1-\nu)}\frac{b\sin\varphi}{r}$$
$$\sigma_{r\varphi}=\frac{G}{2\pi(1-\nu)}\frac{b\cos\varphi}{r};\ \omega_z=-\frac{b\cos\varphi}{4\pi r}$$

where b is the Burgers vector, G is the shear modulus and ν is Poisson's ratio (the crystal is assumed to be elastically isotropic). The dislocation line coincides with the z-axis, the azimuth φ in the case of edge dislocation is reckoned from the direction of the Burgers vector.

In a region with a radius several interatomic spaces long, which is called the dislocation nucleus, the lattice distortions are great and cannot be described in terms of the theory of elasticity. The ener-

gy density in the dislocation nucleus reaches, apparently, a value which is of the same order of magnitude as the latent heat for melting the crystal. The dislocation energy is composed of the elastic energy of the stress field produced by the dislocation and the nonelastic energy of the dislocation nucleus. The total energy is approximately proportional to the length of the dislocation and comprises approximately $0.5\ Gb^2$ (about 10^{-4} erg-cm^{-1} for metals) per unit of the dislocation length.

Local distortions of the lattice and local stresses produced by individual dislocation lines can, by superimposition, produce macroscopic rotations of the lattice and macroscopic stresses. Uniform distribution of parallel edge dislocations (Fig. 4a) corresponds to circular

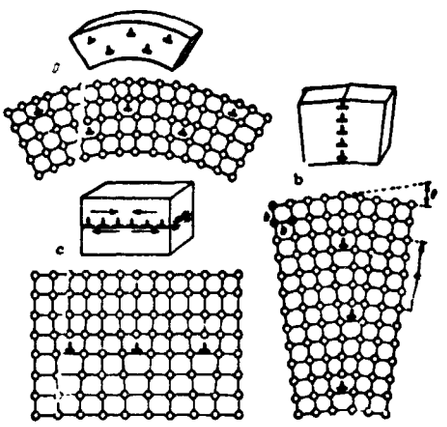

Fig. 4. Distortions of a crystal brought about by edge dislocations. a) Circular bending; b) boundary of symmetrically disoriented blocks (vertical row of dislocations); c) slip line (horizontal row of dislocations).

bending of a crystal about an axis which is parallel to dislocation lines. The networks and rows of dislocations form the boundaries of disoriented blocks. For example, edge dislocations lined up in a row parallel to the extra dislocation planes (Fig. 4b), form the boundaries of blocks which are symmetrically disoriented by the angle $\theta = b/h$, where h is the distance between dislocation lines. If the edge disloca-

tions position themselves in the general slip plane (Fig. 4c), then they do not yield macroscopic rotations of the lattice, but produce macroscopic stresses, i.e., compression at one side of the slip plane and tension at the other. The intensity of these stresses can be characterized by the difference in normal deformations in the direction of slip comprises $\varepsilon = b/h$.

Accumulating on obstacles (for example, at the boundaries of blocks and grains), dislocations can produce local stress concentrations which are sufficient for the formation of nucleating microfissures. The dislocation theory of crystal failure also considers the possibility of microfissure formation on intersection or uniting of moving rows of dislocations.

Forces acting on dislocations. A "mechanical force" which is perpendicular to the dislocation line and parallel to its Burgers vector $\underline{b}$ acts on the dislocation in the field of externally applied stresses. Projections of this force on the slip plane bring about dislocation slip. Nonequilibrium in the concentrations of vacancies or internodal atoms results in the appearance of a "thermodynamic" force, which acts perpendicular to the dislocation line and to its Burgers vector and stimulates the creeping over of edge dislocations and the conversion of screw dislocations into helicoidal dislocations (bent along a cylindrical spiral with an axis along the Burgers vector).

Since the stress fields brought about by individual dislocations overlap, the dislocations interact with one another. Parallel screw dislocations, as well as parallel edge dislocations which lie in a common slip plane interact in the same manner as charged wries, i.e., dislocations of different kinds are attracted while those of the same kind are repelled from one another with a force which is inversely proportional to the distance. In the general case the interaction between

dislocations is more complex (the forces are not central and depend on the mutual orientation of the dislocations), however, the simplified rule is usually valid; two dislocations are attracted if their Burgers vector make an obtuse angle, and are repelled if this angle is acute.

Dislocations and point defects of crystals. When individual moving dislocations intersect, steps, which do not lie in the slip plane can form on the dislocation lines. Each nonsliding step on a dislocation line leaves behind it, attendant to forced displacement, a trace in the form of a chain of point lattice defects, i.e., vacancies or internodal atoms. Conversely, point defects of a lattice can serve as sources of dislocations. In the process of a crystal's growth or on annealing, dislocations can form by collapse of disk-shaped voids,

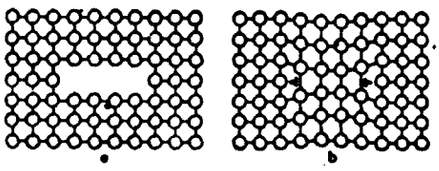

Fig. 5. Collapsing of void a results in the formation of edge dislocations b.

which arise due to coagulation of condensed vacancies (Fig. 5). The interaction between dislocations and admixture atoms results in accumulation of the admixture near dislocation lines and in the formation of the so-called Cottrell's clouds around them. For example, foreign atoms with a small radius can accumulate in the compressed region near an edge dislocation, while atoms with a large radius may accululate in the expanded region. Certain aging effects, which are expressed in the time dependence of crystal properties are determined by diffusion of the admixture to the dislocations. Thickening of Cottrell's clouds can result in condensing the admixture and in the precipitation of nuclei of another phase. Dislocations surrounded by admixtures have a lower mobil-

ity than free dislocations. It is also possible for dislocations to be torn out from Cottrell's clouds, which sometimes determines the yield point of the crystal. The geometric properties of dislocations also determine their relationship with planar defects of the lattice and with twins. Dislocations which lie in densely packed slip planes can cleave with attendant formation of intermediate monatomic twinning interlayers, i.e., packing defects (Fig. 6). Such reactions between dis-

Fig. 6. Cleavage of an edge dislocation a in a face-centered cubic crystal into 2 partial dislocations b, connected by a single layer twin AB (packing defect).

locations can result in the formation of highly mobile dislocations as well as of not too mobile "sitting" defects, which serve as an obstacle to the movement of other dislocations. In the dislocation theory of twinning is introduced the concept of "twinning" dislocation, which corresponds to an atomic step on the interface of twins, i.e., on the edge of the incomplete plane of atoms which have passed into the twinning position. Tangential motion of dislocations, i.e., steps along the twinning boundary, ensures normal displacement of the boundary upon growth of one component of the twin on the expense of another.

Dislocations and crystal growth. When crystals grow by layers from vapors and diluted solutions, when new atoms attach themselves only to growth steps (Fig. 7a), the rate of growth of ideal crystals should be determined by the probability of the formation of planar seeds, which contradicts the observed rate of growth of crystals under low supersaturations. However, if the crystal has at least one screw dislocation, then the addition of growth steps does not result in displacing the steps from the surface of the growing face, as this would

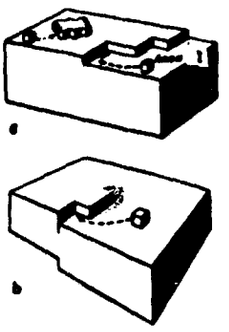

Fig. 7. Layer growth of a crystal. a) Ideal crystal; b) crystal with a screw dislocation. 1) Atom.

happen in the case of an ideal crystal. The growth layers no longer terminate at the side faces, but enveloping the dislocation, successively climb onto one another (Fig. 7b). As a result, the rate of crystal growth is not determined by the process of spontaneous formation of planar seeds, but by the rate of growth of steps already present. Dislocations are not needed for growth from a melt. Lately dislocationless crystals of silicon and germanium which have, according to preliminary data, a strength which is close to the theoretical strength of an ideal lattice, have been grown from a melt.

Dislocations and the various crystal properties. The presence of dislocations increases the electric resistivity of the crystal, reduces its density, increases the internal friction and reduces the value of elastic moduli. The interaction of domain boundaries with dislocations results in increasing the coercive force of ferromagnetic and ferroelectric substances. In semiconductors dislocations serve as defects which have the properties of the acceptor admixture. The first seeds of a new phase may arise at dislocations (for example, on disintegration of a solid solution), although cases exist when the formation of seeds is not related to dislocations.

Experimental study of dislocations. The use of electron microscopes

with large resolving power has made it possible to directly observe atomic planes in platinum and copper phthalocyanides and to detect sec-

Fig. 8. Edge dislocation in a platinum phthalocyanide crystal; top - electron microscope photograph (magnification ~1,000,000); bottom - schematic drawing of the location of atomic planes.

tions at which the relative position of atomic planes points to the presence of dislocations (Fig. 8). In other cases it was possible to realize the possibility pointed out by A.V. Shubnikov of observing dis-

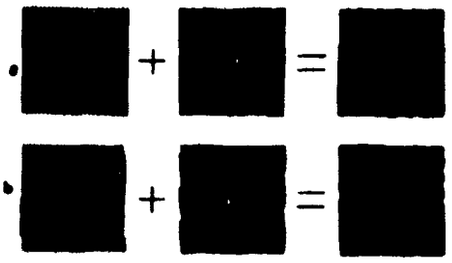

Fig. 9. Schematic drawing of dislocation observations by the Moire chart method. a) Two identically oriented crystals with different lattice parameters are superimposed; b) both lattices have the same parameters, but are slightly disoriented. In both cases the interference fringes on the Moire charts give a magnified description of an edge dislocation located in one of the lattices.

location on a Moire chart, which is obtained by superimposing a distorted and nondistorted crystal lattices (Fig. 9). In electron microscope studies of a thin foil of aluminum and stainless steel dislocations were detected by the increased intensity of electron scattering to stresses. Observation of the fine structure of crystal surfaces makes it possible to discover screw dislocations, which correspond to ends

Fig. 10. Rows of dislocations in the slip planes. A thin foil of stainless steel in a transmitting electron microscope. The slip planes are marked by braces.

Fig. 11. Growth spiral, which has originated at a screw dislocation in a paraffin crystal.

Fig. 12. Dislocation networks in a KCl crystal, decorated by silver. (The cell size is of the order of several microns).

of growth steps (Fig. 11). Optical and electron microscope methods are not always capable of resolving the fine structure of the relief of metallic monocrystal faces. Lately an ion microprojector, which has made it possible to observe the atomic structure of the crystal's surface, was used for this purpose. Methods of selective etching and admixture segregation ("decoration") have come into particularly extensive use for the study of dislocations, when it was found that these known methods of metallographic study of crystal defects can be refined to an extent such that it is possible to distinguish individual dislocations (Fig. 12). In particular, using the method of secondary selective etching it is possible to follow the displacement of disolcations in the process of plastic deformation (Fig. 13). The latest data show that

it is possible to detect dislocations on projected x-ray radiographs and by the optical polarization method.

Fig. 13. Movement of dislocations in an LiF crystal detected by the selective etching method. Etching pits in the form of truncated pyramids denote old, and pits in the shape of acute-angled pyramids denote new positions of dislocations (magnification factor 600).

According to results of direct and indired methods of investigation, the density of dislocations, depending on the type of crystal and on the specimen's previous history, usually varies in annealed crystals from 10^2 to 10^7 and in deformed crystals from 10^7 to 10^{12} lines per cm^2.

The basic difficulty in the theory of dislocations is the problem of the origin of new dislocations in the process of plastic deformation. The multiplication of dislocations by detachment of rings from the dislocation network segments (the so-called Frank-Read source) is geometrically possible and was observed frequently. Judging by the latest data, new dislocations can originate not only by previously existing dislocations, but also by accumulations of point defects of the lattice.

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V.L. Indenbom

DISPERSION COEFFICIENT, or Abbe's number – a quantity which characterizes the relationship between the refraction index of a substance and the light-wave length (color):

$$\nu = \frac{n_D - 1}{n_F - n_C}$$

where n_D is the refraction index for λ = 5893 A (yellow doublet of sodium), n_C and n_F are the same for λ = 6563 A (C red hydrogen line) and for λ = 4861 A (F blue hydrogen line), respectively. Substances with a low dispersior are characterized by a high value of dispersion coefficient (for example, for fluorite ν = 95); substances with high dispersion have their corresponding low values of the dispersion coefficient (for heavy grades of glass ν = 20). Usually (but not always) the dispersion coefficient decreases with an increase in the average refraction index. The quantity which is a reciprocal of the dispersion coefficient is called relative dispersion.

L.S. Priss

DISRUPTION FRACTURE – is formed by the surfaces of a destroyed specimen, which coincide almost with the surfaces perpendicularly to which the maximum stresses and elongations are acting (in the case of elongation of a rod - in the cross section, in the case of torsion - along helical lines, etc.). See Breaking, Breaking Strength.

Ya. B. Fridman

DIVINYL-NITRILE LATICES are aqueous colloidal dispersions of rubber-like copolymers of divinyl and acrylonitrile obtained by emulsion polymerization. As the emulsifiers, use is made of anionic surface-active substances: Nekal, salts of the fatty acids, modified resins, etc. Mercaptans (for example, dodecyl mercaptan) or xanthogen disulfides (for example, diisopropyl xanthogen disulfide) are used to regulate the molecular weight of the polymer. Pyrophosphates are often added to the alkaline emulsion to maintain a constant pH of the system during the polymerization process.

The most common divinyl-to-acrylonitrile ratios for the synthesis of these latices are 82:18, 74:26 and 60:40. The polymers in the divinyl-nitrile latices contain the high-molecular C ≡ N groups and therefore are practically insoluble in the aliphatic hydrocarbons. The oil and gasoline resistance of these copolymers increases with increase of the content of the bound acrylonitrile; there is a parallel increase of the strength of the copolymers and of their heat resistance, but the cold resistance decreases rapidly. The brittle temperature varies linearly with the acrylonitrile content; with 18% bound nitrile it is equal to −56°, with 40% nitrile it is −27°. For the sulfur vulcanizates it is 6-13° higher than for the corresponding raw rubbers; vulcanization using the peroxides gives rubbers analogous in brittle temperature to the original raw rubbers. The cold resistance of products made from the divinyl-nitrile latices can be increased by the introduction of plasticators (for example, dibutylphthalate), which, however, may be washed out during operation of the products in contact with organic

liquids. In connection with the high polarity of the nitrile groups, the products made from the divinyl-nitrile latices swell somewhat more in water than the corresponding products made from the divinyl-styrene latices and have inferior dielectric properties. A very important property of the divinyl-nitrile latices is the good compatibility of the polymers contained in them with many polyvinyl chlorides, polyvinyldene chlorides and other plastics. On mixing with the corresponding dispersions, the divinyl-nitrile latices plasticize the plastics, improving their elasticity, while the plastics, in turn, improve the strength and resistance of the products made from the divinyl-nitrile latices to the attack by hydrocarbons, vegetable and animal oils and fats, to the oxidizing and atmospheric influences. Dispersions of polystyrene, carbon black, titanium dioxide and others can also be added to the divinyl-nitrile latices as strengtheners. The vinyl-nitrile latices are also quite compatible with the thermoreactive resins, particularly the phenol-, resorcin-, melamine- and urea-formaldehydes introduced into the latex in the form of aqueous solutions. These resins also have a strengthening action and are vulcanizing agents; they increase the oil resistance of the products and, in addition, sharply increase the adhesion to the metals and to the polar materials. The divinyl-nitrile latices introduced into the resin solutions in small quantities have a plasticizing effect on them, eliminate brittleness and increase the strength, elasticity, impact strength and other physico-mechanical properties of the corresponding materials. The usual vulcanizing agents are introduced into the mixtures based on the divinyl-nitrile latices: sulfur, zinc oxide, thiuram, Captax, and also the ultra-accelerators - zinc dimethyldithiocarbamate, sodium diethyldithiocarbamate, dimethylammonium dimethyldithiocarbamate and others. To give the vulcanizate stability at elevated temperatures, use is made of systems which exclude

the possibility of over-vulcanization, in particular the thiuram-zinc oxide system (without sulfur) or dicumyl peroxide. Unadulterated vulcanizates made from the divinyl-nitrile latices have a strength of 100-200 kg/cm^2 with a relative elongation of 500-1000%. It is also possible to carry out the vulcanization of the raw rubber directly in the divinyl-nitrile latices. Products made with the use of such latices do not require additional heating for vulcanization. Considerable modifications of the properties of the divinyl-nitrile latices are also achieved directly in their synthesis by the introduction into the polymer mixture of small quantities of methacrylic or acrylic acids (see Carboxylate Latices).

The size of the rubber particles in the various types of divinyl-nitrile latices is different, and this effects the colloidal-chemical and technological properties of the latices and to a lesser degree the properties of the products made from them. The latices with particles of diameter 0.06-0.07 microns with a concentration of about 40% have a viscosity of 100-150 centipoises, while the latices with particles of 0.18-0.20 microns, even with a concentration of about 50%, have a viscosity of only 30-50 centipoises. Latices with small particle size have advantages in the impregnation of various materials, introduction into paper pulp and in other processes which require good penetration of the rubber into the depth of the materials. Latices with large particle size contain a smaller quantity of stabilizing emulsifier, which ensures high water resistance of the product. The divinyl-nitrile latices are thickened well by the water-soluble polymers - caseinates, methylcellulose, starch and others; when introduced in large quantities these substances modify the properties of the products and materials. Freezing and subsequent thawing of the divinyl-nitrile latices causes their coagulation. These latices are widely used in the national economy;

they are used for the fabrication of various oil-resistant rubber products - gloves, small cross-section piping, etc. The concentrated divinyl-nitrile latices obtained with the use of the carboxylic acid emulsifiers are used for the fabrication of rubber products which have no odor and are resistant to fuels and oils. The divinyl-nitrile latices are used for applying waterproof and oilproof coatings (frequently in combination with dispersions of polyvinyl chloride) on paper, fabrics, etc. Mixtures based on these latices with the addition of a small quantity of fillers and pigments are used for the application of coatings on leather and for the reinforcing of unstable dyes; mixtures with large filler content (from 2 to 8 parts by weight to 1 part by weight of the polymer) are used for coating the underside of rugs. For the coating of wrapping paper, use is made of mixtures of these latices with clay, starch or casein which provide for good printing and an attractive surface appearance. These latices are used in mixtures with the cements for water- and fuel-resistant coatings for floors, ship decking, oil tanks, etc. They are also used for binding fibers in the production of nonwoven materials and paper, for sizing fabrics; mixtures of the divinyl-nitrile latices with the urea- and melamine-formaldehyde resins, used as binder for artificial and synthetic fabrics, provide for their freedome from wrinkling, elasticity, resistance to solvents. Oil-resistant gaskets are obtained by modifying paper with the addition of the divinyl-nitrile latices to the paper pulp. Mixtures of these latices with the resins or with casein are also used as bonding agents.

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A.I. Yezriyelev, A.V. Lebedev

DIVINYL NITRILE RUBBER – is the product of the copolymerization of divinyl acrylate and acrylonitrile. The diverse types of the divinyl nitrile rubber differ in the ratio of divinyl acrylate to acrylonitril, in the initial plasticity, the workability, the properties, and the type of the antioxidant (Neozone, Dagyrite, Stalit, etc.). The nonmodified grades SKN-18, SKN-26, and SKN-40 with an initial hardness of 1500-3000 g, and the modified ones with a Defo hardness of 700-1100 g are produced in the USSR. Abroad, diverse types of divinyl nitrile rubber are available: Chemigum, Hycar, Butapren, Paracryle (U.S.), Polysar, Crinac (Canada), Butacone, Hycar (Great Britain), Perbunan (German Federal Republic), Buna-N (German Democratic Republic). The specific gravities are: 0.943 for SKN-18; 0.942 for SKN-26, and 0.986 for SKN-40. T_g: −55° for SKN-18; −42° for SKN-26, and −32° for SKN-40. Divinyl nitrile rubbers are resistant to oil and gasoline, they resist well mineral, vegetable and animal oils, fats, and aliphatic hydrocarbons. The presence of the polar CN group in the molecule involves the resistance of these rubbers to the action of nonpolar solvents. They dissolve relatively well in polar solvents: acetone, methyl ethyl ketone, etc. Divinyl nitrile rubbers swell strongly and dissolve in aromatic hydrocarbons and chlorine-containing organic compounds. Divinyl nitril rubbers possess a high heat conductivity, they are more resistant to the action of oxygen, heat and light than NK. Divinyl nitrile rubbers are semiconductors with regard to their electrical properties (specific resistance 10^{10} ohm·cm): The dielectric constant exceeds by several times that of NK and other types of SK. Nonmodified divinyl nitrile

rubbers must undergo a mastication by means of cold rolls, the modified divinyl nitrile rubbers do not require a pretreatment. The hard divinyl nitrile rubbers possess lower technological properties than divinyl styrene rubbers. The technological properties of the modified divinyl nitrile rubbers are higher. Sulfur and the same accelerants as for the mixtures of divinyl styrene rubbers are used for the vulcanization of divinyl nitrile rubbers. Organic peroxides (dicumyl peroxide, etc.), halogen-containing compounds and formaldehyde resins may also be used for the vulcanization. Active fillers prove to have the same effect on divinyl nitrile rubber as on divinyl styrene rubbers. Plasticizers of the esther type, dibutyl phthalate, dibutyl sebacinate, tricresyl phosphate, etc., are widely used to improve the technological properties of the stocks and also to boost the elasticity and frostproofness of divinyl nitrile rubbers. An increase of the adhesion of divinyl nitrile rubber compounds is attainable by addition of yarresine, indenecoumarone resin, and other substances. Nonfilled divinyl nitrile rubbers have low mechanical properties: the tensile strength of SKH-26 and SKN-40 rubbers amounts to 40-60 and 60-80 kg/cm^2, respectively.

The properties of divinyl nitrile rubbers depend mainly on the proportion of acrylonitrile in them. Increase in tensile strength, resistance to tear and abrasion, resistance to swelling in benzene and oils, and also a lowering of the elasticity and frostproofness of divinyl nitrile rubbers appear when the proportion of nitrile groups is increased. Carbon-black divinyl nitrile rubbers are characterized by high mechanical properties and a good resistance to abrasion, which is by 30-35% higher than that of NK. The heat resistance of divinyl nitrile rubbers is markedly lower than that of NK and equal to that of divinyl styrene rubbers; the heat buildup at alternating deformations is somewhat lower than that in divinyl styrene rubbers. The low elasticity and reduced

frostproofness are disadvantages of the divinyl nitrile rubbers.

Modified SKN rubbers show somewhat reduced tensile strengths (260-280 kg/cm^2 for SKN-26, and 270-300 kg/cm^2 for SKN-40) and moduli of elasticity at a 300% elongation. The good resistance to thermal aging is an essential advantage of the divinyl nitrile rubbers. They surpass in this regard the NK and the divinyl styrene rubbers. Heatproof SKN-26 rubbers filled with calcium silicate, stabilized by mercaptobenzimidazole and dimethylphenyl p-cresol, containing tiuram as an accelerant, maintain a sufficient elasticity after aging at 150° for 7-10 days. Divinyl nitrile rubbers with an increased resistance to thermal aging (in comparison with sulfur rubbers) may be obtained by vulcanization with phenolformaldehyde resins. Divinyl nitrile rubbers surpass markedly rubbers of other polymer types, apart from thiokols and fluorine polymers, with regard to their resistance to gasoline and oil.

Vulcanized divinyl nitrile rubbers with a high resistance to oils at high temperature (200°) may be obtained by using halogen-containing compounds (chloranil, benzotrichloride, etc.). The tensile strength after swelling in Autol-18 at 200° for 24 hours is equal to 165 kg/cm^2 for SKN-26 rubbers, and equal to 344 kg/cm^2 for chloranil-containing SKN-26 rubbers. The gasproofness of divinyl nitrile rubbers surpasses that of other SK and NK, with the exception of butyl rubber and thiokol. The penetrability of water vapor amounts 10-12 g per 1 hr and 1 cm^2 surface at a pressure of 1 mm mercury column and 1 mm thickness of the plate; it is equal to 2-4 g for NK rubbers. The water adsorption of divinyl nitrile rubbers is somewhat higher than that of NK and SK rubbers: it is equal to 7.5% by weight for SKN-26 rubbers, and to 6.5% by weight for NK rubbers. Divinyl nitrile rubbers possess a sufficient resistance to ozone. They have low electrical insulating properties and are used for the production of current-conducting rubbers. The dielec-

tric constant at a frequency of 50 cps is 2.69 for NK rubbers, and 11 for SKN-26 rubbers. Divinyl nitrile rubbers become well adherent to metals by means of diverse methods; they are compatible with NK, other SK, and plastics. Addition of 20% NK improves significantly the technological properties and the stickiness of the raw stocks, not changing the mechanical properties of carbon-black rubbers, not deteriorating the resistance of the rubbers to swelling and thermal aging, and also the resistance to high temperatures. Thiokols are strongly compatible with divinyl nitrile rubbers, and make possible the production of rubbers with an elevated resistance to oil and gasoline; divinyl nitrile rubbers are compatible with polychlorovinyl (PVKh) and phenolformaldehyde resins in any proportion. Addition of PVKh improves the technological properties of the compounds, it increases the tear resistance, the resistance to swelling and natural aging of the rubbers, but it lowers, however, the tensile strength and the elasticity. A comastication of PVKh with 10% SKN-26 at a raised temperature gives blends whose specific impact resilience surpass by 4 times that of viniplast. Divinyl nitrile rubbers are compatible with polystyrene and the styrene-acrylonitrile copolymer. Mechanical treatment of polystyrene with divinyl nitrile rubber in a mixer for 10 min at 135-150° gives a compound with a somewhat increased resilience. A significant increase of the resilience (by more than 6 times) is obtained under the same conditions by mechanically mixing of styrene and acrylonitrile copolymers with divinyl nitrile rubber.

Ebonites, surpassing those from NK with regard to their mechanical properties, the thermostability and oilproofness, can be obtained on the basis of divinyl nitrile rubbers. Divinyl nitrile rubbers are used mainly for products for which a high resistance to oil and gasoline is required. Oil- and gasolineproof hoses, diverse packings working in oil

and solvent media, gasoline containers and other oil- and gasoline-proof rubbers and ebonites are produced from divinyl nitrile rubber. Divinyl nitrile rubbers are used for rubber products working at raised temperatures (up to 150°), owing to their good resistance to thermal aging. Divinyl nitrile rubbers are used as current-conducting rubbers. Fireproof coatings are made from compounds of divinyl nitrile rubber with PVKh.

The properties of divinyl nitrile rubbers are quoted in Tables 1 and 2.

TABLE 1

Properties of Divinyl Nitrile Rubbers with 50 Parts by Weight of Channel Carbon Black

1 Показатели	СКН-18	СКН-26 2	СКН-40 2
3 Прочность на разрыв (кг/см²)	250—270	280—300	300—330
4 Модуль при 300%-ном удлинении (кг/см²)	90—110	100—120	120—130
5 Относительное удлинение (%)	450—550	550—650	600—700
6 Остаточное удлинение (%)	15—20	20—30	20—30
7 Сопротивление раздиру (кг/см)	45—50	55—70	74—78
8 Твердость по ТМ-2	70—72	70—75	74—78
9 Эластичность по отскоку (%)	35—40	28—31	15—20
10 Коэфф. морозостойкости:			
11 при —35°	0.15—0.20	0.02	—
11 при —23°	0.4—0.5	0.15—0.20	0.02
при —15° 11	0.6—0.7	0.3—0.4	0.15—0.20
12 Темп-ра хрупкости (°С)	—58	—46	—23
Коэфф. температуростойкости при 100°: 13			
14 по прочности на разрыв	0.25—0.30	0.25—0.30	0.35—0.40
15 по относительному удлинению	0.43—0.48	0.54—0.57	0.60—0.63

1) Characteristics; 2) SKN; 3) tensile strength (kg/cm^2); 4) modulus at 300% elongation (kg/cm^2); 5) relative elongation (%); 6) residual elongation (%); 7) tear resistance (kg/cm); 8) TM-2 hardness; 9) resilience (%); 10) coefficient of frostproofness; 11) at; 12) coefficient of thermal stability at 100°; 13) for the tensile strength; 15) for the relative elongation.

TABLE 2

Swelling of Carbon-Black Rubbers from Divinyl Nitrile and Natural Rubbers in Diverse Solvents

1 Растворители	Увеличение объема при комнатной темп-ре за 3 недель (%)		
	3 СКН-26	3 СКН-40	НК 4
5 Парафиновое масло	4	1	140
6 Трансформаторное масло 7	5	1	148
Дизельное масло 8	14	5	116
Льняное масло 9	18	5	102
Тяжелый бензин 10	21	12	158
Легкий бензин 11	43	27	226
Скипидар 12	48	21	299
Олеиновая кислота 13	61	29	269
Ацетон 14	98	85	12
Сероуглерод 15	139	72	471
Ортоксилол 16	200	114	336
Бензол 17	207	128	366
Четыреххлористый углерод 18	214	116	671
Этиловый спирт	10	10	2

1) Solvents; 2) increase in volume at room temperature for 3 weeks (%); 3) SKN; 4) NK; 5) paraffin oil; 6) transformer oil; 7) diesel oil; 8) linseed oil; 9) heavy gasoline; 10) light gasoline; 11) turpentine; 12) oleic acid; 13) acetone; 14) carbon disulfide; 15) ortho-xylene; 16) benzene; 17) carbon tetrachloride; 18) ethanol.

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M.D. Gordin

DIVINYL RUBBER – is the product of the polymerization of divinyl in presence of a catalyst lithium metal or a complex catalyst. It is delivered in experimental and industrial scale: SKLD, and SKD (in USSR), cis-1.4, trans-4, ameripol CB (U.S.), Hüls I and II (German Federal Republic). Polymers containing from 100% cis- to nearly 100% trans-links are obtained when a complex catalyst is used. The polymer with a cis-1.4 structure is of the greatest interest; it is amorphous at room temperature, it does crystallize, however, easily at –40°, t°_{pl} of the crystals is –10°. The trans-1.4 divinyl polymer crystallizes at consierably higher temperatures. The cis-polybutadienes are rubber-like products, the trans-polybutadiene "Trans-4," containing about 90% trans-links, is similar to guttapercha; it is hard, resinlike, and has a crystalline structure. Cis-polybutadienes contain Neozone D and other antioxidants. The polymers obtained with a complex catalyst have a more regular structure as polymers obtained with metallic lithium. Polybutadiene polymers possess a relatively high resistance to oxidative degradation. SKD is sufficiently workable and mixes relatively well with ingredients. Addition of gas-channel carbon black reduces strongly the plasticity of the polymer and, therefore, the compounds filled with carbon black have insufficient technological properties. Compounds of SKD with NK, divinyl styrene or synthetic polyisoprene rubbers in the ratios 50:50, 30:70, and 25:75 are used in order to improve the technological properties of the SKD. SKD is not adhesive. Filled rubbers on SKD basis have a tensile strength up to 80 kg/cm^2, the SKLD grades have such one of 20-25 kg/cm^2. Rubbers with 50 parts by weight of channel

black surpass in their tensile strength the rubbers on SKLD basis, but are inferior to NK. Cis-divinyl rubbers have a low heat resistance at 100° in comparison with NK. At 20°, SKD and SKLD surpass NK in elasticity and are significantly more elastic than SKD-30A. The heat buildup and the mechanical losses of SKD and NK carbon-black rubbers are similar to each other and considerably lower than those of SKS-30A rubbers. SKD rubbers maintain well their elasticity and strength after thermal aging, and surpass in this regard consierably the NK rubber. The high frostproofness and abrasion resistance are the main advantages of the SKD rubbers in comparison with NK and SKS-30A rubbers, SKD surpasses SKLD with regard to these characteristics (see Table).

TABLE

Properties of SKD Rubbers Containing 50 Parts by Weight Gas-Channel Carbon Black

1 Показатели	2 СКД	3 СКЛД	СКД:НК (1:1) 4
5 Прочность на разрыв (кг/см²)	220—270	150—190	220
6 Модули при 300%-ном удлинении (кг/см²)	60—75	60—75	95
7 Относительное удлинение (%)	500—700	500—700	600
8 Остаточное удлинение (%)	10—15	10—20	15
9 Эластичность по отскоку (%) при 20°	50—52	50	—
10 при 100°	55	52	—
11 Сопротивление истиранию (см³/квт-ч)	80—100	150—180	--
12 Прочность на разрыв при 100° (кг/см²)	90	—	—
13 Коэфф. морозостойкости при —45°	0,80	—	—

1) Characteristics; 2) SKD; 3) SKLD; 4) SKD:NK (1:1); 5) tensile strength (kg/cm^2); 6) moduli at 300% elongation (kg/cm^2); 7) relative elongation (%); 8) residual elongation (%); 9) resilience (%); 10) at; 11) abrasion resistance ($cm^3/kw \cdot h$); 12) tensile strength at 100° (kg/cm^2); 13) coefficient of frostproofness at −45°.

The valuable properties of the cis-1.4 divinyl rubber permit its use as a rubber for general purposes, for tires and technical rubber products, and also for the production of frostproof products. Motorcar

tires made from cis-1.4 divinyl rubber possess a high abrasion resistance and a low heat buildup.

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M.D. Gordin

DIVINYL-STYRENE LATICES are latices which are obtained by emulsion polymerization of a mixture of divinyl and styrene containing no more than 70% by weight of styrene; it is the most widely used class of the synthetic latices. These latices are sometimes considered to include the corresponding dispersions of the plastics obtained by polymerization of a mixture of these monomers with a content of more than 70% by weight of styrene. As the emulsifiers, use is usually made of the anionic surface-active substances (salts of the fatty acids, modified resin, Nekal), less often the nonionogenic substances are used. We differentiate the "hot" divinyl-styrene latices which are synthesized at temperatures of 50° and higher, and the "cold" varieties which are obtained in the presence of oxidizing-reducing systems at 5-20°. The polymerization initiators in the synthesis of the "hot" latices are usually potassium persulfate, less frequently isopropylbenzene hydroperoxide and diazoaminobenzene, while for the "cold" latices the various organic hydroperoxides are most frequently used. A whole series of different types of the divinyl-styrene latices is produced (in the capitalist countries, for example, there are several dozen bands produced by various firms) which differ, in addition to the polymerization temperature, also in concentration, content of the bound styrene in the polymer, its elasticity, the particle size, the nature of the emulsifiers and antioxidants: in certain commercial latices there are no antioxidants. Increase of the relative amount of styrene in the copolymer leads to increase of the stiffness of the products and to deterioration of their cold resistance as a result of increase of the brittle temper-

ature, which varies approximately in proportion to the bound styrene content in the range from -75-85° (for polydivinyl) to +76° (for polystyrene). On the other hand, increase of the styrene content in the polymer is accompanied by an increase of the strength of the unfilled vulcanizates made from the divinyl-styrene latices. Production of films from the "hot" latices with strength of 150-180 kg/cm^2 is possible only in those cases when the polymer contains no less than 40% styrene; from the latices with 60-65% bound styrene in the polymer, we can obtain unvulcanized films with good physical-mechanical properties and with high resistance to oxidizing aging. The use of the "cold" divinyl-styrene latices makes possible provision of satisfactory strength of the vulcanizates with a lower content of bound styrene. The plasticity of the polymer in these latices is varied with the aid of the molecular-weight regulators, primarily the mercaptans or the xanthogendisulfides, while the particle size and the latex viscosity varies as the result of the variation of the amount and the nature of the emulsifiers and the introduction of small quantities of the mineral salts or of finished latex into the original emulsion. The relative quantity of water in the mixture being polymerized in the synthesis of the commercial divinyl-styrene latices is on the average less than in the production of the corresponding emulsion rubbers, while the conversion of the monomers (at least in the production of the "hot" latices) is usually higher (up to 100%).

The dry substance content in the various dinvinyl-styrene latices varies from 20 to 65-70%. The highly concentrated latices are obtained by evaporation or by precipitation in the presence of precipitation agents. To reduce the viscosity of the concentrates, use is sometimes made of agglomeration of the particles prior to concentration by means of freezing the latices under gentle conditions (with subsequent thaw-

ing), the introduction of certain special agents, or under a pressure of more than 70 atmospheres. The particle size in the various types of the divinyl-styrene latices produced by industry varies in the range of 0.06-0.4 microns. The reaction is usually alkaline (pH of 8-11). In the majority of the cases these latices thicken well with the introduction of small quantities of the caseinates, polyacrylates and other water-soluble polymers. The stability of these latices to various factors (mechanical, temperature, etc.) depends primarily on the nature of the emulsifiers contained in the latices, the degree to which the latices cover the rubber globules and the pH of the aqueous phase. The surface tension of these latices varies over wide limits from 35 to 70 dynes/cm.

The divinyl-styrene latices are used for the production of sponge rubber products, structural paints, cements, leather substitutes and for impregnation of tire cord. To obtain the sponge rubbers, frequently use is made in mixtures with the natural latex of speical highly concentrated "cold" latices which are carefully deodorized and which contain up to 30% styrene by weight in the polymer, and also the "hot" divinyl-styrene latices with a content of about 45% styrene in the polymer which have been plasticized with oils; the salts of the fatty acids are usually used as the emulsifiers in the synthesis of these latices. For cord impregnation, use is made of the "cold" and "hot" divinyl-styrene latices with rubber concentrations of 20-40% containing 25-45% bound styrene; for improvement of the adhesive properties there are frequently added divinyl vinylpyridine or divinylalkyl vinylpyridine latices in the amount of 20% and more. For production of paints, use is made of the "hot" divinyl-styrene latices with a high styrene content in the polymer (55-70 weight %) which are usually obtained by deep polymerization; as a rule, the concentration of these latices exceeds 45%. Almost all the divinyl-styrene latices can be used as bases for cements.

However, in this case, to improve the strength of the bonding there are introduced into the low-styrene latices vulcanizing ingredients (with subsequent heating) or small quantities of other bonding materials (casein, animal glues, etc.); using the concentrated high-styrene latices (50-65% bound styrene) we can obtain strong bonding films even without vulcanization. The use of the divinyl-styrene latices for the production of articles by the methods of ionic deposition and gelatinizing encounters difficulties in connection with the poor physico-mechanical properties of the raw gels made from these latices. For this purpose successful use has been made of the modified, so-called carboxylate divinyl-styrene latices which are synthesized with small additions of methacrylic or acrylic acids to the monomers.

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A.I. Yezriyelev, A.V. Lebedev

DIVINYL STYRENE RUBBER (divinyl alpha-methyl styrene rubber) – is the product of copolymerization of divinyl with styrene or with alpha-methyl styrene. The diverse grades of methyl styrene rubber (KDM) differ in the ratio of divinyl to styrene, in the initial plasticity, workability, the other properties and the type of antioxidant used. In the USSR, nonmodified divinyl styrene rubbers (KDM) are delivered with a Defo hardness up to 2500-3000 g and the following ratios of divinyl to styrene: 90:10 (SKS-10; SKMS-10); 70:30 (SKS-30; SKMS-30); 50:50 (SKS-50; SKMS-50); and modified ones with a Defo hardness of 400-700 g, containing 14-17% PN-6 oil: (SKS-30 ARM-15; SKMS-30 ARM-15; SKMS-30-ARKM-15; SKMS-30 ARKM-15). In the U.S., the divinyl styrene rubbers (KDM), filled with diverse oils and not containing oil, are delivered in the following grades: 1000, 1001, 1002, 1500, 1501, 1512, 1703, 1712, 1023, 1054, etc.; in Canada the Polysars Crilene Crinol, etc., are produced; in Italy the Europrenes; in the German Federal Republic Buna Hüls 150, 152, 301, etc., and in the German Democratic Republic Buna X-3, X-4, etc. Divinyl styrene rubber is soluble in aromatic hydrocarbons, gasoline, and chloroform; it is insoluble in water, alcohol, acetone and other fluids with associated molecules. The specific gravity of SKS-10 is 0.919, that of SKS-30 is 0.944. The specific heat of SKS-30 is 0.472 cal/degree. The refractive indices n_D^{20} are: 1.525 for SKS-10; 1.535 for SKS-30, and 1.5525 for SKS-50. T_g is –75° for SKS-10; –60° for SKS-30, and –14° for SKS-50.

Compared with NK, the divinyl·styrene rubbers are more gasproof, but less vaporproof; they are resistant like NK to the action of oxygen,

light and salts of manganese, iron, or copper, and less resistant to the action of ozone; the solubility of oxygen in divinyl styrene rubber is less than in NK; divinyl styrene rubber has lower technological properties and lower adhesiveness. Nonmodified divinyl styrene rubbers must undergo a mastication by thermal oxidation; the modified ones do not require a pretreatment. Oil-filled modified divinyl styrene rubbers (SKS-30 ARM-15, etc.) have the highest workability. The vulcanization of divinyl styrene rubbers is carried out with sulfur in the same way as that of NK. Captax, Altax, thiuram, guanidine, sulfonamides, etc., are used as accelerants of the vulcanization. The vulcanization rate of the compounds of divinyl styrene rubbers is lower than that of the compounds of NK, and, therefore, higher doses of sulfur and accelerants must be added. Zinc oxide is generally used as a promoter. Carbon blacks are used as fillers: gas-channel carbon black has the highest reinforcing effect; further, chimney soot, PM-70, spray-burner soot, etc., are used. Mineral fillers are used rarely owing to their low reinforcing effect. Softeners are used to improve the technological properties: vaseline oil, black oil, rubrax, polydienes, etc. Plasticizers as dibutyl phthalate, dibutyl sebacinate, tricresyl phosphate, etc. are added to improve the frostproofness of rubbers on divinyl styrene basis. The adhesiveness is increased by yarresin, rubresine, and indene coumarone. Divinyl styrene rubber is strongly compatible with SKB, NK, poly-isobutylene, and reclaimed rubber. Addition of 10-20% poly-isobutylene improves markedly the technological properties and the adhesiveness of the stocks, increasing at the same time the mechanical properties of the rubbers. The mechanical properties of nonfilled divinyl styrene rubbers are low; the tensile strength achieves 35-50 kg/cm^2 (230-300 kg/cm^2 for NK rubbers); the rubbers filled with carbon black are characterized by high mechanical properties. The elasticity and

frostproofness of divinyl styrene rubbers become reduced when the proportion of styrene is increased. A comparison of the properties of divinyl styrene rubbers with a divinyl – styrene ratio of 70:30, filled with 50 parts by weight of carbon black, with the properties of NK is given in Table 1. Compared with NK, the divinyl styrene rubbers have a higher heat building and a relatively low resistance to alternating deformations, the latter property may be improved by addition of antifatigue agents.

TABLE 1

Properties of Conditioned Divinyl Styrene Rubbers

Показатели 1	Дивинил-стирольный каучук 2	Натуральный каучук 3
4 Прочность на разрыв (кг/см²)	240–260	240–310
5 Относительное удлинение (%)	600–750	600–700
6 Остаточное удлинение (%)	20–30	25–40
7 Сопротивление раздиру (кг/см)	70–80	100–130
8 Модули при 300%-ном удлинении (кг/см²)	70–90	80–100
9 Твердость по ТМ-2	65–70	65–70
10 Эластичность по отскоку (%)	34–37	40–45
11 Температура хрупкости (°С)	−52–53	−60–62
12 Сопротивление истиранию (см³ тонн-е)	220–280	240–280
13 Коэфф. температуростойкости при 100°:		
14 по прочности на разрыв	0.60	0.60
15 по относительному удлинению	0.60	1.00
16 Коэфф. старения после 72 час при 100°:		
17 по прочности на разрыв	0.7–0.8	0.7–0.8
по относительному удлинению	0.6–0.7	0.7–0.8
Коэфф. морозостойкости при −45°	0.15	0.85

1) Characteristics; 2) divinyl styrene rubber; 3) natural rubber; 4) tensile strength (kg/cm^2); 5) relative elongation (%); 6) residual elongation (%); 7) tear resistance (kg/cm); 8) moduli at 300% elongation (kg/cm^2); 9) TM-2 hardness; 10) regilience (%); 11) brittleness point (°C); 12) abrasion resistance (cm^3/kwh); 13) coefficient of thermal stability at 100°; 14) for the tensile strength; 15) for the relative elongation; 16) aging coefficient after 72 hours at 100°; 17) coefficient of the frostproofness at −45°.

Divinyl styrene rubbers are sufficiently resistant to the action of steam, and surpass in this view the NK. They are, similarly to the NK rubbers, not resistant to ozone in atmospherical concentrations, they do swell in gasoline, benzene, toluene, carbon tetrachloride,

mineral and vegetable fats and oils (see Table 2).

TABLE 2

Swelling of SKS-30 and NK Rubbers for 8 Weeks at 20° (Volume-%)

	СКС-30 (1)	НК (2)
3 Дизельное масло	75	116
4 Бензин	110	160
5 Бензол	285	350
6 Этиловый спирт	1	2

1) SKS-30; 2) NK; 3) diesel oil; 4) gasoline; 5) benzene; 6) alcohol.

SKS-30 rubber absorbs 4.5% water, NK rubber 6.5%. With regard to the gasproofness, the SKS-30 rubbers are of the same quality as the NK rubbers, but they have a lower water-vapor proofness: 5-10 instead of 2-8 $g \cdot cm/hr \cdot cm^2 \cdot mm$ mercury column $\times 10^{-6}$. The dielectric properties of SKS-30 rubbers are near to those of NK rubbers and are maintained for a long time at rasied temperatures. The specific resistance of SKS-30 rubbers is $7 \cdot 10^{14}$, that of NK rubbers $20 \cdot 10^{14}$ ohm·cm. The specific heat of carbon-black filled SKS-30 rubber is 0.385 cal/g·degree within 20--100°, and the conductivity is 0.21 kcal/m·hr·degree. Compared with SKS-30 rubbers, the carbon-black filled SKS-10 rubbers have a lower tensile strength, a lower tear resistance, a lower resistance to thermal aging, and a higher elasticity. SKS-10 rubbers are practically no different from SKS-30 rubbers with regard to thermal stability, hardness and resistance to abrasion. The high frostproofness is the main advantage of the SKS-10 rubbers (it is higher than that of NK, and significantly higher than that of SKS-30). The lower resistance (in comparison with SKS-30) to the growth of cuts, and the lower resistance to alternating deformations are disadvantages of the SKS-10 rubbers; they may be improved to a high degree by addition of antifatigue agents (see Table 3).

I-23K4

Carbon-black filled SKS-50 rubbers are practically equal to SKS-30 rubbers with regard to tensile strength, relative and residual elonga-

TABLE 3

Exemplary Properties of SKS-10 Rubbers Containing 50 Parts by Weight of Channel Carbon Black

Показатели 1	СКС-10 2
3 Прочность на разрыв (кг/см²)	190—220
4 Относительное удлинение (%)	550—650
5 Остаточное удлинение (%)	15—25
6 Сопротивление раздиру (кг/см)	66—77
7 Твердость по ТМ-2	65—72
8 Эластичность по отскоку (%)	38—45
9 Сопротивление истиранию (см³/квт-ч)	230—280
10 Температура хрупкости (°С)	15 от —74 до —77
11 Коэфф. морозостойкости при —45°	0,40—0,54
12 Коэфф. теплового старения при 100° в течение 72 час.:	
13 по прочности на разрыв	0,65—0,70
14 по относительному удлинению	0,45—0,56

1) Characteristics; 2) SKS-10%; 3) tensile strength (kg/cm^2); 4) relative elongation (%); 5) residual elongation (%); 6) tear resistance (kg/cm); 7) TM-2 hardness; 8) resilience (%); 9) resistance to abrasion (cm^3/kwh); 10) brittleness point (°C); 11) coefficient of frostproofness at —45°; 12) coefficient of thermal aging at 100° for 72 hours; 13) for the tensile strength; 14) for the relative elongation; 15) from ... to ... .

tion, tear resistance, TM-2 hardness and resistance to thermal aging. SKS-50 rubbers have a lower elasticity (14-15%) and a lower coefficient of frostproofness (0.10-0.12 at —20° instead of 0.40-0.60 for SKS-30 rubbers). The tensile strength of SKS-50 rubbers is higher than that of SKS-30 rubbers when inactive fillers (chalk, for example) are used (77 instead of 22 kg/cm^2).

Divinyl styrene rubbers (KDM) with a divinyl-styrene ratio of 70:30 are rubbers for general purposes; they are used for the production of tires, conveyor belts, hoses, diverse packings, molded pieces, ebon-

ite, and light fine-porous soles. SKS-50 may be used as an admixture to improve the technological properties of divinyl styrene rubbers with a divinyl-styrene ration of 70:30.

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E.Ya. Devirts

DOUBLE REFRACTION – the splitting into two of light rays on passing through an anisotropic medium. Here the light wave is broken up into 2 components with mutually perpendicular polarization planes. In single-axis crystals the refraction index for one of the components n_o, which is called the ordinary ray, is independent of the direction of propagation, while the refraction index for the other component n_e (extraordinary ray) varies from the value of n_o when the ray is propagated along the optic axis to a certain extremevalue for a direction perpendicular to the optic axis. Depending on the sign of the difference $n_e - n_o$ a distinction is made between negative (Island spar, etc.) and positive (quartz, etc.) single-axis crystals. In twin-axis crystals (mica, gypsum, etc.) the index of refraction for both rays which are obtained on double refraction depends on the direction of propagation. The double refraction of twin-axis crystal can be characterized by three main refraction indices. Double refraction can be observed also in a medium with an artificially produced anisotropy, for example, upon an application of an electric field (Kerr effect) or mechanical stresses. Methods of discovery and measurement of double refraction are based on the interference of polarized rays.

L.S. Priss

DOUBLE SHEAR – fracture of a material under the action of tangential stresses, occurring along two planes parallel to the action direction of the external forces. Bolts, rivets, and pins in joints of the fork-lug type are subject to double shear. In order to determine shear resistance (τ_{sr}) specimens, wire, and fasteners are generally tested under double shear.

N.V. Kadobnova

DRAVITE – see Tourmaline.

DUCTILE STRENGTH – resistance to failure after preceding plastic deformation. It is usually juxtaposed to brittle strength (see Tearing Strength). Ductile strength is closely tied to failure by shear. Many materials, depending on the shape and dimensions of the specimen, temperature, rate and other loading conditions can yield both brittle failure (with a reduction in temperature, increase in rate, increase in the sharpness of notch and the specimen's dimensions), and ductile failure (when the aforementioned factor change in the opposite direction). The effect of external and internal factors on the ductile strength and brittle strength varies and sometimes it is opposite, for example, when a tension specimen is notched the brittle strength is reduced while the ductile strength increases; when the temperature and loading rate are reduced the brittle strength changes little (sometimes it is reduced) while ductile strength increases; if the carbon content in hardened steel is increased, the brittle strength is reduced while the ductile strength increases, etc.

Ya. B. Fridman

DURABLE SHAPING BRONZE – a bronze with high durability and the ability to resist grabbing, used in the manufacture of friction components. These alloys include Tin bronzes, Aluminum bronzes, Silicon bronzes, and Beryllium bronzes (Table). Tin shaping bronzes contain up to

Properties of Durable Shaping Bronzes

Сплав 1	Вид полуфабриката 2	*HB* (кг/мм²) 3	Коэфф. трения 4	
			со смазкой 5	без смазки 6
БрОФ7-0.2 7	Прутки твердые 20	180	0.11	0.25
БрОФ6.5-0.15 8	» »	170	—	—
БрОФ6.5-0.4 9	Проволока твердая	180	0.10	0.20
БрОФ4-0.25 10	Прутки твердые 21	160	—	—
БрОЦ4-3 11	» »	160	—	—
БрОЦС4-4-2.5 12	Полосы, ленты полутвердые 22	90	—	—
БрОЦС4-4-4 13	Полосы, ленты полутвердые	90	0.012	0.26
БрКМц3-1	Прутки твердые	160	0.016	0.28
БрКН1-3 15 14	Прутки термически обработанные 23	150	0.015	0.28
БрАЖ9-4 16	Прутки прессованные 24	150	0.012	0.18
БрАЖМц10-3-1.5 17	Прутки прессованные	160	0.012	0.25
БрАЖН10-4-4 18	Прутки прессованные	180	0.016	—
БрБ2 19	Прутки термически обработанные	350	—	—

1) Alloy; 2) type of semifinished product; 3) HB (kg/mm^2); 4) coefficient of friction; 5) with lubricant; 6) without lubricant; 7) BrOF7-0.2; 8) BrOF6.5-0.15; 9) BrOF6.5-0.4; 10) BrOF4-0.25; 11) BrOTs4-3; 12) BrOTsS4-4-2.5; 13) BrOTsS4-4-4; 14) BrKMts3-1; 15) BrKN1-3; 16) BrAZh9-4; 17) BrAZhMts10-3-1.5; 18) BrAZhN10-4-4; 19) BrB2; 20) hard bars; 21) hard wire; 22) semihard strips and bands; 23) heat-treated bars; 24) pressed bars.

7% Sn, since a higher tin content hampers pressure working. These bronzes have a monphasic solid-solution structure. Tin gives the alloy high mechanical properties, durability, and the ability to resist grabbing. Phosphorus also gives it antifriction properties and increases its durability. However, casting bronzes, which contain still greater quantities of Sn and P and have a heterogeneous structure, have higher antifriction characteristics than monophasic shaping alloys. Bars of BrOF7-

0.2 and BrOF6.5-0.15 bronze are used for bearings, which are manufactured as bushings that will function at moderately high specific pressures and sliding speeds or under high loads at low sliding speeds. BrOF6.5-0.4 bronze, which is produced in the form of screen wire and wire for paper-making machines and for the slate industry, is distinguished by high durability and good corrosion resistance in solutions of salts and organic compounds. Zinc reduces the technological characteristics of the alloy, while lead increases its antifriction characteristics and improves its cuttability; the lead content should, however, be limited to several %, since this element greatly hampers pressure working. Shaping bronzes containing lead can be worked only when cold. These alloys are used in the manufacture of bushings and bearing linings. Aluminum bronzes, which have higher strength and hardness, have a lower grabbing resistance and durability than tin bronzes, although they function reliably under moderately severe conditions when well lubricated. In many cases gears, worms, guidesleeves, noncritical bush bearings, and other components are made of aluminum bronzes. Aluminum-iron-nickel bronze (BrAZhN10-4-4), which contains 4% Ni and has a very high hot strength, is recommended for components which do not function under thermal stress. The silicon-nickel bronze BrKN1-3 is also intended for use at elevated temperatures and low specific pressures and sliding speeds (See Structural shaping bronze).

Beryllium bronze, which has the highest elasticity, strength, and hardness of these alloys, has been successfully used in cases of vibration friction, where residual deformation of the material is impermissible, as in the ball-and-socket joints of instruments and assemblies. Silicon-manganese bronze is used as a corrosion-resistant durable material in the manufacture of screens and grids which must function in sewage, vaporizers, smoke filters, etc., as well as in the production

of noncritical bearings.

O.Ye. Kestner

DURALUMIN (duraluminum, dural) - multicomponent, shaping, heat-strengthened alloy of aluminum with copper (2.2-5.2%), magnesium (0.2-2.7%), manganese (0.2-1.0%) and mandatory presence of silicon and iron. The chemical composition of all the existing duralumin brands is contained within the abouve limits (D18P, V65, D1, D16, VD17, D19, VAD1, etc.) (see Medium Strength Aluminum Shaping Alloys). By the chemical composition duralumin belongs to the Al-Cu-Mg-Si system. The following phases may be present in duralumin: α-solid solution, S, θ, Mg_2Si, W(Al_2CU MgSi). The Mn present in duralumin forms with Fe and other alloying elements complex intermetallic compounds and solid solution on the basis of these compounds (AlCuMn) - T, AlMnCuFe, AlFeSiMn, $FeMnAl_6$, etc., which do not participate in the processes of the strengthening heat treatment. Mn produces a certain increase in the hardness, strength, imparts the press effect and improves the anticorrosion properties. Duralumin is subjected to strengthening heat treatment, which consists of quenching with natural or artificial aging. The regime of heat treatment of duralumin is determined by the chemical composition and the operating conditions of the alloy (pre-quench heating temperatures 490--514°, and for artificial aging 100-200°).

When naturally aged duralumin is rapidly heated in a short time to 250-300°, "recovery" takes place in it, with the result that the strength is highly reduced and reaches the values of freshly-quenched duralumin. Artificial aging at 190° for 6-20 hours prevents "recovery."

The properties of duralumin depend on the chemical composition, kind of preceding deformation and the heat treatment regime. The cor-

rosion properties of duralumin are moderate, for which reason duralumin sheets are clad by pure aluminum.

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O.S. Bochvar, K.S. Pokhodayev

DYNAMIC HEAT GENERATION – result of elastic hysteresis due to multiple cyclical deformations of materials. In many rubber products, for example, in tires, dynamic heat generation may result in overheating, which has a detrimental effect on the service life. Heating due to dynamic heat generation is expressed by the equation $\Delta T = q\omega k J$, where ΔT is the excess of the material's temperature over the temperature of the surrounding medium, q are the specific mechanical losses per loading cycle, ω is the loading frequency, k is the effective coefficient of heat transfer to the medium, and J is the mechanical equivalent of heat. q depends on the mechanical loading regime. In the case of a harmonic load the following relationships are approximately valid:

$$q = \pi f_0 \varepsilon_0 \sin\varphi = \pi E'' \varepsilon_0^2 = \pi K \varepsilon_0^2 = \frac{1}{2} K \varepsilon_0^2 = \frac{K}{2E''} f_0^2 = \frac{A}{2E''} f_0^2$$

in which f_0 and ε are the stress and strain amplitudes, respectively, φ is the phase shift angle between the stress and the strain, $E^* = E' + iE''$ in the complex dynamic modulus, and K is the internal friction modulus.

M.M. Reznikovskiy

DYNAMIC MODULUS OF ELASTICITY is the modulus of elasticity determined from the rate of propagation of an elastic wave v in the specimen. It is known that $v = \sqrt{E/\rho}$, where ρ is the material density. The most widely used methods of measuring the dynamic elastic modulus involve determining the vibration resonance frequency f_r.

For exciting vibrations in the specimen for determining the dynamic elastic modulus, use may be made of electromagnetic, piezoelectric, electrostatic, electrodynamic, mechanical, and other methods.

For the determin tion of the dynamic modulus of normal elasticity E_d, use is made of longitudinal or transverse vibrations, and for the determination of the dynamic shearing modulus G_d use is made of torsional vibrations. For longitudinal vibrations of thin rods of uniform section ($\lambda \gg d$, where λ is the length of the elastic wave and d is the diameter of the speciment), E_d is related with the resonant frequency by the equation:

$$E_d = 5{,}1916 \cdot 10^{-8} P \frac{l}{d^2(1+\alpha t)} f_{rl}^2 \text{ кг/мм}^2, \text{ kg/mm}^2, \qquad (1)$$

where l and d are the length and diameter of the rod in cm, P is the specimen weight in grams, f_r' is the resonant frequency of the longitudinal vibrations in Hz, α is the coefficient of linear expansion at the test temperature t.

For bending vibrations of a freely supported circular bar:

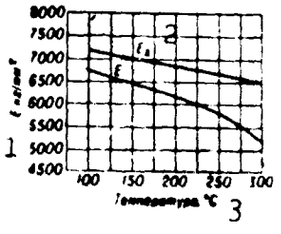
$$E_d = 1{,}6388 \cdot 10^{-8} \left(\frac{l}{d}\right)^4 \frac{P}{l\,(1+\alpha t)} f_{rt}^2 \text{ кг/мм}^2 \text{ kg/mm}^2, \qquad (2)$$

where l, d P and α are the same as in equation (1), f_{rt} is the resonant frequency of the transverse vibrations in Hz. For torsional vibrations of a freely supported rod with discs on the ends

$$G_д = 4{,}024 \cdot 10^{-7} \gamma \frac{l_{пр}^2}{\beta^2 (1 + \alpha t)} f_{rk}^2 \text{ кг/мм}^2, \quad \text{kg/mm}^2, \qquad (3)$$

where l_{pr} is the reduced specimen length in cm, $l_{пр} = l\left(1 + \frac{d^2 L}{D^2 l}\right)$, where l and d are the length and diameter of the rod in cm, L and D are the thickness and diameter of the disc in cm, f_{rk} is the resonant frequency of the torsional vibrations in Hz, γ is the specific weight in g/cm^3, β is a coefficient determined from the equation $\operatorname{tg}\beta/2 = \frac{1}{K\beta}$, where $K = \frac{I_д}{I_{ст}} = \frac{D^4 L}{d^4 l}$. ($I_d$ and I_{st} are the moments of inertia of the disc and rod),

There are arrangements which permit determining the dynamic elastic modulus at temperatures of 2000°. The electrodynamic and piezoelectric methods are used most often for measuring at high temperatures. The capabilities of the electromagnetic and piezoelectric methods are limited in temperature, the first by the Curie point, the second by the temperature at which the crystal loses the piezoeffect (for quartz, for example, 500°) if special measures are not taken to cool the transducers. Tests at high temperatures where the effect of the oxide film may be noted are conducted in a vacuum. The dynamic elastic modulus differs from the elastic modulus determined in static tests more strongly at the higer temperatures (figure). Here there is noted



Effect of test temperature on dynamic E_d and static E moduli of elasticity of D16T alloy. 1) E, kg/mm^2; 2) E_d; 3) temperature, °C.

primarily the effect of creep deformations superimposed on the purely elastic deformations in the static (usually lasting 10-5 minutes) determination of the elastic modulus. The variation of the dynamic elas-

Change of Dynamic Elastic Modulus with Temperature Increase

Сплав 1	Значения $E_д$ (кг/мм²) при темп-рах (°С) 2									
	20	100	200	300	400	500	600	800	1000	1200
ВМ-1 3	32500	–	–	–	31600	–	30500	29300	27900	26000
ЭИ617 4	22000	–	–	–	–	–	19000	17700	–	–
ЭИ437Б 5	22000	–	–	20700	20100	19500	18800	17300	–	–
ЭИ867 6	22600	–	22100	–	20900	–	19600	18100	16100	14000
ЭИ929 7	22600	22350	21900	21350	20800	20100	19500	17800	–	–
10ХГСА 8	21100	–	20100	19400	18750	17750	17000	–	–	–
ВТ5-1 9	12800	–	–	–	11200	–	10100	9100	–	–
ВТ6-С 10	12800	12400	12100	11700	11100	10700	10100	9200	–	–
ВТ3-1 11	12300	11900	11500	11100	10600	–	9800	–	–	–
В95 12	7250	6950	6500	6000	–	–	–	–	–	–
В96	7300	7050	6650	6050	–	–	–	–	–	–
Д16	7400	7200	6800	6500	–	–	–	–	–	–
МЛ10	4500	–	4200	3900	–	–	–	–	–	–

1) Alloy; 2) value of E_d (kg/mm^2 at temperatures (°C); 3) VM-1; 4) EI; 5) EI437B; 6) 10KhGSA; 7) VT5-1 8) VT6-S; 9) VT3-1; 10) V; 11) D16; 12) ML10.

References: Lozinskiy M.G., Vysokotemperaturnaya metallografiya (High Temperature Metallography), M., 1956; Mataushek I., Ultrasonic Engineering, translated from German, M., 1962.

S.I. Kishkina-Ratner, L.A. Stronina

DYNAMIC STRENGTH – resistance to deformation and fracture under nonstatic loading. Dynamic strength refers to fundamentally different groups of properties: strength at very high deformation rates, where inertial forces and wave-like processes have a material influence, strength at elevated deformation rates, where inertial forces and wave-like processes have little influence (e.g., in tests to determine the Impact strength of metals), and strength on repeated loading (see Fatigue).

Ya.B. Fridman

DYNAMOMETER (force-measuring device) - device for measuring the magnitude of foces. The operating principle of the dynamometer is based on measuring the elastic deformation of the working part of the device, that is, of a steel component, usually of intricate shape (spiral, elliptical ring, etc.), due to which the measured deformation is increased and the sensitivity of the dynamometer is improved. Dynamometer are subdivided: 1) by the type of transmission of the elastic deformations to the measuring devices into mechanical, hydraulic and electrical; 2) by the kind of recording devices into arrow, optico-mechanical and automatic recording; 3) by the kind of load which they measure into universal, compression, tension and torsion; 4) by the measurement precision into standard (1st, 2nd and 3rd category) and working. Standard dynamometers of the 3rd category serve for checking testing machines, devices and working dynamometers; they are checked by 1st and 2nd category dynamometers.

Instruction of the Committee of Standards, Measures, and Measuring Instruments establish the rules of checking and calibration of dynamometers and the allowable error of each dynamometer category, which are ±0.1% for 1st category standard dynamometer, ±0.2% for 2nd category dynamometer and ±0.5% for 3rd category dynamometer. The error of class 1 working dynamometers should not exceed ±1.0%, of class 2 dynamometers should not exceed ±2%. Dynamometers are produced in several standard sizes for loads from 200 kg to 1000 tons and more.

N. V. Kadobnova

DYNAMO STEEL – see Electrical Sheet Steel.

DYSCRASITE ("poor alloy") – antimon-silver Ag_3Sb. Is contained in certain silver ores; the composition is not constant, i.e., the Ag content varies from 72 to 84%, on the average it is 72.9%; these substantial variations in composition are due to the presence of solid solutions of Sb in Ag and of Ag in Sb; sometimes As as noted in dyscrasite. The mineral is rare; it forms granular and lamellate precipitations and aggregates; crystals are infrequent. The color of dyscrasite is silver-white to tin-white with a yellow and black iridescence; Mohs hardness is 3.5-4 (can be cut with a knife); specific gravity 9.45-10.027, is nontransparent. The temperature of formation of natural dyscrasite is 483°; it sublimates at 520°, melts incongruently in Ag at 559°. Has been obtained artificially: 1) by fusing Ag and Sb in stoichiometric proportions at 560°; 2) from red hot pyrargyrite ($3Ag_2S \cdot Sb_2S_3$) in a hydrogen stream. Dyscrasite is a good conductor of electricity; it is resistant to HCl, KCN, KOH. Is soluble in HNO_3 with precipitation of Sb_2O_3. Is used as a crystal detector in radio engineering.

References: Betekhtin, A.G., Mineralogiya [Mineralogy], Moscow, 1950.

V.I Magidovich

EDDY-CURRENT METHOD OF FLAW DETECTION – see Flaw detection by electrical induction.

EFFECTIVE LENGTH – characteristic used in buckling calculations which reflects, alongside with the absolute length of the compressed column, the effect of the kind of end restraints. This effect is characterized by the coefficient μ (which is equal to unity when both ends of the beam are hinged, to 1/2 when both ends are rigidly inserted, etc.). The effective length is equal to the product of the column length and the coefficient μ.

Ya.B. Fridman

EFFECTIVE STRESS – 1) see True Stress. 2) For combined materials, foam materials, etc., it is the characteristic of the distribution of stresses between individual construction and structural components.

EFTRELON – is a modified synthetic heterochain fiber made of a mixed polyamide; the copolymerization product of caprolactam (30-45%) with AG salt (70-55%). It is manufactured in East-Germany (GDR). With regard to its properties, it has an intermediate position between capron and nylon 66. t_{pl} is 237°. Eftrelon is characterized by a good colorability, softness and elasticity, its strength is not lower than that of Capron and Nylon 66; it has, however, a high shrinkage (13% in boiling water).

References: Rogovin, Z.A., Osnovy khimii u tekhnologii proizvodstva khimicheskikh volokon [Principles of Chemistry and Technology of the Manufacture of Synthetic Fibers]; Piller, B. and Travnicek, Z., Sinteticheskiye volokna i osobennosti ikh pererabotki v tekstil'noy promyshlennosti [Synethtic Fibers and the Peculiarities of Their Treatment in Textile Industry], translated from Czech, Moscow, 1960.

E.M Ayzenshteyn

Manuscript Page No.

[Transliterated Symbols]

1260 АГ = AG = adipinovokislyy geksametilentetramin = adipic hexamethylene tetramine

ELASTIC AFTEREFFECT – lagging of the deformation of a solid body with respect to the loading process. Elastic aftereffect consists in the fact that, as a result of internal friction or elasticity imperfections in materials, the deformation changes not immediately after changing (or applying) the load, but gradually "catches up" during a certain time interval. Thus, the load "acts afterward" which is the origin of the term "elastic aftereffect." The lagging of deformation behind the load under rapid loading is expressed in the fact that the specimen first yields reduced deformation, which then increases gradually without an increase in the load (direct elastic aftereffect). For the same reason, under rapid unloading (not necessarily to zero) the specimen first does not yield a reduction in deformation which corresponds to the load, but later in time (even in the absence of an external load) the deformation is gradually reduced (reverse elastic aftereffect). Reverse elastic aftereffect is stimulated by heating. It is possible to regard creep as one of the manifestations of direct, and relaxation as one of the manifestations or reverse elastic aftereffect. The elastic aftereffect of plastic materials and of structurally inhomogeneous materials in general can manifest itself quite sharply (fig-

To the left is a specimen of plastic material after it was compressed to 40% of residual deformation. To the right is the same specimen after being heated to 100° and held so for 8 minutes (Rosh and Eykhinger).

ure). In cork type highly inhomogeneous and porous materials the entire deformation consists basically of the elastic aftereffect. The elastic aftereffect also increases highly with an increase in the inhomogeneity of deformation and due to the effect, primarily, of factors which are favorable to plastic deformation, for example, the elastic aftereffect in flexure is smaller than in torsion, and in all-sided compression, due to the absence of tangential stresses, the elastic aftereffect is not observed. The elastic aftereffect for magnesium and its alloys is high due to the low symmetry of the hexagonal lattice. It is very important that the elastic aftereffect be taken into account when straightening products after load removal, which can result in warpage. Hence when tempering after straightening an attempt is made to produce an as complete as possible reverse elastic aftereffect, in order to reduce further warping in every possible way. Direct elastic aftereffect plays an important role for membrane and spring materials. When heating, after plastic deformation, aluminum alloys up to 350-400° and steels up to 400-600°, the presence of residual microstresses and changes in the elastic limits and moduli of elasticity with the temperature, produces an additional residual (unlike that due to reversible thermal expansion) deformation, which is called theremoplastic aftereffect. It can be both positive (an increase in the previously obtained residual deformation) and negative. This phenomenon must be taken into account in straightening and tempering after cold deformation, for example, after winding of springs, etc.

References: see at the end of article Internal Friction.

Ya.B. Fridman.

ELASTIC DEFORMATION – deformation which disappears completely after the external load is removed. Elastic deformation is related to the reversibility of crystal lattice distortions brought about by stresses below the elastic limit; in actual materials it is immediately not completely reversible due to the elastic aftereffect and hysteresis phenomena, which are related to the nonhomogeneity of deformation and structure. Elastic deformation is accompanied by volumetric changes, which are equal to the sum of principal elongations; depending on the stressed state, the volume can increase (extension) or decrease (compression).

N. V. Kadobnova

ELASTIC ENERGY – energy which is accumulated in a body (referred either to the entire body or to a unit of its volume) due to elastic deformation. In the case when Hooke's law holds under static loads the magnitude of the elastic energy of a body is equal to one-half of the product of the force by the displacement corresponding to it: in tension it is $\frac{1}{2}P\Delta$, where P is the tensile force and Δ is the absolute elongation; in bending or torsion it is $\frac{1}{2}M\varphi$, where M is the bending or twisting moment and φ is the bending or twisting angle in degrees. In a unit volume the elastic energy is equal to half of the product of stresses by the corresponding elongation, for example, in tension it is equal to $\frac{1}{2}\sigma\varepsilon$, where σ is the normal stress, and ε is the relative elongation or contraction. The magnitude of elastic energy and its store (see Elastic Energy Store) are of substance for the timely development of deformation and failure.

Ya.B. Fridman.

ELASTIC ENERGY STORE – elastic energy accumulated in a loading system (for example, in a testing machine). The accumulated elastic energy is, at a specific rate, expended for the process of deformation and destruction. This rate is the higher, the higher the elastic energy store, hence the value of the elastic energy store can have a substantial effect on the rate of plastic deformation and failure and, consequently, on the measured mechanical characteristics. After the plastic deformation is localized (for example, in the neck of a specimen under tension) or the destruction is localized (near the apexes of developing cracks) the main volume of the body being deformed outside the localization zones also becomes an elastic energy source. The elastic energy store for a given load increases: with an increase in the dimensions (volume) of the elastic energy source, for example, upon connecting in series with the volume being loaded a large liquid or gas accumulator; on increasing the specimen's dimensions (i.e., in the presence of the scale factor), with a reduction in the rigidity or increase in the system's compliance, for example, upon changing from a hydraulic to pneumatic pressure of the same magnitude or by connecting springs in series with the specimen. The magnitude of the elastic energy store determines the manner in which the loading force changes with time: the greater the elastic energy store, the slower does the force drop with time (Fig. 1), with the greater overload (as a result of a reduction in the body's resistance in the process of failure) and the more avalanche-like does the failure end. A high elastic energy store is particularly dangerous in bi-axial tension, when the flaw sensitivity is higher than

normal, and the plasticity of certain materials is lower than normal. Many brittle explosion-like failures of large installations are due to the large elastic energy reserves accumulated in the system ("explosions" of pressurized duralumin fuselages of English "Comet" jet air-

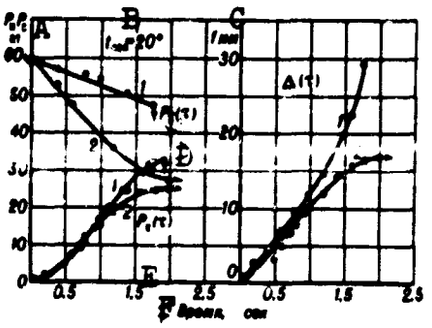


Fig. 1. Effect of the elastic energy store on the kinetics of deformation. Biaxial tension of flat specimen from the AMts alloy (δ = 1 mm). P_{nach} = 60 atm, $P_n(\tau)$ is the change in the external load with time; $P_s(\tau)$ is the change in the specimen's resistance with time; $\Delta(\tau)$ is the change in the specimen's deflection with time; τ is the test time. 1) Elastic energy store of 1540 kgm; 2) elastic energy store of 4.5 kgm (an arrow pointing downward shows that the specimen has failed, a horizontal arrow means that the specimen has not failed). A) $P_n P_s$ atm; B) isp; C) mm; D) n; E) s; F) time, sec.

craft, loaded by the internal pressure, brittle failures of all-welded "Liberty"-type steel ships, brittle failure of steel tanks and large pipelines subjected to internal pressure, brittle failures of jet engine housings, etc.). The degree to which the elastic energy store exerts its effect depends highly on the ability of the material or component to absorb energy (in plastic deformation). Thus, for example, tensile testing under identical initial conditions (with the same starting elastic energy store) has shown that the deformation of a more plastic material develops with time along a damped curve, while that of a less plastic material is more accelerated, up to complete failure. In many cases of tension and flexure the elastic energy store effects the kinetics only after the highest load is reached (Fig. 2), but in certain cases an increase in the elastic energy store results in a perceptible

drop even in the highest breaking load, for example, under the simultaneous effect of tension and torsion when pins are wound onto stacks with different compliance (Fig. 3). In estimating and comparing the ma-

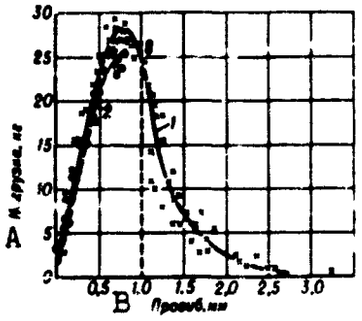


Fig. 2. Deformation diagrams for flexural testing of specimens from the V95 alloy with different compliance (П) of the loading system. 1) П = = 6 mm/ton; 2) П = 31 mm/ton. (The difference in the character of load drop after P_{maks} can be seen.) A) Load, kg; B) deflection, mm.

terials by the ascending branch of the deformation diagram the effect of the elastic energy store on the estimate should be taken into account. To reduce the tendency of designs to avalanche- and explosion-

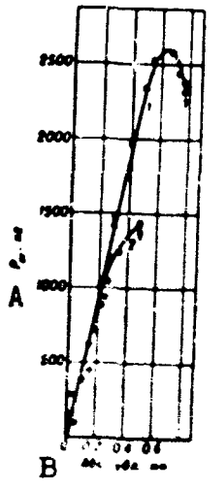


Fig. 3. Deformation diagrams in combined tension and torsion testing of M8 × 1.25 pins from the VT14 alloy by winding onto stacks with different compliance (П). 1) П = 0.06 mm/ton; 2) П = 3.3 mm/ton. (The sharp drop in P_{maks} and absence of a descending section on the diagram with an increase in the stack's compliance can be seen.) A) P_{os}, kg; B) absolute elongation, mm.

like failure it is necessary: to reduce the elastic energy store of the

loading systems by reducing their dimensions and compliance, the degree of compression of contact surfaces, etc.; increase the energy absorption capacity of the material (by creating structures capable of high local energy absorption) as well as of the designs (by introducing shallow and smooth transitions, load relieving grooves, etc.).

References: Zilova, T.K., Petrukhina, N.I. and Fridman, Ya.B., "DAN SSSR" [Proceedings of the Academy of Sciences of the USSR], Vol. 124, No. 6, page 1236, 1959; Shevandin, Ye.M. [et al.], Ibid., Vol. 113, No. 5, page 1057, 1957; Nadai, A., Plastichnost' i razrushenive tverdykh tel [Plasticity and Failure of Solid Bodies]. Translated from English, Moscow, 1954.

Ya.B. Fridman.

Manuscript Page No.	[Transliterated Symbols]
1266	нач = nach = nachal'nyy = initial
1266	н = n = nagruzka = load
1266	с = s = soprotivleniye = resistance
1266	исп = isp = ispytaniye = test
1267	макс = maks = maksimum = maximum
1267	п = p = podatlivost' = compliance
1267	ос = os = osevoy = axial

ELASTICITY – ability of bodies to restore the relative position of points in a body after the effect of external forces has ceased.

ELASTICITY – is the ability of a material or product to withstand without destruction considerable elastic deformations caused by a relatively weak power. The elasticity of an object may be obtained either by the choice of a corresponding material (rubber, for example), where the elasticity is caused by the peculiar molecular structure of the body (see High-elastic deformation), or by special constructions (membranes, springs, etc.). In the first case, great deformations of material are caused by high stress on the material, in the second case – by low stress.

G.M. Bartenev

ELASTICITY OF FIBER – is the ability of a fiber or thread to be restored to its shape after a deformation caused by external conditions. Elasticity depends on the properties of the polymer material and on the design of the object (on the elasticity of its form). Resilient, elastic and plastic deformations occur in fibers under the action of a load; they develop at a different rate, the former two determining the elasticity of the material. The elasticity of the shape of the elementar filaments, depending on the structure of the object, is significant for the elasticity of threads. The value of the elasticity may be expressed by the ratio of the reversible elongation of the specimen to its total elongation (see Elongation of fiber). The elongation, however, depends on the external power acting on the specimen, and the modulus of the deformation (stretching, compression, etc.) expressed by the tangent of the slope of the curve in the load – elongation diagram is, therefore, a more correct characteristic. The determination of the elasticity is difficult in certain products (staple fiber, fiber for artificial fur, etc.). In this case the ability of a fiber tuft to be restored to its volume is determined, and this value is termed volume elasticity. This term is conditional and does not have a physical sense, because the volume of the fibers does not change really and the change of the volume is caused by the change in the elasticity of the form of the discrete elements of the tuft, i.e., it depends on its structure.

V.A. Berestnev

ELASTIC REBOUND METHOD – hardness measurement method on the basis of the elastic rebound of a hammer which falls on a specimen from the specified height. The higher the rebound, the higher the "hardness" which is measured in arbitrary units. For thin specimens the measured hardness increases with an increase in the hardness of the support, which is one of the shortomings of the elastic rebound method. A second shortcoming of the elastic rebound method is the distorting effect of elastic properties (according to this method rubber and glass turn out to be harder than steel), for which reason the elastic rebound method cannot be used for comparing materials with sharply differing moduli of elasticity. The elastic rebound method can be used for comparing various states within the limits of a group of materials with specific values of the modulus of elasticity. See Shore Hardness.

Ya.B. Fridman.

ELBAITE -- see Tourmaline.

ELECTRICAL INSULATING COMPOUNDS – are impregnation or sealing compounds which do not contain volatile solvents and which are used to seal the joints of electrical and radio equipment, to impregnate electrical windings, to seal the junction boxes of cables, etc.

Liquid in the moment of their application, the thermoplastic electrical insulating compounds harden when the melt is cooled, and the thermosetting ones cure owing to the polymerization processes occurring in them. After the impregnation and the sealing of the electrical winding the hardened electrical insulating compound forms an insulating exterior shell, fills the hollows and pores within the winding, and provides a significantly higher degree of imperviousity than an impregnation by means of electrical insulating varnishes (see Electric Insulating Varnish). The products with such a poured (and homogeneous) insulation are highly moisture resistant, and shakeproof have an increased breakdown voltage and a better heat emission. Mineral fillers, usually powdered quartz, are added to the sealing compounds in order to increase the heat conductivity, to reduce the coefficient of the linear thermal expansion, and to improve the mechanical properties. The impregnating electrical insulating compounds, in contrast to the sealing ones, have a reduced viscosity and do not contain fillers.

Thermoplastic electrical insulating compounds are used for objects with a relatively low working temperature (generally not higher than 100°) owing to their tendency to melt. They are prepared by fusing the components together. The following belong to the thermoplastic 1) the bituminous impregnating electrical insulating compound 225 for the im-

Pregnation of the windings of electric motors and devices with working temperatures of not higher than 105°. The softening point (determined by the impression of a ring or ball) is 97-102°, the breakdown voltage is not less than 20 kv/mm and tan δ is not higher than 0.1 at 100°; the compound is not oilproof. The impregnation (compounding) of the windings is carried out in autoclaves at 165-175° in a vacuum or under pressure. 2) the bituminous sealing electrical insulating compounds MB-70 and MB-90 are used to seal both junction boxes of power cables with a voltage up to 3 kv, and terminal boxes of cables with up to 10 kv. The drop point according to Ubbelohde is 70 and 90°, respectively; the breakdown voltage is not less than 35 kv/mm, the frostproofness is from −35° to −45°, it is not standardized; the shrinkage is about 9%. 3) the sealing electrical insulating compound KETs (VTU MEP OAA 504,009-53) is a fusion of ceresin with ethyl cellulose; the frostproofness is −60°. The drop point according to Ubbelohde is not less than 125°; the breakdown voltage is about 20 kv/mm; tan δ is 0.003; ε is 2.8, and ρ_v is not less than 10^{13} ohm·cm after exposition to a relative moisture of 97±2% for 24 hrs; this compound is used to seal coils of devices having a working temperature of up to 80°.

Thermosetting electrical insulating compounds are mixtures of an unsaturated polyester resin which reacts with monomers of the vinyl series, of epoxy resin, curing agents (amines, anhydrides), diisocyanates and hydroxyl-containing components, etc.; plasticizers, fillers, etc., are frequently added to the compound. The fact that low-molecular by-products do not originate, is a characteristic feature of the curing of thermosetting electrical insulating compounds; the resulting polymers are infusible and insoluble. Molds (from metal, plastics, etc.) containing the objects are filled with the sealing electrical insulating compound (usually in a vacuum) in order to obtain a poured insulation; the

polymerization process of the electrical insulating compound also occurs in these molds. The walls of the molds are covered with anti-adhesion separating layers based on silicon organic rubber, polyisobutylene, etc., in order to facilitate the emptying. The thermosetting electrical insulating compounds are used in electric radio engineering and in the design of transformers. To this class of compounds belong: 1) The impregnating electrical insulating polyester compound KGMS-1 (TU MEP OAA.504,010-53), a mixture of a nonsaturated polyester resin and styrene (1:1). A polymer with high insulating properties is formed when an initiator (benzoyl peroxide) is added and the mixture is heated: the breakdown voltage is 20-25 kv/mm at 20° (for specimens with a thickness of 0.8-1 mm); the specific volume resistance is 10^{11} ohm·cm at 120°, and 10^{13} ohm·cm after exposition to a relative moisture of 97±2% for 48 hours; tan δ is 0.02-0.03 and 0.04, respectively, at 20° and 120° and for 50 cps; ε (50 cps) is 3.7-4.5 at 20°. The polymerization of the KGMS-1 is carried out by gradually raising the temperature of the impregnated windings up to 120°, holding at this temperature for 6-12 hours and then cooling slowly. This compound is used for the impregnation of apparatus windings which work under tropical conditions, with working temperatures of up to 120-130°. 2) The impregnating electrical insulating polyester-acrylate compounds KP-10 and KP-18 are used for the impregnation of the windings of electric motors and devices having a permissible long-time working temperature of 130°. These compounds polymerize within 20-30 minutes at 125° and within 5-10 minutes at 150°; they have a high cementing property. The properties of the KP polymers are: breakdown voltage (for 1 mm thick specimens) 23-30 kv/mm at 20°, and 20-25 kv/mm after being immersed in water for 24 hours; specific volume resistance 10^{10}-10^{11} ohm·cm at 100°, and 10^{12} ohm·cm after being immersed in water for 24 hours: tan δ (50 cps) 0.02-0.05 at 20°, and

0.05-0.08 after being immersed in water for 24 hours; ε (50 cps) 3.2-3.7 at 20°. The electrical insulating compounds of the KP type make it possible to use high-speed conveyor lines for the impregnation and drying of electric windings; this process has a performance time of 15-30 minutes (instead of 20-30 hours at the usual method of applying impregnation varnishes). 3) The cold-hardening electrical insulating epoxy compounds are a mixture of the ED-5 epoxy resin (100 parts by weight) and polyethylene polyamine (7-10 parts by weight). A solid polymer is formed within a few hours at room temperature. A mixture of the ED-6 epoxy resin (100 parts by weight), of the unsaturated polyester no. 1 (25 parts by weight) and of maleic anhydride (35 parts by weight) is used for hot-curing; 240 parts by weight of powdered quartz are added for the production of the sealing compound. The electrical insulating compound no. 2, a mixture of the E-37 epoxy resin (100 parts by weight), a fusion of phthalic and maleic anhydrides (40 parts by weight) and powdered quartz (250 parts by weight), is used for the poured insulation of high-voltage at 20° and 38 kv/mm at 100°; specific volume resistance 10^{13} ohm·cm at 120°, and 10^{14} ohm·cm at 20° after being immersed in water for 48 hrs; impact resilience 7-8 kg·cm/cm^2; static bending strength 900-950 kg/cm^2; heat resistance according to Martens 90-100°; tan δ (50 cps) 0.08 at 120°; ε (50 cps) 4.6 at 20°. The electrical insulating epoxy – siliconorganic compound EK-20 is used to impregnate and seal electric windings having working temperatures of up to 200°; it is liquid at 80-100° and becomes cured by phthalic and other anhydrides at 100-200°. The tan δ of the EK-20 remains almost unchanged when the voltage is raised up to 35 kv, and also when the sealing is exposed to tropical moisture for more than 500 hours. The properties of the EK-20 electrical insulating compound (without filler) are: 25-30 kv/mm breakdown voltage at 20°, 9-11 kv/mm at 250°; specific volume re-

sistance 10^{13} ohm·cm at 120°, 10^{8}-10^{9} ohm·cm at 200°, and 10^{14} ohm·cm after being immersed in water for 5 days; tan δ (50 cps) 0.03-0.08 at 130°; ε (50 cps) 3.8-4.2 at 20°; impact resilience 6-10 kg·cm/cm^2; static bending strength 600-800 kg/cm^2; stability under the conditions of tropical moisture; heat resistance according to Martens 60-65°. 4) The impregnating electrical insulating siliconorganic compound K-43 (TU MEP M-312-53) is used for electric windings with a permissible long-time working temperature of 180°. It contains up to 10% volatile substances. The windings are impregnated in a vacuum or under pressure; the polymerization is carried out step by step: 3 hours at 150° and then at 180°, and 18-20 hours at 200°. The tan δ of the polymer is equal to 0.009-0.09 at 180°. 5) The electrical insulating methacrylic compounds MBK (TU GSNKh 10-56-60) are liquids (methacrylic esters) which form transparent polymers at 70-100°; they are resistant to moisture and weathering. They are used to impregnate and seal (with addition of a filler) objects having working temperatures of up to 120°; for electric radio equipment which works under water, and also under considerable vibration loads. The nonplasticized electrical impregnating compound MBK-1 (the plasticized compounds MBK-2 and MBK-3 are more elastic) is the most widely used; its properties are: breakdown voltage (for 1--1.5 mm thick specimens) 20-25 kv/mm at 20°, and 20-23 kv/mm after being immersed in water for 24 hours; specific volume resistance 10^{12} ohm·cm at 100°, and 10^{12}-10^{13} ohm·cm after being immersed in water for 10 days; tan δ (50 cps) 0.05-0.07 at 20°, 0.005 at 100°, and 0.07-0.08 after being immersed in water for 10 days; ε (50 cps) 3.1-3.5 at 20°; impact resilience 14-20 kg·cm/cm^2; ultimate static bending strength (without rupture of the specimens) 100-160 kg/cm^2. 6) The impregnating and sealing electrical insulating polyurethane compounds K-30 and K-31 are mixtures of diisocyanates, castor oil and styrene; they are highly

elastic, frostproof and have only a minimal shrinkage; they are suitable for the sealing of radio units containing electronic tubes; they are sensible to traces of moisture, and toxic in the noncured state; a considerable dependence of the electrical insulating properties (especially of tan δ) on the temperature is characteristic for these polymers; the permissible long-time working temperature is 130° for filled K-30 and K-31, and 120° for the nonfilled; the curing of the polyurethanes is carried out at room temperature within 2-4 days, or at 60-80° within some hours. The properties of K-31 are: breakdown voltage (for 1 mm thick specimens) 29 kv/mm; specific volume resistance 10^{14} ohm·cm at 20°, 10^{11} ohm·cm at 100°, and 10^{14} ohm·cm after being exposed to a relative moisture of 95±3% for 48 hours; tan δ (50 cps) is 0.08 at 20°, and 0.12 at 120°; ε (50 cps) is 4.4 at 20°. Foamed compounds obtained by the introduction of gas-forming substances, porophores, into thermosetting electrical insulating compounds, are also used to fill and seal radio units. The foamed compounds have the properties of foamed plastics, particularly a very low weight by volume, and reduced values of tan δ and ε. The foamed epoxy compound with a weight by volume of 0.08, for example, has a tan δ = 0.006 and ε = 1.5 at 10^6 cps; the values of ε and tan δ rise to 0.03 and 7, respectively, when powdered aluminum is added to the foamed compound.

References: Spravochnik po elektrotekhnicheskim materialam [Handbook on Electroengineering Materials], Vol. 1, Sect. 1, Moscow, 1958; Chernyak K.I., Epoksidnyye kompaundy i ikh primeneniye [Epoxy Compounds and Their Application], Leningrad, 1959.

A.K. Vardenburg

ELECTRICAL-INSULATING GLASS CLOTH – see Electrical-insulating cloth.

ELECTRICAL-INSULATING RUBBER – rubber used in electronics for insulating current-carrying leads and cables, as well as in the manufacture of special gloves and shoes. Rubber of this type is produced from natural rubber and butadiene, butadienstyrene, silicoorganic, and butyl gums. Rubbers manufactured from gums containing polar groups (Cl, CN, etc.) have poor electrical-insulating characteristics. Addition of talc or separated or chemically precipitated chalk to the rubber mixture improves its dielectric properties. Carbon black and mineral fillers containing water-soluble salts cannot be employed in electrical-insulating rubbers. Nonpolar compounds (paraffin, vasoline, wax, special bitumins, etc.) with high dielectric characteristics are used as softeners in such rubbers. Sulfur and tetramethylthiuram disulphide serve as vulcanizing agents for electrical-insulating rubbers based on natural, butadiene, and divinylstyrene gums. Tetramethylthiuram disulphide increases the thermal stability of the rubber, specifically raising the working temperature of current-carrying leads and cables from +55° to +75°. Use of such rubbers does not require preliminary tinning of the copper core. Silicoorganic rubbers are vulcanized with benzoyl peroxide or dicumyl. The dielectric characteristics of electrical-insulating rubbers vary over a wide range, depending on their composition: deep resistance – $1 \cdot 10^{11}$–$1 \cdot 10^{15}$ ohm·cm, tangent of angle of dielectric loss – 0.005–0.01, dielectric permeability – 2.5–4.0, and breakdown strength – 20–35 kv/mm. Rubbers used in the manufacture of leads and cables can be divided into the following basic classes: 1) normal, based on natural, butadiene, and divinylstyrene

gums and used for insulating leads and cables carrying alternating voltages of up to 3 kv. The core working temperature ranges up to 75°; 2) highly thermostable, based on butyl rubber and used for insulating leads and cables carrying voltages of up to 3 kv. The core working temperature reaches 90°; 3) high-voltage, used for insulating leads and cables carrying voltages of more than 3 kv. The core working temperature reaches 65° (for rubbers based on natural, butadiene, and divinylstyrene gums) or 85° (for rubbers based on butyl gum). High-voltage rubber should combine good breakdown-strength indices with a high resistance to ozone cracking, since voltages above 3 kv ionize the air to form ozone, which destroys stressed rubbers of unsaturated gums. Electrical-insulating rubbers based on butyl gum have a high resistance to ozone cracking and are widely employed in the manufacture of high-voltage cables; 4) moisture-resistant, which is used for leads and cables which must function for prolonged periods at a relative humidity of 98%. The electrical characteristics of such rubbers should be little affected by these conditions. The moisture absorption of this type of rubber over 7 days at 70° should not exceed 3.2 mg/cm^2. The core working temperature reaches 65° (for rubbers based on natural gum) or 90° (for rubbers based on butyl gum). Deproteinized natural gum or synthetic gums containing minimal quantities of water-soluble substances are used in moisture-resistant electrical-insulating rubbers; gums with polar groups (Cl, CN, etc.) are not recommended. Talc is the principal filler, while special bitumins, paraffin, and stearic acid are used as softeners; 5) thermostable, which are based on silicoorganic gums and are employed for leads which must function at ambient temperatures of +150° to +200°. The gum most widely used in such rubbers is SKTV-01 (methylvinylpolysiloxane), while aerosol, BS-280, etc. silica gel serves as the filler. Wire and cable with rubber insulation is

manufactured in continuous-vulcanization units, which combine application of the rubber mixture to the current carrier and vulcanization.

P.M. Glupshkin

ELECTRICAL INSULATION FABRIC – is used for making electrical insulation materials (varnished cambric, textolites, micanites, etc.). The greatest bulk of electrical insulation fabrics produced by the textile industry and certain glass fabrics are varnished. The materials thus obtained are called varnished cambric. The varnish coating imparts them their electrical insulation properties. The mechanical properties of these materials are primarily determined by the properties of the fabrics. The thickness is a very important indicator of varnished cambric. It is also primarily determined by the fabric thickness.

Electrical insulation fabrics should have a limited elongation, particularly along the diagonal. In conjunction with this, fabrics which are to be varnished are primarily plain woven.

TABLE 1

Physicomechanical Indicators of Cotton and Silk Electrical Insulation Fabrics

Наименование тканей 1	Артикул 2	Ширина (см) 3	Вес 1 м² (г) 4	Число нитей на 10 см 5	
				основа 6	уток 7
Бязь отбельная	50	112±2	166	275±6	216±6
Перкаль Б-1	4230	89±1,5	65	432±8	500±8
Миткаль отбельный	100	78±1,5	106±5	314±6	272±6
» суровый	1108	106,5±1,5	104±5	278±6	268±6
» отбельный	101	62±1	104±5	311±6	260±6
» суровый	1105	89±1	104±5	279±6	268±6
То же	4150	90±1,5	105±5	277±6	260±6
Широк отбельный	110	75±1,5	109±5	385±8	334±6
То же	111	78,5±1,5	121±5	385±8	334±8
»	112	73,5±1,5	110±5	393±8	334±6
	113	96,0±1,5	111±5	380±8	334±8
Бязь суровая	1115	71±1	154±8	215±5	193±6
То же	1116	89±1,5	154±8	215±5	193±6
	1113	89±1	146±7	247±8	238±6
Бязь гладкокрашеная	26	98±2	162±8	242±6	187±6
Ткань ЭИ	4338	89±1,5	95±5	310±10	310±10
Эпидельскор	1501	74±1,5	22	495	460
Флоретин № 89		89±1	45,5	474±10	290±10
Ткань ЭТ	4243	80±1,5	245±12	200±6	160±6
Капроновое полотно	1530/1516	89±2	47	730±30	400±30
Ткань капроновая эпидельскор для электроизоляции	3360	92±2	75	510	490

1) Fabric designation; 2) type; 3) width (cm); 4) weight of 1 m^2 (g); 5) thread count per 10 cm; 6) warp; 7) weft; 8) minimal tensile strength

концентрациях пыли 20—30 мг/м³ пользовать нерацзонально, т. к. ваются и оказывают бо. ние дыханию. В этих дуется применение шл костюма с подачей чис

На каждом предприя боткой и произ-вом бер нов, должна быть инст преждению загрязнени производственных поме альной защите работак

Все работающие с бе единениями должны п цинским осмотрам не р 6 месяцев.

При соблюдении п предосторожности воз сиональных заболева

Д. М. Бобрищев-П

ТОМПАК — медно содержащие от 88 до 97 мости от содержания ме, от красного (97% Cu) д

of a 50 mm wide strip (kg); 9) thickness of the fabric being produced (mm); 10) GOST or TU; 11) bleached baize; 12) GOST; 13) B-1 percale; 14) bleached calico; 15) unfinished calico; 16) finished calico; 17) same as above; 18) bleached chiffon; 19) unfinished baize; 20) TU; 21) flat-dyed baize; 22) VTU; 23) EI fabric; 24) excelsior; 25) and; 26) No. 99 Florentin; 27) OST; 28) ET fabric; 29) capron cloth; 30) TU MG; 31) excelsior capron fabric for electrical insulation; 32) TUMGSNKh.

Unfinished fabrics which are to be varnished are, as a rule, scoured and finished. In certain cases unfinished, unscoured fabrics are also varnished. The physicomechanical indicators of electrical

TABLE 2

Physicomechanical Indicators of Glass Electrical Insulation Fabrics

Стеклоткани	Толщина ткани (мм)	Ширина ткани (см)	Вес 1 м² (г)	Число нитей на 1 см		Минимальное разрывное усилие полоски шириной 25 мм		ГОСТ, ВТУ
				основа	уток	основа	уток	
1	2	3	4	8	9			7
Э 10	0,06±0,005	60 и 70±1	68±7	20±1	20±1	25	20	ГОСТ 8481-57
То же 13	0,08±0,001	80, 90 и 100±2	100±15	20±1	22±2	30	25	12
»	0,10±0,01	80, 90 и 100±2	105±15	20±1	22±2	30	30	
ЭСТБ-40 14	0,04±0,005	70±2	65 *	20±2	28±3	15	18	
ЭСТБ-Т1	0,027±0,003	70 и 90±2	30 *	36±3	32±3	12	9	ВТУ 215-53
ЭСТБ-Т2	0,025±0,002	70 и 90±2	25 *	32±2	30±2	10	7	
ССЭ-25	0,025±0,003	70, 80 и 90±2		36±3	15±1	10	3	15
ССЭ-40 16	0,04±0,005	70, 80 и 90±2		20±1	10±1	14	5	ВТУ 1521-57
ССЭ-80	0,06±0,005	70, 80 и 90±2		20±1	10±1	19	8	
ССТЭ-6 **		60, 70, 80, 90 и 100	±1190±20	10±1	9±1	110	100	ВТУ 1326-59
ССТЭ-9 **		60, 70, 80, 90 и 100	±1240±20	10±1	9±1	110	100	
17 АСТ1 (б)-СТА		70, 80, 92 и 100±2	310 *	40±1	20±1	220	100	ВТУ МЛП 1381-61
18 АСТТ (б)-С2		70, 80, 92 и 100±2	400 *	24±1	14±1	250	150	
20								19

*Maximum.

**The lubricant content of SSTE-6 and SSTE-9 mesh is not higher than 2.6%, of all other fabrics it is not more than 2.5%.

1) Glass fabrics; 2) fabric thickness (mm); 3) fabric width (cm); 4) weight of 1 m^2 (g); 5) thread count per 1 cm; 6) minimum tensile strength of a 25 mm wide strip; 7) GOST, VTU; 8) warp; 9) weft; 10) E; 11) and; 12) GOST; 13) same as above; 14) ESTB; 15) VTU; 16) SSE; 17) SSTE; 18) AST1 (b)-STA; 19) VTU MLP; 20) ASTT (b)-S2.

insulation fabrics are given in Tables 1 (page 1284) and 2 (page 1285).

References: Spravochnik po elektrotekhnicheskim materialam [Handbook of Electrical Engineering Materials], Vol. 1, Part 1, Moscow-Len-

ingrad, 1958; Ukazatel' gosudarstvennykh standartov [Index of State Standards], Moscow, 1964.

Manuscript Page No.	[Transliterated Symbols]
1284	ГОСТ = GOST = Gosudarstvennyy obshechesoyuznyy standart = = All-Union State Standard
1284	ВТУ = VTU = Obshchesoyuznyye tekhnicheskiye usloviya = All-Union Technical Specifications
1284	ОСТ = OST = Obshchesoyuznyy standart = All-Union Standard
1284	ТУМГСНХ = TUMGSNKh = Tekhnicheskiye usloviya Moskovskogo gorodskogo Sovnarkhoza = Technical Specifications of the Moscow Municipal Sovnarkhoz
1284	ЭИ = EI = elektroizolyatsionnaya = electrical insulation
1284	ЭТ = ET = elektrotekhnicheskaya = electrical engineering
1285	Э = E = elektricheskaya = electrical
1285	ВТУ МЛП = Vsesoyuznyye tekhnicheskiye uloviya Ministerstva lekgoy promyshlennosti = All-Union Technical Specifications of the Ministry of Light Industry

ELECTRICALLY-CONDUCTIVE RUBBER – rubber used principally in electronics, for manufacturing shielded mine cables, high-voltage excavator and other cables carrying voltages of 6 kv or more, long-distance cables, etc. Electrically conductive rubbers are produced from natural, butadienenitrile, and polychloroprene gums; those based on butadienenitrile gum containing nc less than 26% acrylic nitrile have the highest electrical conductivity. Rubbers are made conductive by adding the requisite quantity of carbon black (principally acetylene carbon black) and graphite. The ratio of carbon black to graphite depends on the type of gum used. The gum content of electrically conductive rubbers varies from 30 to 35%. The character and quantity of the filler has a large influence on the conductivity of a rubber; addition of substances with polar groups makes it possible to obtain a rubber with high conductivity. In mine cables for blasting and drilling equipment electrically-conductive rubber is used as shielding for transmitting current pulses to special shut-off devices. Such rubber shielding is located in such fashion that a current pulse passes through it and cuts the cable off from the line before a short circuit develops in the basic conductors, which carry voltages of 127-660 v. The deep resistance of electrically-conductive rubbers for mine cables should not exceed $1 \cdot 10^2$ ohm·cm. In high-voltage cables screens of electrically conductive rubber serve to reduce the electric-field nonuniformity caused by the multiconductor core, to reduce the maximum voltage gradient, and to shut the air layers between the core and the insulation, in order to prevent ionization of the air. The deep resistance of such

rubbers for high-voltage cables should not exceed $1 \cdot 10^4$ ohm·cm. In long-distance cables screens of electrically-conductive rubber reduce the influence of external electrical interference on the functioning of the cable, and, in combination with other elements, make it possible to obtain the requisite kilometric attenuation. In this case the conductivity of the rubber is evaluated from its skin resistance, which should be between $1 \cdot 10^2$ and $1.5 \cdot 10^3$ ohm. Electrically-conductive rubbers are also used for certain radio components, dry batteries, etc.

P.M. Glupshkin

ELECTRIC CAST STEEL – is a nonalloyed special steel used in the cast parts of electric engines which must have a high magnetic permeability and a low watt loss. The chemical composition of electric cast steel is quoted in Table 1.

The typical mechanical properties of electric cast steel are quoted in Table 2.

According to the technical conditions AMTU 432-58, the tensile strength of 10L steel after tempering at 900-930° must not be less than 25 kg/mm^2, and the relative elongation not less than 15%. The mechanical properties of the castings are tested on specimens cut out from separately casted blansk, thermally treated together with the castings. Fig. 1 shows the effect of the carbon content on the mechanical properties of electric cast steel.

TABLE 1

Chemical Composition of Electric Cast Steel

Сталь	Технические условия	Содержание элементов (%)							
		C	Si	Mn	S	P	Cr	Ni	Cu
					не более				
10Л	АМТУ 432-58	0,07–0,15	0,17–0,37	0,35–0,65	0,04	0,045	0,15	0,30	0,30

1) Steel; 2) technical specifications; 3) percentage of elements; 4) not more than; 5) 10L; 6) AMTU.

TABLE 2

Mechanical Properties of Electric Cast Steel

Сталь	Термообработка	σ_b (кг/мм^2)	$\sigma_{0,2}$ (кг/мм^2)	δ_5 (%)	$a_н$ (кгм/см^2)	HB (кг/мм^2)
10Л	Отжиг при 930°	30–35	17–19	18–20	8,0	100–110
10Л	Отжиг при 900–900°	35–40	20–25	20–30	—	100

1) Steel; 2) heat treatment; 3) kg/mm^2; 4) kgm/cm^2; 5) 10L; 6) tempered at.

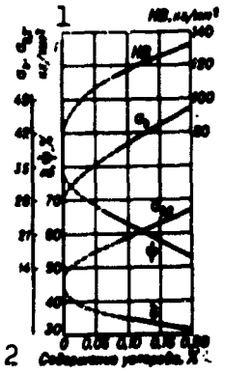


Fig. 1. Effect of the carbon content on the mechanical properties of electric cast steel. 1) kg/mm^2; 2) percentage of carbon.

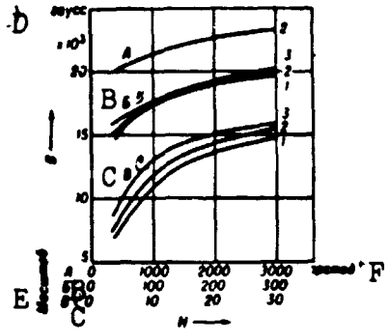


Fig. 2. Magnetic properties of cast and forged 10L steel: 1) Forged piece of the pole of a large electric engine; 2) cast frame of an electric engine; 3) steel with 0.2% C. A) A; B) B; C) C; D) gauss; E) scale; F) oersted.

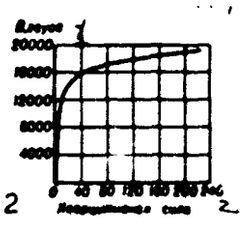


Fig. 3. Magnetization curve of steel castings (steel with 0.12% C; 0.2% Si, and 0.4% Mn). 1) gauss; 2) coercive force.

The physical properties are: γ = 7.85 g/cm^3; α = 10.6$\cdot$10^{-6} (20-100°); 13.6$\cdot$10^{-6} (20-400°); 14.5$\cdot$10^{-6} (20-600°); 15.0$\cdot$10^{-6} (20-700°) 1/°C; λ = 0.185 (100°); 0.10 (500°) cal/cm$\cdot$sec$\cdot$°C; ρ = 11 (20°) ohm$\cdot$mm^2/m; B = 14,500 gauss at 25 ampere turns, and 17,000 gauss at 100 ampere turns. The magnetic properties are measured by the ballistic

method on a ring-shaped specimen cut out from the middle part of a cylindrical casting (the outer and inner diameter of the ring correspond to the dimensions of the finished part, and the height is 10 mm). The magnetic properties of the cast and forged 10L steel is a tempered state are shown in Figs. 2 and 3. The founding of electric cast steel is, as a rule, carried out in high-frequency furnaces. The casting is carried out into ceramic sand molds and into dispensable patterns. The pouring in is carried out at high temperatures and with enlarged casting conduits due to the insufficient flowability. An additional deoxidation of the metal is achieved by aluminum. The free casting shrinkage is 2.0-2.2%. The steel is excellently weldable. The welding up of casting defects is carried out by arc welding.

The steel is used for the following: electric eninge bodies, frames, plates, flanges, boxes for electric devices and apparatuses, various low-loaded parts which must have a high plasticity, and parts which must be cemented.

References: Zaymovskiy, A.S. and Chudnovskaya, L.A., Magnitnyye materialy [Magnetic Materials], [3rd Edition], Moscow-Leningrad, 1957 (Metally i splavy v elektrotekhnike [Metals and Alloys in Electric Engineering], Vol. 1; Akimov, G.V. and Akimova, K.I., Yedinaya spetsifikatsiya metallicheskikh materialov mashinostroyeniya Soyuza SSR [Unitary Specification of Metal Materials for the Machine Building in USSR], parts 1-2, Moscow-Leningrad, 1945; Steel Casting Handbook, 1950, Cleveland, 1950.

N.M. Tuchkevich

ELECTRIC INSULATING ENAMELS – are colored suspensions of pigments and fillers in a binder, and are used in the application of electric insulating coatings on various joints and parts of electric machines, apparatuses, radioelectronic devices, and other electrical and radio engineering equipment. They serve to protect the insulation against the effects of moisture, dust, lubricants, and, in a number of cases, of solvents and chemical reagents.

Varnishes based on various synthetic resins are used as a binder (the film-forming agent) for the following electric insulating enamels: nitroglyphthal, glyphthal resins, modified by oil, melaminoalkyd, epoxy, organosilicon and other resins. Titanium dioxide, lithopone, chromium oxide, azure pigment, phthalocyanine pigment, etc., are used as pigments.

The chemical nature of the film-forming agent determines the class of heat-proofness (the working temperature) of the electric insulating enamels. According to the type of drying, hot and cold drying electric insulating enamels are distinguished. The field of application of the electric insulating enamels depends on the electrical and mechanical properties of the obtained coatings, the class of heatproofness of the electric insulating enamel, and the permissible drying temperature (see the Table).

The coatings of cold drying electric insulating enamels possess lower electrical and mechanical characteristics and a lower moisture-proofness than those of hot-drying electric insulating enamels. The cold drying electric insulating enamels therefore are used mainly for

repair or in such cases when the drying of the parts at high temperature cannot be carried out.

Characteristics and Main Fields of Application of Electric Insulating Enamels

Вид эмали 1	Марка 2	Цвет 3	Рабочая температура (°С) 4	Температура сушки (°С) 5	6 Область применения
7 Нитроглифталевые	№ 1201	Красно-коричневый 8	105	18—20	Покрытие деталей электрич. машин и аппаратов, где требуется воздушная сушка и маслостойкое покрытие 9
Глифталевые, модифицированные маслами 10	ГФ-92ГС 11	Серый 12	130	100—110	Покрытие обмоток и деталей электрич. машин и аппаратов 13
	14 ГФ-92ХС	Серый 12	130	18—20	Покрытие неподвижных обмоток, деталей и узлов электрич. машин и аппаратов, где требуется воздушная сушка; окончательная отделка и ремонт электрических машин 17
	15 ГФ-92ХК	Красный 16 1	130	18—20	
	18 ЭКР-1 Красный 19 ЭКР-2 Оранжевый ЭКР-3 20 Желтый ЭКР-4 Зеленый 21 ЭКР-5 22 Голубой ЭКР-6 Синий 23 ЭКР-7 12 Серый ЭКР-50 Темно-голубой 24		130	135—140	Покрытие и маркировка керамич. конденсаторов 25
	№ 52	Зеленый 21	130	165—155	Покрытие постоянных непроволочных сопротивлений и окраска селеновых выпрямителей 26
Меламино-алкидные 27	У-116 28	Серый 12	130	165—130	Покрытие обмоток трансформаторов и окраска трансформаторных бачков 29
Алкидно-кремний-органические 30	ГК-1 31	Красный 16	155	165—155	Покрытие малогабаритных сопротивлений 32
Эпоксидные	ЭП-91 34	Зеленый 21	155	180—180	Покрытие обмоток и деталей электрич. машин, радиотехнич. изделий и постоянных непроволочных сопротивлений 35
	ЭП-92	Зеленый	155	180—180	
Кремний-органические	ПКЭ-11 38 ПКЭ-19 ПКЭ-22 37	Розовый Розовый Красно-коричневый 8	180 180 180	180—200 120—200 120—200	Покрытие обмоток и деталей электрич. машин и аппаратов и радиотехнич. изделий 39
	КО-911 40	Розовый 38 Красно-коричневый 8	180 180	18—20 18—20	Покрытие обмоток и деталей электрич. машин и аппаратов, где требуется воздушная сушка; окончательная отделка и ремонт электрических машин 41

1) Type of the enamel; 2) grade; 3) color; 4) working temperature; 5) drying temperature; 6) field of application; 7) nitroglyphthal; 8) reddish-brown; 9) coating of parts of electric machines and apparatuses when drying in air and oil-resistant coating are demanded; 10) glyphthal, modified by oil; 11) GF-92GS; 12) gray; 13) coating of windings and parts of electric machines and apparatuses; 14) GF-92KhS; 16) red; 17) coating of stationary windings and parts of electric machines and apparatuses; 18) EKR-..; 19) orange; 20) yellow; 21) green; 22) azure; 23) blue; 24) dark-blue; 25) coating and marking of ceramic capacitors; 26) coating of constant metallized resistors and coloring of

selenium rectifiers; 27) melamide-alkyd; 28) U-416; 29) coating of transformer windings and coloring of transformer tanks; 30) alkyd-organosilicon; 31) TK-3; 32) coating of small-size resistors; 33) epoxy; 34) EP-..; 35) coating of windings and parts of electric machines, of radio engineering and constant metallized resistors; 36) organosilicon; 37) PKE-..; 38) pink; 39) coating of windings and parts of electric machines and apparatuses, and of radio engineering pieces; 40) KO-911; 41) coating of windings and parts of electric machines and apparatuses when drying in air is demanded; finishing and repair of electric machines.

The electric characteristics of the films on electric insulating enamels are lower than those of the corresponding but not-pigmented varnish films (of the film-forming agents). The purity and the degree of dispersion of the pigments and fillers effect strongly the values of the electric characteristics. The electric strength E_{pr} of hot-drying electric insulating enamel is 50-80 kv/mm, it drops by 1.2-1.8 times at working temperature, and by 1.5-2.0 times after the effect of a 95-98% relative humidity for 24 hours. The E_{pr} of cold-drying electric insulating enamels (glyphthal GF-92KhS, GF-92KhK, organosilicon KO-911) drops by 2-2.5 times at working temperature; it drops down to 15-25 kv/mm after being kept in a moist medium for 24 hours. The heating of the coating during the working of the machine or device improves the following characteristics: they reach values which are typical for hot-drying electric insulating enamels. The specific volume resistance ρ_v of a hot-drying electric insulating enamel is 10^{14}-10^{15} ohm·cm. The value of ρ_v drops at higher temperatures in the highest degree in the cast of glyphthal and epoxy electric insulating enamels, and, in a significantly lower degree, in organosilicon enamels (Fig. 1). The properties of organosilicon electric insulating enamels possess also the highest stability during moistening. The values of ρ_v are also poorly changed by the effect of a moist medium in the case of epoxy resins (Fig. 2). The epoxy electric insulating enamels (EP-91 and EP-92) and

the organosilicon enamels (PKE-14, PKE-19, and PKE-22) form electric insulating coatings stable under the conditions of a tropical climate, due to their resistance to mold. The angle of losses (tan δ) at a frequency of 50 cps is 0.01-0.02 for organosilicon enamels, and 0.02-0.05 for epoxy and glyphthal enamels.

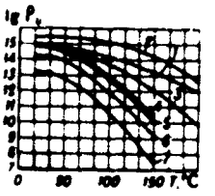


Fig. 1. ρ_v of various grades of electric insulating enamels as a function of the temperature: 1) PKE-14; 2) PKE-19; 3) KO-911; 4) U-416; 5) EP-91; 6) GF-92GS; 7) GF-92KhS.

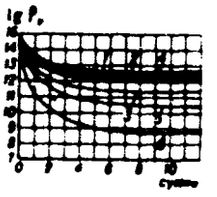


Fig. 2. ρ_v of various grades of electric insulating enamels as a function of the action time of a medium with 95 ± 2% relative moisture. 1) PKE-14; 2) PKE-19; 3) KO-911; 4) EP-91; 5) GF-92GS; 6) GF-92KhS. A) Days.

The epoxy electric insulating enamels possess the highest mechanical properties. The hardness of the film measured by the pendulum device is 0.8-0.95 for epoxy enamels; 0.5-0.8 for hot-drying glyphthal enamels (GF-92GS, EKR, No. 52); 0.4-0.7 for melamine-alkyd enamels (U-416); 0.7-0.8 for organosilicon enamels (PKE-19, PKE-22) and 0.5-0.6 for PKE-14. The film hardness drops at increased (working) temperatures by 1.5-2.0 times for organosilicon enamels, and to a lower degree for the other enamels. The film of cold-drying electric insulating enamels has a lower strength, equal to 0.15-0.25; the strength increases after heating and reaches that of hot-drying electric insulating enam-

els. The epoxy and glyphthal electric insulating enamels have a higher adhesion than the other enamels. The organosilicon electric insulating enamels possess a lower adhesion to metals as well as to many electric insulating materials. Electric insulating enamels resist mineral oils and lubricants. The nitroglyphthal enamel No. 1201 and the melamide-alky enamel U-416 have the highest oil-proofness. These enamels are also resistant to gasoline. The oil-proofness and especially the gasoline-resistance of organosilicon electric insulating enamels are lower than that of other electric insulating enamels.

Electric insulating enamels are applied on joints and parts of electric machines and apparatuses which have been previously impregnated by electric insulating varnishes, or are applied immediately on the parts to be insulated, in most cases without a previous priming of the surface. The application is carried out by dipping, brushing or by paint-spraying. The latter method gives an uniform coating without dripping and is, therefore, the most widespread one. In order to obtain a high-quality coating, the electric insulating enamels are laid on in several thin layers; the total thickness of the coatings must not surpass 50-70 microns. The quality of the coating is affected essentially by the drying conditions. An intensified drying within the limits permissible for the given type of the electric insulating enamel, promotes an increase of the electrical and mechanical characteristics of the coatings.

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ya v mashinostroyenii [Special Paint-and-Varnish Coatings in Machine Building], Moscow-Leningrad, 1959.

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Manuscript Page No.

[Transliterated Symbols]

1294 пр = pr = prochnost' = strength

ELECTRIC INSULATING FILM MATERIALS – are thin and flexible materials delivered usually in rolls, and manufactured from high-polymer compounds (cellulose esters or synthetic resins). The electric insulating film materials possess a high electric strength at a small thickness; this fact allows the engineering characteristics of electric equipment to be improved reducing, at the same time, the total thickness of the insulation.

The following films are widely used in electric-insulation engineering.

Triacetate films, possess high electric insulating properties, good moisture-proofness, sufficient tensile strength, but also a low rupture strength and a small breaking elongation. With regard to the heat-proofness, they belong to class A (105°). Weakly plasticized triacetate films with a thickness of 0.07 and 0.04 mm are manufactured. They are used mainly in slot insulation of electric engines with a random film-board winding. A plasticized film with a thickness of 0.025 mm is also obtainable; it is used for the insulation of wirings and of windings with a rectangular cross section in the coils of asynchronous electric engines with a power higher than 100 kw.

Acetobutyrate films possess properties similar to those of triacetate films; but they possess a somewhat higher elasticity and a somewhat lower electric strength and heat-proofness; they are used generally for the same purposes.

Polyethylene-terephthalate films, are known as Lavsan (in USSR), Melinex (Great-Britain), Mylar (U.S.), and Hostaphan (GFR); they are

of great promise to electrical machine building due mainly to their high mechanical strength including the tear resistance. With regard to the heat-proofness, they belong to class E (120°); possessing high electric insulating properties, good moisture-proofness, high resistance to chemicals and solvents, they are used in the slot and interphase insulation of cables, transformers, tapping and winding wirings, for the bandage of various coils, as an insulation in capacitor building (also in a metallized form), in the preparation of magnetic tapes (for sound recording), and of high-strength adhesive tapes; they resist freons and petroleum oils and are used in the built-in electric motors of refrigerators; due to the high tensile and tear strengths, they are used in the insulation of high-speed cables and wirings; combined with paper, electric cardboard, and glass fabric (in the insulation of nautical engines) and other underlayers, they are used for slot insulation. In the USSR, they are obtainable with a thickness of 0.004-0.02 mm, mainly for capacitor building. The Mylar in the US is manufactured with a thickness of 0.006 0.02 mm.

Polycarbonate films possess good mechanical properties including tear resistance in transversal direction, and high electric insulating properties; with regard to the heatproofness, they belong to class B (130°); they are manufactured in a nonoriented and in a longitudinally oriented form with a thickness of 0.02-0.2 mm; the thickness may be reduced to 0.1 mm by drawing; they resist aliphatic hydrocarbons, alcohols, petroleum and vegetable oils; they swell strongly or dissolve totally in most of the solvents. The main fields of application are as follows: capacitor building, insulation of conductors, slot insulation of electric machines; gaskets in machine coils, transformer windings, etc.

Polyethylene films are used in the body and interphase insulation

of capacitor coils, dry transformers, and also for the repair of windings; they provide a high electric strength for the winding insulation without application of varnish impregnation, a reliable protection against dust and moisture, and a good resistance to overloads.

Polyamide films possess a higher mechanical strength, but poorer electric insulating properties than all other electric insulating film materials. These properties become rapidly reduced by higher temperatures and by moistening. Polyamide films are used to a lesser degree in electric insulating engineering, mainly in the insulation of the slots of asynchronous motors and in fastening the outlet of the slot.

Polystyrene films possess high electric insulating properties especially in the high-frequency range; the working temperature does not exceed 70°; the main usage is in capacitor building and in the manufacture of high-frequency cables (including television cables).

Ftoroplast films possess a high heat-proofness, frost-proofness, and an extremely high proofness to moisture and chemicals. Polytetrafluoroethylene films, manufactured in the USSR as Ftoroplast-4 (termed Teflon and Fluone abroad) are widespreadly used. Ftoroplast-4 films are manufactured in a nonoriented form and also with a various degree of orientation. The oriented film has a higher mechanical strength in the direction of orientation, and also a strongly increased electric strength. The oriented film is used in the insulation of cables and capacitor windings; the film shrinks after heating, and the cover becomes tightened in this way. Nonoriented film must be used for slot insulation. The films are obtainable with a thickness of 0.01-0.2 mm; the working temperature reaches up to 250°. Cold flow, a rapid drop of the electric strength under a prolonged action of voltage, and the necessity of a special treatment for bonding, are the disadvantages of the polytetrafluoroethylene films.

Films of Ftoroplast-3 (Kel-F, Fluorothene, Hosteflon) are similar to the Ftoroplast-4 films with regard to the resistance to moisture and chemicals, but they show higher dielectric losses and they have a considerably lower heat-proofness (class B). These films are developed from a copolymer of tetrafluoroethylene with hexafluoropropylene; they are obtained with a thickness of 0.013 mm and more, and are destined for working at temperatures up to 200-250°; they differ from the polytetrafluoroethylene films by the absence of pores and by the possibility to be bonded by the usual adhesives. A film resistant to atmospherical effects and chemicals is also developed from polyvinyl fluoride.

Physicomechanical and Electric Characteristics of Electric Insulating Films (with a thickness of 0.02-0.07 mm)

1 Свойства	2 Пленки						
	3 ацетобутиратная	4 триацетатная	полиэтилентерефталатная 5	поликарбонатная 6	7 полиэтиленовая	полистирольная 8	политетрафторэтиленовая 9
10 Плотность (г/см³)	1,23—1,24	1,26—1,27	1,4	1,25	0,92	1,05	2,1—2,3
11 Временное сопротивление разрыву (кг/см²)	7—8	9—11	16—18	8—9	1,3—3,0	4—7,5	3—10
12 Удлинение при разрыве (%)	20—40	20—30	70—110	100—120	до 500	2—4	40—400 *
13 Электрич. прочность (кв/мм)	120—140	90—120	160—180	120—140	100—130	160—180	40—120 *
14 Удельное объемное сопротивление (ом·см)	10^{13}—10^{14}	10^{13}—10^{14}	10^{15}—10^{16}	10^{15}—10^{16}	10^{15}	10^{16}	10^{16}
15 tg δ при 50 гц	0,02—0,03	0,02—0,03	0,003—0,006	0,003—0,004	0,0002—0,0005	0,0002—0,0004	0,0002—0,0004
16 Диэлектрич. проницаемость	3,5—4,5	3,5—4	3,0—3,2	3,0—3,2	2,2—2,3	2,5—3,0	1,8—2,1

*Depending on the orientation of the film.

1) Properties; 2) films; 3) acetobutyrate; 4) triacetate; 5) polyethyleneterephthalate; 6) polycarbonate; 7) polyethylene; 8) polystyrene; 9) polytetrafluoroethylene; 10) density (g/cm^3); 11) temporal tensile strength (kg/cm^2); 12) breaking elongation (%); 13) electric strength (kv/mm); 14) specific resistivity (ohm•cm); 15) tan δ at 50 cps; 16) dielectric constant.

The common disadvantage to all film materials described above is the low corona-proofness which limits their use to high-voltage engineering.

The main characteristics for the judgment of the quality of electric insulating film materials are as follows: the shrinkage at higher

temperatures, the weight loss after heating, the hygroscopicity, the permeability of water vapor, the tensile and tear strengths in the initial state and after heating for a certain time (usually to a temperature by 20° higher than that of the heat-proofness class), the breaking of elongation, and the number of double bendings under the same conditions, the electric strength, the specific volume resistance, the dielectric losses, the dielectric constant in initial state, at higher temperatures (usually at the temperature of the heat-proofness class), and after moistening.

A number of characteristics of electric insulation film materials is quoted in the Table.

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ELECTRIC INSULATING FLUIDS – see Dielectrics.

ELECTRIC INSULATING MICA MATERIALS – are materials containing mica or its compositions with resins, fibrous materials, glass, etc. Mica of the Muscovite and Phlogopite type is used in electric-insulating engineering. Depending on its purpose, mica is divided into flake mica (for the production of micanites), capacitor mica (for parts of electron tubes, cut and stamped objects, washers, discs, gaskets, etc.), and ground mica (used as a filler in plastics and rubbers). Flake mica (GOST 3028-57) is thin lamellae with an arbitcontour. The flake mica is subdivided into 9 groups according to the size, and into 3 grades according to the quality of the surface, the quantity of mineral inclusions, and the content of impurities. Capacitor mica is used as a general dielectric and as a protection for membranes; it is manufactured in the form of cut or stamped plates with a rectangular shape, a fixed dimension, and is subdivided into 5 grades according to the thickness: standard mica (SO), filter mica (SF), low-frequency mica (SHCh), high-frequency mica (SVCh), and protective mica (SZ, muscovite and hard phlogopite grades). Mica parts are used in electron tubes for the insulation and the fastening of internal equipment; they are made up only of muscovite due to its high elasticity, mechanical strength and because moisture and gases may be easily removed from it. Muscovite is also used as a gasket in guillotine-shaped coils, as mica membranes for transformers and brush holders. Moreover, artificial mica is used which is prepared by crystal growing in a molten charge. Mica products, compositions of flake mica with organic resins and varnishes, and also with paper or fabric interlayers are widely used in electric-insulating

engineering. Such materials provide an insulation of electrical machines and devices of the A and B classes up to a maximum temperature of 130°. Insulating materials composed of mica and glass fabric, glassply, glass net, alkaliless glass, polyorganosiloxane resins and varnishes are used in the insulation of electric machines of the classes F and H at working temperatures of 155° and 180°.

Electric-insulating mica materials. Commutator micanite (grades KF and KF-1, GOST 2196-60) – is a pressed material, assorted according to the thickness, composed of lamellar phlogopite and bonded by shellac or glyphthal resin. It is used as an interlamellar insujation in commutators of electrical d-c machines. The binding content is 4%; the mean electric strength is not less than 18 kv/mm. Heat-resistant commutator micanite is prepared from phlogopite bonded by diammonium phosphate as a binder. Packing micanite of various grades (GOST 6121-60) is a hard pressed sheet material composed of lamellar muscovite or phlogopite or of their mixture, and bonded by shellac, glyphthal or other resins or varnishes. It is used for electric insulating washers, gaskets, and other plane parts in the building of electric machines and devices. The binder content is 5-25%; the mean electric strength is not less than 20 kv/mm; the specific volume resistance is not less than 10^{13} ohm·cm. Heat-resistant packing micanite is obtained by bonding lamellar phlogopite by a polyorganosiloxane compound and following pressure under heating. It is used electrical machines and apparatuses which must be heat-resistant. Pressed molding micanite of various grades (GOST 6122-60) is a sheet material obtained by the bonding of muscovite or phlogopite by a binding compound and following pressure under heat. Due to the nature of the binder (glyphthal resins or varnishes, shellac), complexly fashioned objects which maintain the given shape after cooling may be formed by heating and pressing. It is used

for the manufacture of commutator cones, flanges, frames, cases of turbogenerator rotors, pipes, cylinders, and other objects of this type. The binding content is 8-14% and 14-20%; the mean electric strength is not less than 27-33 kv/mm; the specific volume resistance is 10^{13} ohm•cm. The heat-resistant modification of pressed molding micanite is obtained by bonding lamellar phlogopite or muscovite by polyorganosiloxane varnish K-40. Flexbile micanite of various grades (GOST 6120-61) is a sheet material prepared from muscovite or phlogopite bonded by a binding material (oil-glyphthal or oil-bitumen varnishes), without papers or with a thin paper which covers both sides of the mica. It is used as a packing for the insulation of slots, coils, etc. The binding content is 10-25%; the mean electric strength is 15-25 kv/mm; the specific volume resistance is 10^{13} ohm•cm. Specific flexible micanite (GOST 8727-58) is a sheet material containing phlogopite bonded by EF-5 polyorganosiloxane varnish or by 1159 oil-glyphthal varnish and glued around it by alkaliless glass fabric or glass gauze. It is used for heat-resistant electric machines and aoparatuses. Mica-foil of various grades (GOST 3686-37) is a material manufacture in rolls or sheets, containing one or sheets, containing one or more layers of lamellar mica bonded by an adhesive, and covered with paper on one side. The material becomes soft when heated and may be formed to objects, maintaining the shape after cooling. It is used to manufacture insulation parts (pipes, cylinders, sleeves, etc.) and also to insulate current-carrying parts of electrical machines. The binding content is 12-30%; the mean electric strength is 13-16 kv/mm. Heat-resistant glass mica-foil is composed of one or more layers of lamellar mica (muscovite or phlogopite) bonded by polyorganosiloxane varnish and glass fabric which cover one side of the mica. Mica-tape (GOST 4268-48) is a material composed of lamellar muscovite or phlogopite bonded by varnish, and paper which

covers both sides of the mica; it possesses a high flexibility in a cold state and, in a wet state, a considerable tensile strength in the longitudinal direction. It is used as an insulating material for coils and frames of electric machines. The binding content is 15-30%, the mean electric strength not less than 14-20 kv/mm; the tensile strength not less than 1.8-3.0 kg/mm^2. Mica-silk (grades LChMShB, LChFChB, LSMShB, and LSFChB) is thin material flexible in cold state, composed of one layer of lamellar muscovite or phlogopite bonded on the one side with silk, on the other with paper by means of oil-bitumen or oil-glypthal varnish. It is used to insulate windings and other parts of electric machines. The binder content is 20-32%; the mean electric strength is 12-13 kv/mm. Mica-linen is a material flexible a in cold state, containing one or more muscovite or phlogopite layers bonded on the one or on both sides by an adhesive with a corresponding underlayer. Heat-resistant glass mica-tape is composed of one phlogopite layer bonded by polyorganosiloxane varnish EF-5 with glass fabric on the one side or on both sides. Glass-ply mica-tape is composed of one layer of lamellar phlogopite bonded by means of polyorganosiloxane varnish with glass fabric on the one side and with glass-ply on the other side.

Electric insulating micaite materials are obtained of muscovite tailings heated to about 800° and losing by this way 50% of the crystal water. Further, the mica is quickly immersed into a soda solution. The mica crystals become loosened and delaminated; this process is intensified by treatment with sulfuric or hydrochloric acid. A pulp results which is formed on paper-making machines to mica-paper with or without a small (1-3%) content of latex or epoxy resin as a binder. Using various binder and under-layer materials, mica paper is made of micaite materials which successfully substitute the materials prepared from lamellar mica by gluing. Micaite materials are manufactured in the

USSR by treatment of mica with hot soda and acid or also by thermohydraulic treatment and pouring on a special paper-making machine by means of binding compounds. The micaite materials surpass the corresponding micanites by a more uniform thickness; the flexible and formable glass-micaite materials may be formed to objects with a complex shape and a small curvature radii. The micaites, however, are considerably inferior to micanites with regard to mechanical strength and moisture-proofness. The following micaite materials are obtainable: Commutator micaite (grades KS-1, KS), a sheet material prepared from micaite board or paper, impregnated with electric insulating varnishes and pressed then under heating. It is used as an interlamellar insulation in commutators of d-c electric machines. The binder content is 8-10%; the mean electric strength is not less than 20 kv/mm. Packing micaite (grades PSK, PSG, PSSh, and PSE) is a sheet material prepared from micaite board or paper impregnated with electric varnishes and then pressed under heating. It is used for electric insulating washers, frames and gaskets in electric machines and apparatuses. The binder content is 8-15%, the breakdown voltage (for 1 mm thick specimens) is 20 kv. Formable micaite of various grades is a solid material composed of micaite paper bonded by an adhesive, with or without an underlayer which covers the micaite paper on the one or on both sides; the material is formable by heating and pressing into complexly shaped objects which maintain their shape after cooling. It is used for the manufacture of pipes, cylinders and other shaped objects. The binder content is 15-35%, the mean electric strength is 30-40 kv/mm. Heat-resistant formable glass-micaite is a sheet material manufactured from alkaliless glass fabric bonded with micaite paper by polyorganosiloxane varnish K-40 and pressed under heating. It is used in heat-resistant electric machines and apparatuses. The mean electric strength is 25 kv/mm;

the specific volume resistance is 10^{13} ohm·cm. Flexible micaite for slot insulation (grades GO-P, GTO-P) is a sheet material manufactured from micaite paper joined together with an underlayer of mica-type paper, bonded by a binder and treated by heating and pressing. It is used as a slot insujator in low-voltage electric machines of the usual design, working at temperatures of up to 130°. The binder content is 20-40%; the mean electric strength is 16-25 kv/mm. Flexible micaite for winding insulation (grades GSO-V, GO-V, GChO-V) is a sheet material prepared from micaite paper joined together with a mica-tape underlayer, bonded by a binder, following pressure under heat. It is used as a turn-to-turn insulator and as a gasket in normal electric machines which work a long time at 130°. The binder content is 20-40%; the mean electric strength is 15 kv/mm. Flexible and heat-resistant glass micaite is a sheet material prepared from alkaliless glass fabric bonded with micaite paper by thepolyorganosiloxane varnish K-56 and by following hot pressing. The mean electric strength is 20 kv/mm; the specific volume resistance is 10^{13} ohm·cm. Flexible glass micaite (grade GSK) is a sheet material manufactured from one or more layers of micaite paper and bonded on one or both sides with glass fabric or glass gauze by means of polyorganosiloxane varnish. It is used as an insulator in heat-resistant electric machines of the B and F classes. The binder content is 20-40%, the mean breakdown voltage is 12.5 kv for 0.5 mm thick specimens. Micaite tape (grades L_2SCh, L_2SS, $L_1SK_1L_2$), a material flexible in a cold state is composed of micaite paper impregnated with an electric insulating varnish and bonded on one or both sides with mica-tape paper or glass fabric. It is used to insulate the windings and framers of electric machines, partially substituting the mica-tape. The binder content is 20-40%; the mean breakdown voltage is 1.5-2.5 kv.

III-4e6

Mica-plast, a new mica material, developed in the USSR, differs from micaite and micanites by having higher mechanical and electrical strengths and a higher resistance to moisture and heat (up to 500-600°). The manufacture of the mica-plast is based on a mechanical grinding of mica in purified water adding a certain amount of salts and mechanical substances without using acids and alkalis for the cleavage. The tensile strength of mica-plast tapes exceeds that of micaite tapes by 5-6 times. Epoxy, polyester polyorganosiloxane and inorganic products are used as binders. Glass tapes, synthetic films, etc., are used as underlayers The working temperature of mica-plast materials is 350-500°.

S.A. Yamanov

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[Transliterated Symbols]

1304 СО = SO = slyuda obraztsovaya = standard mica

1304 СФ = SF = slyuda fil'trovaya = filter mica

1304 СНЧ = SNCh = slyuda nizkochastotnaya = low-frequency mica

1304 СВЧ = SVCh = slyuda vysokochastotnaya = high-frequency mica

1304 СЗ = SZ = slyuda zashchitnaya = protective mica

ELECTRIC-INSULATION CARDBOARD – is a cardboard with dielectric properties used as an insulating material in electrical engineering. The most important properties of the electric-insulation cardboard are the electric strength, the heat resistance, and the durability. Electric-insulation cardboard is made from sulfate cellulose having high electric-insulating properties, and rag fibers which give the material the heat resistance, durability, and an increased ability to soak in oil. The high electric insulation qualities are also obtained by a high pressing of the raw materials during the production. Electric insulation cardboard must not contain current-conducting inclusions and must not exfoliate when stamped and cut with shears of the guillotine type. Electric-insulation cardboards are subdivided into two groups according to their destination. The EV cardboards, destined for working in air, belong to the first group, the EM cardboards, used for working in transformer oil at a temperature up to 95°, belong to the second one. EV is used for make washers and coil bobbins, and also for the insulation of grooves in diverse electric machines. The following grades are deliverable: EVS, EVP, EVT, and EV. EVS is characterized by a high bending strength, it does not crease when set automatically into a groove. EVP is characterized by an increased by volume and, therefore, a high electric strength. EVT contains an increased quantity of rag fibers and has, therefore, an improved heat resistance, durability and ability to absorb oil. The electric-insulation cardboards of this group are delivered in rolls (all grades) and in sheets (the grades EVS and EV). The indices characterizing the cardboards of the EV group are

listed in Table 1. The EM cardboards are used in oil-filled transformers, starting and disconnecting high-voltage devices. The electric insulation properties of these cardboards depend on the properties of the raw materials and oils which fill the cardboard pores. The density of the EM cardboards is lower than that of the EV cardboards in order to secure a high absorbability for oil. Three grades of EM cardboard are delivered according to GOST 4194-62: EMTs, EMS, and EMT (Table 2). The cardboard with a thickness of 0.5 mm is delivered in rolls and sheets, that with a thickness higher than 0.5 mm in sheets only. 0.5, 1.0, 2.0, 2.5, and 3 mm thick electric-insulation cardboards of the EM grades are deliverable. Cardboard with a thickness of 1.25 and 1.75 mm is obtainable by request of the customer. The rule is 1 m wide. The dimensions of the sheets (in m) are 1.65 × 3.8; 0.85 × 1.1; 0.85 × 1, and 0.85 × 0.95. Compared with other electric insulating material, the electric-insulation cardboards possess a higher hygroscopicity and a lower heat resistance.

TABLE 1

Characteristics of the Electric Insulation Cardboard of the EV Group

1 Показатели	Марки 2				
	ЭВС 3	4 ЭВП	ЭВТ 5	ЭВ 6	
				рулон 7	листов 8
Объемный вес (г/см³) 9	1.25	1.25	1.15	0.95	1.15
Предел прочности при растяжении в исходном состоянии (кг/мм², не менее): 10					
в продольном направлении 11	12.0	12.0	12.0	8.5	9.0
в поперечном направлении 12	3.5	3.5	3.25	3.25	3.5
в продольном направлении после 100 перегибов 13	7.2	8.0	6.75	6.75	—
Электрич. прочность (кв/мм): 14					
после сушки 15	11—12	11—12	12—13	9—11	8—10
16 после перегиба в продольном направлении	8—9	8—9	8—9	8	—
17 Влажность (%, не более)	10	10	10	10	10

1) Indices; 2) grades; 3) EVS; 4) EVP; 5) EVT; 6) EV; 7) in rolls, 8) sheets; 9) weight by volume (g/cm3;; 10) tensile strength in initial state (kg/mm^2, not less than); 11) along;

12) across; 13) along after 100 bendings; 14) electric strength (kv/mm); 15) after drying; 16) along after bending in longitudinal direction; 17) moisture content (%, not more than).

TABLE 2

Characteristics of the Electric-Insulation Cardboard of the Group EM

1 Показатели	Марки 2		
	3 ЭМЦ	4 ЭМС	ЭМТ 5
6 Объемный вес (г/см³)	0,9—1,0	0,9—0,95	0,9
7 Предел прочности при растяжении (кг/мм²):			
8 в поперечном направлении	3,5—4,0	3,8	2,9
9 в продольном направлении	7,8	7,6	5,6
10 Электрич. прочность при испытании образцов в трансформаторном масле в течение 1 мин. при 90±5° и частоте тока 50 гц (кв/мм):			
11 при толщине (мм) 0,5	42	—	—
» » 1,0	36	—	—
» » 1,5	31	31	31
» » 2,0	27	27	27
» » 2,5	24	24	24
» » 3,0	21	21	21
12 Усадка при сушке у картона толщиной 2 мм и более (%):			
13 в поперечном направлении	2,0	1,5	1,1
14 по толщине	7,0	5,0	3,5
15 Влажность (%)	10	9	8

1) Indices; 2) grades; 3) EMTs; 4) EMS; 5) EMT; 6) weight by volume (g/cm^3); 7) tensile strength (kg/mm^2); 8) across; 9) along; 10) electric strength of specimens tested in transformer oil for 1 min at 90±5° and a current frequency of 50 cps (kv/mm); 11) with a thickness of (mm); 12) shrinkage when drying a cardboard of 2 and more mm thickness (%); 13) across; 14) in thickness; 15) moisture content (%).

S. Sh. Ryvlin

ELECTRIC INSULATION LACQUER is a film-forming composition used in the production of electrical machines, apparatus, and instruments and also for the fabrication of electric insulating materials and cable products. It contains natural and synthetic resins, natural and artificial bitumens, vegetable oils, cellulose esters, synthetic rubbers, and also compositions made from the listed substances. On the basis of function the electric insulation lacquers are divided into impregnating, coating and bonding. This division is arbitrary, i.e., the same electric insulation lacquer can be used for both impregnating and coating or for coating and bonding.

The impregnating electric insulation lacquers are used for impregnating windings of electrical equipment for the purpose of cementing the windings, improving the heat and moisture resistance of the insulation, improving its mechanical and electrical strength as well as the thermal conductivity; the impregnating lacquers must have a good impregnating capability with a maximal content of the lacquer base; must not be destructive to the insulation and, most of all, must not deteriorate the enamel insulation of the winding wires or the rubber and plastic insulation of the lead wires, must provide secure bonding for the winding turns (particularly the rotating windings), must have high dielectric properties; must be heat-resistant and elastic. In certain cases the impregnating lacquer is also required to have high moisture resistance, resistance to the effect of tropical conditions, resistance to oils and chemicals. The impregnating lacquers also include those for impregnation of paper and fabrics in the preparation of laminated plas-

tics (in this case the lacquers also serve as bonding agents since they bond the individual sheets of paper or fabric), in the production of lacquered fabric and lacquered papers.

The coating electric insulation lacquers serve basically for the protection and preservation of the impregnated windings from the action of lubricating oils, mechanical damage, atmospheric conditions, brush dust, chemical reagents, for the creation of semiconductive coatings, etc. The coating electric insulation lacquers for the protection of the impregnated windings are used primarily in the form of enamels containing mineral pigments, whose introduction improves the surface hardness of the coatings, the heat conductivity and the arc resistance. The coating electric insulation lacquers also include the lacquers for the coating of details made from the plastics and other materials, the lacquers for enameling winding wires, for lacquering the sheets of transformer steel in laminated magnetic circuits, for lacquering sleeving for assembly wiring. For these uses it is particularly important that the lacquers be fast drying, have good adhesion to the surface being covered, have the capability of providing a hard, smooth, mechanically strong film which does not soften at the operating temperature.

The bonding electric insulation lacquers are used for the bonding of mica or micaceous materials with one another or with various substrates, for the bonding of film materials to substrates, for the fabrication of various compositional electric insulation materials, for the bonding of packets of transformer steel.

For the bonding lacquers it is particularly important to have maximal adhesion to the materials being bonded and, in many cases, to have elasticity of the lacquer film. The hot drying (furnace drying) electric insulation lacquers require temperatures of 100° and higher for their drying and to obtain a lacquer film with optimal properties. For

the air-drying electric insulation lacquers, use is made of more volatile and lower-boiling solvents than for the furnace-drying lacquers.

Characteristics of Certain Impregnating Electric Insulation Lacquers

Показатели 1	Масляно-битумные 2		Глифтальмеламиновый МЛ-92 3	Фенолалкидный МЛ-98 4	Полиорганосилоксановые 5		Водоэмульсионные 6		Лак КП-18 без растворителя 7
	447	458			ЭФ-3БСУ 8	К-47	321-Т	ПФЛ-8В 9	
10 Содержание нелетучих (%, не менее)	40	40	50	50	40	60	40—60	—	100
11 Кислотное число (мг КОН/г, не более)	—	—	12	10	10	—	12—30[1]	12—25[1]	
12 Время высыхания (часы, не более)	6 (105°)	3 (105°)	1 (105°)	2 (120°)	2 (200°)	0,5 (200°)	3[2] (105°)	0,5[2] (125°)	0,25[2] (125°)
13 Термоэластичность пленки (часы, не менее)	7 (150°)	3 (150°)	24 (150°)	30 (150°)	40 (200°)	50 (200°)	20 (150°)	10 (150°)	—
14 Водопоглощение пленки за 24 часа (%, не более)	1	1	—	—	0,5	0,5	—	—	—
15 Электрич. прочность пленки (кв/мм, не менее):									
16 при 20°	55	55	60	70	65	60	30[3]	45[3]	20[3]
при 90°	25	25	—	—	—	—	20[3]	35[3]	
при 200°	—	—	—	—	25	30	—	—	—
17 После пребывания в течение 24 час. в воде	22	20	30	40	25[4]	35[4]	8[2]	11[2]	—
18 Уд. объемное сопротивление пленки при 20° (ом·см, не менее)	—	—	$5 \cdot 10^{13}$	10^{14}	10^{14}	10^{13}	—	—	—

[1]) Using a lacquer base; [2]) tests made on paper substrate; [3]) tests made on discs one mm thick; [4]) in atmosphere with 95 ± 3 percent humidity.

1) Charactersitic; 2) bitumen/oil; 3) glyptal melamine ML-92; 4) phenol alkyd ML-98; 5) polyorganosiloxane; 6) water emulsion; 7) KP-18 lacquer without solvent; 8) EF-3BSU; 9) PFL-8V; 10) nonvolatile content (%, not less than); 11) acid number (mg KOH/g, not more than); 12) drying time (hours, not more than); 13) thermoelasticity of film (hours, not less than); 14) film water absorption in 24 hours (%, not more than); 15) film electrical strength (kv/mm, not less than); 16) at; 17) after 24 hours in water; 18) specific volumetric resistance of film at 20° (ohm-cm, not less than).

As the lacquer base in the electric insulation lacquers, use is made of the vegetable oils and their compositions with other natural materials (bitumens, resin and the product of its processing, copas), synthetic resins including those modified with the vegetable oils. Lacquers based on the cellulose esters and their compositions with lacquers made from the synthetic resins have found limited use in the

technology of electric insulation. In the production of the electric insulation lacquers there is seen a tendency for the replacement of the natural raw materials (bitumens, vegetable oils, natural resins) by the higher quality synthetic resins, the replacement of the toxic organic solvents with water, and also changeover to the impregnating compositions which do not contain solvents, permitting impregnation and drying of the windings on the production line. The table presents the basic characteristics of certain most frequently used and most promising impregnating electric insulation lacquers.

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S.V. Shishkin

ELECTRIC IRON – is one of the most important electrical engineering materials with high magnetic, mechanical and technological properties. Impurities (carbon, especially) and also cold hardening and diminishing of the grain size deteriorate the magnetic properties of electric iron (the magnetic permeability drops, the coercive force and the hysteresis loss increase). Martin Armco iron is the most widely used magnetic material. Its properties are fixed by GOST 3836-47, where it is termed thin-sheet electric engineering low-carbon steel (Table).

Magnetic Properties of Electric Engineering Low-Carbon Steel (according to GOST 3836-47)

Сталь	Коэрцитивная сила (а), не более	μ_{max} (отн. ед.), не менее	Магнитная индукция B (гс) в зависимости от напряженности (H) магнитного поля (э/см)						
			H						
			5	10	25	50	100	300	500
Э ЭА ЭАА	1,2 1 0,8	3500 4000 4500	13 800	15 200	16 700	17 100	18 100	20 500	21 800

1) Steel; 2) coercive force (oersted) not more than; 3) μ_{max} (gauss/oersted), not less than; 4) magnetic induction B (gauss) depending on the magnetic field force (H) (amp/cm); 5) E; 6) EA; 7) EAA.

The maximum impurity percentage in the steel is as follows: 0.4 C; 0.2 Mn; 0.2 Si; 0.015 P; 0.03 S; 0.1–0.3 Cu.

Reduced electric iron in the form of powder, pressed to pieces and annealed in hydrogen, in order to cause recrystallization and to remove carbon and oxygen, contains (in %) as follows: 0.01–0.03 C; up to 0.01 Mn, up to 0.01 Si, up to 0.015 P, up to 0.02 S, up to 0.01 Al and up to 0.015 Cu. After remelting in vacuum and annealing, the iron possesses the following higher magnetic properties: initial permeability μ_0 =

= 500 gauss/oersted; μ_{maks} = 15,000 gauss/oersted; residual induction B_r = 10,500 gauss; coercive force H_c = 0.35 oersted. Carbonyl iron possesses the highest properties as follows: μ_0 = 2000-3000 gauss/oersted; μ_{maks} = 20,000-21,500 gauss/oersted; B_r = 5000-6000 gauss; H_c = 0.8 oersted; magnetic saturation $4\pi I_s$ = 21,700 gauss. It is obtained by the decomposition of iron carbonyl $Fe(CO)_5$ as a powder with a grain size of up to 10 microns. Soft steel (with about 0.1% C) may be used instead of Armco iron when H_c and μ are not needed to fulfill high requirements (cores of electric magnetos, for example).

A disadvantage of the electric iron is its high tendency to aging which may be prevented by slow cooling after annealing.

Electric iron is used mainly in d-c equipment: magnetic circuits and pole shoes of electric magnetos and relays, electric measuring devices, magnetic shields, membranes, etc. Carbonyl and electrolytic iron are also used to prepare magnetic dielectrics.

References: Zaymovskiy, A.S. and Chudnovskaya, L.A., Magnitnyye materialy [Magnetic Materials], [3rd Edition], Moscow-Leningrad (Metally i splavy v elektrotekhnike [Metals and Alloys in Electric Engineering], Vol. 1); Mes'kin, V.S., Ferromagnitnyye splavy [Ferromagnetic Alloys], Leningrad-Moscow, 1937; Bothort, R., Ferromagnetism, translated from English, Moscow, 1956.

B.G. Livshits and A.A. Yudin

ELECTRIC RESISTANCE METHOD OF FLAW DETECTION – is based on the determination of the electric resistance between two points on the surface of the tested object. The electric resistance depends on the specific resistance of the material and the geometrical dimensions of the object, as the wall thickness, the length of the tested section, and also on its shape; hence, the electric resistance method of flaw detection may be used to determine the wall thickness, to detect discontinuities (as of lamination or solderless joints in sheet and laminar materials), and to test properties connected with the specific electric conductivity of the material (for example, the quality of heat treatment, the chemical composition, etc.). In some cases, the electric resistance method of flaw detection may be used to estimate the depth of surface cracks detected by any other method (for example, by the magnetic particle inspection or the electric inductive method). Various resistance meters (for example, the microohmmeter M-246) may be used in the electric resistance method of flaw detection. Four contacts from which two serve as feeders, the two other being used to measure the potential difference on the checked section, are used as pickups in this device also as in others in order to measure small resistances. The distance between the contacts (the base) depends on the type of test. Thus, this distance must be at least 5 times greater than the wall thickness when the latter has to be measured. Needle-type contacts fixed in a special holder are usual. Sliding or roller contacts are used in some cases, which allow the increase of the efficiency of the test.

S.M. Rozhdestvenskiy

ELECTRIC SHEET STEEL – is a steel with a silicon content of up to 4.3%, used in the production of stators and rotors of electric engines and generators, for transformer and choking coil cores, and in parts of

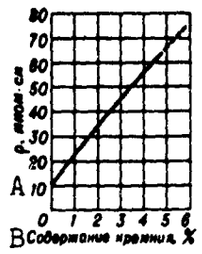

Fig. 1. Effect of the silicon content on the specific electric resistance of electric steel. A) ρ, microhms•cm; B) silicon content, %.

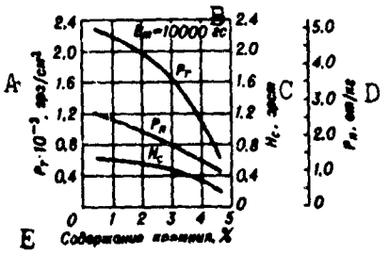

Fig. 2. Effect of the silicon content on the losses. A) erg/cm^3; B) gauss; C) oersted; D) watt/kg; E) silicon content, %.

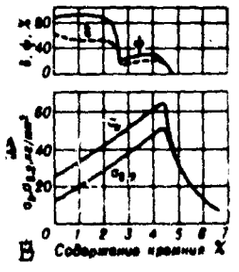

Fig. 3. Effect of the silicon content on the mechanical properties of electric steel. A) kg/mm^2; B) silicon content, %.

electromagnetic devices and apparatuses. Conditionally, electric steel is divided into dynamo steel (with a 0.8-1.5% silicon content) and transformer steel (with a 3.0-4.3% silicon content). Silicon, as an alloying constituent, increases sharply the electric resistance of electric steel (Fig. 1) and reduces, therefore, the eddy current loss; it increases the magnetic permeability, reduces the coercive force and the hysteresis and total loss (Fig. 2); it promotes the growth of the grains, improving by this way the magnetic properties, and weakening the harmful effect of impurities (it transformes the carbon into graphite which is less harmful with regard to the magnetic properties). The mechanical properties of electric steel change rigorously with an increasing silicon content; the tensile strength and the yield strength increase steadily to a silicon content of up to 4.5% and drop then rapidly (Fig. 3). The plasticity (at room temperature) almost does not change when the silicon content rises up to 2.5%, and drops then rigorously. An advantageous fact is the rapid increase of the plasticity at higher temperatures. Steel with 4-4.5% silicon, for example, is brittle at room temperature, but can be rolled with a great amount of reduction to a thickness of 0.10-0.01 mm when heated to 150-200°. Addition of silicon does little to change the specific heat and the thermal expansion coefficient, and, therefore, these values may be taken as equal to those of iron. The heat conductivity decreases strongly when increasing the silicon content. The specific gravity is decreased proportionally to the increasing silicon content.

The grades of electric sheet steel, the sheet thickness, the guaranteed values of the magnetic induction, the specific electric resistance and the total loss are fixed by GOST 802-58. With regard to the technology of sheet production, the electric steel is divided as follows into: hot-rolled steel with an isotropical structure; cold rolled

steel with a small texture, with properties similar to that of the foregoing; and cold rolled steel with an expressed texture, having an increased permeability and reduced losses in the rolling direction in expense of deteriorated properties in the transversal direction. Electric sheet steel possesses a so-called Goss texture (the edge of the cube lies in the rolling direction, a plane of the {110} type lies in the rolling plane). The advantages of electric sheet steel with such a texture become efficient only in the case when the magnetic current flows along the rolling direction. The development of an electric sheet steel with a cubic structure (the <100> edge of the cube in the rolling direction, and the {100} plane of the cube in the folling plane), having improved properties in both the longitudinal and the transverse direction, was a success.

References: Zaymovskiy, A.S. and Chudnovskaya, L.A., Magnitnyye materialy [Magnetic Materials], [3rd Edition], Moscow-Leningrad, Metally i splavy v elektrotekhnike [Metals and Alloys in Electric Engineering], Vol. 1; Livshits, B.G., Fizicheskiye svoystva metallov i splavov [Physical Properties of Metals and Alloys], Moscow, 1959.

B.G. Livshits and A.A. Yudin

ELECTRODEPOSITED COATINGS OF MAGNESIUM ALLOYS – coatings which are applied to component surfaces by the electrodeposition method. Electrodeposited coatings of magnesium alloys increase the wear resistance, electric and thermal conductivity, as well as the soldering ability of magnesium alloys. The difficulty of application of electrodeposited coatings of magnesium alloys are due to the presence of an oxide film on the surface of magnesium alloys and the highly negative potential of magnesium. To ensure close adherance of electrodeposited coatings of magnesium alloys with the metal surface use is made of the following methods of treatment (preparation) of the surface: 1) creating a thin homogeneous film which protects the metal surface from the direct effect of the electrolite. The film should be electrochemically active and be restored partially or totally upon cathodic polarization, thus ensuring electrodeposition of the metal coating on the active surface; 2) preliminary contact deposition of zinc on the metal surface. The zinc layer, which clings tightly to the magnesium alloy's surface, partially protects from the corrosive action of the electrolite and serves as an electrochemical base for the subsequent deposition of the main coating.

The method of contact zinc deposition has come into practical use. This method consists of the following operations: a) preliminary preparation of the surface, which includes cleaning, degreasing by organic solvents and electrical degreasing in an alkaline solution at a temperature of 60-70° and current density of 2-5 amps/decimeter^2; b) etching in 50-60% acetic acid for 15-60 secs for shaping alloys and in 70-85%

steel with a small texture, with properties similar to that of the foregoing; and cold rolled steel with an expressed texture, having an increased permeability and reduced losses in the rolling direction in expense of deteriorated properties in the transversal direction. Electric sheet steel possesses a so-called Goss texture (the edge of the cube lies in the rolling direction, a plane of the {110} type lies in the rolling plane). The advantages of electric sheet steel with such a texture become efficient only in the case when the magnetic current flows along the rolling direction. The development of an electric sheet steel with a cubic structure (the <100> edge of the cube in the rolling direction, and the {100} plane of the cube in the folling plane), having improved properties in both the longitudinal and the transverse direction, was a success.

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B.G. Livshits and A.A. Yudin

ELECTRODEPOSITED COATINGS OF MAGNESIUM ALLOYS – coatings which are applied to component surfaces by the electrodeposition method. Electrodeposited coatings of magnesium alloys increase the wear resistance, electric and thermal conductivity, as well as the soldering ability of magnesium alloys. The difficulty of application of electrodeposited coatings of magnesium alloys are due to the presence of an oxide film on the surface of magnesium alloys and the highly negative potential of magnesium. To ensure close adherance of electrodeposited coatings of magnesium alloys with the metal surface use is made of the following methods of treatment (preparation) of the surface: 1) creating a thin homogeneous film which protects the metal surface from the direct effect of the electrolite. The film should be electrochemically active and be restored partially or totally upon cathodic polarization, thus ensuring electrodeposition of the metal coating on the active surface; 2) preliminary contact deposition of zinc on the metal surface. The zinc layer, which clings tightly to the magnesium alloy's surface, partially protects from the corrosive action of the electrolite and serves as an electrochemical base for the subsequent deposition of the main coating.

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phosphorus acid for 0.5-3.0 minutes for casting alloys; c) "activization" in 20% phosphorus acid, containing 100 g/liter of ammonium bifluoride (NH_4HF_2), the processing time for alloys of the Mg-Mn system is 15-60 seconds, for alloys of the Mg-Al-Zn system it is up to 3 minutes; d) chemical (contact) zinc-coating in a solution with the composition: 45 g/liter $ZnSO_4 \cdot 7H_2O$, 200 g/liter $Na_4P_2O_7 \cdot 10H_2O$, 10 g/liter $KF \cdot 2H_2O$, Na_2CO_3 or NaOH up to pH 10; the temperature of the solution is 70±5°, the duration of treatment for alloys of the Mg-Mn system is 3-7 minutes, for alloys of the Mg-Al-Zn type system it is 5-15 minutes; e) copper coating in the cyanitic electrolite with the composition: 40-45 g/liter CuCN, 5-7 g/liter $NaCN_{svob}$, 45-50 g/liter $KNaC_4H_4O_6$, 25-30 g/liter Na_2CO_3, 6-8 g/liter NaOH. The copper coating regime is: solution temperature 60±5°, current density 1-2 amps/decimeter^2, current reversal, cathodic intermixing, loading of components under a current (current "kickback" at a density of 2-4 amps/decimeter^2 for 0.5-1.0 minutes), coating thickness 20-25 microns; f) heating (control of the copper coating quality) at a temperature of 150-200° for 15-30 minutes. The absence of bubbles and blow-up spots shows that the coating is of good quality; g) electrodeposition of the main coating (nickel, chromium, silver, cadmium, etc.) is performed by making use of usual electrolites (see Electrodeposited Coatings of Steel, Anodizing Magnesium Alloys, Oxidation of Magnesium Alloys).

Due to the highly negative potential of magnesium alloys, all the electrodeposited coatings are cathodic with respect to them and can have protective properties only in the absence of pores, for which reason the protective properties of coatings are improved by applying a sublayer and increasing the coating thickness. For protection from atmospheric corrosion the total thickness of electrodeposited coatings of magnesium alloys (sublayer + main coating) should be at least 40 microns.

For rigorous service conditions it is recommended that 1-2 layers of lacquer and paint be applied over the electrodeposited coating of magnesium alloys (see Lacquer and Paint Coatings of Magnesium Alloys).

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S.A. Romanov

ELECTRODEPOSITED COATINGS OF STEEL – coatings applied to the component surfaces by the electrodeposition method. Methods of electrodeposited coatings of steel have been elaborated for almost all the metals and many alloys. In addition to standard methods of electrodeposition of coatings on steel such as nickel and chromium electroplating, methods such as: double-layer nickel and chromium electroplating, coating by alloys (particularly with nickel as a base), smoothing out nickel plating, coating from anhydrous solutions, are coming into use.

TABLE 1

Properties of Electrodeposited Coatings of Steel

Покрытие 1	Свойства 2
Цинковое 3	НВ = 30–50 кг/мм², σ_b = 7–20 кг/мм², δ = 15–30%, стойкость против коррозии в атмосфере 4 и слабоагрессивных средах
Кадмиевое 5	НВ = 12–53 кг/мм², к = 31% трения по стали 0,24, стойкость против коррозии в морских и тропических условиях 6
Медное 7	НВ = 40–160 кг/мм², σ_b = 30–70 кг/мм², δ = 20–30% между трения по стали = 16, легко полируется, на воздухе тускнеет 8
Никелевое 9	НВ = 120–600 кг/мм², σ_b = 60–80 кг/мм², δ = 15–20%, легко полируется, коэф. отражения света 59–64%, на воздухе тускнеет, можно получить покрытие черного цвета 10
Хромовое 11	НВ = 400–1000 кг/мм², хрупкое, легко полируется коэф. отражения света 62–67%, обладает большой износостойкостью, на воздухе не тускнеет, можно получать черное покрытие различных оттенков, пористое покрытие с хорошими адгезионными св-ва 12
Оловянное 13	НВ = 6 [illegible] кг/мм², коэф. трения по стали [illegible], на воздухе тускнеет, стойкое против действия [illegible] 14
[illegible]вое 15	НВ = [illegible] кг/мм², коэф. трения [illegible], [illegible] на воздухе тускнеет 16
Серебряное 17	НВ = [illegible] кг/мм², легко полируется, коэф. трения по стали [illegible], коэф. отражения света [illegible]%, на воздухе тускнеет, обладает [illegible] 18
[illegible] 19	НВ = [illegible] 160 кг/мм², легко полируется, на воздухе не тускнеет, цвет от розового до белого 20
Сплав никель-олово 21	НВ = 6 [illegible] кг/мм², хрупкое, легко полируется, на воздухе не тускнеет, цвет белый 22
Сплав никель-кобальт 23	НВ = [illegible] кг/мм², σ_b = 145 кг/мм², [illegible] %, цвет блестящий белый без [illegible] 24

1) Coating; 2) properties; 3) zinc; 4) HB = 30-50 kg/mm^2, σ_b = [illegible]-80 kg/mm^2, δ = 15-30%, corrosion resistant in the atmosphere and weakly ag-

gressive media; 5) cadmium; 6) HB = 12-53 kg/mm^2, coefficient of friction over steel 0.24, corrosion resistant under marine and tropical conditions; 7) copper; 8) HB = 40-160 kg/mm^2, σ_b = 30-70 kg/mm^2, δ = 20--40%, coefficient of friction over steel 0.36, is easily polished, tarnishes in the air; 9) nickel; 10) HB = 120-600 kg/mm^2, σ_b = 40-80 kg/mm^2, δ = 15-20%, is easily polished, light reflection coefficient 59-65%, tarnishes in air, a black-colored coating can be obtained; 11) chromium; 12) HB = 400-1000 kg/mm^2, brittle, is easily polished, light reflection coefficient 62-67%, is highly wear resistant, does not tarnish in air, it is possible to obtain a black-colored coating of various shades, a porous coating capable of satisfactory holding of a lubricant; 13) tin; 14) HB = 8-10 kg/mm^2, coefficient of friction over steel 0.24, tarnishes in air, resistant to the effect of food products, when heated to 240-300° it fuses, taking on a shiny or crystalline form (crystallite); 15) lead; 16) HB = 3-5 kg/mm^2, coefficient of friction over steel 0.33, serves as a good lubricant in final finishing of components, tarnishes in air, 17) silver; 18) HB = 60-130 kg/mm^2, is polished easily, coefficient of friction over steel 0.31, light reflection coefficient 90-92%, tarnishes in air, has a good electrical conductivity; 19) bronze; 20) Hb = 250-400 kg/mm^2, is easily polished, does not tarnish in air. Color from pink to white; 21) nickel-tin alloy; 22) HB = 60 kg/mm^2, brittle, is polished easily, does not tarnish in air, white color; 23) nickel-cobalt alloy; 24) HB = 120-250 kg/mm^{2}m σ_b = 145 kg/mm^2, δ = 3-4%, is shiny without polishing.

Electrodeposited coatings of steel are divided into protective – for protection from corrosion, protective-decorative – for decorative finish and protection from corrosion, and special – for imparting special properties to components.

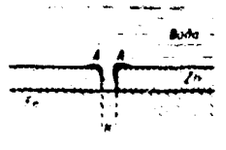

Fig. 1. Schematic of anodic protection of a coating in the presence of pores. 1) Water.

A number of requirements is put to electrodeposited coatings of steel for the purpose of ensuring their quality: minimum porosity, good adherance to the base, maximum thickness uniformity over the entire component surface, absence of internal stresses, fine-crystalline structure, good external appearance, etc. Low-carbon, low-alloy

steel are the best materials for coatings. Coatings from special alloys and metals such as titanium molybdenum, etc., have come into use. In

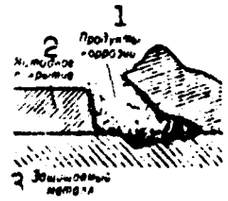

Fig. 2. Schematic of corrosion in pores of a cathodic coating. 1) Products of corrosion; 2) cathodic coating.

designing components with an electroplated coating preference is given to cold-rolled steel. The process of industrial application of electro-

TABLE 2

Intended Service of Electrodeposited Coatings of Steel

1 Назначение	2 Металл покрытия	Толщина 3 (мк)
Защита от атмосферной коррозии 4	Цинк 5	5—30
Защита от коррозии в атмосферных, морских и тропич. 6 условиях	Кадмий 7	5—30
То же 8	Сплавы цинк — олово, кадмий — олово 9	10—20
Защитно-декоративная отделка 10	Никель 11	10—30
13	Многослойные: 12 никель — хром, медь — никель — хром 14	10—30; 0,5—20 Суммарно 10—50 15
Защита от коррозии пищевых продуктов (консервная жесть, посуда и т. п.) 16	Олово 17	18 2 и более
	Белая бронза	19 10—30
	Серебро 20	10—30
	Сплав никель — олово 21	10—40
22 Защита от износа трущихся поверхностей	Хром 23 пористый хром 24	10—50 200—700
Восстановление размеров изношенных деталей 25	Никель химич.	26 20—80
	Хром	23 до 1000 27
	Никель	11 до 3000
	28 Железо	до 2000
Обеспечение сцепления резины со сталью при горячем прессовании 29	Латунь 30	5—10
Улучшение пайки мягкими припоями 31	Медь, олово, сплав свинец — олово 32	3—10
Улучшение прирабатываемости 33	Медь, олово, свинец 34	2—3
Приработка деталей 35	Олово, свинец 36	5—15
Повышение антифрикционных свойств 37	Серебро, сплав свинец — индий 38	5 и более 39
Светотехний. и оптич. отражающие поверхности 40	Серебро, золото, хром, родий 41	1—20
Специальные покрытия 42	Черные покрытия никелем и хромом 43	5—20

1) Intended service; 2) coating metal; 3) thickness (microns); 4) pro-

tection from atmospheric corrosion; 5) zinc; 6) protection from corrosion under atmospheric, marine and tropical conditions; 7) cadmium; 8) same as above; 9) zinc-tin, cadmium-tin alloys; 10) protective-decorative finish; 11) nickel; 12) multilayer; 13) nickel-chromium; 14) copper-nickel-chromium; 15) total 10-50; 16) protection from corrosion by food products (can tin, dishes, etc.); 17) tin; 18) 2 and more; 19) white bronze; 20) silver; 21) nickel-tin alloy; 22) wear protection of rubbing surfaces; 23) chromium; 24) porous chromium; 25) restoration of dimensions of worn models; 26) chemical nickel; 27) up to; 28) iron; 29) ensuring a bond between rubber and steel in hot pressing; 30) brass; 31) improving of solder by soft solders; 32) copper, tin, lead-tin alloy; 33) improving press workability; 34) copper, tin, lead: 35) final finishing of components: 36) tin, lead; 37) improving antifriction qualities; 38) silver, lead-indium alloy; 39) 5 and more; 40) illumination engineering and optical reflecting surfaces; 41) silver, gold, chromium, rhodium; 42) special coatings; 43) black nickel and cnromium coatings.

deposited coatings of steel consists of the preparation, coating proper and finishing operations.

In addition to electroplated coatings, use is made of chemicals which are based on the restoration of salts to the metal under the action of strong reducing agents: chemical nickel plating, cobalt plating, gold plating. The subsequent processing of the coatings (polishing of decorative coatings, passivation of zinc and cadmium, fusing of tin coatings, removal of hydrogen embrittlement) has as its purpose to improve their quality.

The properties of electrodeposited coatings of steel are checked by their external appearance, coating thickness, porosity and other indicators. Methods have been elaborated, including automatic methods, for control of the production process and the quality of the electrodeposited coating thus obtained.

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M.I. Gamov

ELECTROINDUCTIVE FLAW DETECTION (eddy-current flaw detection) – is a complex of methods used to check the quality of objects made up of metallic or electric conducting nonmetallic materials (graphite, semiconductors, etc.) based on the generation of eddy currents (VT) in the checked object and measuring their retroaction on the pickup.

The methods of electroinductive flaw detection allow the structural and chemical state of an electric conducting material to be tested, and the thickness of coatings, of sheets and foils, of tube walls, the diameter of wires, etc., to be measured.

The effect of the eddy currents induced in a section of the checked object is usually determined by the value of the amplitude and (or) the voltage phase of the secondary measuring coil placed either in the exciting coil or side by side with it.

The electroinductive flaw detection allows the testing of the material quality only to a certain depth of the material due to the fact that the density of the eddy currents decreases in the depth of the checked object (the more higher the frequency of the exciting field). The depth of penetration of the eddy currents is determined by that thickness of the material beyond which the indication of the pickup does not change any more. The penetration depth of eddy currents may reach from some hundredths up to tens of millimeter, depending on the frequency of the exciting field (usually in the range from 5 cps to 100 Mcps) and the properties of the checked object. Together with the frequency, the electric conductivity and magnetic permeability of the material effect also the intensity and the manner of propagation of the

eddy currents. The test of the structural and chemical state of nonmagnetic materials, therefore, is possible in cases in which these properties are unequivocally connected with the electric conductivity, or, in the cases of ferromagnetic materials – with the electric conductivity or the magnetic permeability. Discontinuities of the material, causing a change in the distribution of the eddy currents, the shape and the dimensions of the object, and also the mutual position of the coil and the object, affect the interaction between the coil and the object.

There exist the following principal variants of the electroinductive flaw detection: the method of the passage-coil, in which the coil encompasses concentrically the checked object; and the method of the laid on coil, in which the butt of the coil is laid on the object. In the first case, the information obtained concerns an average of the quality along the periphery of the object; in the second case, information is given on the quality of separate sections of the object, which allows the local inhomogeneities in the material to be determined. Miniature contact pickups are used in the testing of hardly accessible sections of complexly shaped objects, and also in the determination of small flaws. Internal passage coils placed in the hollow of the object are used in the testing of pipes and openings.

In the screening method used mainly to measure the thickness of sheets, foils, etc., the checked material is placed between the exciting and the measuring coils. It is substantial in the practical application of the electroinductive flaw detection to single out a certain factor from a number of other factors affecting also the characteristics of the measuring coil. It is necessary, for example, to exclude the interfering effect of the changes in the thickness of the object, and the electric conductivity and magnetic permeability of the material,

must be tested. The following methods used to separate the signal caused by the factor to be tested and to suppress the interferences at the same time are significant for an efficient application of the electroinductive flaw detection:

1. The differential method, in which two pairs of coils, interacting with neighbored sections of the checked object (or one coil interacting with the checked object, and the other with a standard) are connected in series opposing, and the voltage difference of the secondary coils is led to the measuring device. The interferences caused by fluctuations of the line voltage, by changes in the temperature of the coils and the objects, and by the edge effect, are reduced by this method. The interferences caused by changes in the dimensions and properties of the material are reduced in the variant of comparison of the neighbored section, widely used in flaw detection.

2. The method of phase selection measures the projection of the vector of the measuring voltage in that phase direction in which the checked factor has the highest intensity, and the interferences, a lower one.

3. The method of frequency selection is based on the choice of the optimum frequency of the excitating field at which the highest sensitility to the checked factor or optimum conditions for the phase selection are achieved, or it uses the difference between the frequency spectra of the signals caused by flaws and those of the slower changing interference signals (changes in electric conductivity, in dimension, etc.). This method is applicable to devices working with a pickup moved with a high uniform velocity relative to the checked object.

4. The method based on the intensification or suppression of the effect of the magnetic permeability operates by the control of the voltage of the exciting field or by the superposition of a d-c field

of corresponding voltage. The saturated magnetization of the checked material in the d-c field allows the strong interferences caused by inequal internal stresses to be eliminated, exciting sharp fluctuations of the magnetic permeability, when ferromagnetic steel semiproducts are checked; and also the interferences caused by ferromagnetic sections may be eliminated in the checking of austenitic steels. The magnetization allows also the increase of the penetration depth of the eddy currents, and, therefore, the enlargement of the checked zone of the object.

Flaw detectors with contact coils are used in the manual testing of objects. These devices are insensible to changes in the gap between the measuring coil and the object surface in the range of 1 mm; and, therefore, a precise adjustment of the pickup is not necessary; painted or soiled objects may also be checked. Pickups having miniature coils with a diameter of about 1.5 mm are designed for the detection of small flaws or for the testing of hardly accessible sections. Flaws in a 0.5-3 mm thick surface layer are detectable, depending on the working frequency and the dimensions of the pickup. The devices allow the depth of cracks to be estimated, a fact which is especially significant to the testing of fatigue cracks under working conditions. The minimum determinable depth of cracks is about 0.005 mm; the length is about 0.3-0.4 mm. The devices are also used in combination with mechanically scanning devices.

Flaw detectors with passage-coils are used in the mechanized (the recent devices for the totally automated one) testing of wire, rods, pipes and profile parts. The semiproducts to be checked are fed with a speed of 1-10 m/sec (depending on their dimension). The automatic flaw detectors are equipped with a signal device, with devices for recording, for making the defective places, for separating the defective

pieces, and with counters for the number of flaws and that of the checked pieces, etc. Automated flaw detectors with contact pickups are used mainly in the testing of semiproducts and finished pieces having the shape of solids of revolution. Rotation of the pickup (speeds up to 3000 rpm are realized) and transfer of the object in the axial direction, or rotation of the object and the axial transfer of the pickup are used in order to scan the whole surface. Devices are also used to check the plane surfaces of objects and the inner surface of tubes by means of rotating pickups. A maximum sensibility for small surface flaws (having a depth of 0.01-0.02 mm when a polished surface is tested) may be achieved with flaw detectors of this type.

Devices with contact- or such ones with passage-pickups are used in the sorting of materials according to grades in the testing of the quality of heat treatment (instead of the measurement of hardness), in the checking of the degree of purity of Cu, Al, and other metals, in the determination of the C content in steel, of the depth of nitrided and carburized layers, of the depth of surfacial decarbonization, in the detection of total or local overheatings (grinding burns and other technological overheatings, material overheatings under working conditions), in the determination of liquation zones, of porosity, of "soft" spots, and also for a quick contactless measuring of the electric conductivity of nonmagnetic materials, etc. The former are used in all cases when local inhomogeneities of the material must be detected, and in the checking of complexly formed large and small-lot objects, and also in the testing of parts in assembled constructions, etc. Devices of this type are equipped with counting devices used to measure immediately the electric conductivity of the surface layer of diversely shaped objects, the time for one measurement being in the range of about 3 sec. For this purpose, only an approximately plane

surface section with a diameter of 10-15 mm must be present at a thick-ess of 0.5-1.5 mm in the tested cross section (depending on the working frequency and the electric conductivity of the checked material). The precision of the measurement is about 1% of the measured value.

Devices with passage-coils are used in the test of semiproducts and, preponderantly, of small parts (fastening pieces, balls, rolls, drills, etc.). An efficiency of some hundred parts per hour or a test of the parts with a speed of up to 2 m/sec may be achieved when the material is fed by hand, and the indications are observed visually. Totally automated devices with equipment for sorting the objects automatically into 2-3 grades according to the quality, are also used. Their efficiency achieves some thousand parts per hour or 10 m/sec when semifinished products are tested.

Devices used in testing the quality of the material are also able to indicate flaws, with a lower sensibility, however, than flaw detectors.

Devices with passage-coils may be adjusted (using phase selection) to the measurment of the diameter of wire, rods, rolls, balls, etc.; and may also be used as a contactless checking of the size (with automatic recording of the results or with sorting according to the size) of objects which pass the pickup-coil at a high speed. Special devices which operate at higher frequencies are also used for this purpose as well as for the checking of quality, the interference of changes in the electric conductivity of the material being almost eliminated due to this fact Special electric inductive devices are also used for the continuous measuring and recording of the thickness of pipes, foils, strips, and thin sheets of nonmagnetic metals.

The following methods of electroinductive flaw detection are used to measure various types of coatings: 1) nonconductive coatings on non-

magnetic metals, for example, lacquers, paints, anodic coatings, paper, plastics, ceramics, etc. Thicknesses in the range of some microns (decorative or anticorrosive coatings) may be measured up to tens of mm (heat-protecting coatings). The precision of the measurement depends on the shape of the object and the degree of homogeneity in the conductivity of the material (lying between 2 and 5%); 2) in order to measure the coatings of a nonmagnetic metal on a nonmagnetic metal whose electric conductivity differs from that of the coating (for example, electroplatings, and plating layers of bimetallic objects). The higher the precision of the measurement the higher is the difference between the electric conductivity of the coating and that of the base material, and the more uniform is the electric conductivity; 3) in order to measure the metal coating on nonconducting materials, the metal layers on capacitor paper, printed circuits, etc , for example.

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V.Yu. Sila-Novitskiy

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[Transliterated Symbols]

1332 ВТ = VT = vikhrevyy tok = eddy current

ELECTROLYTIC COATINGS OF MOLYBDENUM – see Protective coatings of molybdenum.

ELECTROLYTIC MAGNESIUM is magnesium produced by electrolysis from molten chloride salts. Raw electrolytic magnesium is contaminated with various impurities, including chloride salts in the amount of 2-3%. Along with the chloride compounds, in raw magnesium there are encountered magnesium oxide (MgO), nitride (Mg_3N_2) and carbide (MgC_2). The metallic impurities include Ka, Na, Ca, Fe, Si, Al, Cu, Ni, Mn. Raw electrolytic magnesium is subjected to purification – refining of the chloride inclusions and metallic impurities. As a result there is obtained technical magnesium corresponding in chemical composition to the All-Union standard (see Technical Magnesium).

A.A. Lebedev

ELECTRONIC GLASS – glass and glass semifinished products used in the manufacture and assembly of electronic, radio, and vacuum-tube devices and instruments. Glasses of this type are arbitrarily divided into vacuum-tube glasses and insulator glasses. Vacuum-tube glasses should have elevated electrophysical characteristics and function reliably for extended periods under high vacuum; the coefficients of thermal expansion of the glass and the metal fused into it should correspond precisely. When such correspondence is not obtained internal stresses generally develop where the glass is fused with the metal, leading to destruction of individual elements and units of the device.

TABLE 1

Characteristics of Soviet Vacuum Glasses

Марка стекла 1		Плотность (г/см³) 4	Модуль упругости E (кг/мм²) 5	Предел прочности 6 (кг/мм²)	
старая 2	новая 3			при растяжении 7	при сжатии
	2				
П-15	С-33-15	2,21	(7000)	7—12	160—200
20 ЗС-9	С-35-9	2,25	6250	(8,1)	(114)
№ 40	С-37-40	2,11	5900	8,1	112
№ 17	С-39-17	2,56	(9200)	8,4	(106,2)
ЗС-11	С-40-11	2,30	6040	7,8	111
№ 46	С-47-46	2,20	(7040)	7	109
ЗС-8	С-48-8	2,33	6300	9,0	109
ЗС-5К	С-49-5К	2,25	6450	7,7	108
24 ЗС-5	С-49-5	2,29	6250	3—5	85
№ 35	С-54-35	2,29	6250	3—5	80
№ 36	С-82-36	2,32	(7150)	(7,6)	(107)
№ 401	С-82-401	2,53	(7480)	(9,6)	(100)
№ 402	С-87-402	2,57)	(7600)	(8,3)	(101)
ЗС-4(№ 12)	С-88-4	2,50	(7700)	3,2	(98,4)
№ 2	С-89-2	(4,81)	(6790)	4—6	85
ВИ-1	С-90-1	(2,64)	(7650)	8	106
№ 23	С-89-23	(2,79)	(7630)	(5,0)	(101,2)
—	С-88-8	(2,56)	(7600)	8,3	91
—	С-88-11	2,5	(7260)	7—8	94
—	С-88-13	(2,67)	7160	10,5	(98,7)
713	С-89-713	2,40	(7470)	7,9	99
		2,58	(7600)	5—6	92

Алюмосиликатные (Гунделакс)	ГДР	86—100	(5в2)
Мягкие свинцовосиликатные. .			
0 (1953) . . .	Англия	87	470
0	Польша	93	(455)
KS	Чехословакия	92	445
PN	»	86	550
	»	82	580

Примечание. Цифры в скобках получены расчетным путем.

Табл. 4 — [illegible] нительная характеристика стеклянных и фарфоро

[illegible]	Единица измерения	М П-4,5 стекло	М П-4,5 фарфор
[illegible] высо[illegible]	мм	120	170
Наибольший диаметр	мм	255	270
Допустимый вес	кг	4,0	6,4
Вес изолирующей детали	кг	2,3	3,9
Вес шапки	кг	1,0	1,7
Электромеханич. минимальная разрушающая нагрузка	т	9,0	7,0
Пробивная прочность	кв	135	110
Термостойкость	°С	120	70

[illegible] ричается в от[illegible] личие от дру[illegible] полимеров и [illegible] ние T_g в свя[illegible] при механиче[illegible] ниях.

При охла[illegible] если не прои[illegible] людается обы[illegible] характерное

Note: The figures in parentheses were obtained by calculation.

*$TK-100$ is the temperature at which the deep resistance of the glass equals 10^9 ohm·cm.

1) Type of glass; 2) old; 3) new; 4) density (g/cm^3); 5) modulus of elasticity E (kg/mm^2); 6) ultimate strength (kg/mm^2); 7) on extension;

8) on compression; 9) thermal conductivity λ (cal/cm·sec·°C) over the temperature range 20-100°; 10) coefficient of linear expansion $\alpha \cdot 10^7$ (1/°C) over the temperature range 20-200°; 11) softening initiation temperature (°C); 12) heat resistance (°C); 13) annealing-temperature range; 14) minimum; 15) maximum; 16) tg $\delta \cdot 10^4$ at 20° and 6 mc; 17) dielectric permeability ε; 18) metal fused with glass; 19) chemically stable hydrolytic flask; 20) P-15; 21) 3S-9; 22) 3S-11; 23) 3S-8; 24) 3S-5K; 25) 3S-5; 26) 3S-4 (No. 12); 27) BD-1; 28) S; 29) tungsten; 30) the same; 31) molybdenum, kovar; 32) platinum, platinite.

TABLE 2

Characteristics of Insulator Glasses Used for Glass Insulators

1 Обозначение стекла	2 Плотность (г/см³)		3 Модуль упругости (кг/мм²)		4 Тангенс угла диэлектрических потерь при				5 Средняя электрическая прочность (кв/мм)		6 Удельное объемное сопротивление		7 Глубинное сопротивление при 20° (ом·см)	8 Поверхностное сопротивление при 65% относительной влажности (омы)	9 Предел прочности при изгибе (кг/см²)	10 Микротвердость (кг/мм²)	11 Температура начала размягчения	12 Коэффициент теплопроводности (ккал/м·час·°С) в интервале температур 700-350°	13 Теплоемкость (ккал/кг·°С) в интервале температур 25-360°
					20°		90°												
	1	2	1	2	1	2	1	2	1	2	1	2							
14) Стекло завода имени Дзержинского	2,4—2,5		6800		4,5	6,5	—	—											
15) Стекло Львовского завода № 1	2,5		6800		6,0	7,3	42,8	58,2											
Малощелочное № 13-в (ГИС)	2,55—2,60		7500		2,0	3,0	7—10	—											
17) Барийборосиликатное № 24	3,58		—		3,0	—	3,0	—											
18) То же, № 19	3,30		—		3,0	—	—	—											

ышения механич. и термич. стойкости стеклянных изоляторов их подвергают закалке, однако это повышает электропроводность стекла. Стеклянные изоляторы обладают рядом преимуществ по сравнению фарфоровыми. Так, напр., стеклянный изолятор ПС-4,5 легче фарфорового изолятора П-4,5 приблизительно на 40%, что позволяет уменьшить его размеры по высоте на 25% и значительно сократить высоту линий электропередач. Изоляторы из стекла № 13-в имеют более благоприятные в-ва по электрофизич. показателям и механич. прочности. Из СЭИ вырабатывают телеграфные изоляторы ТС-2, ТС-3 и электрич. высоковольтные изоляторы (штыревые ПС-3 и ПС-10, опорные ОБ-6 и ОА-10

ния, по температ сти и др. терм зависящих от с ратурной завис ка выше и ниже рости охлажде

При воздейст обнаруживает вязкотекучее, в отвердое. При чала происходи в высокоэластич лообразное (уп следнее состоян темп-ры структ тем выше, чем С Механич. с. т

Note: 1) Annealed glass; 2) quenched glass. The figures in parentheses were obtained by calculation.

1) Type of glass; 2) density (g/cm^3); 3) modulus of elasticity (kg/mm^2); 4) tangent of angle of dielectric loss at; 5) mean breakdown strength (kv/mm); 6) specific resistance; 7) deep resistance at 20° (ohm·cm); 8) skin resistance at 65% relative humidity (ohms); 9) ultimate bending strength (kg/cm^2); 10) microhardness (kg/mm^2); 11) softening initiation temperature (°C); 12) coefficient of thermal conductivity (kcal/m·hr·°C) over the temperature range 700-350°; 13) heat capacity (kcal/kg·°C) over the temperature range 25-360°; 14) glass produced by plant imeni Dzerzhinskiy; 15) glass produced by L'vov Plant No. 1; 16) low-alkali No. 13-v (GIS); 17) barium-borosilicate No. 24; 18) the same, No. 19.

Vacuum glasses should also have good adhesive characteristics with respect to metal, since reliable fusion of glass and metal can be obtained only if the former thoroughly wets the surface of the latter. In order to improve the adhesion of glass to metal its surface tension must be reduced by adding small quantities of As_2O_3, V_2O_5, MoO_3, etc. A device fabricated from vacuum glass can function reliably for extended periods only if a vacuum of 10^{-4}-10^{-5} mm Hg is maintained in its cavity. In this connection vacuum gases should exhibit as little evolution of gas

TABLE 3

Certain Characteristics of Foreign Vacuum Glasses

Сорт стекла (1)	Страна (2)	Коэффициент линейного расширения $\alpha \cdot 10^7$ (1/°C) до 300° С (3)	Температура начала размягчения (°С) (4)
Е (5)	Чехословакия (12)	54	730
Суперманс (6)	ГДР (13)	33—40	(775)
Твердые боросиликатные (Викор) (7)	США (14)	8	930
То же (Пирекс) (8)	»	33—35	650
7740	»	32	820
7720	»	36	755
7050	»	46	703
Дюран (9)	ГДР	34	(640)
1646	»	42	(600)
Алюмосиликатные (Гунделакс) (10)	ГДР	86—100	(582)
Мягкие свинцовосиликатные. (11)	Англия (15)	87	470
0 (1953)	Польша (16)	93	(455)
0	Чехословакия	92	445
KS	» (12)	86	550
PN	»	82	580

Note: The figures in parentheses were obtained by calculation.

1) Type of glass; 2) country; 3) coefficient of linear expansion $\alpha \cdot 10^7$ (1/°C) at temperatures of up to 300°C; 4) softening initiation temperature (°C); 5) E; 6) supermax; 7) hard borosilicate (Vicor); 8) the same (Pyrex); 9) Duran; 10) aluminosilicate (Gundelax); 11) soft lead-silicate; 12) Czechoslovakia; 13) German Democratic Republic; 14) USA; 15) England; 16) Poland.

TABLE 4

Comparison of Glass and Porcelain Suspension Insulators

Основные показатели (1)	Единица измерения (2)	Марка изоляторов (3)					
		П-4,5 (4)		П-8,5 (7)		П-11 (8)	
		стекло (5)	фарфор (6)	стекло	фарфор	стекло	фарфор
Строительная высота (9)	мм	120	170	160	204	170	215
Наибольший диаметр	мм	255	270	270	320	270	350
Полный вес (11)	кг	4.0	6.4	8.5	12.3	6.8	14.2
Вес изолирующей детали (12)	кг (17)	2.3	3.9	3.0	6.5	3.7	8.5
Вес шапки (13)	кг	1.0	1.7	1.8	3.1	2.0	4.0
Электромеханич. минимальная разрушающая нагрузка (14)	т (18)	8.0	7.0	15.0	11.0	18.0	14.5
Пробивная прочность (15)	кв (19)	175	110	135	125	135	125
Термостойкость (16)	°С	120	70	120	70	120	70

1) Basic characteristics; 2) unit of measurement; 3) type of insulator; 4) P-4.5; 5) glass; 6) porcelain; 7) P-8.5; 8) P-11; 9) structural height; 10) greatest diameter; 11) total weight; 12) weight of insulating component; 13) weight of cap; 14) minimum electromechanical frac-

ture load; 15) breakdown strength; 16) heat resistance; 17) kg; 18) t; 19) kv.

as possible. Degasification is carried out by heating and simultaneous evacuation of gases from the cavity of the device. Among the most important drawbacks of vacuum glasses are their tendency toward electrolysys, a process during which the layer directly adjacent to the cathode is enriched with alkali metal and a layer with an elevated silica content develops near the anode. As a result, the glass loses its homogeneity and the coefficient of thermal expansion in the region bounding the metal is altered. One layer of the glass becomes less conductive and the others more conductive, which often leads to rupture of the envelope. Gases are liberated during electrolysis and these reduce the vacuum in the device. This tendency toward electrolysis can be reduced by employing glass with a high specific resistance, by increasing the distance between the fused joints in the device, or by using heat-shielding screens and artificial cooling. Table 1 shows the characteristics of Soviet vacuum glasses.

Table 2 shows the characteristics of electrical-insulating glasses used in the manufacture of glass insulators.

Insulator glasses are distinguished by reliable electrical-insulating, thermophysical, and mechanical characteristics and high specific resistance. Alkali-free, aluminosilicate, and borosilicate glasses have such properties. Despite their high electrophysical indices, borosilicate glasses are not widely employed, since they contain the scarce compound B_2O_3 and are consequently expensive. Low-alkali aluminosilicate insulator glasses, particularly No. 13-v in the USSR, are the most widely employed. This glass is used in the manufacture of insulators for high-voltage transmission lines. High-voltage insulators can also be fabricated from ordinary alkali silicate glasses, but these are

suitable only for indoor installations, where they are not exposed to humid air and sharp temperature fluctuations. Glass insulators are quenched to increase their mechanical and thermal stability, but this raises their conductivity. Glass insulators have a number of advantages over porcelain insulators. Thus, for example, glass insulators of type PS-4.5 are approximately 40% lighter than porcelain insulators of type P-4.5, which permits a reduction of 25% in insulator height and a substantial decrease in transmission-line height. Insulators of No. 13-v glass have more favorable electrophysical characteristics and a higher mechanical strength. Insulator glasses are used in the manufacture of TS-2 and TS-3 telegraph insulators and high-voltage electrical insulators (ShS-6 and ShS-10 shaft insulators, OB-6 and OA-10 bracket insulators, and PS-4.5, PS-8.5, PS-11, and PS-16 suspension insulators). Table 3 shows certain of the characteristics of foreign vacuum glasses.

A comparison of the characteristics of glass and porcelain suspension insulators is made in Table 4.

G.G. Sentyurin

ELECTRONIC GLASS TEXTOLITE – laminated sheet materials manufactured by pressing layered glass electrical-insulating cloth impregnated with polymer binders. The glass insulating cloth is produced from alkali-free glass fiber, (with an alkali content of less than 0.7%). The initial glass cloth is often subjected to special thermochemical processing in order to increase the insulating characteristics of the glass textolite. Phenol-formaldehyde, melamine, epoxy, and silicoorganic resins and polytetrafluorethylene are used as binders. Glass textolites with good insulating characteristics contain 40-45% resin. These materials can function for prolonged periods (10 years) at 130-180°, limited periods (200 hr) at 180-200°, and brief periods at 250°, depending on the type of binder (polyamide, polycarbonate, etc.).

In manufacturing electronic glass textolite the glass cloth is impregnated with a resin solution, dried, and cut into sheets; a definite number of layers of glass cloth is assembled into a packet and pressed under a pressure of 25-150 kg/cm^2. These materials are subjected to heat treatment in certain cases. Electronic glass textolites based on phenol-formaldehyde resins have a working temperature of 130-150° and are employed at comparatively low voltages when a higher mechanical strength than that of getinaks or textolite is required. Type STU glass textolite is produced from glass cloth with a structure that ensures a material with virtually the same cracking resistance as getinaks. Type SVFE-2 glass textolite, which is based on a phenol-formaldehyde resin modified with tetraethoxysilane has a higher heat resistance. Electronic glass textolites based on melamine resins are intend-

III-130s1

Characteristics of Electronic Glass Textolite (actual data)

Показатели 1	Тип смолы (связующего)						
	фенолоформальдегидная 2		меламиновая 4	эпоксидно-фенольная 5	кремнийорганическая 6		политетрафторэтиленовая 7
	Марка стеклотекстолита						
	СТ 9	СТУ 10	без марки 11	СТЭФ 12	СКМ-1 13	СТК-41 14	без марки
15 Предел прочности (кг/см²): при растяжении	1100—2450	1500	1400—2450	2200—2500	2100	2500	630
16 при изгибе	1750—2200	1200—1500	1400—3500	3500—5000	1400	800	—
17 Удельная ударная вязкость (кг·см/см²)	50	250	30—55	160—300	60	—	—
19 Удельное объемное электросопротивление (ом·см)	10^{10}—10^{12}	10^{12}	10^{12}	10^{13}—10^{14}	$5\cdot10^{13}$	10^{14}	—
20 Тангенс угла диэлектрич. потерь при 10^6 гц	0,02—0,06	—	0,01—0,06	0,02—0,05	0,003—0,006	0,002*	0,0002
21 Электрич. прочность перпендикулярно слоям (кв/мм)	10—12	14	8—12	25	11	20	16
22 Теплостойкость по Мартенсу (°С)	185	200	—	200	215	250	—
23 Водопоглощение за 24 часа (%)	0,3—0,6	—	0,3	0,1	0,1—0,5	0,1—0,35	0,01

*At 50 cps.

1) Characteristic; 2) type of resin (binder); 3) phenol-formaldehyde; 4) melamine; 5) epoxy-phenolic; 6) silicoorganic; 7) polytetrafluorethylene; 8) type of glass textolite; 9) ST; 10) STU; 11) undesignated; 12) STEF; 13) SKM-1; 14) STK-41; 15) ultimate strength (kg/cm^2); 16) on extension; 17) on bending; 18) impact strength ($kg\cdot cm/cm^2$); 19) deep electrical resistance (ohm·cm); 20) tangent of angle of dielectric loss at 10^6 cps; 21) breakdown strength perpendicular to layers (kv/mm); 22) Martens thermostability (°C); 23) water absorption over 24 hr (%).

ed for operation at 150° and are used in cases where arc resistance and a refractory character are required (e.g., in the manufacture of spark-extinction sheaths). They have a higher water resistance than textolites based on phenol-formaldehyde resins. Electronic glass textolites based on silicoorganic resins are employed for prolonged operation at temperatures of up to 180°. They are characterized by increased water resistance and low dielectric losses. The tangent of the angle of dielectric loss and the dielectric permeability of these materials vary little over a wide frequency range or at elevated temperatures. The principal drawback of electronic glass textolites based on silicoorganic resins is their comparatively low breakdown strength, which is further reduced

by heating. Glass textolites based on polymethylsiloxane resins have a high spark and arc resistance; textolites based on polytetrafluorethylene have low dielectric losses. Glass textolites based on silicoorganic resins are employed in electric motors, stack transformers, containers, and marine and aviation instruments. Electronic glass textolites based on silicoorganic and epoxy resins and coated with copper foil are used as printed-circuit bases. Most electrical-insulating components manufactured from glass textolites are produced by machining and only a small number of comparatively large glass-plastic components based on polyester and epoxy resins are produced by forming.

B.A. Kiselev

ELECTRON-OPTICAL X-RAY CONVERTER – is vacuum device used to convert the nonvisible part of x-ray of gamma ray images into a visible one by means of electron conversion and subsequent amplification; this results in an increase of the brightness of the initial visible image by 1000 or more times. The electron-optical x-ray converter is used in flaw detection by means of x- or gamma-rays (visual method). The x-ray beam or gamma-ray beam, collimated by a lead diaphragm, passes the object to be tested and falls on to the fluorescent screen of the electron-optical x-ray converter, causing the luminescence of the screen. The light image causes the emission of electrons in the photocathode of the electron-optical x-ray converter; this cathode being immediately contacted with the screen, and the light image being in this way converted into an electron image. The electron beam is accelerated by the applied voltage (about 20-25 kv) and is focused by means of an electrode system on the second screen, the output fluorescing screen having a considerably smaller area (50-100 times). In comparison to the initial image, the brightness of the image caused by the electron bombardment is increased on the output screen as well as by the increase of the kinetic energy of the electrons in the accelerating field, as by the concentration of the electron beam on a smaller area. The image on the output screen is examined by means of a trihedral prism and a magnifying optical device which allow the checked object to be inspected in the full or magnified size. The control results may be recorded photographically.

L.K. Tatochenko

ELECTROSTATIC METHOD OF FLAW DETECTION – is a complex of methods based on the utilization of various electrostatic phenomena. The electrostatic powder method is one of the principal methods used to detect surface cracks or other dicontinuities in objects of nonelectric conducting materials (porcelain, glass, ceramics, plastics, etc.).

The previously degreased surface of the objects to be checked is covered by an inogenic fluid (for example, by a 0.25-0.5% aqueous solution of the "wetting agents" SV-1057 or SV-1019), then, electrified dust (chalk powder) is sprinkled on the surface. The loaded powder particles interact with the ions of the fluid, which has penetrated into the hollow of the flaw, and accumulate on its edges, which fact allows the flaw to be detected. Wetting with an ionogenic fluid is not necessary when the checked object section has a metallic base layer. The accumulation of the powder above the flaw is caused in this case by the stronger interaction of the loaded particles with the metallic base on the discontinuities. An atomizer with an ebonite nozzle is used to spray and electrify the dust. The powder particles become electrified by friction on the nozzle walls.

X-ray flaw detection by means of xerographic image recorders is one of the methods of electrostatic flaw detection. Metal plates covered with a thin photoconductor layer (selenium, for example; the plate is termed xerographic plate) are used in this case instead of an x-ray film (see Xerographic x-ray and gamma-ray flaw detection). Before exposition, the photoconductor layer is uniformly loaded in a direction normal to the plate surface. The conductivity of the material in the

layer increases under the action of the x-rays, and the discharge process is accelerated. The higher the intensity of the x-ray irradiation, the higher the discharge rate. Therefore, an "electric image" of the checked object is formed on the xerographic plate during the transillumination, and the thin section on the object (including discontinuities) correspond to the more discharged parts on the plate. The development of the electric image is carried out by spraying electrified dust on the plate; the particles of the dust accumulate more intensely on the sections which have maintained a higher load. The triboelectric method of flaw detection used in the sorting of objects and semifinished products belongs also to the electrostatic methods of flaw detection.

References: Kornishin, K.I., "Zavodskaya laboratoriya," 1963, Vol. 29, No. 1; the same, Kserograficheskiy metod polucheniya izobrazheniy pri rentgenovskoy defektoskopii [Xerographic Method of Production of Images in the X-Ray Flaw Detection], Moscow, 1959.

S.M. Rozhdestvenskiy

ELECTROTECHNICAL CERAMICS – are ceramic materials destined for electrical insulation in low- and high-voltage circuits for currents

TABLE

Basic Properties of Electrotechnical Porcelain

1 Показатели	2 Фарфор	
	3 низковольтный	4 высоковольтный
5 Объемный вес ($г/см^3$)	2.2–2.4	2.3–2.5
6 Предел прочности ($кг/см^2$):		
7 при сжатии	3000–4000	4000–5000
8 при разрыве	200–300	250–350
9 при статич. изгибе (глазурованный образец)	500–800	600–900
10 при динамич. изгибе	1.5–2.2	1.7–2.5
11 Модуль упругости ($кг/мм^2 \cdot 10^6$)	0.5–0.7	0.6–0.8
12 Коэфф. линейного расширения ($(20–200°) \alpha \cdot 10^{-6}$)	5.0–6.5	5–6.5
13 Теплопроводность ($ккал/м \cdot час \cdot °C$)	0.8–1.2	1.0–1.2
14 Удельное объемное сопротивление (20°) ($ом \cdot см$)	10^{12}–10^{14}	10^{12}–10^{14}
15 Удельное поверхностное сопротивление (ом)	10^{12}–10	10^{12}–10^{4}
16 Диалектрич. проницаемость при частоте 50 гц	–	5.5–7.5
17 Тангенс угла диалектрич. потерь при частоте 50 гц	0.025–0.060	–
18 Электрич. прочность при частоте 50 гц ($кв/мм$)	15–25	25–28

1) Characteristics; 2) porcelain; 3) low-voltage; 4) high-voltage; 5) weight by volume (g/cm^3); 6) ultimate strength (kg/cm^2); 7) at compression; 8) at stretching; 9) at static bending (glazed specimen); 10) at dynamic bending; 11) modulus of elasticity ($kg/mm^2 \cdot 10^6$); 12) coefficient of linear expansion (20-200°), $\alpha \cdot 10^{-6}$; 13) heat conductivity ($kcal/m \cdot hr \cdot °C$); 14) specific volume resistance (20°) ($ohm \cdot cm$); 15) specific surface resistance (ohm); 16) dielectric constant at 50 cps; 17) tangent of the loss angle at 50 cps; 18) electric strength at 50 cps (kv/mm).

with commercial frequency (50 cps). Porcelain and its varieties are the main material for electrotechnical ceramics. They are subdivided into low-voltage and high-voltage ceramics. The former are used at voltages up to 500 v and are termed installation ceramics. High-voltage ceramics

are destined for currents from 1 to 500 kv. According to the purpose, the ceramics are subdivided into insulators: insulators for leads (suspension and bracket insulators); for stations (supporting, suspended bracket, and bushing insulators); and apparatus insulators (supporting, supporting-backet, bushing and lead-in insulators).

The industry produces a large number of insulators of diverse types and sizes. The requirements of the electric porcelain depend on the type of the insulator and of its working conditions, according to GOST 2366-49, 6256-52, 8608-57, etc. The Table on page 376 gives the main properties of electrotechnical porcelain.

V.L. Balkevich

ELEKTRON – is an obsolete term for magnesium-based alloys (see Magnesium-alloys).

The firm I.G. Farbenindustrie has manufactured the magnesium alloy grades AM503, AZ-31, AZG, A9V, etc., under the name Elektron; these alloys corresponding almost to the Soviet alloys ML2, ML4, and ML5.

A.A. Lebedev

ELEKTRONIT (TU MKhP 3485-58) – is an electric insulating material used as an insulation in electric machines and apparatuses working at voltages of up to 600 v. It is obtainable in sheets with a 300 x 400-1500 x 1200 mm dimension, and 0.2-3.0 mm thickness. The specific gravity is 1.5-1.8. The electric strength is not less than 7 kv/mm; the water absorption within 24 hours is not higher than 7% of weight; the calcination loss (at 100°) is not higher than 32%; the tensile strength of an 1 mm thick elektronite is not less than 1.4 kg/cm^2 along the sheet. Elektronite is plastic, it is easily stampable and doesnot deform during long-time storage, it does not change its properties under mechanical effects. Elektronite is composed of asbestos fiber and synthetic rubber and is a heatproof material which is suitable to insulate electric equipment of the classes B and BC. Elektronite resists bacteria and molds and is efficiently used in electric equipment being used in the tropics Elektronite is used as a substitute in electric insulating materials of mica, varnish and glass fabrics; and it is used in the manufacture of insulating terminal plates of the stator and rotor cores of asynchronous electric engines working under normal, sea and tropical conditions with an insulation of the classes A, AB, and C and for interphase packings in the end winding, etc. The use of elektronite in the motor-starting devices of cranes, in the insulation of the tightening dowels and as a high-quality interlayer between the elements, where micanite was used previously, has proved to be of a high economical and technical efficiency.

N.T. Dodonov

ELEKTRONIT COMPOSITION (Asbodin) (TU MKhP 4109-53) – is a material composed of chrysotil asbestos fibers and active fillers bonded by synthetic resin. It is widely used for the hot molding of parts of electric machines and apparatuses working under normal, sea and tropical conditions. The solvent content (gasoline) is not higher than 1%. The calcination loss is not more than 32% at 700-800°. Elektronit composition objects have a high mechanical strength, heatproofness and sufficient dielectric characteristics; they are moisture-proof and resistant to mold; they may substitute parts made of vulcanized fiber, glass-textolite, plastics with organosilicon binder and other electric insulating materials. The main characteristics of objects made of elektronit composition are as follows: specific gravity 1.9-2.0; specific impact resistance not less than 10 $kg \cdot cm/cm^2$; static bending strength not less than 600 kg/cm^2; water adsorption not more than 0.5%; heatproofness according to Martens not less than 200°; arc-proofness at a 10 mamp current not shorter than 60 sec; electric strength not less than 6 kv/mm; specific surface resistance being 10 ohm.

N.T. Dodonov

Manuscript Page No.

[Transliterated Symbols]

1356 ТУ МХП = TU MKhP = tekhnicheskiye usloviya ministerstva khimicheskoy promyshlennosti = Technical Specifications by the Ministry of Chemical Industry

ELINVAR – is an alloy with a temperature coefficient of the modulus of elasticity close to zero (up to the Curie point). The temperature coefficient of the mudulus of elasticity is expressed by the equation $\gamma = 1/E \cdot dE/dt$, where E is the modulus of elasticity, and $\underline{t}$ is the temperature. Elinvar is used in the production of tuning forks, springs, hair springs for watches, and other pieces which must have resilient properties not depending on the temperature. The chemical composition of foreign alloys of the elinvar type is quoted in the Table. With regard to the type of alloying, the elinvar is divided as follows into: carbide-containing elinvar with the addition of carbon (up to 1%) and carbide forming elements (W, Mo, and others) in order to increase the hardness; and dispersion-hardening elinvar with intermetallide hardeners, such as additions of Be, Ti, and Al (the intermetallic compounds NiBe, Ni_3Ti, and Ni_3Al acting as hardeners). From the alloys of the elinvar type, quoted in the Table, the first three belong to the carbide-containing ones, the others are dispersion-hardening alloys. The carbide-containing elinvar obtains a high hardness only after hammer hardening (shrinkage by 90% and more) and following annealing, a fact which encumbers the production of complexly shaped pieces. A disadvantage of the dispersion-hardening elinvar is the strong effect of the annealing temperature on the temperature coefficient of the elasticity modulus.

The Soviet industry produces the dispersion-hardening elinvar grades N41KhT and N43KhT, and the carbide-containin elinvar grades N35KhMV, N34KhGV (EI 574) and N35KhV (EI 278). The alloy N35KhMV possesses the best properties, providing a temperature fault of a "hairs

balance" pair of not more than 0.5 sec per degree and day.

Chemical Composition of Alloys of the Elinvar Type

1 / Сплав	2 Содержание элементов (%)							
	C	Si	Mn	Ni	Cr	Ti	Fe	3 др. элементы
4 Элинвар	0,7—0,8	0,5	2—3	33—35	7—9	—	остальное	W 4,0
Метелинвар	0,6	0,5	1,8—2,2	39—41	5,5—6,5	—		W 2,5—3,5, Mo 1,5—1,7
5 Изоэластик 6	0,6—0,7	0,9—1,1	0,4—0,8	35—37	7,5—8,5	—		Mo 0,6—1,0
7 Ниспен С	0,05	0,3—0,6	0,3—0,6	41—43	5,1—5,7	2,2—2,6		Al 0,4—0,8
Дюринваль 8	0,05	—	1,9—2,1	40—42	—	2,1—2,3		Al 1,9—2,1
9 Нивароис N	0,05	0,1—0,3	0,6—1	36—38	—	1,9—2,1		Be 0,9—1,1
Нивароис СТ	0,05	0,1—0,3	0,6—1	30—32	8—10	0,9—1,1		Be 0,9—1,1
10 Контраацид Be	0,05	0,5	1,5—2,5	59—61	14—16	—		Be 0,55—0,75, Mo 6—8

1) Alloy; 2) percentage of elements; 3) other elements; 4) Elinvar; 5) Metelinvar; 6) Isoelastic; 7) Nispen; 8) Durinval; 9) Nivarox; 10) Contraacid; 11) the rest.

References: Livshits, B.G., Fizicheskiye svoystva metallov i splavov [Physical Properties of Metals and Alloys], Moscow, 1959; Pretsizionnyye splavy [Precision Alloys], Moscow, 1956-59 (Sbornik trudov TsNIIChM [Collection of Transaction of the Central Scientific Research Institute of the Ferrous Metallurgy], Nos. 15, 22); Smolyarenko, D.A. and Kaplan, A.S., "Standardizatsiya" [Standardization], 1959, No. 3, page 13.

B.G. Livshits and A.A. Yudin

ELOXATION OF ALUMINUM ALLOYS — is the electrochemical oxidation of aluminum alloys in order to obtain opague enamel-like films of a milky color. The decorative properties of the films are achieved by introduction of the hydroxides of titanium, throium or zironcium, formed by the hydrolysis of their salts, into the anodic film during anodization. The coatings possess a high resistance to corrosion and wear, a high dielectricity constant, and they are nontoxic. The thickness of the obtained filsm is 12-18 microns. The coatings may be colored by organic dyestuffs.

The series of alloys which are capable of being eloxated includes deformed AD-1 alloys, plated D16 Duralumin, AV, AMg, and other low-alloys containing magnesium, manganese and silicon. A dark grayish-brown or black film as formed respectively on alloys of the Duralumin and Silumin type.

The preparation of the surface is carried out in the same way as in the case of anodizing.

The composition of the electrolytes and the working conditions of the eloxation are quoted in the Table.

One of the electrolytes, which is used in industry, contains oxalic, boric, and citric acids, and titanium-potassium oxalate. The electrolyte is prepared from distilled or softened water. The citric acid makes the film tight. The boric acid is a buffer admixture. Aluminum or carbon cathodes covered with glass fabric are used. The bath for the eloxation of aluminum alloys is made of viniplast, enameled iron, or stainless 1Kh18N9T steel.

Composition of Electrolytes and Characteristics of the Eloxation of Aluminum Alloys

1 Компоненты электролита и параметры режима (%) /	2 Номера процессов						
	I	II	III	IV	V	VI	VII
3 Двойная щавелевокислая соль калия и титана [1]	5,0	—	—	—	4,0	—	—
4 Двойная сернокислая соль калия и титана [1]	—	2,2	—	—	—	—	—
5 Двойная щавелевокислая соль натрия и циркония [1]	—	—	2,0	—	—	—	—
6 Двойная щавелевокислая соль аммония и тория [1]	—	—	—	2,0	—	—	—
7 Сернокислая соль циркония (в пересчете на ZrO_2)	—	—	—	—	—	5,0	—
8 Щавелевокислая соль циркония (в пересчете на ZrO_2)	—	—	—	—	—	—	3,0
9 Кислота:							
10 лимонная	1,5	2,5	—	2,0	0,1	—	—
11 фосфорная	0,6	—	—	—	—	—	—
борная 12	—	—	2,0	—	0,8	—	—
щавелевая 13	—	—	—	—	0,1	—	8,5
серная 14	—	—	—	—	—	7,5	—
уксусная 15	—	—	—	—	—	—	4
16 Щавелевокислая соль калия	—	0,2	—	—	—	—	—
Бура кристаллическая	—	—	2,0	2,0	—	—	—
18 Глюкоза	2,0	—	—	—	—	—	—
19 Глицерин	—	1,3	—	2,5	—	—	—
20 Декстрин	—	—	0,5	—	—	—	—
21 Анодная плотность тока ($a/дм^2$)	5	7	[2]	[2]	[2]	8	5
22 Напряжение (в)	110	120	120	120	[3]	18	40
23 Температура (°C)	25	45	70	70	55	35	45
24 Выдержка (мин.)	—	—	2	3	30—60	30	45
25 Количество электричества ($a \cdot ч/дм^2$)	2,5	1,5	—	—	—	—	—
26 Ток	Переменный	Постоянный	Постоянный	Постоянный	Постоянный	Постоянный	Постоянный
	27	28	28	28	28	28	28

*Crystallizes with two water molecules.

**The process is carried out until the initial current density (6 amp/dm^2) drops to the half (at constant voltage).

***The same, at an initial current density of 3.5 amp/dm^2.

****The voltage rises during the first 10 minutes from 60 to 100 v, after which the current density (3 amp/dm^2) begins slowly to drop.

1) Electrolyte components and treatment characteristics; 2) number of processes; 3) potassium and titanium dioxalate*; 4) potassium and titanium disulfate*; 5) sodium and zirconium dioxalate*; 6) ammonium and thorium dioxalate*; 7) zirconium sulfate (on conversion to ZrO_2); 8) zirconium oxalate (on conversion to ZrO_2); 9) acid; 10) citric; 11) phosphoric; 12) boric; 13) oxalic; 14) sulfuric; 15) acetic; 16) potassium oxalate; 17) crystalline borax; 18) glucose; 19) glycerol; 20) dextrin; 21) anodic current density (amp/dm^2); 22) voltage (v); 23) temperature (°C); 24) time of the treatment (min); 25) quantity of electricity (amp·hr/dm^2); 26) current; 27) a-c; 28) d-c.

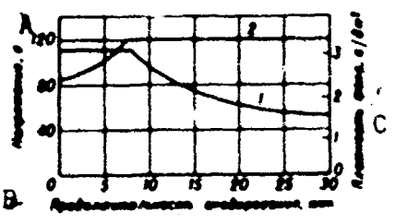

Fig. 1. Change of the current density and the voltage during the eloxation process: 1) Current density; 2) voltage. A) Voltage, v; B) period of anodizing, minutes; C) current density, amp/dm^2.

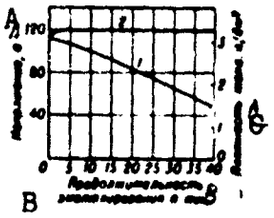

Fig. 2. Voltage and current density as a function of the eloxation period of the V95 alloy: 1) Current density; 2) voltage. A) Voltage, v; B) period of eloxation, minutes; C) current density, amp/dm^2.

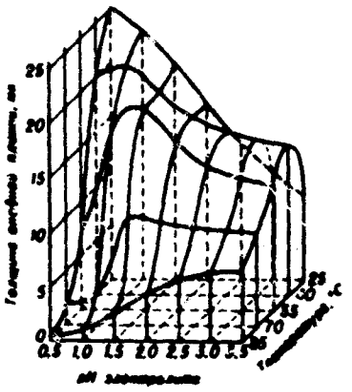

Fig. 3. Growth of the anodic film in a 4% titanium-potassium oxalate solution acidified by oxalic acid, as a function of the pH and the temperature of the electrolyte. The current density is 2 amp/dm^2; the anodizing period is 40 min, at d-c with a voltage of up to 120 v.

During the eloxation of aluminum alloys, the electrolyte is stirred by means of compressed air. The control of the process is carried out by controlling the voltage. The current density is equal to 3 amp/dm^2 at an inital voltage of 80 v. Then the voltage is increased within 5-10 minutes to 120 v and is kept constant until the end of the process (Fig. 1). The current density drops gradually during this time. In the case of alloys with a high content of zinc, copper, and also magnesium, the current density drops to the half of the initial value (Fig. 2) or it remains constant. The eloxation of aluminum alloys lasts 30-40 minutes. During the first 30 minutes of the eloxation, the thickness of the film grows rather quickly, then the growth of the film is decelerated, and after 50 minutes eloxation, it is almost stopped.

The thickness of the anodic film depends considerably on the pH and the temperature of the electrolyte (Fig. 3). At a reduced temperature of the electrolyte, the milky-gray color of the film turns to dingy-green. 2.5 g titanium salt, 0.5 g oxalic acid, and 0.4 g boric acid are consumed for the eloxation of 1 dm^2 aluminum surface. 0.1 g/liter aluminum is dissolved during the process. The maximum permissible aluminum content of the electrolyte is 30 g/liter.

The breakdown voltage of the film on specimens kept at 250° for three hours, was within 0.30-0.70 kv in the case of a 50 cps alternating current.

After the eloxation, the film is tightened for 20-30 minutes in distilled water heated at 95-100°. When the parts are to be colored by adsorption, the tightening then is carried out after the coloring.

The eloxation of aluminum alloys may also be carried out in electrolytes based on chromium anhydride with additions of oxalic, boric, and phosphoric acids. White and grayish-yellow colored films are formed when the anodizing is carried out at a-c.

Eloxized objects are resistant to organic solvents, mineral and organic fats and oils, and also to foodstuffs. The coating is not destroyable by thermal shocks.

Eloxation is carried out on dishware, illumination engineering equipment, medical instruments, shop equipment, parts of coolers, accessories, parts of building constructions, etc.

References: Bogoroditskaya, V.A., Ematalirovaniye alyuminiya i yego splavov v shchavelekislom elektrolite [Eloxation of Aluminum and Its Alloys in an Oxalic Electrolyte], Leningrad, 1960 (Leningr. dom nauch.-tekhn. propagandy. Ser "Zashchytnyye pokrytiya" [Leningrad House for Popularization of Scientific and Engineering Progress. Series "Protective Coatings", No. 6); Gracheva, M.P. and Grinberg, A.M.,

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Zashchitno-dekorativnyye plenki na alyuminii [Protective and Decorative Films on Aluminum], "Mashinostroitel' [Mechanical Engineer], 1961, No. 5; Shreyder, A.V., Oksidirovaniye alyuminiya i yego splavov [Oxidation of Aluminum and Its Alloys], Moscow, 1960; Vernick, S. and Pinner, R., Khimicheskaya i elektroliticheskaya obrabotka alyuminiya i yego splavov [Chemical and Electrolytical Treatment of Aluminum and Its Alloys], translated from English, Leningrad, 1960; Schenk, M., Werkstoff Aluminum and seine anodische Oxydation [The Material Aluminum and Its Anodic Oxidation], Bern, 1948; HÜbner, W.W.G. and Schildknecht, A., Die Praxis der anodischen Oxydation des Aluminiums [Practice of the Anodic Oxidation of Aluminum], 2nd Edition, DÜsseldorf, 1961.

Ye.M. Zaretskiy

EMERALD – see Beryl.

EMERY is a fine-grained mineral of black and black-green color containing a considerable amount of the hard mineral corundum which is used as an abrasive material. We differentiate the following varieties of emery: 1) chloritoid-corundum emery with corundum content from slight to 40-70%; 2) magnetite and spinel-magnetite emergy with corundum content to 30-40%; 3) diaspore-corundum emery with Al_2O_3 content from 40 to 65% and more. A salient feature of emery as an abrasive material is the presence of low-melting impurities, in connection with which emery may be used only in articles which do not require high temperatures for fabrication (using cold bonding). In emery the most important characteristic of the abrasive materials — abrasive capability — depends primarily on the corundum content and is highest (for the Soviet raw materials) for the chloritoid ores of the Ural deposits, but is lower by a factor of 2-3 than for the high-quality corundum ores. Emery is used in flexible discs (felt base) primarily for grinding noncritical metallic articles. In addition, using a binder made of Sorel cement, emery is sometimes used to fabricate synthetic grinding stones, special polishing stones for file-making plants, pulping mill rolls (for pulverizing wood); emery powders are used to prepare abrasive paper which finds various application in industry and the home. Emery is most effective in working metals of low hardness (untempered steel, iron, nonferrous metals), where it gives a flatter and smoother surface than corundum. Particularly smooth surfaces are obtained with the use of chloritoid emery. Primarily coarse powders are produced — grinding powder with particle diameter of the main fraction 90 microns and

over (No. 90 and over per GOST 3647-59).

References: Nemetallicheskiye iskopayemyye SSSR (Nonmetallic Minerals of the USSR), collection of articles, Vol. 1, Moscow-Leningrad, 1936; Trebovaniya promyshlennosti k kachestvu mineral'nogo syr'ya (Industry Requirements on Quality of Raw Materials), No. 37 – Koyfman M.I., Korund i nazhdak (Corundum and Emery), Moscow-Leningrad, 1947; Abrazivnyye instrumenty. Katalog – spravochnik (Abrasive Tools. Catalog – Handbook), Moscow, 1961.

P.F. Smolin

ENAMELS – see Paints.

ENANT – is a synthetic heterochained fiber, being the product of the polycondensation of aminoeanthic acid. It is produced in the USSR tentatively in the forms of filament (cord thread and silk) and staple fiber. Enant may also be obtained in the form of monofilament or bristle. The chemistry and technology of the production of the Enant polymer and fiber was developed firstly by Soviet scientists. The physico-mechanical properties are as follows: 1.10 specific gravity; 2.2-2.4% moisture content (under standard conditions), and 2.6-2.8% at 20° and 95% relative moisture; softening point 205°; t_{pl} 225°; specific heat 0.452 kcal/kg·°C. The heatproofness and resistance to thermal aging are higher than those of Capron (the loss in strength being 15-17% for Enant, and 45-50% for Capron when kept at 150° for 24 hours). Compared with Capron and Nylon 66, Enant has a higher light- and weatherproofness; it is more resistant to alkalis and acids and to repeated deformatons; it resists microorganisms; it is insoluble in dichloroethane, acetone, carbon tetrachloride; it dissolves in certain compounds of the phenol type and in concentrated formic acid. The poor colorability of the fiber is the main disadvantage of Enant. The breaking length of the normal fiber is 40-47 km (75-79; 40-45) (the figures in parentheses quote the data for the high-strength filament thread and the staple fiber, respectively). The loss in strength in a wet state is 1-4% (12-18; 10-13). The temporary breaking strength is 44-52 kg/mm.^{2} (83-87; 43-50); the breaking elongation is 24-26% (15-17; 50-65); it increases negligibly in wet state up to 25-26% (17-18; 51-64). The degree of elasticity when elongated by 4% is 100% (100; -); when elongated by 10%, it is

96-98% (100; -). The elasticity of a tuft of staple fiber 1 minute after the compressing load is removed, is 89%, increasing to 96% after 30 min. The resistance to alternating deformations (on the DP-15 device, 110 cycles per min) at a stress of 5 kg/mm^2 lies within 27,000 to 40,000 bendings for the normal fiber, and 20,000-50,000 for the reinforced fiber; it is $1 \cdot 10^6$ for staple fiber (on a "Sinus" device) at a stress of 10 kg/mm^2. The wear-resistance of the reinforced fiber is 2 times higher than that of the normal fiber. The shearing modulus on twisting is 6000-7600 kg/cm^2 and 4900-5250 kg/cm^2, respectively; the modulus of elasticity is 275-305 kg/mm^2. Enant has a round cross section and a smooth surface, which cause the disadvantages of this fiber inherent to all polyamide fibers (see Polyamide fiber).

Enant may be used in the production of tire cord, in the manufacture of electric insulating materials, filter fabrics, tents, sails, parachute yarn, washing sacks, fishing tackles, ropes, cords, etc. Concerning the use of Enant for commodities, see Polyamide fiber.

References: Freydlina, R.Kh. and Karapetyan, Sh.A., Teplomerizatsiya i novyye sinteticheskiye materialy [Heat-Polymerization and New Synthetic Materials], Moscow, 1959; Natanson, I.A., Fizicheskiye i khimicheskiye svoystva novykh sinteticheskikh volokon [Physical and Chemical Properties of the New Synthetic Fibers], Moscow, 1960; "Tr. VNIIV" [Transactions of the All-Union Scientific Research Institute of Synthetic Fiber], 1958, No. 4; Demina, N.V. [et. al.], "Khimicheskiye volokna," 1960, No. 5, page 40.

E.M. Ayzenshteyn

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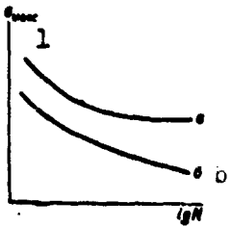
[Transliterated Symbols]

1369 ВНИИВ = Vsesoyuznyy nauchno-issledovatel"skiy institut iskusstvennogo volokna = All-Union Scientific Research Institute of Synthetic Fiber

ENDURANCE – ability of metals to resist fatigue failure. It is evaluated by the fatigue limit which, in conjunction with this, is also called the endurance limit, as well as by the number of cycles which are needed for failure at the given stress amplitude which exceeds the fatigue limit (see Fatigue). Endurance is more completely characterized by the endurance curve (Veler's curve, fatigue curve), which determines the dependence of the maximum stress of the cycle σ_{max} on the number of the reversed stress cycles N (figure); it is depicted in the (lg N, σ_{max}) coordinates. For steels the endurance curve has two sections (curve a). The left sloping section characterizes the endurance of metal which is limited by the number of cycles for the corresponding values of maximum stresses; the right rectilinear section parallel to the abscissa axis corresponds to stress values below which no fatigue failure is observed. The transition from the sloping to the horizontal section (break) takes place at 1-3 million cycles. No horizontal section of the endurance curve exists if aggressive media are acting or if the properties of the material change in the process of specimen testing. For aluminum, magnesium and other alloys the endurance curve has no clearly expressed horizontal section (curve b), and its ordinates decrease continuously as the number of cycles is increased. The sloping section of the endurance curve is described by the equation [illegible]

where N_0 is the number of cycles corresponding to the break in the endurance curve, σ_{-1} is the endurance limit and m is a parameter. The position of the endurance curve depends on the design of the specimens, the state of their surface, test conditions, character of the

stressed state, etc. A family of endurance curves constructed for vari-



Endurance curve. a) For steels; b) for aluminum, magnesium and other alloys. 1) Max.

ous failure probabilities is called the complete fatigue probability diagram (see Complete Fatigue Probability Diagram).

S. V. Seresen, M. N. Stepnov

ENERGY TO FRACTURE – is the energy absorbed in the process of fracture. It is not yet possible to determine reliably the specific energy to fracture related to the unit volume or the unit area, due to the fact that the fracture process is localized nearly to the apex of the forming crack, and some (or many) cracks may be developed at the same time. In Griffit's theory, the most simple assumptions of a "surface energy" are made in the case of a brittle (elastic) fracture, and, as an energy of plastic surface deformation, in the case of a plastic fracture. Connections between the energy to fracture, related to the unit volume and the melting energy were also to be assumed. The relation of the energy to fracture to the area of the cross section in the case of determination of the impact strength is very conditional, owing to the sharply expressed nonuniformity of the process.

Ya.B. Fridman

EPOXY ADHESIVE – is a compound based on linear epoxy resins obtained by the condensation of bivalent phenols (mainly of diphenylol propane) with epochlorohydrine or dichlorohydrine. Reacting with catalysts (curing agents), the epoxy resins are transformed into polymers of a three-dimensional structure and with high adhesive properties. Epoxy adhesives are used to join metals, plastics, porcelain, ceramics, fabrics, etc. The curing process depends upon the chemical type of the catalyst; it may be carried out without heating (in the presence of basic substances) or at high temperatures (in the presence of acid substances). Fillers (powdered aluminum, quartz, titania, etc.) are added to the epoxy adhesives; they have a faborable effect on the strength and the heat-resistance of the joints. The working life of the adhesive compounds is 0.5-2 hrs with a basic catalyst, and 1-2 days with acid anhydrides.

The adhesives are delivered in liquid state and also in the form of sticks and powders. The processing is as follows: the surfaces to be joined are previously heated to 100-120°, then the powder is either applied to them or they are treated with the adhesive stick; the adhesive melts and spreads readily over the surfaces. The bonding is carried out at 240-140° at a pressure of 0.5-3.0 kg/cm^2 for 10 minutes or for as long as 7 hours. The best results are obtained at 200° and a holding time of 1 hr. The holding time under the press is 24 hours at normal temperature, when amines are used as curing agents. The holding time at higher temperatures depends upon the degree of the latter.

Cold-curing adhesives (based on ED-5, ED-6, E-40, etc. epoxy re-

sins) form joints which, especially at higher temperatures have a low strength; they are, therefore, used only limitedly in stressed structures. Hot-curing epoxy adhesives (based on maleic anhydride) have favorable strength characteristics in the temperature range of -60° to +60°. The ultimate strength in the case of uniform peel is 450 kg/cm^2 for Duralumin at ±60°, and 6-10 kg/cm^2 for Duralumin with foamed plastic; it is 15-20 kg/cm^2 for Duralumin in the case of non-uniform peel at 20°; the shearing endurance limit is 30 kg/cm^2 at 20° (on the basis of $5 \cdot 10^6$ cycles). Adhesive joints of Duralumin withstand a shearing stress of 100 kg/cm^2 for 300 hours at 60°. The strength of the joints is reduced by 40-50% at 20° after 30 days exposure to water, and by 15-18% at 60°. The joints based on epoxy adhesives resist alternating temperatures (from -60 to 100°). The weathering strength of the joints may be improved by a varnish and paint coating of the butts. Adhesives modified by phenol resins and by polysulfides possess favorable strength characteristics. The epoxide glues are toxic, therefore, a fresh air supply, sufficient circulation and individual protective measures for the workers (gloves, aprons, etc.) are necessary when working with them.

D.A. Kardashev

EPOXY RESINS – are resins based on compounds which possess an epoxy group. Epichlorohydrin, reacting with substances containing mobile hydrogen (phenols, multivalent alcohols and amines) is usually taken as the raw material for epoxy resins. Industrially produced epoxy resins are obtained mainly by condensation of epichlorohydrin with diphenylol propane. The small shrinkage and the strong adhesion to metals, glass, wood and a number of other materials are the advantages of the epoxy resins. Epoxy resins do not separate in water and volatiles during curing and they are easily compatible with other polymers. The following combined epoxy resins are of the greatest interest: epoxy phenol resins (with increased heatproofness), epoxy polyester resins (with increased heatproofness), epoxy polyester resins (with increased resistance to impact loads), etc. The curing is the most important stage in the application of epoxy resins; amines (polyethylene polyamine, hexamethylene diamine), maleic and phthalic anhydride and other substances are used as curing agents. The curing by amines is carried out at 20-80°, by anhydrides at 100-200°. The highest strength characteristics are obtained by hot curing. The properties of the cured epoxy resins may be changed in a wide range by the following addition of: 1) plasticizers and modifiers [polyesters, thiokols, aliphatic epoxy resins (see below), dibutyl phthalate] which increase the elasticity, the strength characteristics, and the frostproofness; 2) fillers (cement, sand, quartz, porcelain powder, metallic powders, asbestos, graphite, etc.) which increase the hardness and heat-resistance and decrease the shrinkage and the coefficient of linear expansion. High-

strength sandwich panels may be obtained by the use of glass fabrics and glass fiber as a filler.

TABLE 1 Classification of Epoxy Resins

Марка 1	Содержание эпоксидных групп (%) 2	Молекулярный вес 3	Вязкость при 40° 4 (сантипуазы)	5 Применение
ЭД-5 6	Не менее 18 9	370—450	900—2000	12 Для пропитки, заливки, в качестве герметиков, связующих для стеклопластиков и клеев холодного отверждения, для заливки малогабаритных изделий
ЭД-6 6	14—18	450—600	30 000—80 000	
ЭД-П 7	11—14	600—750	При комнатной температуре твердая 10	13 Для изготовления изделий средних и крупных габаритов в электро- и радиотехнич. пром-сти, в качестве связующих для стеклопластиков, лаков и клеев горячего отверждения
ЭД-Л 8	8—11	750—1000	Размягчается при 40—60° 11	

1) Grade; 2) content of epoxy groups (%); 3) molecular weight; 4) viscosity at 40° (centipoises); 5) field of application; 6) viscosity at 40° (centipoises); 5) field of application; 5) ED-; 7) ED-P; 8) ED-L; 9) not less than; 10) solid at room temperature; 11) softens at 40-60°; 12) for impregnation, sealing, as binders for glass plastics, and as cold-curing adhesives, for sealing low-scale objects; 13) for manufacture of mean- and large-scale objects used in electrical engineering and radio engineering industries, as a binder for glass plastics, lacquers and hot-curing adhesives.

A classification of the epoxy resins delivered by the industry is quoted in Table 1.

The properties of the cured epoxy resins are as follows: specific gravity 1.19-1.23; shrinkage (curing at 150° for 5 hrs) is 1.3-3.5%; frostproofness down to −60°; specific impact strength 5-25 kg·cm/cm^2; heat-resistance up to 60-110°.

The solubility of the epoxy resins in acetone, benzene, toluene, xylene, cellosolve, etc., decreases with the increase of the molecular weight.

Epoxy resins are used in machine building and ship building for sealing blisters, cracks, openings, performations, and for smoothing the surfaces of large-scale objects. Dies for cold-pressing of metals are made of epoxy resins. Epoxy resins are used for sealing and pourable compounds, as chemically resistant coatings, and as insulation and

impregnation varnishes.

The good electric insulation properties of the epoxy resins together with an insignificant shrinkage explain the widespread use of epoxy resins as sealing compounds (see Electric insulating compounds). Epoxy polyester compounds are also obtainable (see Table 2).

TABLE 2

Properties of Epoxy Compounds Cured by Amines

Свойства 1	К-115 2	К-153 2	К-168 2	К-201 2	К-293 2
3 Удельный вес	1,15	1,18—1,20	1,15	1,15	1,16
Усадка при отверждении (%) 4	~0,5	~0,5	0,5	0,5	0,5
Теплостойкость по Мартенсу (°С) 5	60—65	50—60	50—60	45—55	~50
Твердость по Бринеллю (кг/мм²) 6	10—12	10—11	10—12	10—11	8—10
Удельная ударная вязкость (кг·см/см²) 7	10—13	8—10	8—10	15	8—10
Предел прочности при изгибе (кг/см²) 8	900—1200	900	—	700	800
Адгезия к стали (кг/см²) 9	100	200	—	—	—
Удельное объемное сопротивление (ом·см) 10	$1 \cdot 10^{14}$	$1 \cdot 10^{14}$	$2 \cdot 10^{14}$	$1 \cdot 10^{14}$	$2 \cdot 10^{14}$
11 Удельное поверхностное сопротивление (ом)	$5 \cdot 10^{14}$	$2 \cdot 10^{14}$	$5 \cdot 10^{14}$	$2 \cdot 10^{14}$	$5 \cdot 10^{14}$
Диэлектрич. проницаемость 12	4	4	4	4,5	4
Тангенс угла диэлектрич. потерь при 10^6 гц и 20° 13	$3 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	$3 \cdot 10^{-2}$	$2 \cdot 10^{-2}$
Пробивное напряжение (кв/мм) при толщине образца 1 мм 18	25	20	20	20	20

1) Properties; 2) K-...; 3) specific gravity; 4) curing shrinkage; 5) heat-resistance according to Martens (°C); 6) Brinell hardness (kg/mm^2); 7) specific impact strength ($kg \cdot cm/cm^2$); 8) bending strength (kg/cm^2); 9) adhesion to steel (kg/cm^2); 10) specific volume resistance (ohm·cm); 11) specific surface resistance (ohm); 12) dielectric constant; 13) tangent of the loss angle at 10^6 cps and 20°; breakdown voltage (kv/mm) of an 1 mm thick specimen.

TABLE 3

Properties of Compounds Based on Aliphatic Epoxy Resins

Свойства 1	Компаунды 2	
	отвержденные аминами 3	отвержденные ангидридами 4
5 Теплостойкость по Мартенсу (°С)	70—95	95—120
Твердость по Бринеллю (кг/мм²) 6	~1900	~1000
Предел прочности при изгибе (кг/см²) 7	850—1400	800—1400
Удельная ударная вязкость (кг·см/см²) 8	10—30	—
9 Удельное объемное сопротивление (ом·см)	$2 \cdot 10^{14}$	$2 \cdot 10^{14}$
10 Удельное поверхностное сопротивление (ом)	$1 \cdot 10^{13}$—$5 \cdot 10^{13}$	$3 \cdot 10^{14}$
Тангенс угла диэлектрич. потерь при 10^6 гц и 20° 11	0,03—0,04	0,025
Пробивное напряжение (кв/мм) при толщине образца 4 мм 12	15—18	14,8—17

1) Properties; 2) compounds; 3) cured by amines; 4) cured by anhydrides; 5) heatproofness according to Martens (°C); 6) Brinell hardness (kg/

/mm^2); 7) bending strength (kg/cm^2); 8) specific impact strength (kg•cm/cm^2); 9) specific volume resistance (ohm•cm); 10) specific surface resistance (ohm); 11) tangent of the loss angle at 10^6 cps and 20°; 12) breakdown voltage (kv/mm) of a 1 mm thick specimen.

Epoxy compounds are widely used as pourable compounds and impregnating materials, as adhesives and sealings for electro and radio engineering, instrument manufacture, etc. The technology of the manufacture of the various complex shaped insulation objects is implified due to the low viscosity of the epoxy compounds. The laborious processes are substituted by a simple molding process, thereby allowing the price of the object to be reduced. The good electric insulation properties of these compounds allow the reduction of the shape and the weight of the objects under normal as well as under poor climatic conditions. Aliphatic epoxy resins, low-viscous fluids (10-15 centipoises viscosity at 40°) soluble in water, alcohols, and acetone, are also obtainable; they are the product of the condensation of multivalent alcohols with epichlorohydrin, and contain epoxy and hydroxy groups: MEG-1 and MEG-2 are based on ethylene glycol; DEG-1 is based on diethylene glycol, and TEG-1 is based on triethylene glycol.

Aliphatic epoxy resins are used as active diluters and plasticicers, and also as pouring, impregnating, adhesive and sealing compounds.

Aliphatic epoxy resins may be used in the finishing of fabrics (for crease-resistant finish and sanforizing).

Compounds containing 10-50 parts of aliphatic resins per 100 parts of epoxy resins possess a low viscosity and are characterized by a high elasticity, impact strength and adhesion to glass, metals and plastics in a cured state. These compounds may be cured by any curing agents used for hot- or cold-curing epoxy resins. The cured compounds have the following characteristics (see Table 3).

Adhesives (see Epoxy adhesive), priming colors (see Priming colors), Foamed Polyepoxides, Putties, and enamels (see Paints) based on epoxy resins are manufactured.

The epoxy resin ED-6 combined with minearal fillers, curing agent and lubricant yields the pressing material K-81-39 which is used for pressing heat- and moisture-proof mica capacitors and in the manufacture of insulating radio parts with a high mechanical strength. The properties of the material are as follows: specific gravity not more than 1.95; specific impact strength not less than 4.5 kg•cm/cm^2; bending strength not less than 650 kg/cm^2; water adsorption not more than 0.03%; specific surface resistance not less than 10^{14} ohms; specific volume resistance not less than 10^{14} ohm•cm; electric strength not less than 160 kv/mm; tangent of the loss angle at 10^6 not higher than 0.03; shrinkage not more than 0.6%. Commutator micaite, a hard pressed sheet material of micaite board or paper, impregnated by epoxy resins, is used in the insulation of d-c electric machines. The electric strength of this material is 20-28 kv/mm.

N.P. Gashnikova

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[Transliterated Symbols]

1378 МЭГ = MEG = monoetilenglikol' = monoethylene glycol

1378 ДЭГ = DEG = dietilenglikol' = diethylene glycol

1378 ТЭГ = TEG = trietilenglikol' = triethylene glycol

ERICCSON TEST – is a technological trial used to form a spherical hole in metallic sheets, plates, or strips in order to obtain a qualitative motion of the deformational behavior of the sheet metal under conditions near to those of stamping.

References: Shaposhnikov, N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Tests of Metals], 2nd Edition, Moscow-Leningrad, 1954.

Yu.S. Danilov

EROSION — is the gradual destruction of the surface layer of objects (parts) in a gas or fluid stream. The term erosion is also used for a wider field of phenomena of surface-layer destruction caused by various mechanical, thermal and electrical effects.

The processes on which are based such technological operations as sandblasting, shotblasting, electro-erosion machining, and ultransonic treatment, and also such phenomena as destruction by cavitation, friction and wear, belong also to the erosion processes.

Owing to the evolution of rocket engineering, atomic power engineering, the design of new electric-current sources and of electro-jet engines, a new class of structural materials was generated as follows: erosion-resistant materials working at high-speed and high-temperature flows of fluids, gases and plasma. The erosion process of these materials consists of removing successively the material from the surface. Many of the erosion-resistant materials work under unsteady conditions. In this case, the erosion process is divided into a number of steps and it is caused by a combination of phenomena which are different in their nature and which depend on the intensity of heat transfer or on the mechanical characteristics of the gas or fluid flow (velocity, pressure, density). In high-temperature flows with a heat transfer to the order of 10^6 kcal/m^2·hr·°C, the erosion destruction of ceramics may begin by a brittle destruction under the effect of the thermal stress, and by the removal of the products of the thermal shock from the gas flow. Rapid heating may cause a layer-by-layer or the total destruction of laminar materials, plastics and polymers due to the separation of

gases or vapor. Surface layers of nonmetallic materials may sublimate into the gas or vapor phase. Surface layers of metal alloys which are softened and go over into the liquid state are removed by the stream which flows round the object (Ablation).

Metal alloys, cermet and ceramic materials may react with the gases which form the outer gas flow, forming oxides, Carbides, Nitrides, etc.

Depending on the properties of the formed compounds, this process may intensify the removing of material. The ablation is increased in the case of Mo and W carbides because these have a lower melting point than pure metal. In the case of Mo and W oxides, the sublimation is accelerated owing to the high vapor tension of these oxides at high temperatures.

A universally adopted theory of erosion does not exist as yet. The analysis and calculation of the erosion process at unsteady conditions are encumbered by the fact that the initial and boundary conditions change during the erosive destruction. The counterflow of sublimation products may essentially change the nature of the boundary layer, the conditions of the heat transfer and the mechanism of the action of the outer gas flow. The material properties, especially those of polymers, change strongly; thermodestruction and coking occur, endothermic effects take place, and the conductive heat transfer is increased. Hence, the resistance to erosion is determined not only by the resistance of the material to the thermal or mechanical effects of the outer flow, but also by the manner in which this interaction is changed under the influence of processes taking place on the interface between the boundary layer and the erosion-resistant material.

Owing to the fact that erosion under unsteady conditions is a stepwise process, an increased resistance to erosion may be achieved

by a directed change in the parameters of each layer, by reinforcing and using carcasses, i.e., by using the material as one having structural elements.

N.M. Sklyarov

ESPECIALLY LOW-MELTING SOLDERS — alloys containing bismuth, tin, lead, cadmium, indium, gallium, and zinc.

Especially Low-Melting Solders

1 Припой	2 Химич. состав (%)							Темп-ра плавления (°С)3	
	Ga	In	Bi	Sn	Pb	Cd	Zn	4 начало	5 конец
6Припой	62	25	—	13	—	—	—	5	5
7То же	67	29	—	—	—	—	4	17	17
•	—	19.5	44.3	8.3	22.6	5.3	—	—	46.7
•	—	21	49.4	11.6	18	—	—	—	58
•	—	—	49.5	13.1	27.3	10.1	—	71	71
•	—	26	57	17	—	—	—	78.9	78.9
•	—	—	50	18.75	31.25	—	—	96	96
•	—	—	53.9	25.9	—	20.2	—	102.5	102.5
•	—	52.2	—	46	—	—	1.8	108	108
•	—	52	—	48	—	—	—	117	117
•	—	—	56.5	—	43.5	—	—	125	125
•	—	50	—	50	—	—	—	115.6	125.6
•	—	—	56	40	—	—	4	130	130
8ПОСВ33	—	—	33.3	33.3	33.4	—	—	—	130
9ПОСК50	—	—	—	49.8	32	18.2	—	145	145

1) Solder; 2) chemical composition (%); 3) melting temperature (°C); 4) initiation; 5) termination; 6) solder; 7) the same; 8) POSV33; 9) POSK50.

Eutectic alloys of these elements are the most efficient when using soldering irons; solders with a broad crystallization range are employed when using the abrasion method. The table shows the compositions of certain eutectic and noneutectic solders with low melting points.

Especially low-melting solders, particularly those containing bismuth, are characterized by low mechanical characteristics, but provide electrical conductivity, thermal conductivity, and hermetic joints and are used for soldering iron, steel, and copper. Solders with a melting temperature below 100° are used with fluxes such as FIM, which is composed of 200 cm^3 of orthophosphoric acid (specific gravity — 1.7), 1 liter of ethyl alcohol, and 1 liter of distilled water. Residues of

this flux do not corrode iron or steel, but should be removed from soldered joints in copper by washing in hot running water. Indium-rich low-melting solders are used for making tight joints in glass intended to operate under vacuum conditions (soldering without flux, by the abrasion method). Bismuth-rich low-melting solders are characterized by an increase in volume during the transition from the liquid to the solid state and as a result of aging during cooling. Bismuth-containing solders wet certain metals (e.g., iron and structural steel) poorly and are distinguished by a comparatively high electrical resistance. In order to improve their wettability these metals are galvanized or coated with lead-tin solder before soldering. Solders with low melting points are used principally in warning devices for fire-alarm systems, in electrical equipment where a low soldering temperature is required as a result of the danger of overheating components, in stepwise (secondary) soldering, and in diffusion soldering.

References: Apukhtin, G.I., Tekhnologiya payki montazhnykh soyedineniy v priborostroyenii [Techniques for Soldering Fitting Joints in Instrument Building], Moscow-Leningrad, 1957; Lakedemonskiy, A.V., Khryapin, V.Ye., Spravochnik payal'shchika [Solderer's Handbook], Moscow, 1959; Lashko, N.F., Lashko-Avakyan, S.V., Payka metallov [Soldering of Metals], Moscow, 1959; Lueder, E., Handbuch der Loettechnik [Handbook of Soldering Technique], Berlin, 1952; Cole, V., Tekhnologiya materialov dlya elektrovakuumnykh priborov [Technology of Vacuum-Tube Materials], translated from English, Moscow-Leningrad, 1957.

N F. Lashko and S.V. Lashko

ETCHING OF MAGNESIUM ALLOYS – dissolving of metal in order to remove contaminants or to bring blanks to the required dimensions and shape (dimensional etching). Etching is performed by chemical or electrochemical methods; the first method is more extensively used. Magnesium and alloys are dissolved in the majority of acids and are practically insoluble in alkalis, for which reason acids are extensively used for chemical etching. Chromic acid is a good solvent of magnesium hydroxides and of many salts, but it does not dissolve the magnesium alloy, with the result that it is extensively used for removing nongreasy contaminants from component surfaces, for dissolving production of corrosion and flux inclusions, when the component dimensions must be retained. Chromic acid is also a good passivator for magnesium alloys. With an addition of saltpeter, nitric acid and other activators in specified quantities, chromic acid, alongside with dissolving contaminants, can dissolve the metal, which removes impurities lying in deeper metal layers. The solutions used for etching of magnesium alloys are given in the table.

In the electrochemical method of magnesium alloy etching the components are etched with electrolitic assistance in a 10% solution of ammonium difluoride. Dimensional etching is used for making thin-walled components of intricate shape and variable cross section and when a uniform reduction in the component thickness is necessary. Dimensional etching is achieved by solutions which do not produce slime on the surface and which protect the relative surface smoothness. The etching rate can be adjusted by the concentration of the solutions used as well

Solutions for Etching Magnesium Alloys

Наименование компонентов 1	Концентрация компонентов 2	Режим травления 3	
		температура (°С) 4	время (мин.) 5
CH_3COOH (ледяная) 6 $NaNO_3$, или NH_4NO_3	175 г/л 7 50 г/л	20–25	0.5–1
H_3PO_4	85%	20–25	0.5–1
H_2SO_4 (уд. в. 1,84)	30.5 мл/л 10	20–25	0.5–1
HNO_3 (уд. в. 1,42)	30–50 мл/л	20–25	До 5
HNO_3 (уд. в. 1,42) H_2SO_4 (уд. в. 1,84)	30 мл/л 60 мл/л	18–20	0.5–1
H_3PO_4 (85%-ная) NH_4HF_2, или KHF_2	2.6 мл/л 100 г/л	20–30	До 2
CrO_3 *	150–250 г/л	15–30	8–12
CrO_3 *	20–30 г/л	60–70	8–12
CrO_3 $NaNO_3$ MgF_2	180 г/л 30 г/л 0.25 г/л	75–80	0.5–2
CrO_3 HNO_3 (70%-ная) HF (5–52%-ная)	280 г/л 25 мл/л 8 мл/л	15–20	0.5–3
CrO_3 $NaNO_3$	180 г/л 280 г/л	15–20	0.5–2
CrO_3 $NaNO_3$, или $Ca(NO_3)_2$	50–[illegible] г/л 5–8 г/л	15–20	2–15

1) Names of components; 2) component concentration; 3) etching regime; 4) temperature (°C); 5) time (min.); 6) glacial; 7) g/liter; 8) or; 9) specific gravity; 10) milliliter/liter.

as by appropriate stimulating or retarding additives. The domestic [Soviet] industry uses a solution of the following composition for contour etching of the ML5 and MA2 alloys: H_2SO_4 10%, 5-7 g/liter of the PV5 inhibitor; the temperature is 13-35°. To protect sections which are not to be etched, use is made of acid-resistant organic coatings with a good adhesion to the metal and which are relatively easy to remove after etching. For example, it is possible to use a coating from the AG-10s primer and KhV enamel (one layer) (see Dimensional Etching of Aluminum Alloys).

M.A. Timonova

ETHINOL – is a varnish based on the polymerization products of divinylacetylene (DVA) with a molecular weight of 800-1200. DVA is obtained as a secondary product in the production of the raw material used for polychloroprene rubber. DVA is a colorless fluid which turns yellow in light and has a garlic odor. The boiling point is 83.6°; the density at 20° is 0.785; the decomposition temperature is 105-110°. The polymerization of DVA must be carried out in the absence of oxygen, otherwise peroxide polymer compounds may be formed which will decompose and explode spontaneously. Commercial DVA (VTU MKhP 1267-54) is a 46% solution of DVA in xylene or chlorobenzene with the addition of 2% α naphthylamine as a stabilizer. Xylenes, cresols, and other aromatic compounds are used as solvents.

Technical requirements of ethinol as follows: 43-46% dry residue; content of antioxidant: 2.5% of the polymer; intrinsic viscosity of a 10% solution at 20°: 0.3-0.6; gelatinization time at 100°: 20 min; a varnish sample must not explode under an artillery drop hammer after being exposed to oxygen absorption in an eudiometer tube for 3 days; the acid number is 1.0; drying time (in hours) on glass: 4 as a powder, 14 totally.

Ethinol is used in its pure form and with fillers (aluminum powder, dry carbon black, graphite, iron ocher, minimum, chromium oxide, zinc yellow, asbestos powder, talcum, cement) as a binder for core bodies in metallurgy and, as a substitute for drying oil, in the impregnation of wood; in the production of chemically resistant coatings on metals, resistant to the combined effect of water and petroleum products; as a

priming in coatings resistant to water and atmospheric effects; for putties, and for stable lutes. The physicomechanical properties of coatings based on pigmented ethinol varnish exceed considerably those of the nonpigmented varnish. The elasticity of pur ethinol (according to the scale of NIILK) is equal to 15 mm, and the adhesion of the film to metal (according to the method of lattice notches) is 60-75%; the elasticity of pigmented ethinol is 1 mm, and the adhesion is 10-15%. Paints with a base of ethinol contain 45-95% varnish. The film of ethinol-based paints is extremely waterproof and resistant to the effect of many salts, acids, and alkalis; it does not swell in organic solvents; it is lustrous; it has a high hardness; it is polished easily; it dries quickly, and it does not soften at temperatures up to 200°. Ethinol paints are applicable even under highly moist conditions and at very low temperatures (-25°); the paints dry quicker than oil paints (and cost at least 10 times less than the latter). The high waterproofness is maintained also in the presence of sea water (the paints are usable in the covering of the bilges of nautical vessels).

The technical requirements of ethinol paints are as follows: all kinds of colors; drying time of the powdered paint 50 minutes at 20°; total drying time not longer than 10 hours; viscosity determined by the VZ-4 device (at 20°) not less than 10 sec; flexibility not more than 5 mm; pendulum hardness 0.6-0.5; impact strength 15-35 kg/cm^2; water adsorption not more than 0.5%; consumption of the paint 60-120 g/m^2.

Disadvantages of the ethinol-based films are as follows: instability of the properties of the raw material; ethinol coatings are brittle due to the weak adhesion to other materials, and they are not lightproof. The lightproofness may be increased by the addition of vinyl copolymers to ethinol. Ashovinyl, an anticorrosion coating compound (putty) is prepared from ethinol and asbestos fiber of the 5-6th

grades. Carbon-graphite impregnated with ethinol is used in the chemical industry; it has a low porosity, a good heat conductivity, and is decomposed only by strong oxidizers. Ethinol may be used to modify various polymers. Ethinol, modified by epoxy resin, is very interesting; epoxy resin is easily compatible with ethinol in each ratio; it improves the adhesion of the latter to various materials, and it increases the elasticity and retards the aging, preserving its very high protective properties.

References: Drinberg, A.Ya., Tekhnologiya plenkoobrazuyushchikh veshchestv [Technology of Film-Forming Substances], 2nd Edition, Leningrad, 1955; Iskra, Ye.V., Etinolevyye kraski [Ethinol Paints], Leningrad, 1960.

N.P. Gashnikova

ETHYL CELLULOSE PLASTICS – see Plastics based on cellulose esters.

ETHYLENE-PROPYLENE RUBBER – is the product of the copolymerization of ethylene with propylene; it is a rubber-like copolymer with a high molecular weight, a dense and hard white-colored mass, which is relatively readily workable on rolls. The specific gravity is 0.8-0.86. Ethylene-propylene rubber is easily miscible with a relatively great number of solvents. The vulcanization of the ethylene-propylene rubber is carried out by means of organic peroxides at 150-160°. The vulcanization by organic peroxides in presence of small amounts of sulfur improves significantly the mechanical properties of the vulcanized products. Comparative data for the properties of carbon-black filled rubbers (50 parts by weight of KhAF chimney soot per 100 parts by weight of rubber) from the ethylene-propylene copolymer and for those of natural rubbers (NK) are given in the Table.

TABLE

Показатели 1	К.э. 2	НК 3
4 При 20°:		
5 прочность на разрыв (кг/см²)	280—500	300
6 относительное удлинение (%)	540	400—480
7 эластичность по отскоку (%)	52	41
8 сопротивление истиранию (см³/квт-ч)	220—250	—
9 После старения при 150° в течение 72 час.:		
5 прочность на разрыв (кг/см²)	160—190	—
6 относительное удлинение (%)	450—500	—

1) Characteristics; 2) ethylene-propylene rubber; 3) NK; 4) at 20°; 5) tensile strength (kg/cm^2); 6) relative elongation; 7) resilience (%); 8) resistance to abrasion (cm^3/kwh); 9) after aging at 150° for 72 hrs.

Apart from the high mechanical and elastic properties, the ethylene-propylene rubbers prove an exclusively high resistance to aging at elevated temperatures, which is due to the fact that double bonds are almost absent in the copolymer. Ethylene-propylene rubbers maintain their high tensile strength even after aging at 175°. The excellent resistance to thermal aging provides the good operation qualities of the products from ethylene-propylene rubber. Ethylene-propylene rubbers are equal to natural rubbers with regard to the resistance to swelling in organic solvents, fuels and oils, but they are significantly inferior to divinylnitrile rubbers. Ethylene-propylene rubbers surpass all types of synthetic rubbers, excluding fluororubbers, in the resistance to acids and alkalis, but they are weakly stable to concentrated nitric acid. With regard to the resistance to abrasion, the ethylene-propylene rubbers are almost equivalent to natural rubbers. The ozone-proofness of the ethylene-propylene rubbers surpasses that of all types of synthetic rubbers used at the time in industry. The resistance to the growth of cuts at alternating deformations, and the excellent dielectric properties are also valuable properties of the ethylene-propylene rubbers. The gasproofness of the ethylene-propylene rubber is near to that of natural rubbers. The valuable complex of properties of ethylene-propylene rubbers, the cheapness and ready availability of the initial monomers determine the possibilities of their wide application in industry.

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the Interval Between the XXth and XXIIth Congress of the Communist Party of the Soviet Union], ibid., 1961, no. 10; Natta G. [a.o.], "Rubber and Plast. Age," Vol. 42, 1961, No. 1, page 536.

M. D. Gordin

EXTRA HARD BRASS is brass which is pressured worked with a high degree of deformation. In this condition the extra hard brass has high strength (hardness). Semimanufactures are obtained from this brass by cold pressure working (rolling and drawing). Ribbon (GOST 2208-49) is made from the L68 and L62 brasses, and strip (GOST 931-52) is made from the L62 brass, with tensile strengths of no less than 62 kg/mm^2 and a relative elongation of no less than 2.5%. Ribbon and strip (GOST 4442-48) with tensile strength of no less than 64 kg/mm^2 and relative elongation of no less than 5% are fabricated from the LS63-3 watchmaker's leaded brass.

Ye.S Shpichinetskiy

EXTRUSION – is the preparation of plastic pieces pressed through the forming parts of machines termed extruders. Extrusion serves for the manufacture of pipes, various profiled objects, sheets, films and fibers (from polyethylene, polyvinyl chloride, polystyrene and other polymer materials); for the electric insulating coating of wire, etc. Extrusion is also used for the pressing out of blanks for the manufacture of hollow objects by blowing, for the plastification in pressure die-casting, etc. Screw extruders with a screw diameter of 20-[illegible] mm and a length of the working part of 15-25 diameters are the most widespread extruder types; the material to be processed passes three temperature zones and is heated to 120-200°. The driving power of this extruder type reaches up to 100 kw; the screw rotates with a velocity of 5-60 rpm (with four-speed control); the pressure reaches up to 300 kg/$/cm^2$. There are also extruders in which the heating is carried out by transforming the mechanical energy into thermal energy ("adiabatic" machines). Extruders of the piston type (stuffers), and pumps with gear and pinion drive (spinnerets) are used to a lesser extent. Recently, extruders were developed in which the smelt was fed from the periphery to the center of a rotating disc (Weissenberg effect). The continuity of the multi-purpose action (besides the formation of the necessary pressure for pressing the material through the forming openings, mixing, plasticization, heating, drying by exhaustion of volatiles, etc., are also carried out) is of an advantage to the screw extruders.

A diagram of the working part of an extruder is shown in the Figure. The powder or the grains poured into the hopper are caught by the

screw and moving forward pass the temperature zone I, II and III, becoming heated to the viscous-liquid state at the end of the screw; the material is pressed through a screen pack (preceding the head) and through the forming appliance. The screen pack causes a resistance necessary for thickening the smelt; it arrests large, insufficiently heated material particles and eliminates a harmful effect to the screw on the material.

Diagram of the working part of an extruder: I, II, III and IV are electric heaters. 1) Supporting bush of the screw with bearings and with the driving gear wheel; 2) feed hopper; 3) screw; 4) barrel of the screw; 5) screen pack; 6) head; 7) hollow for cooling water.

When pipes are manufactured by extrusion, the hot pipe is drawn through a cooled pipe (the calibrating device) and pressed on its inner surface by means of compressed air or vacuum. The inner-size calibration is carried out by drawing the hot pipe over a cylindrical straightening device which is cooled on the side of the head and is a continuation of the mandrel. The obtained rigid pipes are cut into sections of the demanded length (behind the drawing device); soft pipes are wound on corresponding bobbins. Various designs of the head and of the forming appliance are used in the manufacture of profiled objects. The speed of the extruded material is equalized by means of a set of resistors (narrowing or lengthening the passageways) in order to avoid a sharp change of the shape after the forming appliance has been left.

A slot-die is used for the manufacture of sheets: the sheet being formed in it and then polished on rolls (heated by a circulating fluid); it passes then drawing rolls and, after cooling, it is wound on a drum

(in the cases of soft sheets) or cut and put together into packs (in the case of rigid sheets).

For the manufacture of a film, a thin-walled mantle is pressed out by the extruder heat; this mantle is blown by air pressure to the demanded dimensions and then folded by guide rolls into a double sheet.

References: Mindlin, S.S. and Samosatskiy, N.N., Proizvodstvo izdeliy iz polietilena metodom ekstruzii [Manufacture of Polyethylene Objects by Extrusion Method], Leningrad, 1959; Voprosy ekstruzii termoplastov [Problems of Extrusion of Thermoplastics], a Collection of translations, edited by A.N. Levid, Moscow, 1963; Schenkel, G., Shnekovyye pressy dlya plastmass [Screw Presses for Plastics], translated from German, Leningrad, 1962; Fisher, E.G., Extrusion of Plastics, London-New York [1958]; Processing of Thermoplastic Materials, ed. by E.C. Bernhardi, N.Y.-London, 1959.

Ye.Ye. Glukhov

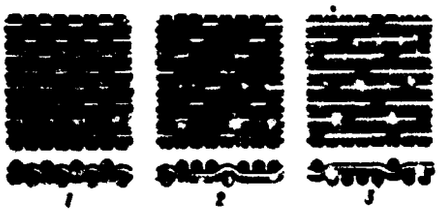
FABRIC – material formed in the weaving process by interweaving mutually perpendicular systems of textile threads. The longitudinal fibers of a fabric are called basic (warp) while the transverse are called weft (weft) threads.

Fabrics (belt, conveyor belt, parachute, sail, sieve, filter, hose, etc.) are used directly for making articles, others are used as a supporting skeleton for composite laminated materials, i.e., textolites, automative, aircraft and bicycle covers, rubber hose, soft fuel tanks, rubberized or polymer-film coated materials, electrical insulation, certain systems of varnish and paint coats and gluing compounds. The thickness of fabrics varies within the limits of 0.1-5.0 mm, the width comprises 0.3-1.6 m (infrequently it can be as much as 10-12 m). The length of a commercial cut is 20-50, 100, 150, 180, 360 and more, piece products (technical filter cloth, etc.) are produced in the form of short pieces. The weight of a m^2 of a fabric is 20-2000 g and more (most frequently 60-75 g), the breaking load (in tension) of a strip of 50 × 200 mm along the warp and along the weft is 5-350 kg and higher, the elongation is 3-80%.

The structure of a fabric is determined by the fiber composition, the character of the weaving interlacing, the numbers of warp and weft threads, their number per unit of length of the fabric (density with respect to the warp and weft) as well as by the features of the right (face) and wrong (reverse) surfaces. For a more profound characterization of fabric structure use is made of filling indicators (specific density), the structural and supporting surface phases. Fabrics are

made: of the same kind, i.e., entirely from threads of an any given fiber composition (cotton, flax, capron, etc.), not of the same kind, i.e., from threads which are most frequently of two different fiber compositions (the warp being cotton, the weft – wool, silk, etc.), and mixed, i.e., from threads containing various fibers. Fabrics not of the same kind and mixed are usually further differentiated by the more valuable fiber component which they contain (semi-wool, semi-silk fabrics, etc.).

The weave of fabrics determines the order in which the warp and weft overlaps (i.e., passes, when the warp thread covers the weft threads, and skips when it is covered by the weft thread) are situated on its surface. In the production of technical fabrics use is made primarily of basic or simple interlacings (Fig.): plain, serge and satin



Main weave interlacings. 1) Plain weave; 2) warp-faced serge weave; 3) weft-faced satin weave (satin). In all the cases the vertical threads are the warp while the horizontal are the weft.

(satin) and derivatives of these weaves. In the most extensively used plain (calico, cloth, taffeta) weaves the greatest bound between the warp and weft threads is achieved. Hence plain weave fabrics are the stiffest and have the highest tensile strength. On the right side of serge fabrics the narrow slanted strips of the warp passes (diagonals) go from the bottom up to the right (on the wrong side the weft pass diagonals go from the bottom up to the left). The threads in a serge weave are not as closely bound as in plain weave fabrics. Serge is softer and has better resistance to being cut, for example, by sewing

thread. In the satin (satin) weave the bound between the threads is even weaker and a continuous facing of predominant long warp (weft) interlacings is formed on the fabric surface. This weave is used for obtaining fabrics with a smooth surface (cover, lining, decorative). Derivatives of simple weaves are obtained by doubling or tripling the warp or weft passes (warp or weft repp, reinforced serge, reinforced satin-moleskin), doubling both (coarse canvas), changing the direction of the diagonals (broken serge), etc. For decorative fabrics which are used for upholstering ceilings, walls, furniture and curtains of transportation facilities, use is made of combined (from simple) and fine-design (diagonal, waffle, crepe), and also coarse-design (jacquard) weaves. Complex weaves are used for carpet fabrics and for velours (nap weave), sieve fabrics (interwoven or openworked), drive belts, certain cloth types, filtering and other fabrics (multilayer). More than two thread systems, i.e., two and more warps, two-three and more weft participates in the formation of complex weaves.

The density of fabrics with respect to the warp or the weft, i.e., the thread count of the warp (weft) per a length of 10 cm, is specified by standards and is checked on delivery and acceptance of fabrics. To estimate the degree to which the fabrics are filled by the fibreous material and to compare densities of fabrics made from threads of various thickness (numbers), use is made of the formulas

$$E_0 = \frac{1.13\Pi_0}{\sqrt{\delta_0 \cdot N_0}} \qquad E_y = \frac{1.13\Pi_y}{\sqrt{\delta_y \cdot N_y}},$$

where E_0 and E_u are the linear warp and weft fillings, which show what percent of any rectilinear section in the warp or weft direction of the fabric is filled by threads; Π_0 and Π_u are the densities of the fabric's warp and weft, respectively; δ_0 and δ_u are the specific weights of the warp and weft threads in mg/mm^3, N_0 and N_u are the thread numbers for

the warp and weft. Typical specific weights of threads (mg/mm^3) are: 0.8-0.9 for cotton threads, 0.9-1.05 for flax, 0.85-0.9 for long-staple hemp and 0.55-0.65 for short-staple hemp, 0.7-0.8 for wool threads, 1.12 for silk, 0.75 for short-staple (yarn), 0.9 for viscose (warp) threads, 0.84 for viscose staple fiber (yarn), 0.9 for capron, 0.8-2.0 for glass threads. Surface (complete) filling of fabrics. E_s is the ratio of the projected area of both thread systems in a fabric cut to the area of this cut, which is calculated by the formula $E_s = E_0 + E_u - 0.01 E_0 E_u$. If calculations show that E_0, E_u or $E_s > 100\%$ this means that the theoretically round thread cross sections have been flattened as a result of the high fabric density. Nondense fabrics, i.e., gauze, AOD (for the facing of wood) have E_s = 35-65%, the main bulk of medium density fabrics has an E_s = 65-85%, E_s for dense sailcloth, moleskins, tents, certain filter fabrics is higher than 85%.

The specific weight of fabrics is calculated from the formula $\delta = 0.01\, g_1/b$, where g_1 is the weight of 1 m^2 of the fabric in g, and b is the fabric thickness in mm. E_v, the volume filling of fabrics shows what percent of the total volume of the fabric is occupied by the warp and weft threads. $E_v = \delta/\delta_n \cdot 100\%$, where δ_n is the specific weight of the thread. The weight filling of fabrics is $E_g = \delta/\gamma \cdot 100\%$, where γ is the specific gravity of the fiber or thread substances. The porosity D, which shows the air content of fabrics, is calculated by the formula $D = \gamma - \delta/\gamma \cdot 100\%$. The structural phases of fabrics (according to N.G. Novikov) characterize the curvature of the warp and weft threads in the fabric. The phase which is most favorable for obtaining the smallest thickness, maximum specific weight and smoothness, and also close warp and weft extensions, is that in which the curvatures of the warp and weft threads (with the same number) are the same. In this case the fabric has the maximum support surface, which ensures its lowest abrasion.

The weight of a square meter of a fabric, y_1 is related to the warp (Π_0) and weft (Π_u) densities and with the thread numbers (N_0 and N_u) by the approximate formula $g_1 = a(\Pi_0/N_0 + \Pi_y/N_y)$, where a is 10.4 for cotton fabrics, 9 for bleached flax fabrics, 10.7 for combed wool, 12.5 for thick cloth and 13.0 for thin cloth fabrics.

By the character of the facing surface fabrics may be smooth, carded (baize, flanel, etc.), pile (velvet, velours, carpet) and fulled (cloth), as well as with identical sides, having the same right and wrong sides, and of different sides, i.e., with only the right sides finished (one-sided) or with the right and wrong sides finished differently (two-sided). Raw fabrics or unfinished fabrics, which have not been finished after weaving, are contaminated. The warp threads of such fabrics frequently contain starch or synthetic glues (sizing). In the finished process the unfinished fabric can be subjected to searing (burning off of fibers sticking out at the fabric surface); desizing (removal of the sizing and washint); scouring (more thorough washing); blanching (or "bleaching"), which frequently reduces somewhat the mechanical strength of fabrics; mercerizing, which consists in an alkali treatment which increases the strength, resistance to atmospheric effects, smoothness, luster, softness and dyeability (only for cotton fabrics); dyeing, and sometimes also to special impregnation: water resistant, anti-rot, preservation, combined (water-resistant-anti-rot), fireproofing (interfering with flame propagation on the fabric surface, but not imparting nonflammability properties), washable (by minearal antipyrenes) or nonwashable (by reinforced organic antipyrenes). Features of wool fabric finishing include felting (thermomechanical processing of cloth in a soda-soap or other solution) to obtain a felt-like surface facing and carbonization, i.e., sulfuric acid impregnation with subsequent drying and washing of vegetable admixtures. Wool fab-

rics are also impregnated by antimole fluorine compounds, DDT, etc.

The main and standard characteristics of mechanical properties of fabrics are the rupture load (kg) and the elongation at break (%), which are obtained by tensile testing strips made separately by warp and weft of the fabric on special machines.

To compare the strengths of fabrics of various thickness with one another the rupture length of fabrics (for the warp, weft or the average) is calculated by the formula $L = 20 P/Q$, where L is the rupture length in km, P is the rupture load of a strip 5 cm wide (in kg), and Q is the weight of a m^2 of the fabric in g. An average L of 4 km for the warp and weft is considered low, of 4-7 km it is considered medium, of 7-9 km high, and of 9-15 km and above it is regarded as very high. For deeper characterization of the mechanical and other fabric properties use is made of methods presented in the following GOSTs: 1090-41 "Textile Fabrics. Testing Methos"; 3810-47 "Sampling Methods for Laboratory Tests"; 3811-47 "Methods for Determining the Linear Dimensions and Weight"; 3812-47 "Methods of Density Determination"; 3813-47 "Methods of Strength Determination"; 3814-56 "Methods for Determining the Wrinkling, Separation and Shedding," 3815-47 "Methods for Determining the Pile Quality," 3816-61 "Methods for Determining Hygroscopic Properties," 5012-61 "Methods for Determining the Shrinkage of Wool Fabrics After Wetting," etc.

References: Sobolev'yev, A.N. and Kukin, G.N., Tekstil'noye materialovedeniye [Textile Materials Science], Moscow, 1955, by the same authors, Tekstil'noye materialovedeniye, Part 1, Moscow, 1961; Sheydeman, I.Yu., Tekstil'nyye materialy [Textile Materials], in the book Spravochnik po mashinostroitel'nym materialam [Handbook of Machine-Building Materials], Vol. 4, Chapter 8, page 508, Moscow, 1958; Moskalev, V.M., Tekstil'nyye materialy primenyamyye v khimicheskoy promyshlennosti

III-64t6

[Textile Materials Used in the Chemical Industry], Moscow, 1954.

I. Yu. Sheydeman

Manuscript Page No.	[Transliterated Symbols]
1401	у = u = utok = weft
1402	н = n = nit' = thread
1404	ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standart = All-Union State Standard

FABRICS FOR AIRCRAFT COVERING – textile fabrics (cotton and flax) with a card (plain) weave, which is characterized by a high specific strength, small elongations of the warp and weft and the necessary shrinkage upon varnish application. Cotton fabrics of the AM-100 (TU 30465-47), AM-93 (GOST 1883-46), AST-100 (GOST 2328-43) brands and flax fabrics of the ALL (SMTU-240) and ALVK (SMTU-240) are currently produced. Fabric covering of wings, ailerons and other parts of aircraft (gliders, light planes), which tkae up and transfer to the structure air loads, make it possible to impart to the surfaces an advantageous aerodynamic shape, reduce the weight of the structure; they are easily installed and repaired. To impart to the fabric air and moisture impermeability, resistance to atmospheric effects, to improve the strength, eliminate surface roughness and for creating the required tensions, it is, after sheathing the frame and fastening, covered on the face side (which is not so pile-textured) first by special colorless aircraft varnishes and then by pigmented varnishes. When fabric cuts are sewn together for sheating large aircraft surfaces, the joining seams should not be located perpendicular to the flight direction, and the sewing threads should conform to the requirements of GOST 6309-59 (for brand AM-100 and ALL – No. 30, for brand AM-93 – No. 20, for brand AST-100 and A[illegible] fabrics – No. 10). When using interchangeable (with respect to [illegible]ength) fabrics of the AM-100 and ALL brands and AST-100 and ALVK brand fabrics it must take into account that flax fabrics are characterized by smaller elongations and that to create tension in the covering it is necessary to apply a smaller num-

ber of colorless varnish layers, while cotton fabrics have a smoother surface and a lower weight and they require a smaller number of joining seams. For the main characteristics of fabrics for aircraft covering see the table.

Main Characteristics of Fabrics for Aircraft Covering

1 Марка	2 Размеры		3 Вес 1 м² (г)	4 Влажность (%)	5 Разрывная нагрузка полоски 50×200 мм (кг, не менее)		6 Удлинение (%, не более)		7 Разрывная длина (км)		8 Плотность (число нитей на 10 см)		9 Прочность на раздир (кг)	
	ширина (см) 10	толщина (мм) 11			по основе 12	по утку 13	по основе 12	по утку 13	по основе	по утку 13	по основе 12	по утку	по основе	по утку
АМ-100	137±2	0,18—0,22	127+7	8,5	60	37,5	13	13	9,5	9,1	328±8	322±14	—	—
АМ-93	137±2	0,27—0,3	не >160	14 8,5	70	70	13	13	8,8	8,8	не <320	не <290	3,1	3,1
АСТ-100	135±2	0,34—0,4	195+10	8,5	90	90	15	15	9,2	9,2	320—310	320—310	5,3	5,2
АЛЛ	89±1	0,26—0,28	165+5	10	60	60	11	11	7,3	7,3	344±12	341±8	5,8	5,2
АЛВМ	89±1	0,34—0,36	220+10	10	90	90	11	11	8,3	8,3	300±10	300±10 14	8,8	7,5

1) Brand; 2) dimensions; 3) weight of 1 m^2 (g); 4) moisture content (%); 5) rupture load of 50 × 200 mm strip (kg, not less than); 6) elongation (%, not more than); 7) rupture length (km); 8) density (thread count per 10 cm); 9) tearing strength (kg); 10) width (cm); 11) thickness (mm); 12) for the warp; 13) for the weft; 14) not.

A.S. Konstantinov

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[Transliterated Symbols]

1406 ГОСТ = GOST = Gosudarstvenny obshchesoyuznyy standard = All-Union State Standard

1406 ТУ = TU = Tekhnicheskiye usloviya = technical specifications

FABRICS FOR DRIVE BELTS, CONVEYER AND ELEVATOR BELTING - fabrics used as the power element of belts. Single and multilayer cotton fabrics are used primarily in the manufacture of rubberized belting and drive belts.

Multilayer cotton fabrics are produced in the form of all-woven materials of different width and layer number, which are impregnated by bitumen-ozocerite compounds and are stretched in the longitudinal direction. Unfinished materials can also be produced. The impregnation imparts water-repelling properties to the fabrics.

Fabrics from polyamide fibers are used for ubberized conveyer and elevator belting. The physicomechanical indicators of capron fabrics for conveyer belting are presented in Table 1.

In addition to load-transmitting fabrics, fabrics with fastened weave cells are used for conveyer and elevator belting. The warp of these fabrics is 34/5 capron thread, the weft is No. 40/2 cotton yarn.

Cotton cord fabrics from wet twisted yarn (see Fig. 2) are used for the strength layer (core) of rubberized V drive belts.

In the manufacture of V belts extensive use is made of chemical fibers which comprise the warp of the fabric, with cotton yarn used as the weft. The physicomechanical indicators of these fabrics are given in Table 3.

The outside sheating of the V belt core is made from OT-40 and OT-65 cotton fabrics (see Table 4). To impart a greater transverse rigidity to the V belt use is made of rubberized cotton fabrics in the stretching layer of the belt (see Table 5).

TABLE 1

Physicomechanical Indicators for Capron Fabrics for Conveyer Belting

Наименование тканей 1	Толщина (мм, не более) 2	Вес 1 м² (г, не более) 3	Структура нити 4		Разрывная нагрузка полосы 50×200 мм (кг, не менее)		Удлинение при разрыве (%, не более) 6		Тип переплетения 7
			8 основа	9 уток	основа	уток	основа	уток	
10 К-4-3 основная	0,9±0,1	370±20	34/4/3	34/1	950	—	25+2	—	Полотняное 11
12 К-4-3 уточная . .	0,9±0,1	350±20	34/3	34/4/3	200	750	27+2	25+2	То же 13
14 К-8-3Т основная	1,4	655	34,5/8/3	34,5/1	1600	—	27	—	»
15 К-8-3Т уточная	1,3	630	34,5/3	34,5/8/3	200	1200	—	27	»
16 К-10-2-3Т основная	1,35	665±20	10,7/2/3	34,5/1	1600	—	28	—	»
17 К-10-2-3Т уточная	1,1	575±20	34,5/3	10,7/2/3	200	1200	—	28	»
18 Ткань «Целина» из № 34,5 .	0,73+0,05	360+20	34,5/6	34,5/4	650	270	25	25	Уточный репс 19
20 Ткань «Целина» из № 10,7 . .	0,74+0,05	370±20	10,7/2	10,7/1	700	290	25	25	То же 13

1) Fabric designation; 2) thickness (mm, not more than); 3) weight of 1 m^2 (g, not more than); 4) thread structure; 5) rupture load of a 50 × × 200 mm strip (kg, not less than); 6) elongation at break (%, not more than); 7) weave type; 8) warp; 9) weft; 10) K-4-3 warp; 11) plain; 12) K-4-3 weft; 13) same as above; 14) K-8-3T warp; 15) K-8-3T weft; 16) K-10-2-3T warp; 17) K-10-2-3T weft; 18) "Tselina" fabrics from No. 34.5; 19) weft repp; 20) "Tselina" fabric from No. 10.7.

TABLE 2

Physicochemical Indicators of Cotton Cord Fabrics from Wet Twisted Yarn*

Артикул 1	Марка корда 2	Толщина нити основы при влажности не более 6,5% (мм) 3	Разрывная нагрузка нити, приведенная к 6,5% влажности (кг, не менее) 4	Неровнота крепости основы (%, не более) 5	Удлинение (%) 6		Число нитей на 10 см 7		Ширина ткани (см) 12
					при нагрузке 4,5 кг 8	при разрыве 9	основа 10	уток 11	
2181 . . .	11Т	0,87 ±0,5	11,0	5,0	6,5 ±1,5	13,0 ±2,5	9[illegible] ±1	8 ±1	150 ±1
2182 . . .	11Т	0,87 ±0,05	11,0	5,0	6,5 ±1,5	13,0 ±2,5	94 ±1	8 ±1	153 ±2
2183 . . .	114Т	0,87 ±0,05	11,0	5,0	6,5 ±1,5	13,0 ±2,5	70 ±1	10 ±1	150 ±1

*The fabric is produced in cuts 180 ± 5 m long, No. 40 cotton yarn is used for the weft.

1) Type; 2) cord brand; 3) thickness of the warp thread with a moisture content not higher than 6.5% (mm); 4) rupture load of the thread, reduced to 6.5% moisture content (kg, not less than); 5) nonuniformity in the warp strength (%, not more than); 6) elongation (%); 7) thread count per 10 cm; 8) when loaded by 4.5 kg; 9) on break; 10) warp; 11) weft; 12) fabric width (cm).

TABLE 3

Physicomechanical Indicators of Fabrics with a Warp from Chemical Fibers

Марка 1	Толщина (мм) 2	Вес 1 м² (г) 3	Структура 4: основа 8	Структура 4: уток 9	Разрывная по основе нагрузка полоски 50×200 мм (кг, не менее) 5	Удлинение при разрыве по основе (%, не более) 6	Примечание 7
К8-2	1,15±0,15	580±30	34/8/3 капрон 10	34/1 хл.-бум. 11	1100	27	Выпускается полотняным переплетением шириной 80—105±2 см 12
К10-2 3	1,10±0,15	580±30	10/2/3 капрон 10	34/1 хл.-бум. 11	1200	27	Выпускается полотняным переплетением шириной 90±2 см 13

1) Brand; 2) thickness (mm); 3) weight of 1 m^2 (g); 4) structure; 5) rupture length for the warp of a 50 × 200 mm strip (kg, not less than); 6) elongation at break of the warp (%, not more than); 7) remarks; 8) warp; 9) weft; 10) capron; 11) cotton; 12) is produced with a plain weave with a width of 80-105 ± 2 cm; 13) is produced with a plain weave with a width of 90 ± 2 cm.

TABLE 4

Physicomechanical Indicators of the OT-40 and OT-65 Cotton Fabrics

Марка 1	Ширина (см) 2	Вес 1 м² (г) 3	Толщина (мм) 4	Номер пряжи 5: основа	Номер пряжи 5: уток	Число нитей на 10 см 6: основа	Число нитей на 10 см 6: уток	Разрывная нагрузка полоски 50×200 мм (кг) 7: основа	Разрывная нагрузка полоски 50×200 мм (кг) 7: уток	Разрывное удлинение (%) 8: основа	Разрывное удлинение (%) 8: уток
ОТ-40 . .	107 ±1,5	303 ±10	0,7 ±0,05	40/4	40/4	124 ±2	143 −3	72 −3	92 −4	18 ±3	15 ±3
ОТ-65 . .	103 ±2	156 ±8	— —	65/2	34	228 ±6	250 ±6	40 −4	45 −5	14 ±3	14 ±3

1) Brand; 2) width (cm); 3) weight of 1 m^2 (g); 4) thickness (mm); 5) yarn number; 6) thread count per 10 cm; 7) rupture load of a 50 × 200 mm strip (kg); 8) elongation at break (%); 9) warp; 10) weft.

TABLE 5

Indicators of Cotton Fabrics for the Stretching Layer

Артикул 1	Ширина (см) 2: по норме 7	Ширина (см) 2: допускаемое отклонение 8	Номер пряжи 3: основа	Номер пряжи 3: уток	Число нитей на 10 см 4: основа 5: по норме	Число нитей на 10 см 4: основа 5: допускаемое отклонение	Число нитей на 10 см 4: уток 6: по норме	Число нитей на 10 см 4: уток 6: допускаемое отклонение
2071	87	±1	20/2	12	90	±2	120	±2
2072	100	±1	20/2	12	90	±2	120	±2

1) Type; 2) width (cm); 3) yarn number; 4) thread count per 10 cm; 5) warp; 6) weft; 7) according to the norm; 8) permissible deviation.

S. Ye. Strusevich

FAIENCE – is a ceramic material characterized by a white porous body. It is covered with a low-melting glaze in order to improve its impermeability to moisture. It is permeable to fluids and gases. It is widely used in the manufacture of sanitary engineering objects, and also as a filter material. The main properties of faience are: specific gravity about 2.6; density 1.9-2 g/cm^3; water absorption 9-12%; compression strength 1000-1100, tensile strength 70-120, and bending strength 150-250 kg/cm^2; modulus of elasticity about 2400 kg/cm^2, and linear expansion coefficient $\alpha \cdot 10^{-6}$ = 7-8.

V.L. Balkevich

FAOLITE – is an acidproof plastic obtained from a resolphenol formaldehyde resin with chrysotile asbestos and graphite as fillers. Faolite is prepared by mixing the liquid resol resol resin with the fillers in a two-vane mixer at 20°, rolling at 70-90°, and calendering; it is available either as a crude faolite (sheets, cements, molding composition) or as shaped objects (pipes, fittings, sheets, vats, scrubbers, adsorbers, coolers, ejectors, reservoirs, etc.). The objects made from faolite are hardened and varnished by bakelite varnish. The crude faolite is moldable at normal temperatures without applying high pressure, a fact which makes it possible to shape large-size objects on the spot and to apply acidproof coatings. Cured faolite has a specific gravity of 1.5-1.67; a specific resilience of not lower than 2 $kg \cdot cm/cm^2$, a temporary bending strength of 260-600 kg/cm^2, a tensile strength of 120-385 kg/cm^2, a compression strength of 580-900 kg/cm^2, and a shearing strength of 240-250 kg/cm^2; the heat resistance according to Martens is not lower than 100°; the coefficient of linear expansion at 20-200° is $2\text{-}3 \cdot 10^{-5}$; the hea5 conductivity of faolite containing asbestos and graphite is 0.90 kcal/m•hr•°C, and that of faolite containing asbestos 0.25 kcal/m•hr°C; the Brinell hardness is 20 kg/mm^2; it is usable at temperatures up to 130°. Faolite resists sulfuric acid (up to a concentration of 40%), hydrochloric acid (up to 37%), phosphoric, acetic, formic, lactic, and citric acids (up to 70°), chlorine, hydrogen chloride, hydrogen sulfide, some solvents (aniline, carbon tetrachloride, ethyl chloride, benzene, methylene chloride, ethyl acetate, etc.), chlorinated hydrocarbons, mineral oils, and salt solutions; it does not

resist oxidizing agents (nitric and chromic acids), iodine, bromine, pyridine, alkalis, alcohol, and acetone. The curing of crude faolite is carried out in drying rooms within 30 hours under the following conditions: 6 hrs at 60-70°; 5 hrs at 70-80°; 4 hrs at 80-90°; 3 hrs at 90-100°; 4 hrs at 100-110°; 5 hrs at 110-120°; and 3 hrs at 120-130°. Raw faolite sheets shrink 2% during the curing, raw faolite pipes shrink 2-3%. The bakelite varnish is applied on the surface by dipping or brushing, the curing lasts 10 hours under the following conditions: 2 hrs at 60-70°; 1 hr at 70-80°; 1 hr at 80-100°; 1 hr at 100-110°; 1 hr at 110-120°; 2 hrs at 120-125°, and 2 hrs at 125-130°.

Faolitization of metal surfaces. The metal surface is cleaned and degreased before covering with faolite. A layer of bakelite varnish is applied on the degreased surface of the object (a jacket or rotor of a pump, a mixer, etc., for example), and a cut out sheet of raw faolite or a uniform layer of a faolite cement is put on; the joints are covered with bakelite varnish, and the gaps are filled with faolite cement. The faolitized object is cured in the same way as the crude faolite. The cured objects are covered with bakelite varnish, and cured in the same manner as a varnish film. Faolite sheets and faolite objects are joined by means of faolite cements (with subsequent curing) or by means of Arzamit cements. Pipes and fittings are manufactured with collars and joined by metal flanges with packings. It is not recommended to join the pipes by threaded muffs because the brittleness of faolite objects makes the threading difficult. Faolite may be easily drilled, turned, planed, polished and sawed on the usual metal-working machines. Reinforcing of the objects with cotton or glass fabric (textofaolite) or with high-quality asbestos gives a faolite with an increased stability. Faolite is often substituted for nonferrous metals, especially lead, as a structural material, surpassing the lead in the resistance

to hydrochloric acid of all concentrations, and sulfuric acid of low and middle concentrations. The light weight of faolite, its chemical stability and its shaping ability make it suitable for use instead of metal in the construction of apparatuses. Faolite is usable at higher temperatures than other chemically stable materials (rubber, viniplast, polyisobutylene, and bitumen materials).

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M.S Krol'

FATIGUE – Change in the state of a metal as a result of multiple repeated (cyclical) deformation, which results in its progressive failure. The fatigue process is divided into two main stages, the 1st consisting of accumulation of irreversible changes which result in the formation of cracks and the 2nd consisting of development of these cracks. In the first stage the crack formation is preceded by accumulation of submicroscopic and microscopic changes, which are expressed in dislocation displacements, vacancy concentration and formation of slip of packets of automatic layers in crystals relative to one another. This slip, which takes place along crystallographic planes with the smallest shear resistance, can result in extrusions, i.e., the creeping of atomic layer packets out from the crystal surface. The accumulation within of the crystalline slips, which develop in individual crystals is observed through a microscope in the form of a system of shear lines and twins.

The irreversible processes in alternating deformation are manifested in the absorption of energy, which is characterized by the elastoplastic hysteresis curve, heat generation, and accumulation of local residual stresses. The formation of slips, under cyclical deformation of monocrystals arises at quite early stages, which comprise several percents of the number of cycles necessary for the formation of microscopic cracks. In polycrystals the inhomogeneity of irreversible processes under cyclical deformation is deepened by microinhomogeneity in the stressed state of the conglomerate, which results from the random orientation of individual crystals, their structural defects, boundary

aberrations and other imperfections. The initial stages of slip phenomena arise in individual, most stressed and weakened, crystals. On further deformation the slip processes extend to increasingly greater volumes of the crystalline conglomerate. At the present time no generally accepted theory of fatigue failure as yet exists. According to one of widely accepted theories, at a certain level of cyclical stress the accumulation of slips results in a zonal exhaustion of the metal's ability for further deformation, in its limiting workhardening and formation of microscopic failures in the form of cracks which form at points of high density of slip phenomena. The workhardening, which extends to a part of the stressed volumes of the conglomerate, is manifested in increasing the metal's resistance to plastic deformation, i.e., in increasing the hardness and yield strength (see Physical Yield Strength, Conventional Yield Strength). The process of inhomogeneous elastoplastic deformation of a polycrystal under repeated loading was simulated on silver chloride ("transparent metal") and has substantiated the assumption of accumulation of plastic deformations and increase in the residual stresses in individual crystals with accumulation of the number of cycles.

According to other theories, the physical nature of the fatigue process differs from the nature of static workhardening. The formation of microscopic cracks under cyclical loads is regarded in this case as a process of gradual weaking of interatomic bounds and development of irreversible "damages" at specific sections of the structure (for example, at mozaic block boundaries). The model of inhomogeneous elastoplastic deformation of the conglomerate of random oriented crystals has served as a basis for the theory of the fatigue process treated in the deterministic as well as in the probability approach. Under stresses not exceeding the yield point of the metal the fatigue processes are

related only to local plastic deformation phenomena which are not manifested macroscopically, and are regarded as quasielastic. The number of cycles needed for fatigue failure at these stress levels are measured in hundreds and of thousands and millions. At stresses exceeding the yield strength the fatigue phenomena are accompanied by macroscopic plastic deformations and are regarded as elastoplastic. The number of cycles needed for failure in this region is measured in hundreds and thousands. Depending on the conditions under which it takes place, the fatigue process can also be accompanied by phase transformations in metals. Thus, precipitation and redistribution of hardening phases takes place at elevated temperatures under alternating loading, which sometimes results in accelerated weakening of the grain boundaries, and under prolonged functioning fatigue failure cracks form in this case at grain boundaries. Physicochemical transformations in the structure are observed also at room temperature under cyclical loads above the fatigue limit. The fatigue failure stage, which is due to crack formation, arises at various stages of the effect of alternating stresses. In the case of high structural inhomogeneity which is peculiar, for example, of cast irons, the microcrack system is formed at points of graphite inclusions much before the development of the main crack which results in final fatigue failure. In metals with a higher structural homogeneity, for example, structural steels, the formation of individual micro- and then macrocracks is preceded by prolonged accumulation of changes, and the cracks form at relatively late stages, developing at an increasing rate.

The rate of accumulation of fatigue changes increases with an increase in the variable stress level, for which reason the number of cycles needed for crack formation or for final failure depends on the value of the stress. This relationship, in the form of a fatigue curve,

is the main characteristic of resistance of metals to varying stresses (see Endurance, Total Fatigue Probability Diagram). Figure 1 represents fatigue curves of various materials, which are drawn for the end of the 1st and 2nd stages of the fatigue process. The effect of time on the

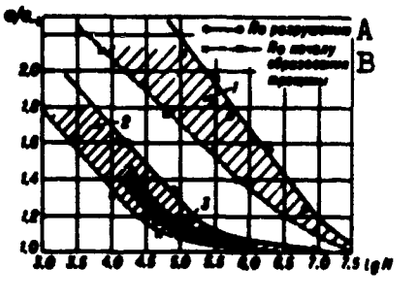

Fig. 1. Fatigue curves for steel, cast iron and aluminum alloys on the basis of the start of crack formation and of final failure. 1) Aluminum alloys; 2) cast iron; 3) structural steel. A) On the basis of failure; B) on the basis of the start of crack formation.

metal's resistance to mechanical effects is manifested in the effect of the frequency of changes in varying stresses on the fatigue curve and limits, i.e., the number of cycles to failure increases with an increase in the frequency. This effect manifests itself particularly under the effect of high temperatures, corrosion (see Corrosion Fatigue), as well as of other conditions, which result in a change in state with respect to time, and then time, rather than the number of cycles, becomes the major factor in failure.

A relationship, characterized by the dependence of the fatigue limit on the ultimate strength, exists between the fatigue resistance and static strength. In regions of high strength values the above relationships deviate from linearity and the increase in the fatigue limit is slowed down, which is due to the increased effect of surface and structure defects on the coming about of fatigue failure. Since fatigue failures have their origin in the region of defects and these defects are usually random in character, the fatigue characteristics are peculiar by their scattering which is governed by laws of probability. Thus,

the number of cycles needed for fatigue failure of a sufficiently large number of specimens for a specified magnitude of variable stresses is usually governed by a normal distribution in logarithmic coordinates, as this is shown in Fig. 2, where the accumulated failure probabilities as a function of the cycles are plotted on a logarithmic coordinate scale. As the stress amplitude is decreased, the scattering is usually increased, it depends to a large extent on the metal's inhomogeneity. In less homogeneous coarse-grained cast alloys it is higher than in the more homogeneous fine-grained alloys.

In static interpretation, the fatigue strength is characterized by a family of fatigue curves with the failure probability as the parameter, as this is described in Fig. 3. The distribution of the number of

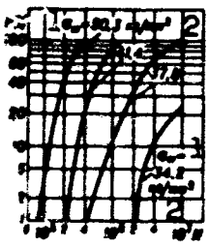

Fig. 2. Curves of normal distribution of the number of cycles to failure as a function of the amplitude of variable stresses for steels, in logarithmic coordinates. 1) t; 2) kg/mm^2.

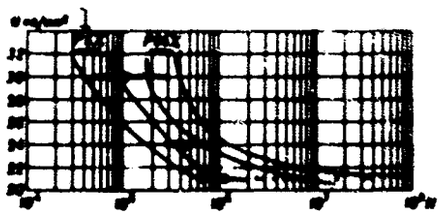

Fig. 3. Family of fatigue curves with the failure probability P as the parameter for aluminum alloys. 1) Kg/mm^2.

cycles to failure has a lower limit, which is called the sensitivity threshold (with respect to the number of cycles), i.e., such a number of cycles at the given stress for which the practical probability of failure is zero. Fatigue resistance is due to the effect of metallurgi-

cal factors and the production process (see Mechanical Properties Under Repeated Loads). It decreases with an increase in contamination by nonmetallic inclusions, nonuniformity in the distribution of alloying elements and increasing the grain size. Heat treatment, which reduces the grain size, and increases the static strength, has a favorable effect on fatigue characteristics; decarburization of the surface layer or oxidation of grain boundaries reduces it perceptibly. A substantial effect on fatigue resistance is exerted by the qualify of the machining finish of the surface; it is the higher, the more homogeneous and strong the metal is. Workhardening, residual stresses, thermal effects, which arise on turning, milling and grinding, together with the microrelief which is thus formed, can reduce the numbers of cycles to fatigue failure by several orders of magnitude, reduce the fatigue limits by several tens of percents and substantially increases the scattering. High-strength steels, titanium alloys and nickel heat-resisting steels are particularly sensitive in this respect; to reduce the effect of machining on their fatigue properties use is made of finishing processes which yield a high surface finish and reduce residual stresses (polishing, hydraulic-feed honing, vibration tumbling).

The probability nature of fatigue failure, which depends on defects of the metal's structure and surface, is reflected in relationships governing similarity phenomena for these failures. As the volumes subjected to variable stresses increase, the probability of weakening the material's resistance to failure by more substantial defects and their combination increases, the fatigue limit is reduced and the scattering is weakened. The effect of absolute dimensions on fatigue properties of a metal increases with an increase in its inhomogeneity, being particularly sharply manifested in cast and coarse-grained structures. As the probability of failure decreases, the effect of absolute

dimensions is reduced, since, in accordance with statistical concepts, the scattering is decreased with an increase in the stressed volumes, and the fatigue curves for low failure probabilities for different cross-sectional dimensions come closer together. Under complex stressed states fatigue failures for metals in the ductile state are basically determined by maximum or octahedral tangential stresses, which follows, for example, from data of fatigue studies for structural steels. The majority of results lies between the bounding hexagonal of tangential and ellipse of octahedral stresses. Failures for metals in the brittle state are determined by the principal normal tensile stresses, they are situated nearer to the bounding square of limiting normal stresses. The form of fatigue fracture in torsion for ductile materials shows that the fatigue failure originated along the direction of action of the highest tangential stresses. In brittle metals the crack originates immediately in the direction of action of the highest normal stresses. The crack development usually follows surfaces of highest normal stresses. Of significance to fatigue failures is the combination of the variable and static stressed states, which is characterized by

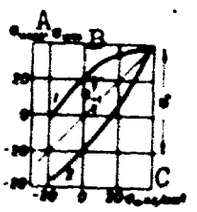

Fig. 4. Diagram of limiting stresses for an asymmetric cycle for structural steel in compression-tension. 1) σ_{maks}; 2) σ_{min}. A) Maks; B) min; C) σ_t, kg/mm^2.

the cycle's asymmetry, the coefficient of which is the ratio of the minimum and maximum stresses of cycle, taken algebraically. The effect of the cycle's asymmetry is characterized by the limiting stresses diagram (see Smith's Diagram), a schematic of which, with the maximum and

average stresses of the cycle as coordinates, is represented in Fig. 4 for a metal in the brittle state. For this combination the role of the static component is substantial and makes it possible to increase the fatigue strength in the static compression region, which is extensively utilized in surface hardening processes.

In the presence of stress concentration the fatigue failure is determined by the maximum stresses, by the gradient of their distribution over the cross section, as well as by the structure of the metal's inhomogeneity. This follows from probability concepts about the formation of the fatigue crack as a function of the stressed volumes, the stressed state level and the scattering of properties. With a reduction in the failure probability, for different values of which limiting stress surfaces are constructed, the effect of absolute dimensions and the gradient is weakened. This effect is also weakened with an increase in the structural inhomogeneity of the metal, i.e., the metal's sensitivity to stress concentration is reduced.

Features peculiar to the metal's resistance to fatigue damage are characterized by accumulation of damages under the effect of nonsteady regimes of variable stresses, when the amplitude of the latter varies. Assuming that the accumulation of damages is proportional to the number of cycles during which they act at each stress level and that the processes for each interval of cycle numbers are independent of one another, this accumulation "a" is evaluated by the summation of cycle ratios $a = \Sigma \frac{n_i}{N_i}$, where n_i is the number of cycles of stress application with the amplitude σ_i and N_i is the number of cycles according to the starting fatigue curve, which is needed for forming the initial stages of the fatigue crack or for failure under the action of stresses σ_i.

The limiting state with respect to the accumulation of fatigue damage in the sense of forming a crack or complete fatigue failure is

characterized by reaching a certain limiting value a = A, which in general depends on both the type of material and the progress of changes in the variable stresses, which is characterized by the appropriate spectrum. Secondary fatigue curves are used to characterize the resistance of metals to damage accumulation not only with respect to the number of cycles, but also in terms of stresses. Total numbers of cy-

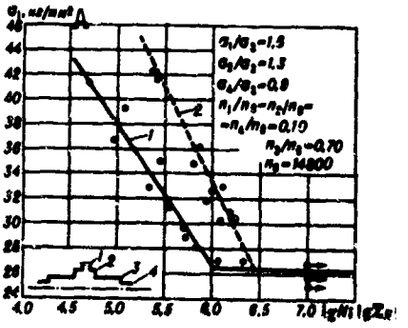

Fig. 5. Initial and secondary fatigue curves for cast iron, drawn in terms of maximum stresses for multistep changes in stresses. 1) Initial fatigue curve; 2) secondary fatigue curve. A) Kg/mm^2.

cles accumulated at all the stress levels which are needed for crack formation or failure are drawn on these curves as a function of the magnitude of one of the stresses of the spectrum (for example, the minimum stress), which characterizes its level. Upon transition from a spectrum with one level to a spectrum with another, all the stresses of spectrum change proportionally. Figure 5 shows the initial and secondary fatigue curves for cast iron. The value of the secondary fatigue strength follows from the secondary fatigue curve. When the damage accumulation is linear and the same at all levels, the left branches of the initial and secondary curves are parallel.

Vibrational processes, which result in fatigue failure, can be originated by acoustic phenomena and have a wide sprectrum of frequencies and amplitudes corresponding to variable stresses. The metal's fatigue in this case is called acoustic and is characterized by accumulation of

damage which arises under conditions of imposition of vibrational stresses, which are described by applicable spectra, the parameters of which can be characterized statistically. Fatigue damage under non-steady-state variable stresses arises also due to stresses with amplitudes lower than the fatigue limit, since the damage which is being accumulated in the metal reduces the fatigue resistance and, as this damage increases, the fatigue limit is reduced, if it is determined for the fatigue-damaged material.

Under variable stresses which exceed the yield strength, the fatigue processes take place in the elastoplastic region (in the sense of macrodeformations) and hence the deformation amplitude can be used for describing the fatigue processes, instead of the stresses. The fatigue curve in this case represents the relationship between this amplitude and the number of cycles needed for crack formation or failure. In tests with a constant force amplitude the fatigue curve is drawn as the relationship between the amplitude and the number of cycles to failure; in this case a monotonical accumulation of plastic deformation is observed. The number of cycles to failure in the elastoplastic region for steel usually does not exceed ten-twelve thousands; this region is characterized as low-cycle fatigue. The fatigue resistance in the low-cycle region is reduced with a reduction in the frequency. If the cyclical deformations and stresses arise as a result of periodic temperature changes, then the low-cycle failure periods are called <u>thermal fatigue</u>. When drawn in logarithmic coordinates, the relationship between the deformation amplitude and the number of cycles is found to be linear, which corresponds to a power-law equation for the low-cycle fatigue curve $\Sigma^m N = \text{const}$.

The fatigue failure process can be transformed into brittle fail-

ure, since the damage being accumulated increases the critical brittleness temperature and aids in the initiation of instantaneous brittle failure cracks, when the metal is found to be in the region of below-critical temperatures (see Static Endurance).

The fatigue characteristics are substantially dependent on the surface finish, absolute dimensions and the stressed state, in a number of cases on the frequency. Hence in order for results to be comparable it is necessary to perform tests on specimens of a specific shape and dimensions, which are made in accordance with a proscribed production process (see Fatigue Testing). The appropriate requirements put to specimens and fatigue test conditions are established by GOST. Due to the substantial scattering, which is perpendicular to fatigue characteristics, evaluating the reliability and comparability of the pertinent experimental data requires a volume of tests which is sufficient for statistical interpretation of the results.

S.V. Serensen.

Manuscript Page No.

[Transliterated Symbols]

1419 m = t = tekuchest' = yield

1421 макс = maks = maksimum = maximum

1421 мин = min = minimum = minimum

1425 ГОСТ = GOST = Gosudarstvennyy obshchesoyuznyy standard = All-Union State Standard

FATIGUE FRACTURE – is the surface of the place of total destruction of a specimen or a working piece caused by the development of a fatigue crack. Fatigue fracture is frequently observable in the case of destruction of parts of engines or constructions. Fatigue fracture shows three characteristic zones (Fig.): 1) the focus of destruction (zone A) being the macroscopic place of the generation and the initial stadium of the development of a crack, characterized by an intense luster and a fine-grained surface structure; 2) the zone of the proper fatigue development of the crack (zone B) is characterized by luster and a strain-hardned surface due to the repeated opening and closing of the crack; 3) the zone of the final fracture (zone V) corresponds to the final brittle destruction of the part and has a more coarse surface structure. The dimensions and the shape of the zones B and V depend on the constructive peculiarities of the specimen, on the load conditions, and the magnitude of the stresses; this makes it possible to determine in a number of cases the causes of the fatigue destruction of parts outgoing from the aspect of the fatigue fractures.

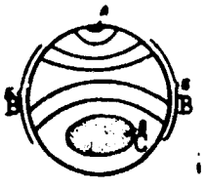

Fig. The characteristic zones of the fatigue fracture.

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M.N. Stepnov

FATIGUE OF MATERIALS – reduction of strength with an increase in the time during which the material is in a stressed state. This phenomenon is called static fatigue of materials or time-dependence of strength, if the material is in a static stressed state, and dynamic fatigue of materials, if it is subjected to cyclical loads. Fatigue of materials is the main factor in determining the service life of many products.

The main mechanism of failure and the relationships governing it are the same for dynamic and static fatigue of materials, however, in dynamic testing other specific processes such as loosening the structure (polycrystalline materials), substantial overheating of the material at points of overstress (plastics, rubbers), mechanochemical processes, relaxation and aftereffect phenomena (rubbers), adsorption aftereffect (if the failure takes place in a surface-active medium), etc., are superimposed on the main failure process. In order to set off the complexity of dynamic fatigue of rubbers in comparison with their static fatigue, the processes which take place attendant to their multiple deformations have been called exhaustion.

Development of methods for calculating the strength and service life of materials under various loading regimes in terms of the time dependence of the given material's strength is of tremendous practical importance. The latter is determined relatively simply by experimental means, while in the case of dynamic loads the experiments have to be repeated each time under complex conditions.

Fatigue failure of plastics and metals is conventionally divided

into two classes: 1) typically fatigue failure, which takes place under loading frequencies from hundreds to tens of thousands of cycles per minute, with the number of cycles to failure being not less than 100,000; 2) repeated static failure, when the number of cycles to failure does not exceed 10,000 and the frequency of load application is less than 10 cycles per minute. The latter case is intermediate between dynamic and static fatigue. In addition, for metals it is conventional to differentiate between: impact fatigue failure, which is a particular case of typically fatigue failure; corrosion fatigue failure, in which cracks are formed similar to carcks due to corrosion in an unstressed material, and the oxidized material, opening up the cracks, substantially accelerates the failure process; thermal fatigue, which is produced by cyclical temperature stresses on alternating heating and cooling; fretting fatigue failure, i.e., crumbling away of metal from the contact surfaces of components with substantial mutual displacements; here the surface is covered by characteristic "pock marks."

The dependence of the number of cycles to failure on the magnitude of the alternating stress in dynamic testing of metals is expressed by Veler's curve (see Endurance). The stress toward which the curve tends asymptotically is called the fatigue limit. However, in certain cases (aluminum alloys, very large specimens, corrosion fatigue failure) the fatigue limit is not observed.

In dynamic testing of plastics their strength is highly affected by the heating up of the material due to hysteresis losses; the temperature of the entire specimen does not increase substantially, however, at points of overstress the thermal effects can be substantial. As a result, the rate of microcrack growth increases perceptibly and the endurance will correspond to the endurance of the material at elevated temperatures. Hence the hysteresis losses per unit time and the fatigue

of plastic materials increase with an increase in the test frequency. For a moderate number of cycles to failure (high stresses) these thermal effects are less substantial and the dynamic endurance is higher than the static endurance at a constant stress, which is equal to the stress (maximum for the cycle) in cyclical loading. For a large number of cycles to failure the endurance in dynamic tests is, for the aforementioned reason, lower than the endurance in static tests.

In dynamic testing of rubbers use is made usually of two testing regimes, which correspond to two main operational regimes: 1) regime of constant maximum deformations ε-const and 2) regime of maximum constant loads or conventional stresses calculated for the initial cross section, f-const. The first regime is obtained by specifying maximum swing to the instrument's clamp and is accompanied in the testing process by accumulation of "residual" deformations of one or another magnitude in the rubber specimen, depending on the properties of rubber tested, specified maximum deformation, stretching frequency and temperature. The maximum load per cycle is here, unlike the second regime, reduced, relaxing with time to a certain limit. Hence for identical initial maximum deformations the rigidity of the first regime is smaller than that of the second. The second regime is obtained by using a device which makes it possible, after each stretching cycle, to select the "residual" deformation in such a manner that a constant load interval from 0 to $\underline{f}$ be achieved in the testing process. With time the maximum deformation per cycle is increased, unlike the first regime where it is always constant. Hence, if we compare both testing regimes for identical maximum deformations at the end of testing, then the first regime will be found more rigorous.

The number of cycles to failure N and the maximum deformations per cycle ε for both rubber testing regimes is related by: $N\varepsilon^{\gamma} = C$, where γ

and C are not frequently dependent, and γ, in addition, is independent of the temperature and test regime. The fatigue of rubbers in dynamic testing is expressed by a relationship, similar to the time dependence of their strength: $\tau = B\sigma^{-b}$, where the constant b is independent of the temperature and testing regime and has the same value as in the time dependence of rubber strength; B for static tests is higher than for dynamic tests. The static testing regime is more favorable for rubbers than the dynamic, although in the first case the material is subjected to stresses for the entire time. This is due, firstly, to complete relaxation of overstresses at microdefects under static loading (under dynamic loading not enough time is available for the relaxation to occur during each cycle), and secondly, by mechanochemical processes, which accelerate failure under cyclical stretching.

Cyclical stresses accelerate the processes of rubber aging (chemical processes which proceed under the action of oxygen and heat and which result in changing the structure and impairing the service properties). In particular, this is expressed in reducing the activation energy. A substantial role is played by nonuniformity of microstresses and in the distribution of oxygen, inhibitors and other ingredients in the rubber. All this results in nonsimultaneous progress of oxidation processes in difference in the character of exhaustion processes in various parts of the specimen. By virtue of the chain character of processes, many failure origins are formed on relatively moderate changes in the specimen's properties as a whole. One of the more specific mechanisms of rubber exhaustion is mechanically activated exhaustion of raw rubbers. However, exhaustion of polymers is due not only to oxidation, but also to direct degradation of the polymer by the stresses.

A direct proof of the role played by mechanochemical processes is the anomalous dependence of the endurance on the specimen's thickness,

if the rubber is poorly protected from aging processes. A well protected rubber gives a normal scale strength effect. The reason for this consists in the fact that aging will in part proceed by oxygen which diffuses in from the air. The diffusion rate in thin specimens is higher and the strength is reduced rapidly.

During each cycle of rubber deformation a part of the work is converted into heat (hysteresis phenomenon). Since the thermal conductivity of rubber is low, in repeated deformations the heat generation due to hysteresis results in substantial overheating of the material. This is particularly dangerous due to the fact that the rate of aging processes increases rapidly with an increase in the temperature. The temperature increase in multiple deformations sharply reduces the fatigue strength. The internal friction almost always (with the exception of shock-absorbing devices) plays a negative role in the service of rubber, since the overheating has a negative effect not only on the fatigue strength, but also on the wear of rubber as well as on the strength of coupling between elements of multilayer constructions.

Due to the relatively slower heat removal from massive products, their overheating is more pronounced and they break down more rapidly (effect of the thermal scale factor attendant to rubber exhaustion). The mechanical losses depend on the frequency and rate of deformation. The losses for rubbers with fillers are greater than for rubbers without fillers.

The main effect on the dynamic fatigue of rubbers is exerted by the type of raw rubber and, to a lesser extent, by the rubber's composition. Together with this, comparison of fatigue properties of rubbers made from different rubber raw materials when changing from one testing regime to another can give directly opposite results, which must be taken into account in selecting rubber for specific service conditions.

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G.M. Bartenev.

FATIGUE STRENGTH – see Durability.

FATIGUE TEST – is a test in which the specimen is loaded by alternating loads. Fatigue test determines the fatigue limit or limited endurance limits, and a large straggling of the results of tests of a series of specimens occurs. In some cases, the ratio of the maximum of cycles of alternating stresses which cause the rupture to the minimum of cycles amounts to some tens for specimens tested on the same level of maximum stresses. This straggling is caused by the statistical nature of the process of fatigue rupture owing to the microscopical and macroscopical inhomogeneity of the properties of the specimens to be tested, the inhomogeneity of the diverse melting processes and of the semifinished products, the imperfection of the technology of preparation of the specimens and also of the testing methods. The straggling of the ultimate number of cycles caused by the latter fact may be reduced to a minimum by improving the technique for the preparation of specimens, and by a careful adjustment and control of the test machine and an exact fixing of the specimens in it. The method of metal fatigue tests and also the requirements of the equipment are standardized by GOST 2860-45.

The main methods of loading in fatigue tests are the pure bending or the bending of a cantilever specimen. Tests with asymmetrical load cycles (asymmetrical stretching, joint effect of a static stretching load and an alternating bending load) are also widespread. Shape and size of the specimen depend, as a rule, on the type of the fatigue test machine; the influence of the specimens shape on the experimental results must be taken into account. Cylindrical and flat specimens are

mostly widespread. The endurance limit of flat specimens is by 5-15% lower than of cylindrical ones. The working part of smooth specimens has either a constant cross section (Fig. 1, a) or a corset shape (Fig. 1, b). In the first case, the mean endurance is somewhat lower as in the second case, owing to the considerable volume of material exposed to the action of high alternating loads. The corset form of the working part permits to predetermine the point of the fracture. The state of the surface of the specimens influences significantly the fatigue strength of the material. Scale, scratches, machining traces, stretching residual stresses, brands and cracks reduce strongly the endurance limit of the material. Thus, scale reduces the endurance limit of steel to 70%, raw machining to 40%, grinding cracks to 2 times and more, brands to 25%. Therefore, the working part of the specimens must be free from the above-mentioned defects. The preparation of steel specimens consists in the following operations: turning, grinding with an allowance of 0.10-0.15 mm, heat treatment, final grinding, and polishing. The machining of aluminum alloys is carried out after heat treatment in the following order: raw turning with an allowance of 0.3-1.0 mm, finish turning in two operations (the last shavings are taken off with an advancing of 0.03-0.08 mm/revolution, a depth of 0.1-0.2 mm and a cutting speed not exceeding 15-20 m/sec), grinding with fine-grained emery paper, and polishing with felt and paste in longitudinal direction. Specimens of plastics are prepared by pressing or machining for the fatigue test. The pressing is carried out according to the conditions given in the TU for this material. The conditions for the machining depend on the type of plastics and must exclude melting or burning of the surface layer of the specimen. Plastics are, in the fatigue test, as a rule, less sensitive to the purity of the surface than metals. The testing machines must be examined and adjusted carefully from time to

time. Twist and eccentricity, which may effect supplementary indeterminable stresses, must be avoided when fixing the specimens in the machine clamps.

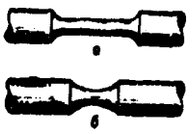

Fig. 1. Shape of the working parts of specimens for the fatigue test: a) With constant cross section; b) with corset shape.

A series of 8-10 specimens is tested for the design of a usual endurance curve. When symmetrical load is applied, the first specimen is tested at a maximum stress σ_{maks} = (0.6-0.7) σ_b for steel, and σ_{maks} = 0.5-0.6) σ_b for light alloys. The maximum stress must not exceed the yield limit of the material. The testing of a series of specimens is carried out diminishing gradually the maximum stresses by 3-4 kg/mm^2 until the next specimen withstands the basic number of cycles without fracture. The maximum stress for the next specimen is then taken by 2 kg/mm^2 higher than for the not broken specimen; the stress for the subsequent specimen is then reduced or increased by 1 kg/mm^2, respectively, depending on whether the foregoing specimen is broken or not. The tests are continued according to this program until the maximum stresses of the last – broken and not broken – specimens differ less than 5%. The remaining specimens are tested in order to define more accurately the endurance limits and some sections of the fatigue curve. When asymmetrical cycles are applied, the testing of the whole series of specimens is carried out either at a constant average stress or at a constant coefficient of asymmetry of the cycle. Usually, the limit stress diagrams designed by these methods do not differ from each other. At an asymmetrical cycle of stresses, the first specimen is tested at a maximum stress equal to 0.8-0.9 of the yield limit of the material. The testing

of the following specimens is carried out in the same way as in the case of symmetrical cycle. 15-20 specimens are tested on four stress levels for the design of the whole probability diagram, and the results are processed statistically. The following peculiarities must be taken into account in the fatigue test of plastics: 1) the specimens become heated up to 80-100° due to the high damping properties of plastics, they must be cooled, therefore; 2) the test results carried out at "fixed load" or at "fixed deformation" differ essentially from each other owing to the relaxation of the statical and dynamical components of the stress; 3) it is not expedient to use machines with rotating specimens for the test of anisotropic plastics. Such materials must be tested in machines with a stress-compression cycle; 4) the test of thermoplasts (without cooling of the specimens) by stress – compression is usually carried out at a frequency of 10-15 cycles per 1 minute, and when bending is applied, at a frequency of ~ 200-600 cycles per 1 min; the stress-compression test of glas-textolites and of textolites is carried out by a frequency of 200-400, and in the case of bending by 1000-1500 cycles per 1 min.

The base for the testing of steels is usually selected in the range of 10 million cycles. For light alloys, polymer materials, and also for steels working at high temperatures or in aggressive media, for which the endurance curve lowers constantly when the maximum stress is reduced, the base is selected, depending on the concrete requirements, in the range of 10^7-10^8 and more cycles.

Tests at raised or reduced temperature or under the influence of aggressive media are carried out to evaluate the fatigue strength under working conditions, changing programmatically the stresses corresponding to the spectrum of loads which acts on the piece in service, etc.

The fatigue test at high temperatures is usually carried out on

special fatigue-test machines. Machines are widespread in which an alternating bending of the rotating or resting specimen is carried out. Machines with a resting specimen and a rotating force field (inverse machines) are the most convenient ones owing to the facility of the measurement of the heating temperature of the specimen. The heating of the specimen is carried out in a tubular electric resistance furnace. The length of the furnace muffle must be at least 3-5 times so long as the working part of the specimen in order to secure a uniform heating of the specimen along its length and its diameter; the pitch of the electric winding of horizontal furnaces is shortened on both ends. In vertical machines, the winding pitch is usually most short in the lower part of the furnaces. The heating temperature is controlled by thermocouples, their hot junctions are fixed on the specimen (when resting specimens are used) and protected by asbestos from the direct effect of the radiation heat of the muffle. The cold junctions are kept in a thermostat. Nickel-nichrome and chromel-alumel thermocouples are used for temperatures up to 900°, platinum/platinum-rhodium thermocouples are applied at higher temperatures. The temperature is controlled during the test by means of dilatometer controllers or by an electronic device for which the thermocouples jointed with the furnace muffle serve as pickups. Both usual and special machines are used for tests in corrosive medium. The scheme of I.V. Kudryavtsev's fatigue test machine with inertial excitation for bending in aggressive media is shown in Fig. 2. Fatigue tests at low temperatures may also be carried out in this machine. The specimen is fixed on the one end and surrounded by the corrosion or freezing medium contained in the vessel. The alternating bending load of the specimen is achieved by the rotation of a beam with a nonequilibrium weight. The rotation of the beam is realized by an electric motor via a flexible shaft and a fork.

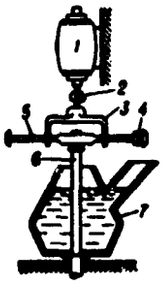

Fig. 2. Scheme of the fatigue test machine for tests in corrosive media; 1) Electric motor; 2) flexible shaft; 3) fork; 4) nonequilibrium weight; 5) beam; 6) specimen; 7) vessel.

Full-scale tests of machine units or of single structural parts, caused by the increased requirements of the operational reliability of machines and the reduction of their weight, become more and more widespread. The full-scale tests are carried out on both usual and special test machines and stands.

Besides the usual fatigue test machines, machines exist for fatigue test in a complex stressed state, for contact fatigue, for fatigue caused by repeated impact load, for thermal, acoustical, etc. fatigues.

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M.N. Stepnov, V.S. Strelyayev

FATIGUE ZONE – see Fatigue Breaking.

FEKHRAL' – see Alloys for heating elements.

FELSITE – see Natural acidproof materials.

FERRITE – is a component of the structure of iron-carbon alloys, the solid solution of carbon in α and δ iron (see Iron).

Ferrite is plastic; , possesses a high ductility (in the range of 40%) in tempered state; it is soft (65-130 kg/mm^2 HB, depending on the size of the crystals); it is a strong ferromagnetic (up to 770°); it is a relatively good conductor for electricity and heat, it has a body-centered cubic crystal lattice.

M.L. Bernshteyn

FERRITES – see Oksifers [= Ferroxcubes].

FERRITIC AND SEMIFERRITIC STAINLESS STEELS are alloys of iron with chromium and other alloying elements with low carbon content (0.1%) whose structure consists of ferrite (ferritic steel) and ferrite and austenite (semiferritic steel). The position of the boundary of the

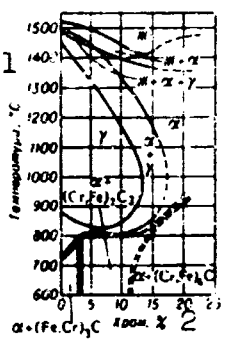

Fig. 1. Regions of ferritic and semiferritic type steel in the Fe-Cr system with 0.1% C: γ is hardenable martensitic steel; α + γ is semiferritic steel; α is ferritic steel; ж is the liquid phase. 1) Temperature, °C; 2) chrome, %.

TABLE 1

Chemical Composition and Applications of Ferritic and Semiferritic Stainless Steel

Сталь по ГОСТ 1	Заводская марка 2	Содержание элементов (%, не более) 3						Применение 4
		C	Si	Mn	Cr	Ni	Другие элементы 5	
X17 5a	ЭЖ17 5b	0.12	0.8	0.7	16–18	0.6	–	Оборудование химических заводов: абсорбционные башни, теплообменники для горячих нитрозных газов и горячей азотной кислоты, бани для азотной кислоты (сталь 0X17T более стойкая в отношении межкристаллитной коррозии) 7
0X17T 5c	ЭИ645 5d	0.08	0.8	0.7	16–18	–	Ti>5C до 0.8% 6	
X28 7a	ЭЖ27 / ЭИ349	0.15	1	0.8	27–30	0.6	–	То же 8
X25T 8a	ЭИ439	0.15	1	0.8	24–27	0.6	Ti>5C до 0.8%	Чехлы к термопарам; коррозионностойкая аппаратура 9
X28H 9a	ЭИ457 / ЭИ657	0.15	1	1.5	23–28	1–1.7	0.18–0.25 N	Печное оборудование и окалиностойкие детали 10
–	ЭИ499	0.15	1	0.5	27–30	1–1.7	0.15–0.22 N	То же
X25C3H 10a	ЭИ261	0.35	2.5–3.5	0.7	23–27	0.7–1.3	–	Детали печного оборудования повышенной прочности 11

1) Steel per GOST; 2) plant designation; 3) element content (%, no more than); 4) applications; 5) other elements; 5a) Kh17; 5b) EZh; 5c) OKh-17T; 5d) EI; 6) to; 7) chemical plant equipment: absorption towers,

heat exchangers for hot nitrose gases and hot nitric acid, tanks for nitric acid (the OKh17T steel is moreresistant to intercrystalline corrosion); 7a) Kh28; 8) same; 8a) Kh25T; 9) thermocouple sheaths; corrosion-resistant equipment; 9a) Kh28N; 10) furnace equipment and scale-resistant parts; 10a) Kh25S3N; 11) parts for high-strength furnace equipment.

TABLE 2

Mechanical Properties and Heat Treatment Regimes for Ferritic and Semiferritic Stainless Steel

Сталь 1	Заводская марка 2	Полуфабрикат 3	ГОСТ 4	Термич. обработка 5	6 HB ($d_{отп.}$, мм)	σ_b (кг/мм²)	$\sigma_{т.т}$ (кг/мм²)	δ (%)	ψ (%)
Х17	ЭЖ17	Лист 8	ГОСТ 5582–61	Отжиг при 740–780°, охлаждение на воздухе	–	50	–	18	–
7a	7b	Пруток 9	ГОСТ 5949–61	Отпуск при 760–780°, охлаждение на воздухе 10	<4.8	40	25	20	50
0Х17Т 10a	ЭИ645 10b	Лист	ГОСТ 5582–[illegible]	Отпуск при 740–780°, охлаждение на воздухе	–	50	–	18	–
Х28 10c	ЭЖ27 ЭИ349	Пруток	ГОСТ 5949–61	Без термич. обработки или отжиг при 750 ± 20°	–	45	30	20	45
				Отпуск при 760–790°, охлаждение на воздухе или в воде 11	140–190 (кг/мм²)	50	25	20	55–40
Х25Т 12a	ЭИ439	Пруток 9	ГОСТ 5949–61	Без термич. обработки или отжиг при 750 ± 20°	<5.0	45	30	20	45
		Лист 8	ГОСТ 5582–61	Отпуск при 740–780°, охлаждение на воздухе или в воде 12	–	50	–	17	–
Х28Н 12b	ЭИ457	Пруток 9	–	Горячекатаная сталь 13	–	66	50	11–23	–

1) Steel; 2) plant designation; 3) mill product; 4) GOST; 5) heat treatment; 6) HB (d_{otp}, mm); 7) (kg/mm²); 7a) Kh17; 7b) EZh; 8) sheet; 9) rod; 10) temper at [illegible], air cool; 10a) OKh17T; 10b) EI; 10c) Kh28; 11) no heat treatment or anneal at; 12) temper at –, air or water cool; 12a) Kh25T; 12b) Kh28N; 13) hot rolled steel.

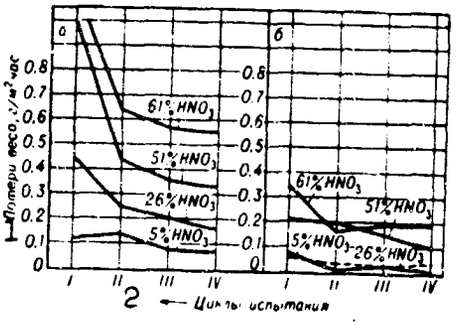

Fig. 2. Variation of corrosion rate of chrome steel in boiling nitric acid as a function of the number of cycles (25 hours) and the acid concentration: a) semiferritic steel with 17% Cr and 0.1% C; b) ferritic steel with 27% Cr and 0.2% C. 1) Weight loss, g/m²-hr; 2) test cycles.

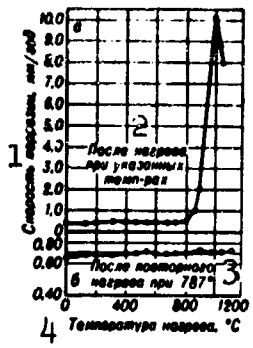

Fig. 3. Effect of heating 17% chrome steel on corrosion rate in boiling 65% nitric acid (a) and repeated heating at 787° (b). Prior to heating at 787° the specimens were treated using the regime indicated in the upper portion of the figure. 1) Corrosion rate, mm/hr; 2) after heating at indicated temperatures; 3) after repeated heating at 787°, 4) heating temperature, °C.

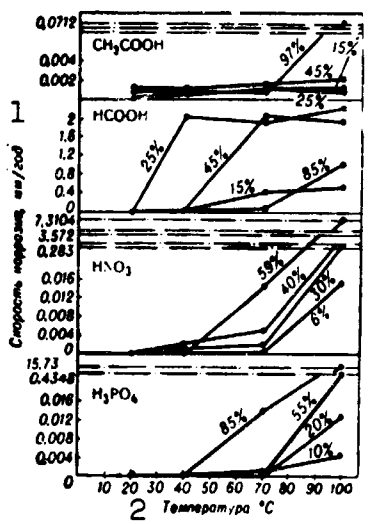

Fig. 4. Corrosion resistance of OKh17T steel in various media. 1) Corrosion rate, mm/hr; 2) temperature, °C.

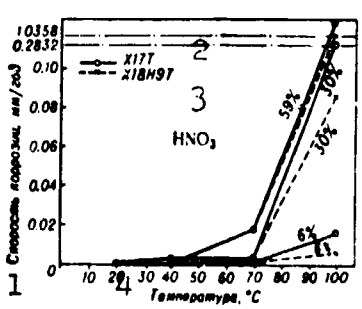

Fig. 5. Corrosion resistance of the OKh17T and Kh18N9T steels in nitric acid of varying concentration. 1) Corrosion rate, mm/year; 2) Kh17T; 3) Kh18N9T; 4) temperature, °C.

$\alpha + \gamma$ region (Fig. 1) depends not only on the chromium content, but also on the carbon content and also on the presence of other ferrite- and austenite-forming elements. The chemical composition of the steels of these types with an indication of their application is presented in Table 1 and the mechanical properties are given in Table 2. A typical semiferritic stainless steel is the 17% chrome steel Kh17 with carbon content about 0.1%. This steel has high corrosion resistance in atmospheric condition and in nitric acid. In hot (60-70°) nitric acid the Kh17 steel is resistant with said concentrations not over 66%; the concentration of boiling nitric acid must not exceed 50-60%) (Fig. 2). The properties and corrosion resistance of the 17% chrome steel depend on the structure and the heat treatment. With predominance of the ferritic component in the structure, heating the steel above 850° leads to grain growth and increased brittleness. Subsequent heat treatment of the steel does not eliminate this brittleness, so that hot mechanical working of the steel must be terminated at lower temperatures. Annealing at 760-800° after half-hot deformation gives the steel a fine-grained structure and quite satisfactory mechanical and technological properties. With heating above 1000° the semiferritic steel acquires a heterogeneous coarse-grained structure which determines the high brittleness and proneness of the steel to intercrystalline corrosion (Fig. 3). Subsequent heating at 700-800° does not eliminate the coarse-graininess and brittleness; however, the equalization of carbides which takes place with this heating facilitates an increase of the corrosion resistance of the Kh17 steel. In connection with this, the tendency of the chrome steels to intercrystalline corrosion which occurs in the weld seam in the zone affected by the high temperatures during welding may be eliminated by reheating the part to a temperature of 760-780°. Addition of titanium (OKh17T steel) reduces the amount of austenite at high

temperatures, binds the carbon in titanium carbides, somewhat reducing the grain growth during high temperature heating. Addition of titanium improves the corrosion resistance of the weld joints in the heat affected zone. The effectiveness of the titanium is noted only in those cases when all the carbon in the steel is bound into titanium carbides. This is achieved with a titanium content approximately 6-8 times greater than the carbon content, which makes the steel immune to intercrystalline corrosion in the weld joint if the testing is conducted in a standard solution of copper sulfate with nitric acid (method A or AM, GOST 6032-58). With testing in boiling 65% nitric acid, weld specimens made from the OKh17T steel show intercrystalline corrosion. The OKh17T steel welds well with the use of electrodes made from the Kh18N9T steel using electric-arc and automatic argon-arc welding. Figure 4 shows the corrosion resistance of weld specimens of the parent material of OKh17T steel in phosphoric and acetic acids; in formic acid, which has reducing properties, the corrosion resistance is less. With regard to corrosion resistance in nitric acid, the OKh17T steel is not inferior to the Kh18N9T austenitic stainless steel, which is easily seen from the data presented in Fig. 5.

A typical ferritic steel is the chrome stainless steel with 25-30% chromium content. The 27% chrome steel has better corrosion resistance in boiling solutions of nitric acid than the 17% chrome steel. The high chromium content also increases the steel resistance to corrosion in solutions of sodium hypochlorite and in sulfuric acid (saturated aqueous solution of SO_2), in chemically pure phosphoric acid, in an aqueous solution of sodium sulfide. With heating above 850°, the ferritic steel acquires a coarse-grained structure and associated brittleness which cannot be eliminated by heat treatment (high-temperature brittleness). A second form of brittleness of the high chrome steel, caused by preci-

pitation of the intermetallide σ-phase, is noted on heating to temperatures of 700-750°. Heating at 475° also leads to steel brittleness which is greater, the higher the chrome content. Satisfactory mechanical and technological properties of the ferritic steel are obtained only in those cases when after hot mechanical working and short-time anneal at 760-780° the steel acquires a fine-grained structure. Cooling

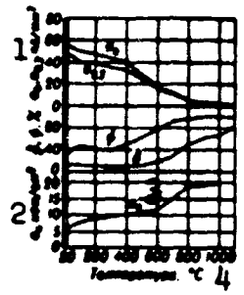

Fig. 6. Variation of mechanical properties of the Kh25T steel as a function of test temperature. 1) kg/mm^2; 2) a_n, kgm/cm^2; 3) a_n; 4) temperature, °C.

TABLE 3

Mechanical Properties of Weld Joints of Kh25T Steel (no less than)

Применяемый электрод 1	2 Наплавленный металл		Сварное соединение 3	
	4 σ_b (кг/мм²)	δ (%)	4 σ_b (кг/мм²)	δ (%)
5 Х25Н13 (Э3Б)	50	20	48	6
6 Х25Н5Б (Э40)	55	17	48	5

1) Electrode used; 2) filler metal; 3) weld joint; 4) σ_b (kg/mm^2); 5) Kh25N13 (E3B); 6) Kh25N5B (E40).

after annealing should be performed so that the time the steel is in the temperature range 450-520° will be as short as possible. The brittleness of the 27% chrome steel which occurs as a result of heating at 475° may be eliminated by means of subsequent heating at high temperatures. Brittleness of the chrome steel may also show up during welding, particularly of massive parts; in this case additional tempering of the weldments at temperatures of about 600° must be performed. The proces-

ses which lead to the formation of the brittleness after heating at 475° cause reduction of the corrosion resistance of the steel, and to a considerably greater degree than after heating to high temperatures, which is accompanied by precipitation of the σ-phase. The ferritic steel has high resistance to oxidation, even in a medium of the products of combustion of a fuel with high sulfur content at temperatures to 1100°.

With respect to strength at high temperature, the semiferritic and ferritic steels differ little from carbon steel. At 800° these steels have such low high-temperature strength that parts made from them frequently bend under their own weight.

Ferritic steel with titanium (Kh25T) has approximately the same properties as the 25-30% chrome ferritic steel. In spite of the favorable effect of the titanium, heating the steel to high temperatures (above 1000°) severely reduces the impact strength and somewhat reduces the ultimate. Subsequent heat treatment at 760-780° with water cooling somewhat reduces σ_b and does not change a_n. Data on the variation of the mechanical properties of the Kh25T steel as a function of temperature indicate that above 600° the steel has very low strength, but has high plastic properties (Fig. 6). The low resistance of the Kh25T steel to deformation makes it possible to carry out rolling and piercing of tubing at relatively low temperatures.

Metal which is to be welded must be used in the as-delivered condition or after annealing.

Welding of the Kh25T steel is performed by the electric-arc method with the use of electrodes made from the Kh25N13 and Kh25N5B steels; in the first case the E3B coating is used, in the second - E40. The welded parts can operate in nitric, phosphoric, and acetic acid media at temperatures not over 40-70°.

During welding, each succeeding seam is performed after cooling of the preceding seam to 70-150° and hammering the slag to avoid cracking of the parent metal in the heat-affected zone. All bending, straightening, etc. operations associated with the application of impact loads should be performed with preheating of the weld parts to 150-250°.

The chrome ferritic steel with 25-30% Cr may be used as a scale-resistant material to 900-1100°, and with increased silicon content it may be used in a medium of hot (1150°) furnace gases which are rich in sulfur. Alloying of the high chrome steel with nitrogen leads to refinement of the grain in the initial condition, slowing of grain growth with heating, and expansion of the γ-region.

The best mechanical properties of the nitrogen-containing ferritic steel are obtained after quenching from 1100-1150°. A high combination of the mechanical and technological properties is obtained in those cases when nickel is added along with the nitrogen (Kh28N steel). As a result of this, a steel is formed with austenitic or austenitic-ferritic structure which is close in properties to the type 18-8 chrome-nickel steel.

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F.F. Khimushin

FERRITIC CAST IRON — is a cast iron with a ferritic structure of the base, i.e., it is characterized by an almost total absence of combined carbon, and pearlite and structurally free carbides in the metal

1 Структурная составляющая	Темп-ра магнитного превращения (°С)	Макс. насыщение (гс) 3	Остаточный магнетизм (гс) 4	Коэрцитивная сила (э) 5	Магнитная проницаемость (гс/э) 6
Феррит 7	768	21600—32600	13000	0,9—1,0	5000—10000
Цементит 8	210	12400	—	55	—

1) Component of the structure; 2) temperature of the magnetic transformation (°C); 3) maximum saturation (gauss); 4) residual magnetism (gauss); 5) coercive force (oersted); 6) magnetic susceptibility (gauss/oersted); 7) ferrite; 8) cementite.

base. Ferritic cast iron is obtained by annealing castings of gray iron containing lamellar or spheroidal graphite (see Magnesium-alloy cast iron) or such of malleable cast iron, and also by alloying the cast iron with silicon or aluminum (see Scale-resistant cast iron, Aluminum-alloy cast iron). Ferritic cast iron with sperhoidal graphite and malleable cast iron are characterized by an increased plasticity and good ferromagnetic properties (this does not concern the scale-resistant cast irons, including the aluminum-alloy cast iron). The characteristics of the magnetic properties of ferrite and iron carbide, i.e., cementite, are quoted in the Table.

The following types of ferritic cast iron are used in electrical machine building for castings with high ferromagnetic properties: gray cast iron with lamellar graphite (3.25-3.6% C; 2.5-2.9% Si; 0.4-0.7% Mn; 0.4-1.0% P, up to 0.12% S); high-strength cast iron with spheroid-

al graphite and malleable iron. The 2 latter types are preferable because the spheroidal graphite of the high-strength cast iron and the floccular temper carbon of the tempered malleable iron have a lower demagnetizing effect than the lamellar graphite of the gray iron.

References: Levi, L.I., Elektrotekhnicheskoye chugunnoye lit'ye [Cast Iron in Electrical Engineering], in the book: Spravochnik po mashinostroitel'nym materialam [Handbook on Machine-Building Materials], Vol. 3, Moscow, 1959.

A.A. Simkin

FERROELECTRICS – dielectric materials exhibiting spontaneous polarization (not caused by an external field) over a certain temperature range. The Russian term for ferroelectrics [segnetoelektriki] is taken from Seignette's (Rochelle) salt, which was first found to display the properties characteristic of this class of dielectrics (anomalously high dielectric permeability, dielectric permeability and dielectric losses markedly dependent on temperature, field intensity, and frequency). Ferroelectrics are also distinguished by pronounced hysteresis on polarization by an external field, by deformation on polarization, and by a number of other characteristics. Spontaneous polarization occurs in these materials under the action of an internal field, resulting from dipole alignment; it is observed in certain crystalline substances lacking a center of symmetry (Rochelle salt, barium titanate, etc.).

Ferroelectric properties are detected in virtually all ionic (ionic covalent) crystals in which a small multivalent cation is loosely surrounded by anions, so that mutual displacement and development of constant dipole moments is possible. These substances include $BaTiO_3$, $SrTiO_3$, $PbTiO_3$, $PbZrO_3$, $NaTaO_3$, $KNbO_3$, etc., as well as a number of solid solutions based on these compounds. In addition, the ferroelectrics include certain hydrogen-bonded substances, such as Rochelle salt ($C_4H_4O_6KNa \cdot 4H_2O$), KH_2PO_4, KH_2AsO_4, etc.

Development of spontaneous polarization in Rochelle salt results from mutual orientation of its hydroxyl (OH) groups, which have a dipole moment. Polarization in titanates results from displacement of the titanium ions from the center of the crystal cell and polarization (de-

formation) of the oxygen ions. Since thermal displacement in solids occurs collectively in small volumes, when dipoles develop in some cells the displacement is directed along the cells adjacent to the existing dipoles. The entire body is divided into regions of spontaneous polarization (domains), which consist of crystal cells with identically oriented electric moments. Many such regions are generated, but their relative orientation is such that the total electric moment of the body equals zero. When an external stress is applied the dipole moments are oriented in accordance with the external field and the polarization may reach very high values. The dielectric permeability ε reaches 10^4-10^5.

The ε of ferroelectrics, like the magnetic permeability of ferromagnetics, varies greatly as the field intensity changes. Ferroelectrics share with ferromagnetics the hysteresis-loop character of the relationship between the voltage applied to the casing of a ferrocapacitor and the charge produced, which resembles the magnetic-reversal curve. The time required for polarization is markedly greater over the ferroelectric temperature region than at other temperatures and depends to a large extent on the field intensity. Use of the term ferroelectrics is based on these similarities to the properties of ferromagnetics. Saturated polarization occurs when the dipole moments are almost completely oriented along the field. Deformation of the specimen (electrostriction) is observed when spontaneous polarization occurs at the Curie point or when the external electric field is varied. Polarized ferroelectrics are piezoelectric in the ferroelectric temperature region. Losses in ferroelectrics are due both to leakage and to electrostrictive deformation. Such substances behave like ordinary dielectrics above and below the ferroelectric region: their domain structure disappears and ε no longer depends on E. The temperature at which the transi-

tion from the ferroelectric to the nonferroelectric state occurs is the so-called Curie point (θ). This point marks the transition from one crystallographic modification to another. The Curie point is characterized by the maximum of the dielectric permeability versus temperature curve. The use of Rochelle salt as a ferroelectric is extremely limited, since it has low mechanical strength, a narrow piezoelectric temperature range, poor moisture resitance, and a number of other drawbacks. The principal ferroelectric materials are ferroceramics (see Ceramic radio-engineering materials), which are characterized by sufficient mechanical strength, thermal stability, and moisture resistance and properties that vary widely in accordance with their composition and production regime. The dielectric permeability ε of these materials ranges from 400 to 20,000 and may vary slightly or very widely with the field strength and temperature, but drops sharply at frequencies above 10^9 cps. The tangent of the angle of dielectric loss is of the order of $(20\text{-}2000)\cdot 10^{-4}$, decreasing as one approaches the Curie point and also depending on the field strength. The electric strength E_{pr} = 2-6 kv/mm.

The Curie point θ varies widely, ranging from -260° ($KTaO_3$) to 740° (WO_3). The piezoelectric modulus d_{ik} reaches $2\cdot 10^{-10}$ coulombs/newton (c/n).

Ferroelectrics can be divided into two basic groups in accordance with their properties and applications: 1) materials exhibiting a slight nonlinearity over the range of working field strengths E and temperatures T ($\Delta\varepsilon \leq 30\%$). They include SK-1 (based on $BaTiO_3$), SK-2 [(Ba, Ca, Sr)TiO_3], SM-1 [Ba(Zr, Ti)O_3, (BaPb)(Ti, Sn)O_3], etc. These materials are used for light miniature capacitors with a high specific capacitance and are produced in sheets (KPS), disks (KDS), and tubes (KPTS). Preliminarily polarized ceramics of this group are widely used

as piezoelements for generation and reception of ultrasound, piezosensors, mechanical filters, etc., since their piesoelectric modulus is rather high. For example, at a coercive field strength E_c = 25 kv/mm (as against E_c = 5 kv/mm for $BaTiO_3$) the ferroelectric $(Ba_{0.9}Pb_{0.1})TiO_3$ has an almost constant piezoelectric modulus from room temperature to 90°: $d_{33} = (1.3\text{-}1.7)\cdot 10^{-10}$ c/n and $d_{31} = (6.6\text{-}7.3)\cdot 10^{-11}$ c/n. This material has commended itself for high-power ultrasonic generators, whose shape is to a considerable extent arbitrary (e.g., concave in order to concentrate power). The solid solution $(Pb_{0.45}, Sr_{0.3}, Bi_{0.17})TiO_3$, with $d_{31}/\varepsilon = (1.2\text{-}1.4)\cdot 10^{29}$ CGSE and θ = 280°, is distinguished by high piezosensitivity. 2) Materials exhibiting a large nonlinearity, so-called variconds, whose capacitance varies by several hundred per cent over the working range of $E_=$, E_∞, or T. They are most frequently formed during the sintering of substances whose coefficients of electrostriction differ in sign, e.g., $BaTiO_3$-$BaSnO_3$, $BaTiO_3$-$BaZrO_3$, etc., and are distinguished by low piezoelectric moduli. Polycrystalline types (BK-1, BK-2, etc.) are usually used as nonlinear elements; monocrystals and very thin films, which a greater nonlinearity and a more nearly rectangular hysteresis loop, are also employed. As a result of the fact that their capacitance is a nonlinear function of voltage, variconds are employed as dielectric amplifiers, frequency multipliers and dividers, voltage stabilizers, signal limiters, dielectric phase inverters, contactless switches (relays), and various elements of computer memories, as well as for producing pulses in circuits supplied with sinusoidal ac current, etc.; the sharp variation in their ε with temperature makes them suitable for use as dielectric-thermometer sensors.

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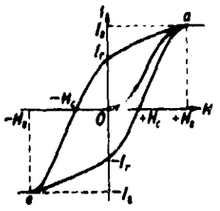
densatory [Ferroelectric Capacitors], Moscow-Leningrad, 1956; Kentsig, V., Segnetoelektriki i antisegnetoelektriki [Ferroelectrics and Antiferroelectrics], translated from English, Moscow, 1960; Verbitskaya, T.N., Segnetoelektriki [Ferroelectrics], in book: Spravochnik elektrotekhnicheskim materialam [Handbook of Electrical-Engineering Materials], Vol. 2, Moscow-Leningrad, 1960; Segnetoelektriki [Ferroelectrics], collection of articles, Rostov-on-Don, 1961.

Sh.Ya. Korovskiy

FERROMAGNETIC PROPERTIES – are all the properties (characteristics) of a ferromagnetic which characterize its magnetic state (intensity of magnetization) in different magnetic fields.

The initial magnetization curve and also the limit hysteresis curve are the most important technical characteristics of ferromagnetic materials. The magnetization intensity (I) of a ferromagnetic (being essentially in a totally demagnetized state) changes along the initial magnetization curve Oa (see Fig.) under the action of a gradually increasing magnetic field. The ferromagnetic obtains the magnetic saturation I_s at a definite magnetization-field intensity H_s, and a further increase of the magnetic field cannot increase its intensity of magnetization further. The values of the magnetic field and of the intensity of magnetization at which magnetic saturation occurs are termed saturation field and saturation magnetization, respectively. The intensity of magnetization decreases in a diminishing magnetic field not along the initial curve, however, but along the hysteresis curve aI_r. The value of the intensity of magnetization I_r at a magnetic field equal to zero is termed residual magnetization. A magnetic field opposite to the primary one must be applied to reduce the intensity of magnetization of a ferromagnetic to zero. The magnetic field N_c at which the intensity of magnetization becomes equal to zero is termed the coercive force (of magnetization). The section I_r-H_c of the hysteresis loop is termed "back of the loop." A further increase of the negative magnetic field involves a magnetization of the ferromagnetic with the opposite sign, and the intensity of magnetization $-I_s$ is reached at

the field $-H_s$. The intensity of magnetization of the ferromagnetic changes along the lower section of the hysteresis loop via the points b, $-I_r$, $+H_c$, and a when the magnetic field changes from $-H_s$ to $+H_s$.



Initial magnetization curve and magnetic hysteresis loop.

The values I_s, H_s, I_r and H_c allow one to represent the shape of the hysteresis curve of a ferromagnetic with an exactness which is normally sufficient. These values depend on the type of the ferromagnetic and are its magnetic characteristics. According to the value of the coercive force which characterizes the width of the hysteresis loop, the ferromagnetic materials are subdivided into soft-magnetic ones with a low coercive force H_c (permalloy, transformer iron, etc.) and rigid-magnetic ones with a strong coercive force (alloys for permanent magnets, iron oxide, etc.). Structural steels may be both soft-magnetic steels (the steel grades st.10 and st.20, for example) and rigid-magnetic steels (cobalt and tungsten steels in hardened state) depending on the degree of alloying and the type of heat treatment.

The terms flux density B and permeability μ are often used to characterize the magnetization of a ferromagnetic. The intensity of magnetization I, the magnetic field intensity H and the flux density are connected together by the function

$$B = H + 4\pi I. \qquad (1)$$

The magnetic permeability

$$\mu = \frac{B}{H}. \qquad (2)$$

characterizes the connection between the flux density and the magnetic field intensity.

The form of the B = f(H) curves, which characterizes the change of the flux density during magnetization and remagnetization, is almost similar to that of the I = f(H) curves. A qualitative difference is the fact that the change of the flux density, after the saturation is reached, is characterized by an incline and not by a horizontal straight line (as the intensity of magnetization I). The saturation flux density B_s, the remanent flux density B_r, and the coercive force $_BH_c$ are also magnetic characteristics of the material, quoted in various reference tables.

The value of the magnetic permeability μ determined by the ratio of the flux density B to the corresponding value of the magnetic field (Eq. 2) is termed total magnetic permeability; the word "total" is usually omitted. Sometimes, other varieties of the permeability are used, the maximum permeability μ_{maks}, for example, equal to the tangent of the slope angle of the tangent drawn from the origin of coordinates to the initial induction curve; the initial permeability μ_a defined by the function $\mu_a = \lim_{H \to 0} \frac{B}{H}$, the differential permeability μ_{dif} in any fixed point of the initial induction curve, defined by the function: $\mu_{dif} = \lim_{\Delta H \to 0} \frac{\Delta B}{\Delta H}$, etc.

The ferromagnetic properties mentioned above characterize the behavior of a ferromagnetic in constant or slowly changing magnetic fields. In magnetic field alternating with a high frequency, the curves of the intensity of magnetization or those of the flux density (the dynamic curves) do not more coincide with the "static" curves. In these cases the initial induction curve and also the dependence of the total losses (for the hysteresis and the eddy currents) on the flux density

are used in practice; these characteristics are appliable, however, only to the magnetic fields of the given frequency.

References: Kifer, I.I., Ispytaniye ferromagnitnykh materialov [Testing of Ferromagnetic Materials], 2nd Edition, Moscow-Leningrad, 1962; Chechernikov, V.I., Magnitnyye izmereniya [Magnetic measurements], [Moscow], 1963; see also the References to the article Ferromagnetism.

S.M. Rozhdestvenskiy

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[Transliterated Symbols]

1464 макс = maks = maksimal'nyy = maximum

1464 диф = dif = differentsial'nyy = differential

FERROMAGNETISM – is the totality of the properties of certain substances which make them capable to attain a considerably high intensity of magnetization in relatively weak magnetic fields, and also to retain partially this magnetization after the external magnetic field is removed. Materials with ferromagnetic properties (ferromagnetics) are: the metals iron, cobalt, nickel, gadolinium, dysprosium, and erbium, certain alloys of these elements and their oxides (the Ferrites, for example), and also certain alloys of chromium and manganese, and a number of uranium compounds. The ferromagnetic properties of the substances are present only at temperatures which do not surpass the so-called "Curie point," which is different for the various ferromagnetics.

The atoms of the elements with ferromagnetic properties possess unfilled inner electron shells, and the ratio of the atom diameter in the crystal lattice to the diameter of the unfilled shell is greater than 1.5. Under these conditions, the electron spins tend to a parallel alignment due to the forces of the so-called exchange interaction. The magnetic interaction, however, which acts between the electrons, hinders the parallel alignment of the electron spins. Regions, domains, with a volume of 10^{-6}-10^{-8} cm^3, result owing to the counteraction of the magnetic and the exchange interaction forces, and a spontaneous magnetization, caused by the exchange interaction, occurs within each domain. Adjacent domains have a different direction of magnetization due to the magnetic interaction. Therefore, the domains are arranged in the ferromagnetic body, which was not exposed to magnetization, in a manner such that the mean intensity of magnetization is equal to

zero in spite of the fact that the intensity of magnetization of each domain approaches saturation. The magnetization of the domain coincides generally with the so-called direction of the most ready magnetizability of crystals. Thus, for example, the directions of the most ready magnetizability of iron coincide with the edges of the cubic lattice. The domains are separated by transition interlayers (with a thickness up to 1000 A) whose direction of magnetization changes smoothly within the thickness and coincides on the layer boundaries with the direction of magnetization of the corresponding adjacent domains.

Under the action of an external magnetic field, the domains whose direction of magnetization is near to the direction of the magnetic field begin to grow at the expense of the domains whose direction forms an obtuse angle with that of this field. Moreover, the interlayers (or the "boundaries") become displaced or totally vanish in many cases. A further increase of the intensity of the magnetic field involves the next stage of the magnetization consisting in the turn of the electron spins in the direction of the external magnetic field until in total coincidence with it. A further intensification of the magnetic field cannot increase the intensity of magnetization of the ferromagnetic any more; this state is termed magnetic saturation. All the described phenomena proceed in the opposite sense when the external magnetic field decreases; the initial magnetic structure, however, becomes restored only partially even when the magnetic field is switched off totally because the magnetization and demagnetization processes involve energy losses for the transition of the interlayer between the domains. This energy is the greater the more the lattice of the ferromagnetic is distorted, and the more it includes various impurities causing internal stresses. Thus, the residual magnetization is greater in alloys than in pure metals.

Ferromagnetism has a great importance for electrical engineering, radio engineering, sound recording, automatics and other branches of engineering. Many methods of nondestructive testing (see Magnetic testing) are based on the phenomena of ferromagnetism. The peculiarities of the behavior of ferromagnetic materials (of steels, for example) in magnetic fields must be taken into account in the design of complex machines and aggregates.

References: Vonsovskiy, S.V., Shur, Ya.S., Ferromagnetizm, Moscow-Leningrad, 1948; Yeremin, N., Yelchin, P., Magnetizm v tekhnike [Magnetism in Engineering], Moscow, 1959; Kirenskiy, L.V., Magnetizm, Moscow, 1963.

S.M. Rozhdestvenskiy

FERROXDURE — see Oksifers [= Ferroxcubes].

FIBER – a thin, strong, easily deformable thread whose length exceeds substantially the very small cross sectional size. Fiber is divided into 1) natural, of plant (cotton, flax, jute, ambary, Indian hemp, sisal hemp, etc.) and animal (wool, natural silk) origin; 2) chemical, which are subdivided in their turn into artificial and synthetic. The term artificial is used to denote fibers obtained by chemical processing of natural high-molecular compounds, such as cellulose which is produced from wood or cotton production waste and its esters; of proteins, for example casein, which is made from milk or vegetable proteins which are extracted from soya, lupine, etc. (see Protein Fiber, Viscose Cord Fiber, Acetate Fiber, Cupprammonium Fiber). The term synthetic si used to denote fibers which are produced from high-molecular compounds which are obtained by synthesis from elementary molecules, for example, from ethylene, propylene, caprolactam, etc. [see Polyamide Fiber (capron, nylon), Polyester Fiber (dacron, terylene), Polyacrilonitrile Fiber, Polyolefin Fiber, Polypropylene Fiber, Polyethylene Fiber]. Chemical fibers are produced in the form of threads of infinite length (filament fiber) or, not unlike cotton and wool, in the form of short cut fibrils (staple fiber). Fibers of inorganic origin (Glass Fiber and Asbestos Fiber) are also known. Glass fiber is similar to chemical fiber and is obtained artificially. The classification of natural fibers is presented in Fig. 1, of artificial in Figs. 2, 3 and 4; here kinds of fibers which are of greatest significance to the national economy are framed with a heavy line on the figure.

The world production of the main kinds of fibers is shown in Table

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1.

The production volume of the main groups of chemical fibers are characterized by the following data (%).

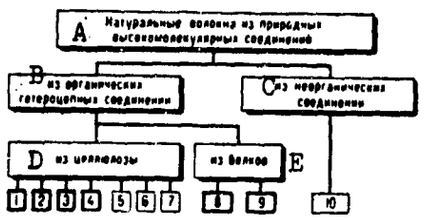

Fig. 1. Classification of natural fibers from natural high-molecular compounds. 1) Cotton; 2) flax; 3) hemp; 4) jute; 5) ambary; 6) sisal hemp; 7) others; 8) from keratin (wool); 9) from fibroin; 10) asbestos. A) Natural fibers from natural high-molecular compounds; B) from organic hetero-chain compounds; C) from inorganic compounds; D) from cellulose; E) from proteins.

TABLE 1

World Production of Fibers

Волокно 1	1950		1960	
	2 тыс. т	% к общему 3 выпуску	тыс. т 2	% к общему выпуску 3
4 Натуральные				
Хлопок 5	5 816	67.9	10 212	68.1
Шерсть 6	1 055	13.0	1 444	9.7
Шелк 7	19	0.2	30	0.2
Химические 8	1 636	18.9	3 317	22.0

1) Fiber; 2) thousand tons; 3) % of total output; 4) natural; 5) cotton; 6) wool; 7) silk; 8) chemical.

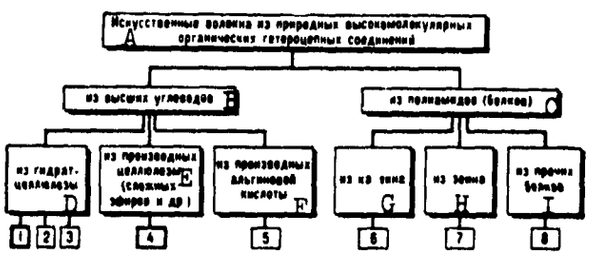

Fig. 2. Classification of artificial fibers from natural high-molecular organic hetero-chain compounds. 1) Viscose; 2) cuprammonium; 3) saponified acetate; 4) acetate from di- and triacetate; 5) alginic; 6) kasein; 7) zein; 8) others. A) Artificial fibers from natural high-molecular organic hetero-chain compounds; B) from higher hydrocarbons; C) from polyamides (proteins); D) from hydrated celluloid; E) from cellulose derivatives (compound esters, etc.); F) from alginic acid derivatives; G) from kasein; H) from zein; I) from other proteins.

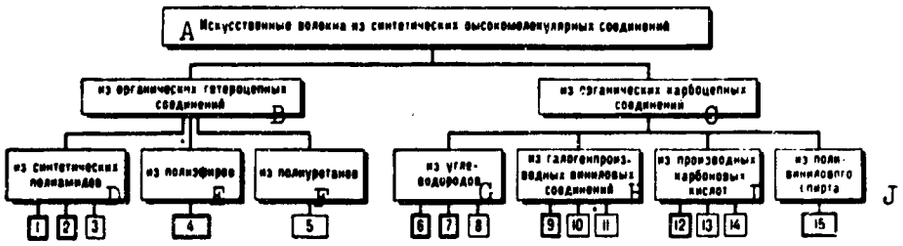

Fig. 3. Classificiation of artificial fibers from synthetic high-molecular compounds. 1) From polyhexamethylenadipamide [nylon (Anid, etc.)]; 2) from polycaprolactam [capron (Perlon, etc.)]; 3) from other polyamides and their copolymers; 4) from polyethyleneterephthale [lavsan (Terylene, etc.)]; 5) from the hexamethylenediazocyanate and tetramethyleneglycol copolymer (Perlon V); 6) from polyethylene [Polythene (Courlene, etc.)]; 7) from polypropylene (Moplen); 8) from polystyrene (polyfiber); 9) from chlorine-containing [PeTse V chlorinated polyvinyl chloride fiber (Pe+Tse, etc.), Saran]; 10) from chlorine-containing copolymers with other compounds [vinyl chloride-vinyl acetate copolymer fiber (Vinyon), saniv (from a vinylidene chloride and acrylonitrile copolymer) etc.; 11) from fluorine-containing (Teflon, Ftorlon, etc.); 12) from polyacrylonitrile [nitron (Orlon, etc.)]; 13) from acrylonitrile copolymers (Acrilan, Verel, etc.); 14) from a copolymer of vinylidene cyanide with vynil-acetate (Darvan); 15) Vinylon, etc. A) Artificial fibers from synthetic high-molecular compounds; B) from organic heterochain compounds; C) from organic carbon-chain compounds; D) from synthetic polyamides; E) from polyesters; F) from polyurethans; G) from hydrocarbons; H) from halogen-derivative vinyl compounds; I) from carbon acid derivatives; J) from polyvinyl alcohol.

TABLE 3

World Production of Fibers

1		
3		

1) Fiber; 2) viscose; 3) acetate; 4) synthetic.

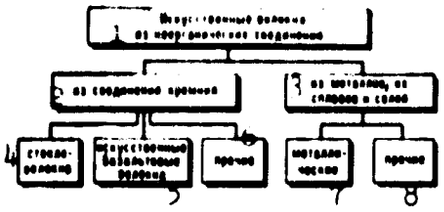

Fig. 4. Classification of artificial fibers from inorganic compounds. 1) Artificial fibers from inorganic compounds; 2) from silicon compounds; 3) from metals, their alloys and salts; 4) glass fiber; 5) artificial basalt fibers; 6) others; 7) metallic.

According to the seven-years plan of the development of the USSR economy it is planned to increase the production of chemical fibers dur ing the 1958-1965 period by a factor of 3-4, including an increase in the more valuable synthetic fibers by a factor of 11-12, bringing the production of fibers in 1965 to 680 thousand tons.

Chemical fibers possess an ensemble of important physio-chemical properties which determine their high service qualities in engineering products (cord, electric insulation materials, etc.) and in consumer products. Chemical fibers have a high rupture length. Of importance under service conditions is the fact that fibers should retain their strength in the wet state. As the tensile strength of wet fibers is reduced, their resistance to various deformations is decreased. The strength of many synthetic fibers, including polyamide and polyester changes very little in the wet state and some of them do not at all lose strength. Many chemical fibers are characterized by high elasticity, which determines the high resistance of the fiber to the action of cyclic loads and by absence of shrinkage, which is important for the

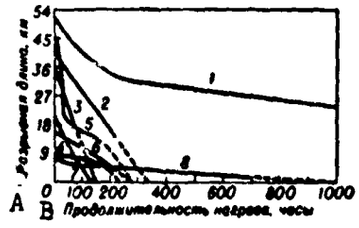

Fig. 5. Change in the strength of fibers subjected to prolonged heating. 1) Terylene; 2) Orlon; 3) natural silk; 4) cotton; 5) nylon; 6) viscose rayon; 7) acetate rayon; 8) wool. A) Rlpture length, km; B) duration of heating, hours.

production of high-quality articles. The elasticity of fibers varies in the following sequence: caprone > wool > dacron > nitron > viscose fibers > acetate fibers. The high initial modulus which is determined by the load needed to elongate a fiber by 1% of its initial length, characterizes the ease of deformation of fibers on application of a speci-

fied load. The higher the initial modulus the more difficult does the fiber deform, which of importance in the production of tire cords and other engineering products. The resistance of chemical fibers to multiple deformations and to wear is also of importance. Polyamide and polyester fibers have this property. Fibers used for electrical insulation must have minimum hygroscopicity; this property is peculiar to polyvinylchloride, polyethylene, polypropylene and particularly glass fibers. Heat resistance is an important indicator for chemical fibers which are used in the production of cord threads, electric insulation, etc. Asbestos and glass fibers are most stable (up to 1200-1300°), fluorine-containing vinyl fibers are heat resistant up to 300°, celluloid fibers fail at 150-160°, protein fibers fail at 170°, chloride fibers are the least heat resistant; they melt at 80°.

All fibers are typical dielectrics; as the hygroscopicity is increased the dielectric losses of fibers increase substantially. The electrical insulation properties of fibers are reduced if the polymer contains polar groups. Hydrophobic fibers which do not contain polar groups (polyolefin, dacron, triacetate, and other fibers) have the highest electric insulation properties. Fibers of the carbon-chain series are sufficiently resistant to the action of alkalis and acids. Particularly high chemical resistance is characteristic of Ftorlon, Teflon and chlorinated polyvinyl chloride fiber. These fibers do not change for a relatively long time under the action of such a strong agent as aqua regia. Hetero-chain fibers are less resistant to alkalis and acids. Celluloid fibers are easily hydrolized by acids, particularly at elevated temperatures. Fibers which contain polar groups resist nonpolar solvents and, conversely, fibers which do not contain polar groups resist polar solvents. As a rule, fibers are soluble in a limited number of solvents. Natural and artificial fibers are susceptible to the

action of micro-organisms, synthetic fibers resist micro-organisms and are not susceptible to decay. The fineness of fibers, which is characterized by the number of meters of fiber per gram, is of importance. Porous chemical fibers with a high resistance to sound penetration and a very low specific gravity were obtained in the last few years. Fibers with a high thermal resistance and heat-resisting properties were obtained. An important advantage of chemical fibers it the feasibility of rapidly changing the character of the articles being produced in conformance with revised requirements of the national economy. Properties of natural fibers vary within very narrow limits, while the properties of chemical fibers which are produced from various synthetic polymeric materials and processed by a variety of methods can be changed within very wide limits. Modern technology makes it possible to obtain chemical fibers with various physicochemical properties from different starting products. An important advantage of chemical fibers is the high economic efficiency and lower capital, operating and labor expenditures than in the production of natural fibers. For the same labor expenditures chemical fibers can be obtain in greater quantities than natural fibers. Table 3 presents data on the labor expenditures per ton of fiber.

A very important economic advantage of the production of artificial and synthetic fibers consists in the fact that is developed by processing chemical products which are obtained from extensively available kinds of raw materials; it can be organized in any economic region of the country. Various semifinished products (phenol, xylene, ethylene, propylene, vinyl chloride, and many others) which are obtained in the processing of petroleum, coking of coal, from natural and concurrently-produced petroleum gases, whose extraction and production scales have reached gigantic proportions, serve as the raw materials for the pro-

duction of synthetic fibers. The growth of the production of chemical fibers in the USSR for 1958-1965 is given in Table 5.

TABLE 3

Labor Expenditures per ton of Fiber (Man-Hours)

Волокно 1	Всего затрат 2	В том числе на произ-во 3	
		исход-ного сырья 4	волокна 5
Хлопок 6	1 660	—	—
Натуральный шелк 7	35 000	—	—
Вискозное штапельное волокно 8	150	90	60
Вискозный шелк 9	800	230	570
Капроновый шелк 10	1 400	210	1190
Штапельное волокно нитрон 11	225	140	85
Штапельное волокно лавсан 12	340	170	170

1) Fiber; 2) total expenditures; 3) including for the production of; 4) starting raw material; 5) fiber; 6) cotton; 7) natural silk; 8) viscose staple fiber; 9) viscose rayon; 10) capron rayon; 11) nitron staple fiber; 12) dacron staple fiber.

The net cost of chemical fibers is substantially lower than of fibers of natural origin (see Table 4).

TABLE 4

Comparative Data on the Net Cost of Natural and Chemical Fibers

	Волокно 1	Себестоимость (%) 2
1-группа 3	хлопок-волокно 4	100
	вискозные штапельные 5	65—70
2-группа 6	шелк натуральный 7	100
	шелк капрон 8	30—50

1) Fiber; 2) net cost (%); 3) 1st group; 4) cotton fiber; 5) viscose staple; 6) 2nd group; 7) natural silk; 8) capron rayon.

The use of fibers in the national economy is ever-increasingly ex-

panding, this being particularly true of chemical fibers, which are used for producing conveyor belts, drive belts, tires of various purposes, incombustible and chemically stable fabrics for gasoline tanks,

TABLE 5

Growth in the Production of Chemical Fibers in the USSR for 1958-1965

Годы 1	Производство 2 химич. волокон	
	тыс. т 3	%
1958 (фактически) . 4	166,6	100,0
1959 » . . .	180,0	108,0
1960 » . . .	211,0	127,0
1965 (план)	666,0	400,0

1) Years; 2) production of chemical fibers; 3) thousands of tons; 4) actual; 5) planned.

oil and gasoline carrying hoses, incombustible fabrics for internal upholstery of aircraft, autobuses, ships; light and strong fibrous materials for parachutes, filtering fabrics, sieves for chemical, metallurgical, food and other branches of industry.

References: Kukin, G.N. and Solov'yev, A.N., Tekstil'noye materialovedeniye [Textile Materials Science]. Part 1, Moscow, 1961; Rogovin, Z.A., Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fiber Production]. 2nd edition, Moscow, 1957; Fedorenko, N.P., Ekonomika promyshlennosti sinteticheskikh volokon [The Economics of the Synthetic Fibers]. Moscow, 1961.

A.A. Konkin

FIBERBOARD TUBES – see Fiberboard.

FIBER FROM COPOLYMERS OF ACRYLONITRILE WITH VINYL CHLORIDE AND POLYVINYLIDENE CHLORIDE – synthetic carbon-chain fiber which is called modified polyacrylic fiber in the foreign literature. The fibers are formed from acetone-soluble copolymers of acrylonitrile (40%) with vinyl chloride (60%) these being Vinyon N fibers (rayon), Dynel (staple fiber), or vinylidene chloride (60%), these being X-51 and X-54 fibers, Creslan (staple fiber), Saniv (rayon, staple fiber). The rupture length of the fiber in the dry state is 30-38, remains practically unchanged in the wet state, since the fiber is highly hydrophobic, at 65% relative humidity it absorbs ~ 0.5% of its own weight in moisture; the rupture elongation is 10-25%; specific weight 1.28-1.37; inflammability is lower than that of polyacrylic fibers; high chemical resistance (sensitive to the action of acetone and certain organic solvents); have a heat resistance perceptibly inferior to that of polyacrylic fibers; temperature of zero strength of fibers from acrylonitrile and vinylidene chloride copolymers is by 10-20% higher than that of copolymers of acrylonitrile with vinyl chloride. A shortcoming of these fibers is low dyeability. They are extensively used in technology and in the production of consumer goods.

References: Rogovin, Z.A., Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fibers Production]. 2nd edition, Moscow, 1957; Monkriff, R.W. Chemical Fibers, translated from English, Moscow, 1961.

Yu. Ye. Vasil'yev

FIBER ELONGATION – an Increase in the length of a fiber upon deformation; is usually expressed in percents of the initial length of the specime. A distinction is made between reversible fiber elongation, which arises as a result of resilient and elastic deformation of a polymer material and is characterized by the magnitude of reduction in the length of a fiber or thread after the load is removed (in percents of the specimen's length before testing), and irreversible fiber elongation, which arises as a result of plastic deformation and is characterized by the difference between the specimen's length before and after testing (in percents of the initial length). The total of reversible and irreversible fiber elongation comprises the total or entire elongation of the fiber or thread. The fiber elongation at break is characterized by the increase in the fiber length in tension up to the instant of rupture. The fiber elongation at break determines the maximum deformation of a product. The elongation of a fiber or thread is determined by structural changes in individual fibers, the thread construction, the shape of fibers in the thread. The fiber elongation is determined by tensile test machines simultaneously with strength measurement, using diagram-type instruments. The magnitude of fiber elongation as a function of the load is depicted graphically. Fiber elongation is also determined in other kinds of tests, as well as using special instruments, i.e., relaxation meters. The fiber deformation has a clearly expressed relaxational character. The magnitude of fiber elongation obtained in test on tensile testing machines depends on the test conditions and, consequently, it is arbitrary to a certain extent. When de-

termining the true fiber elongation corresponding to a given load it is necessary to take into account the magnitude of the elastic aftereffect, i.e., the deformation of the specimen which takes place under the effect of a constant load for a prlonged period of time, necessary for relaxation processes to take place.

V.A. Berestnev.

FIBER FROM FLUORINE-CONTAINING POLYMERS – synthetic fiber from olefin polymers containing fluorine in the monomer molecule. Are produced in the USSR (poligen and ftorlon) and in the USA (Teflon and Teflon-100X). The raw material for making polifen (and Teflon) is polytetrafluoroethylene (PTFE), for ftorlon it is acetone-soluble polymers of fluorine derivatives of ethylene, and for Teflon-100X these are copolymers of tetrafluoroethylene (TFE) and hexacluoropropylene (GFP). PTFE is not soluble and does not swell in any of the known solvents (and also does not melt and does not soften without decomposition), for which reason Teflon (polifen) is formed from colloidal water dispersions, while Teflon-100X is formed from a melt and the ftorlon fiber is formed by the wet method from acetone solutions. Teflon is produced in the form of monofiber, filament and staple fiber (N_{el} 1400-1500); ftorlon is made in the form of filament fiber (N_{el} 6000-30,000); Teflon-100X is formed as monofiber. Fibers from fluorine containing polymers are characterized by very high chemical resistance (PTFE fibers are resistant to the action of concentrated solutions of alkalis, boiling aqua regia, nitric acid, strong oxidizers and hydrofluoric acid). They are destroyed by molten alkaline metals; ftorlon up to 100° is resistant to aqua regia, nitric acid and to other oxidizers, it is resistant to alkalis at standard temperatures and to the action of aliphatic and aromatic hydrocarbons; it is soluble in ketones (acetone, cyclohexanone, etc.) and swells in chlorinated hydrocarbons. Fibers from fluorine-containing polymers have a high resistance to outside weather (higher than that of polyacrylonitrile fibers), heat resistance (PTFE fibers), strength

(ftorlon), incombustibility and noninflammability, high electric insulation properties, perfect hydrophobic nature. A disadvantage of these fibers is their high specific weight and high cost. Following are the comparative physicochemical and mechanical properties of Teflon, polifen and ftorlon (numbers in parentheses pertain, respectively, to polifen and ftorlon): the structure of all the fibers is crystalline; specific weight of Teflon 2.1-2.3 (2.2-2.3, 1.96), working temperatures region for Teflon is −150+270° (−150+270°, −80+120°), the moisture content under standard conditions and at 95% relative humidity for Teflon and polifen is 0 and for ftorlon 0.04%; the softening temperature for Teflon is 327° (320-326, 132-136), shrinkage in boiling water for all these fibers is 0; dielectric permeability at 60-10^8 cps for Teflon is 1.9-2.2 (1.9-2.2,−); specific volume resistivity of Teflon is 10^{16}-10^{17} ohm-cm (10^{16}-10^{17}, −), the breakdown voltage for Teflon is 25-27 kv/mm (25-27, −), the heat resistance of Teflon and polifen is very high (they can be used for several minutes at 315°). When held at a temperature of 260° for 300 secs the shrinkage comprises only 20%, after heating at 260° for 8 days the strength drops by 25-30%, at a temperature above 330° it decomposes with attedant liberation of poisonous vapor; the heat resistance of ftorlon is much lower. The mechanical properties do not change up to the temperature of 120°, in tension it withstands prolonged heating up to 145°; ftorlon is dyed in the mass by acetone soluble dyes. The rupture length of Teflon is 15.3 km (5-7, 46-55). The ultimate tensile strength is 35 kg/mm^2 (11.5-16.1, 90-108). The elongation of Teflon is 13% (15-40, 6-9). The strength and elongation of all the fibers does not change in the wet state. The initial modulus of elasticity for Teflon is 320 kg/mm^2 (102, 1500). Fabrics with fluorine-containing polymer fibers are a base and are used in the chemical industry for filtration of aggressive fluids and gases, for the produc-

tion of protective clothing, as packing material for packing glands, gaskets and other products working in highly aggressive media.

References: Sigal, M.B. [et al.], "KhV" [Chemical Fibers], No. 2, page 3, 1959; Zazulina, Z.A. Yakovleva, I.I. and Rogovin, Z.A., "Nauchno-issledovatel'nyye trudy Moskovskogo tekstil'nogo instituta" [Scientific Research Transactions of the Moscow Textile Institute]. Vol. 18, page 71, 1956; Zazulina, Z.A., Martsinkovaya, R.N. and Rogovin, Z.A., "TP," No. 5, 1957; Dodonov, T. and Zazulina, Z.A., "KhV," No. 4, 1960; Demina, N.V. [et al.], "KhV," No. 5, page 40, 1960.

Z.A. Zazulina

FIBER FROM POLYVINYL ALCOHOL – synthetic fiber from water-soluble polyvinyl alcohol with a linear structure. It is produced in the form of filament thread and staple fiber under various names: Vinylon, Kuralon, Gremona, sovinol, Vinyl, FO Vinol, monrew, Mewlon, Kanebian, Vinylan, etc. The fiber is obtained by wet spinning from water solutions in a brine bath. To convert the water soluble into a nonwater soluble fiber, it is heat treated at 200-260° with subsequent acetylation by formaldehide. FO Vinol, which is a high-strength and high-modulus polyvinyl alcohol fiber with a stereoregular structure, is spun from the melt in the presence of a moderate quantity of solvent with subsequent drawing and heat treatment.

The physicochemical and mechanical properties of the fiber. The structure is crystalline, specific weight of standard fiber 1.26-1.27, of stereoregular fiber 1.32-1.34, moisture content under standard conditions 4.5-5%, at 95% relative humidity 8%, at 100% relative humidity 12%; softening temperature 220°, melting temperature 232-237°, shrinkage in boiling water 0-2%, high heat resistance (at 215° it shrinks by 15%, retains 50% of its strength up to 190°, softens and yellows at 220°); specific volume resistivity $1.3 \cdot 10^{11}$ ohm-cm. Resists decay micro-organisms, high light resistance (after irradiation by the PRK-2 lamp for 30 hours it loses 25% of its strength). Resists the effect of outside weather (the strength does not change after 100 days), the action of chemical substances (15% phosphoric acid, glacial acetic and butyric acids; cuprammonium solution, pyridine, alcohols, chlorinated hydrocarbons, carbon disulfide, petroleum ether, kerosene, castor and mineral

oils), greases and sea water. It is soluble in 20% hydrochloric, concentrated phosphoric, 35% sulfuric and 80% formic acids; it is dyeable by substantive, naphthenic, sulfur and indanthrene dyes, by acetate-fiber dyes, etc. The rupture length of standard fiber is 27-63 km, of stereoregular fiber 80-100 km (numbers in parentheses for the subsequently enumerated indicators pertain to stereoregular fibers); strength loss in the wet state 10-15%, in the loop 20-25%, ultimate tensile strength 34-80 kg/mm^2 (105-130); elongation in the dry state 15-30% (8-10), in the wet state 20-40% (13-18), elasticity in 2% elongation 65%, in 3% elongation 55%, in 5% elongation 43%, in 10% elongation 33%; initial modulus of elasticity 250-1100 kg/mm^2; by its wear resistance it exceeds the majority of chemical fibers but is inferior to polyamide fibers. It is used for making fishing nets, rope, upholstery fabrics, carpets, silk fabrics and knitwear, clothing fabrics (mixed with wool) and other products. Water soluble polyvinyl alcohol fibers are used as surgical thread.

References: Ushakov, S.N. [et al.], "Khv," No. 4, 1959; Ushakov, S.N., Sinteticheskoye volokno iz polivinilnogo spirta [Synthetic Fibers from Polyvinyl Alcohol]. Leningrad, 1959; Rogovin, Z.A., Osnovy khimii i tekhnologii proizvodstva khimicheskikh volokon [Fundamentals of the Chemistry and Technology of Chemical Fiber Production]. 2nd edition, Moscow, 1957.

Z.A. Zazulina

FIBROIAN — see Protein fiber.

FIBROUS METAL CERAMICS – metal ceramic material, consisting of pieces of thin metal fibers in the form of wire not more than 50-70 microns in diameter and 3-10 mm long. Fibrous metal ceramics are obtained by felting the metallic fiber, whose suspension in a viscous fluid (for example, in glycerine) is then sucked through a perforated bottom of an appropriate vessel, and then felt thus obtained is then slightly compressed and sintered. Use is made of aluminum, copper, nickel, stainless steel and other fibers.

The characteristic features of fibrous metal ceramics are: high porosity and higher strength in comparison with powdery metal ceramics with the same porosity. Fibrous metal ceramics are used to produce articles in the form of strips, liners, etc.

Properties of Fibrous Metal Ceramics

Свойства 1	Единица измерения 2	3 Показатели свойств: материала из алюминиевого волокна 4	материала из медного волокна 5	материала из волокна нержавеющей стали 6
Пористость 8	%	56—64	58—62	64—67
Объемный вес	г/см³	0.9—1.1	1.2—1.6	1.3—2.2
$\sigma_в$ 7	кг/мм²	0.5—0.8	1.8—2.3	2.8—3.8

1) Properties; 2) unit of measurement; 3) property indicators; 4) materials from aluminum fibers; 5) materials from copper fibers; 6) materials from stainless steel fibers; 7) porosity; 8) specific weight; 9) g/cm^3; 10) kg/mm^2.

Fibrous metal ceramics have not come into industrial use; prospects exist for their utilization as sound insulation and filtering materials.

References: "Materials and Methods," Vol. 42, No. 5, pages 96-98, 1955.

V.S. Rakovskiy

FIBROVYL – see Polyvinyl chloride fiber.

FILM MATERIALS – thin, flexible sheet materials of natural (the membranes of animal bladders, intestines, etc.) or synthetic (polystyrene, polyamide, etc.) origin. They can be organic or inorganic (see Glass film and Aluminum foil).

Organic film materials differ from cloth in their lack of porosity, higher moisture resistance, and, often, gas-impermeability. The electrical-insulating characteristics of these materials (especially their electrical strength) are higher than those of cloth based on the same polymer. Films are substantially cheaper than cloth and are consequently often suitable replacements for cloth and lacquered cloth. The majority of organic films are transparent. Synthetic films are produced from thermoplastic polymers by: a) pouring a polymer solution onto a smooth metallic surface and permitting the solvent to evaporate (cellulose ester films); b) pouring and melting a polymer on a smooth metallic surface (polyamide films); c) pressing tubes, which are immediately inflated with compressed air; or forcing the polymer through a slit die (polyethylene and polystyrene films); d) calendering a plasticized polymer (vinyl plastic film); d) mechanical cutting of a thin film (veneer) from a blank and subsequent calendering (polytetrafluorethylene films); f) coagulation of polymer solutions (cellophane), etc. Such films are generally 0.01-0.1 mm (less frequently 0.002-0.5 mm) thick.

Film materials are often characterized by a high degree of crystallinity and orientation of their molecules in the direction of extension during production. This gives them high strength in the extension direction (up to 50-300% higher than the strength of amorphous materi-

Physicochemical Characteristics of Certain Film Materials

1 Материал пленки	2 Нагревостойкость (°С)	3 Плотность (г/см³)	4 Содержание воды при 65% относит. влажности воздуха (%)	5 Постоянная диффузии паров (г/ч·см²) 10⁻⁸	6 Предел прочности при растяжении (кг/мм²)	7 Удлинение при разрыве (%)	8 Предел прочности при растяжении в смоченном водой состоянии (% начальной прочности)	9 Электрическая прочность (кв/мм)	10 Объемное удельное сопротивление (ом·см)	11 Тангенс угла диэлектрич. потерь при 50 гц и 20°	12 Диэлектрич. проницаемость
13 Пластифицированная вискоза (целлофан)	90	1.35	16—18	200	7—9	10—20	65	40	10^{10}	0.2	5—6
14 Непластифицированный триацетат целлюлозы	120	1.27	3.7—4.5	80	8—12	10—25	65	90—100	10^{13}	0.01	3.5—4
15 Пластифицированный триацетат целлюлозы	120	1.22	2.0—3.3	300	6.5—9.5	20—35	65	90—100	10^{11}—10^{13}	0.012—0.014	3.5—4
16 Непластифицированный ацетобутират целлюлозы	105	1.25	4—5	60	7—9	20—30	85	до 150	10^{11}—10^{13}	0.01	3.5
17 Пластифицированный ацетобутират целлюлозы	105	1.24	3—4	—	6—8	25—40	85	до 150	10^{10}	0.012	3.5
18 Полимер гидрированного винилхлорида	60	1.67	0.2—0.5	1.0	6—8	10—50	100	75	10^{13}	0.01	3.4
19 Полиамидная пленка, не вытянутая дополнительно	105	1.08	—	—	4—6	250	100	11—15	$1—5 \cdot 10^{15}$	0.07—0.1	6
20 Полиамидная пленка с дополнительной вытяжкой	105	1.10	—	—	8—15	до 150	до 100	15—65	10^{15}	0.02—0.1	6
21 Полистирол	80	1.05	0	3.0	4—7.5	до 15	до 100	50	10^{16}	0.0002—0.0004	2.5
22 Полистирол изотактический	120	1.085	0	—	12—18	2—4	до 100	50	10^{16}	0.0002—0.0004	2.5
23 Полиэтилен высокого давления	80	0.93	0	0.17	1.5—3.0	до 50	до 100	25	10^{15}—10^{17}	0.0002—0.0005	2.2
24 Полиэтилен низкого давления	120	0.96	0	—	6—16	20	до 100	25	10^{15}—10^{17}	0.0002—0.[illegible]	2.2
25 Полипропилен	140	0.91	0	—	3.5—4	600—700	до 100	60	10^{15}—10^{17}	0.0002—0.[illegible]	2.2
26 Политетрафторэтилен	270	2.1—2.3	0	—	1—3	100—400	100	40—100	10^{15}—10^{17}	0.0002—0.[illegible]	2
27 Политетрафторэтилен ориентированный	270	2.2—2.3	0	—	3—10	20—40	100	40—100	10^{15}—10^{17}	0.0002—0.0004	2

1) Film material; 2) heat-resistance (°C); 3) density (g/cm^3); 4) water content at 80% relative humidity (%); 5) water-vapor diffusion constant 10^{-8} ($g/hr \cdot cm^2$); 6) ultimate tensile strength (kg/mm^2); 7) tensile elongation (%); 8) ultimate tensile strength when wetted with water (% of initial strength); 9) electrical strength (kg/mm); 10) deep resistance (ohm·cm); 11) tangent of dielectric-loss angle at 50 cps and 20°; 12) dielectric permeability; 13) plasticized viscose (cellophane); 14) unplasticized cellulose triacetate; 15) plasticized cellulose triacetate; 16) unplasticized cellulose acetobutyrate; 17) plasticized cellulose acetobutyrate; 18) chlorinated vinyl chloride polymer; 19) polyamide film not subjected to additional elongation; 20) polyamide film subjected to additional elongation; 21) polystyrene; 22) isotactic polystyrene; 23) high-pressure polyethylene; 24) low-pressure polyethylene; 25) polypropylene; 26) polytetrafluorethylene; 27) oriented polytetrafluorethylene.

als based on the same polymers). Such an isotropic film, while having a high ultimate tensile strength, are very susceptible to transverse tears. Cracks formed at the edge of the film readily propagate. In order to avoid this cloth underlayers are sometimes glued to the film, biaxial extension is employed during production, or the sheet is doubled, i.e., films oriented in different directions are glued one on top of the other. Oriented films often exhibit shrinkage and relaxation, especially on heating, i.e., become partially or completely amorphous.

Film materials are used for insulating capacitors, leads, (e.g., of the LPL type), and electrical machinery and equipment, or sounding balloons, photographic and movie film, magnetic tape, and insulating tape, as a packing and decorative material, etc. The principal characteristics of film materials are shown in the table.

Sh.Ya. Korovskiy

FILTER FABRICS – are used for removal of mechanical impurities from liquids; for obtaining a fine suspension when filtering viscous fluids; trapping finely divided solid substances and dust from gases. In the latter cases filter fabrics aid in creating healthy working conditions and elimination of atmospheric contamination. In many branches of industry fabrics from fibers of vegetable, animal, mineral and chemical origin are used for filtration. Filter fabrics are made in the form of cloth and hoses with various strength, porosity and weight. The selection of a filter fabric type depends on the character and properties of the substance being filtered, requirements put to the filtrate and sediment, the mechanical strength of the fabric, its ability to resist various chemical and thermal effects, its prices, filter designs, etc.

Cotton fabrics, which are comparatively cheap, have a sufficient strength in low-aggressive and neutral media and which can be properly cleaned by washing have come into the most extensive use as filter fabrics; their service life in aggressive media does not exceed 8-30 hours.

Burlap fabric from bast and jute fibers is used in neutral and weakly alkaline media for rough filtration.

Wool fabrics, which have a high elasticity and resistance to acids, which withstand with ease compressive and tensile strains for which reason they are used with success in hydraulic press filters, are utilized in more aggressive media. Wool fabrics, the pores of which are reduced in the rolling process, are less stopped up by dust and the

dust is easily removed from them by shaking. However, at temperatures above 95° wool fabrics lose their strength and elastic properties. They are insufficiently resistant to the prolonged effect of acids and alkalis. Wool fabric which is used in nonferrous metallurgy plants at a temperature of 95° and in an atmosphere of gases containing aggressive components (sulfur oxides), serves for 3-6 months, while at cement industry enterprises it serves not longer than 3 months.

Fabrics from polyacrylonitrilic (Orlin, Nitron, Dacron), polyester (Terylene, Lavsan, Dynel), polyamide (Nylon, Capron, Perlon), polychlorovinyl (Khlorin) fibers and their mixtures, which have (in comparison with vegetable and animal origin fabrics) a higher mechanical strength in combination with thermal (with the exception of Khlorin) and chemical resistance, are also used for filtering.

The use of filter fabrics from Nitron in nonferrous metallurgy and other branches of industry makes it possible to increase the productivity of filtering installations, reduce the capital investment for their construction, reduce the losses of nonferrous metals, improve the hygiene of working conditions, obtain a large saving in natural wool which is used for making filtering fabrics. Fabrics from pure Khlorin with and without carding have come into extensive use in certain branches of the chemical industry for filtering concentrated acid suspension solutions at temperatures not above 45°.

To satisfy the needs of the aluminum, zinc, phosphorus, porcelain, coal, cellulose, paper and chemical industries various filter fabrics from chemical fibers, for example, from Capron for filtering lacquers and resins, from Lavsan and Nitron for filtering concentrated acid suspension solutions, are made. Capron fabrics are used in coal beneficiation in filter presses and vacuum filters, etc.

Filter fabrics from glass fiber are made, depending on the intend-

Physicomechanical Indicators of the Main Forms of Filter Fabrics

1 Наименование ткани	2 Артикул	3 Ширина (см)	4 Вес 1 м² (г)	5 Номер пряжи: основа	5 Номер пряжи: уток	6 Число нитей на 10 см: основа	6 Число нитей на 10 см: уток	7 Минимальное разрывное усилие полоски ткани шириной 50 мм (кг): 9 основа	7 Минимальное разрывное усилие полоски ткани шириной 50 мм (кг): 10 уток	8 Вид переплетения
11 Хлопчатобумажные ткани										
12 Бельтинг фильтровальный	2020	84,5—128	950	12/6	12/6	98	58	285	170	Полотняное 13
14 Фильтродиагональ	2073	86,5—105	590	20/3	20/3	220	110	200	100	Саржа 15
Фильтромитраль 16	2076	70—105	590	20/3	20/3	178	110	135	100	Полотняное
Фильтросванбой	2079	90—107	445	40/2	12	266	312	80	54	Полутораслойное
17									18	
Бумазея суровая 19	1100	66	255	40	12	271	200	41	47	Саржа
20 Байка суровая	4015	98,5	380	40	9	223	264	29	35	
Бязь отбельная	55	79	143	34	34	278	230	42	38	Полотняное
21 Шифон отбельный	113	90	111	65 гр	65 гр	380	334	38	26	Полотняное
22				23						
24 Шерстяные ткани										
Байка чистошерстяная	21	137	480	5	5	117	98	61	21	Саржа
Ткань ЦМ 25 26	83 рукав = 22 см		500	5	5	117	98	98	27	Саржа
28 Сукно серошинельное 27	1190	139	745	4,8	4,6	132	120	38	18	Полотняное
29 Сукно № 2	20	132	341	40 х/б*	5	228	147	42	30	Саржа
31 Льняные ткани										
32 Фильтросетка	926	125	250	16/6	16/6	20	17	90	80	Полотняное
Ткань мешочная	967	110	372	5	3,5	74	68	70	70	Полотняное
33				34						
Капроновые ткани										
35 Капроновая	21615	89	250	34	34	270	180	445	173	Полотняное
То же	21689	115	164	34	34	260	240	243	246	Саржа 1/2
36 »	21626	95	279	34/2	34/2	330	110	6/2	195	Двойная саржа 2/2
»	21452	94	150	200/2	200/2	720	520	160	95	
38 Хлориновые ткани										
39 Хлориновая	2088	105	500	20/2	20/2	192	140	70	40	Саржа 2/2 40
»	2089	105	550	20/3	20/3	208	90	120	45	Саржа
Из смеси 70% хлорина и 30% хлопка 41	—	—	556	16/2	16/2	124	298	59	120	Полутораслойное
42 Нитроновая ткань										
43 Рукав НЦМ	—	36,5	420	20/4	5	91	98	115	55	Саржа 2/2

*Cotton.

1) Fabric designation; 2) type; 3) width (cm); 4) weight of 1 m^2 (g); 5) yarn number; 6) thread count per 10 cm; 7) minimum rupture strength of a 50 mm wide fabric strip (kg); 8) weave type; 9) warp; 10) weft; 11) cotton fabrics; 12) filter belting; 13) plain; 14) filter diagonal; 15) serge; 16) filter calico; 17) filter flock; 18) one-and-a-half layer; 19) unfinished fustian; 20) unfinished baize; 21) bleached coarse calico; 22) bleached chiffon; 23) gr; 24) wool fabrics; 25) pure wool baize; 26) TsM fabric; 27) hose = 22 cm; 28) gray overcoat cloth; 29) No. 2 cloth; 30) kh/b*; 31) flax fabrics; 32) filter mesh; 33) burlap fabric; 34) capron fabrics; 35) Capron; 36) same as above; 37) 1/2 serge; 38) Khlorin fabrics; 39) Khlorin; 40) 2/2 serge; 41) from a mixture of 70% Khlorin and 30% cotton; 42) Nitron fabric; 43) NTsM hose.

ed use, either from nonalkaline aluminum borosilicate glass which is resistant to the effect of water and not resistant to acids, or from alkaline sodium-calcium silicate glass, which is less resistant to water but which has a high resistance to acids (except for hydrofluoric

and phosphorus) and alkalis. These fabrics, being distinguished by their chemical resistance to various aggressive media at temperatures of 300-400° and even up to 1000°, high resistance to a moist medium, fire and a high strength, are irreplaceable in the tire, petroleum refining, zinc-white, magnesium and pharmaceutical branches of industry. The shortcomings of these fabrics include moderate resistance to repeated deformations, to abrasion wrinkling and flexure.

In the purification of liquid fuels the cotton and wool fabrics are extensively replaced by nonwoven fabrics made from sacking by the knit stitching method or by gluing with synthetic latex and thermosetting resins. These materials resist oxidizing and photochemical processes, particularly under warm and most medium conditions.

The table on page shows the physicomechanical indicators of the main kinds of filter fabrics.

M.N. Fomina, A.S. Talanina

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[Transliterated Symbols]

1495 х/в = kh/b = khlopchatobumazhnaya = cotton

FINAL FRACTURE ZONE – see Fatigue Breaking.

FIREPROOF CERAMICS — are ceramic materials characterized by a high refractoriness and good thermomechanical properties. Pure oxides (Al_2O_3, ZrO_2, etc.) and also high-melting non-metallic compounds (sulfides, nitrides, carbides, borides) are used for the production of fireproof ceramics. For the properties of refractory oxides see Oxide Ceramics.

V.L. Balkevich

FIREPROOF LACQUER AND PAINT COATINGS are paints and finishes applied to the surface of a material and providing for improved resistance of the material to fire. The fireproof finish differs from the paint in less strength of the film, less thickness of the applied coating, coarser grind of the filler. As binders for the fireproof lacquer/paint coatings, use is made of: liquid glass, sulfite liquor, mineral binders of the type of cement, gypsum, lime, clay, linseed oil, chlorine compounds of the hydrocarbons, complex and simple esters of cellulose (acetal cellulose, ethyl and benzyl cellulose), artificial resins (perchlorvinyl, phenyl-formaldehyde, carbamide and others). As fillers (antipyrenes) use is made of gypsum, chalk, talc, asbestos, ground blast furnace and open hearth slags, andesite, basalt, chloro-paraffin with antimony trioxide, ammonium phosphate and sulfate salts and others. With regard to the form of the binder, the fireproof lacquer and paint coatings are combined into the groups: silicate, chloride, carbamide, sulfite-cellulosic paints, finishes based on the simplest binders (lime, superphosphate), paints using an oil base and those using the organochlorine compounds.

The use of these coatings is an effective measure for the prevention of fires which occur as a result of the action of comparatively low-calorie sources of ignition (short circuits, heating of wires to a white heat, action of heated surfaces, soldering torch flame, small quantity of spilled kerosene, self-ignition of oil soaked materials, burning cigarettes, match flames, sparks, etc.). These coatings find application for the protection of wooden structural elements in casting

and smelting shops, steam locomotive depots, boiler shops, shops for cold working of metals, in lofts and certain warehouse areas.

References: Taubkin S.I., Osnovy ognezashchity tsellyuloznykh meterialov [Fundamentals of Fireproofing Cellulosic Materials], M., 1960; Taubkin S, Kolganova M., Pozh. delo [Fire Prevention], 1958, No. 7; 1959, No. 2; 1961, No. 3; Sbornik rukovodyashchikh dokumentov po pozharnoy profilaktike [Collection of Instructions on Fire Prevention], M., 1961.

S.I. Taubkin

LIGHT-REFLECTIVE LACQUER AND PAINT COATINGS are coatings which have the capability of reflecting the incident radiant energy. The white reflective coatings have the highest degree of reflection, which is explained by the capability of the pigments contained in the coatings to provide multiple reflection of the light from a large number of internal surfaces. The higher the pigment content (to a definite level) in the coating, the higher its reflective capability. Depending on the structure of the reflective coating, the reflection of the incident flux may be either specular or diffuse (scattered). The reflective capability of the coatings is characterized by the reflection coefficient, i.e., by the number indicating the ratio of the reflected flux to the incident. The general-purpose white enamels, particularly the glossy ones, have a low reflection coefficient. Special white phototechnical enamels No. 2 and No. 11 of VNISI and the AS-1sp enamel are produced in order to obtain light-reflective lacquer/paint coatings with high reflection coefficient. The VNISI enamels (reflection coefficient 0.85-0.9) are intended for diffuse-reflection coatings for lighting fixtures with luminescent lamps and incandescent lamps with operating temperature not over 100° (for the No. 2 enamel) or 200° (for the No. 11 enamel). The enamels are applied by atomizer in two layers on a pre-primed surface. The AS-1sp enamel has high atmospheric and thermal resistance (to 180-200°) and good reflective capability (reflection coefficient 0.8), is resistant in tropical climate conditions. The enamel is applied by paknt sprayer in 2-3 layers on a pre-primed surface. In addition to the enamels mentioned, as light-reflective coatings use is made

of the aluminum-color enamels (reflection coefficient 0.5-0.6), primarily for painting gasoline tanks in order to maintain their temperature as low as possible and reduce evaporation losses.

References: Organic Protective Coatings, coll. of articles transl. from Eng., M.-L., 1959; Dolgopolov V.I., Pozhalkina L.N., Svetotekhnika [Illumination Engr.], 1955, No. 3.

I.I. Denker

FIRE RESISTANT TURBINE OILS are intended as replacements for the petroleum oils in systems for the regulation of high-power turbogenerators with high steam superheat or for gas turbines. They have a high self-ignition temperature (> 700° compared with 350-370° for the corresponding petroleum oils), as a result of which fires are prevented in case of oil contact with hot portions of the units during operation. So far, inflammable fluids are used as fire resistant turbine oils only as the working fluid in systems for the regulation of steam turbines. The organic fire resistant oils Ivviol'-2 (self-ignition temperature 740° in air, flash point 238°; viscosity, congealing temperature, antioxidation stability, acid number, demulsification rate and other characteristics correspond to the norms of GOST 32-53 for turbine oil 22) and Ivviol'-3 (self-ignition temperature >750°, other constants close to those for Ivviol'2) which are capable of operation, as shown by tests, in both the control and lube systems for turbines are being introduced in the USSR. The primary component of all the known organic fire resistant turbine oils are the phosphoric acid ester, principally tricresylphosphate, and in this connection they differ from the petroleum oils in higher specific weight (about 1.1), frequently lower viscosity, etc. Thickeners are added to increase the viscosity (most often the chlorinated aromatic hydrocarbons), and alkhlpolsiloxane additives are used to reduce the tendency to foam formation. The drawbacks of the fire resistant turbine oils are high cost (higher by a factor of 15 or more than the petroleum turbine oils) and the toxicity; most toxic is the o-isomer of tricresylphosphate and in this connection fire resistant turbine

oils have been suggested with an o-isomer content of 1-3% (Ivviol'-2 in the USSR) in contrast with the 20-25% concentration for the fire resistant turbine oils prepared from conventional technical tricresylphosphate. Ivviol'-3, which does not contain tricresylphosphate nor thickeners, has very low toxicity.

References: Ivanov K.I., Vilyanskaya Ye.D., T, 1959, No. 9, Ivanov I.I., et al., ibid, 1961, No. 11; Legutke G., Geiseler G., Technik, 1955, Bd 10, No. 12; Knoop E., Erdol und Kohle, 1956. H. 9, S. 613; Souillard G., Elewyck J., van, Erdol und Kohle Erdgas. Petro-Chemie, 1962, H. 3, S. 201.

K.I. Ivanov

FKP AND FKPM PRESS-MATERIALS – see Phenolic press-powders.

FLAK – see Vulcanized fiber.

FLAKES – are internal metallurgical flaws of steel, very fine cracks of an oval or rounded with a diameter from parts of a millimeter up to 100 mm. Flakes serious impair the quality of steel. Flakes occur most often in rolled or forged blanks (rods), more rarely in cast steel. The appearance of flakes in macrographs is shown in Fig. 1. Flakes are also observable on the fractures of steel specimens in the form of stains (Fig. 2).

Fig. 1. Appearance of flakes in macrographs.

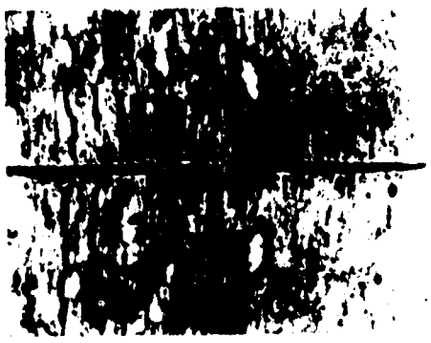

Fig. 2. Appearance of flakes on fractures of specimens.

Measures to prevent the formation of flakes are: 1) diminution of the hydrogen content in steel by careful firing and drying of the charge and of the slag-forming materials, a longer rimming time of the steel or blasting in of oxygen, casting under a vacuum. 2) Heat treatment at a temperature at which the hydrogen is removed from the steel, or a retarded cooling of the steel after hot deformation. 3) Increased number of hot-workings.

M.L. Bernshteyn

FLAW DETECTION – nondestructive testing of materials, semifinished and finished products. Flaw detection makes it possible to detect all kinds of flaws in materials as well as to measure the linear dimensions of semifinished and finished products (see Flaws of Metals). Flaw detection includes the elaboration of: nondestructive inspection methods, b) special apparatus (flaw detectors) used in inspection, c) methods for testing of products of the given type and d) norms for rejecting these products. Structural flaws of materials, disturbance in their continuity or homogeneity which are encountered in products as a result of imperfection of the process used in their manufacture result in changes in the physical characteristics of the material, i.e., density, electric conductivty, magnetic permeability, elastic properties, etc. The study of these changes and the detection of flaws in materials by this method is the physical basis for methods of nondestructive materials quality control. Nondestructive testing methods make it possible to evaluate each product individually, which is of particular importance for products destined for critical service, for which sampling quality control methods, consisting of testing samples taken from a part of a product batch are insufficient, since they make it impossible to judge about the absence of flaws in each product. Physical methods of nondestructive testing which are based on the study of conditions for the propagation of various kinds of penetrating radiations (electromagnetic and elastic vibrations), of the magnetic and electrical properties of materials and also of capillary phenomena have come into the most extensive use.

The basic flaw detection methods are: visual flaw detection methods, gamma-ray flaw detection, magnetic flaw detection, flaw detection by electrical induction, ultrasonic flaw detection, capillary flaw detection. Testing of products by the enumerated methods is performed by using apparatus, i.e., optical instruments, such as: gamma-ray flaw detection installations, betatrons, magnetic flaw detectors, ultrasonic flaw detectors, luminescent flaw detectors, instruments for electrical induction, thermo- and triboelectric flaw detection, instruments for testing by the electrical resistance method, etc. Flaw detection-methods are not universal, each of them has its field of application, within the limits of which certain types of flaws are most effectively detected provided that certain limiting conditions are observed. Hence, in order to improve the reliability of highly critical service products use is made of several flaw detection methods. The acceptability of inspected products is determined on the basis of rejection norms. These norms differ for different product types, for products of the same type working under different conditions, and also for different zones of the same product, since these zones can be subjected to different effects of mechanical and thermal stresses, aggressive media, etc. Rejection norms should be elaborated by designers of the products together with production engineers. Flaw detection is an integral part of the industrial production process. When used rationally, flaw detection makes it possible to improve the product quality and, consequently, the reliability of articles produced. Flaw detection yields tremendous economic advantages: it saves machine and worker time which is used for the processing of products with internal flaws, ensures metal savings, and also prevents breakdown of products, improves the reliability and increases the service life of designs.

References: Defektoskopiya metallov [Detection of Metal Flaws].

I-54G2

Collection of articles under the editorship of D.S. Shrayber, Moscow, 1959; Nondestructive testing handbook, vols. 1-2, N.Y., 1959; Hinsley, J.F., Nondestructive testing, London, 1959; Müller, E.A.W., Handbuch der zerstörungsfreien Materialprüfung [Handbook of Nondestructive Materials Testing], Parts 1-2, Oldenburg, München, 1960.

D.S. Shrayber

FLAW DETECTION BY X-RAY AND GAMMA-RAY FLUOROSCOPY – detection of flaws in materials and articles by bombardment with x-rays and gamma rays with attendant obtaining of a visible image on a fluorescent screen (similar to the x-ray dianosis method used in medicine). In the simplest form (without amplification of the image brightness) this method has only limited use – inspection of products made from light alloys and plastics or thin -walled steel articles. Here use is usually made of x-ray radiation due to the greater power of its sources in comparison with radioactive isotopes; radiation of betatrons is not used since it is difficult to provide reliable biological protection from the scattered radiation. An installation for fluoroscopic inspection

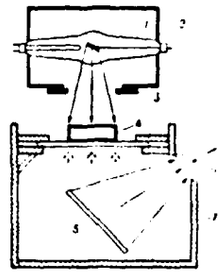

Fig. 1. Diagram showing the setting up of a diascope for fluoroscopic inspection of an article. 1) X-ray tube; 2) protective hood; 3) diaphragm; 4) inspected object; 5) mirror; 6) lead inspection glass; 7) protective jacket.

(diascope) consists of an x-ray tube with a supply source and a protective hood, diaphragm which limits the radiation beam to the required size, a fluorescent screen (usually made from ZnCdS activated by silver), reflecting mirror, lead inspection glass and a protective jacket which absorbs the scattered radiation (Fig. 1). When inspecting a large num-

ber of identical articles it is possible to mechanize the supply of the products being inspected. The inspection results can be photograph-

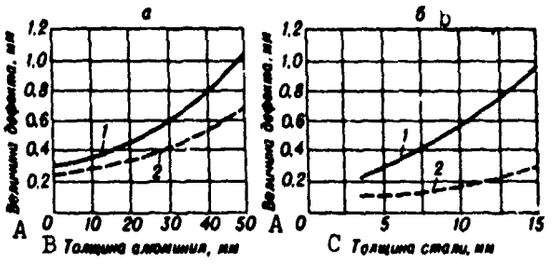

Fig. 2. Comparison graphs of relative sensitivity when inspecting by the diascope and fotographic method of x-ray flaw detection. a) X-raying of aluminum; b) x-raying of steel. 1) Inspection using a diascope; 2) inspection by the photographic method. A) Size of flaw, mm; B) thickness of the aluminum, mm; C) thickness of the steel, mm.

ed. The sensitivity of diascope inspection is always lower than when using the photographic method of radiodefectoscopy (Fig. 2).

The use of x-ray electron-optical transducers which substantially increase the brightness of the visible image, expands the possibilities of this method of flaw detection; here its sensitivity becomes close to that of radiographic methods, in addition, it becomes possible to inspect moving articles.

L. K. Tatochenko

FLAW DETECTION IN BAR STOCK – see Flaw Detection in Pressworked, Rolled and Drawn Semi-Finished Products.

FLAW DETECTION IN CASTINGS. In flaw detection of cast semifinished and finished products a distinction is made between inspection of intricately-shaped castings, which is an almost finished product, and the inspection of ingots, which are subjected to subsequent pressworking, since certain defects in an ingot can be welded together during working, while others may open up. The main flaws in ingots are shrinkage cavities, porosity, cracks, foreign inclusions, and other internal flaws. Surface defects are not of great importance, since the surface layer is removed, as a rule. Effective inspection of the ingot quality after the surface layer is removed consists in visual inspection and capillary flaw detection, which are used to detect flaws which emerge on the machined surface of the ingot. Then the length of the shrinkage cavity is determined in order to establish the boundary of the ingot's riser, which is due to be cut off. X-ray fluoroscopy is used for aluminum and magnesium ingots, while steel, nickel, molybdenum and other ingots are inspected by gamma-ray fluoroscopy, which has a higher productivity than the x-ray method, since it is possible to place several ingots around the radiation source and test them simultaneously. X-ray and gamma fluoroscopy can be used for inspecting ingots with unfinished surfaces, which is a known advantage. However, the low productivity, complexity of x-ray fluoroscopy apparatus, as well as the necessity of using protective measures in x-ray and gamma-ray fluoroscopy, make it unprofitable to use these methods under foundry conditions.

It is most expedient to use ultrasonic flaw detection, which makes it possible to detect and determine the limits of the shrinkage cavity

boundaries, as well as to detect gas holes, porosity zones, cracks, foreign inclusions, etc. Coarse grain substantially attenuate ultrasonic vibrations by scattering them by their boundaries. Hence, ultrasonic inspection of an ingot can be performed only at low frequencies (in certain cases up to 0.5 megacycles); the sensitivity of the method which is thus reduced is still sufficient for detecting the main flaws in an ingot. The contact and immersion versions, and in certain cases the shade version of ultrasonic inspection are used. Ultrasonic vibrations are introduced either through the end or through the side surface of the ingot. In the latter cases, inspection of cylindrical ingots can be mechanized; then scanning is performed along a spiral line as a result of rotation of the ingot and moving the search head along its directrix. Inspection from the back surface is usually manual. The possibilities of this kind of inspection are limited by the length of the ingot, since when the ingot is very long or when the ultrasound is substantially attenuated in the ingot material (when the bottom echo signal is not visible on the flaw detector screen) the inspection is not reliable.

Ingots are inspected by visual inspection and by capillary flaw detection, and for ingots from ferromagnetic alloys use is also made of magnetic flaw detection, which makes it possible to detect surface and subsurface flaws. Internal defects are detected primarily by x-ray and gamma-ray fluoroscopy, and also by irradiation by betatron radiation. X-ray inspection of aluminum and magnesium castings is performed by apparatus such as RUM-7 (RUP-) which is expedient to use for the inspection of aluminum castings with the thickness of up to [illegible] mm. Castings with a greater thickness should be inspected by apparatus such as RUP-[illegible] with plate voltage of [illegible] kw or RUP-1M2 (RUP-1M3) with 200 kw plate voltage. The RUP-1M2 apparatus is also used for inspecting steel castings up to [illegible]-60 mm thick, castings with greater thickness should

be inspected by gamma-ray sources (Co^{60}). In addition to the radiographic method castings from light alloys can also be inspected by visual x-ray flaw detection, which is cheaper and more productive than the radiographic method.

S.V. Chernobrovov, D.S. Shrayber

FLAW DETECTION IN CEMENTED JOINTS. Cemented joints in multilayer designs are inspected by methods of ultrasonic flaw detection, acoustic flaw detection, as well as by the vacuum method. If the product to be inspected can be immersed into a fluid in such a manner that both sides of the cemented joint area are accessible, then it is possible to use the immersion version of the ultrasonic shade flaw detection method. The flaw in the cemented joint (lack of adhesion) does not permit the passage of ultrasonic waves through the product from the generating to the receiving head, which is noted by a reduction in the level of the received signal. Sometimes, particularly when inspecting cemented joints of metals, the flaws are detected by the contact and immersion versions of the ultrasonic echo method. The flaw in the cemented joint substantially increases the reflection of ultrasonic waves from the seam's region, which is registered by the shape of the image on the flaw detector screen. Defects in a cemented joint between metallic elements and zones in which the adhesion of the cement to the metal has been disturbed when metallic elements are cemented to nonmetals can be detected by the ultrasonic resonance method. Ultrasonic methods are used to detect flaws with an area greater than 1-3 cm^2. The impedance method and the method of free vibrations are the most extensively used acoustic flaw detection methods. The impedance method is used primarily to detect regions where the connection is disturbed between a thin (up to 2 mm for aluminum alloys) skin and reinforcing elements or fillers (foam plastic, honeycomb) in products from various metallic and nonmetallic materials. The IAD-1 and IAD-2 flaw detectors are used for inspection. This method

does not require two-sided access to the seam zone or the use of a contact lubricant and makes possible inspection of articles with substantial surface curvatures. The method of free vibrations is used primarily to detect regions at which joints are disturbed at a depth from 4-5 mm to several tens of mm between layers of nonmetallic and combined (from metallic and nonmetallic materials) designs. The ChIKP-1, ChIKP-2, etc.,

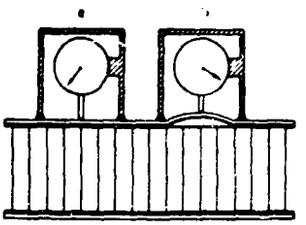

Fig. Schematic of an instrument for cemented joints inspection by the vacuum method. a) Proper cementing; b) disturbance of the connection between the skin and the filler.

flaw detectors are used for inspection. Flaws in cemented joints between a thin skin and a honeycomb filler are detected by the vacuum method. A cap (see Fig.) is placed on the article's skin, from which air is evacuated. The skin bends due to the effect of atmospheric pressure. If the cemented joint has a flaw, the deflection of the skin is increased, which is recorded by an indicator. A disadvantage of the vacuum method is its low productivity. The Dutch company Fokker has created a device which makes it possible to directly evaluate the strength of cemented joints in several types of multilayer designs. The cemented joint's tensile or shear strength is determined in the process, depending on the intended service conditions of the design.

References: Lang, Yu.V., Sovremennyye metody defektoskopii kleyevykh soyedineniy [Modern Methods of Flaw Detection in Cemented Joints], in the collection: Klei i tekhnologiya skleivaniya [(Gluing) Cements and the Technology of Cementing], Moscow, 1960; "Aircraft Prod.," Vol. 22, No. 2, 1960.

Yu.V. Lange

FLAW DETECTION IN FORGINGS AND STAMPINGS. Internal flaws of stamped blanks of the type of metal continuity disturbance (slag inclusions, cracks, porosity zones, flakes, etc.) and zones with coarse grained structure are detected by the ultrasonic echo method (see Ultrasonic Flaw Detection). This method, which is used in its contact and immersion versions, is particularly effective for the inspection of medium and large size blanks, which are simple in shape (products with plane parallel surfaces, bodies of revolution, etc.). It is advantageous to perform ultrasonic inspection of shaped blanks at the initial stages of the component-production process, when they are simplest in shape and have allowances for machining; this ensures the most complete checking of the entire metal volume (particularly, if the allowances exceed the "dead zone" of the flaw detector). If the blanks passes through several stages of hot pressure working, inspection is usually performed after each such operation. In the case of use of the contact (and sometimes also of the immersion) version of the echo method, the surfaces at which the ultrasonic waves are introduced must be given a surface finish of ∇5-∇7, which is needed for reliable acoustic contact between the flaw detector head and the blank being inspected. The surfaces at which ultrasonic waves are introduced are selected in a manner such that the axis of the ultrasonic beam be oriented, as far as possible, perpendicular to the surface of the expected flaws. The orientation of expected flaws is determined on the basis of the blank's macrostructure; metallurgical defects are usually situated along the fiber. Flaws which are oriented parallel to the surface at which the ultrasonic waves are

introduced are detected by longitudinal waves which are introduced into the product along the normal or at a moderate angle (for example, when working with split search heads) to the surface. Flaws situated at substantial (25-90°) angles to the surface at which the vibrations are introduced (for example, radial cracks in turbine rotors), are detected by transverse ultrasonic waves introduced at angles of 30-80°. Combined prismatic search heads are usually used for this purpose. The angles of introduction of transverse waves and the sounding direction are selected in such a manner that the angle between the axis of the ultrasonic wave beam and the flaw surface be as close as possible to being a right angle. An optimum frequency of ultrasonic vibrations, at which the best sensitivity to distant flaws is obtained exists for each type of blanks. High frequencies (above 2 megacycles) are used for exposure of small (~ up to 50 mm^2) flaws in blanks of moderate (up to ~ 100 mm) and medium (up to ~ 400 mm) thickness from metal with a finely grained structure. In coarsely-grained metal ultrasonic vibrations of these frequencies are rapidly attenuated and cannot propagate over large distances. Hence, blanks with medium and particularly large thickness from coarsely-grained metal are inspected by ultrasonic vibrations with lower frequencies (0.5-2.0 megacycles). Reducing the frequency increases the range (penetration power) of the flaw detector and reduces the level of interference signals which are due to reflections from boundaries of individual metal grains. However, this increases the minimum size of a defect which can be detected. Small flaws cannot be detected in coarsely-grained metal. The use of high frequencies requires that the surfaces of products being inspected have a better finish. Zones with coarsely-grained structure in finely-grained metal are detected by the sharp reduction in or the complete disapparance of the bottom echo signal. Flaws in these zones can usually be detected by using a lower

operating frequency. Flaws filled by foreign bodies (oxide films, slag inclusions, etc.), all other conditions remaining equal, are not as easily detected as gas-filled flaws (for example, flakes). This reduction in detection ability is the more perceptible the smaller the opening of the flaw in the direction of propagation of the ultrasonic wave and the closer the specific wave resistances of the main metal and the foreign body (the specific wave resistance is defined as the product of the material's density and the rate of propagation of an elastic wave of the given type through it). When the openings are smaller than 0.005--0.03 of the wave length, the oxide or slag filled flaw may not give a perceptible echo signal and will remain undetected. The detectability of effects with small openings is improved as the working frequency is increased (reduction in the wavelength). In certain cases the detection of these flaws is aided by heat treatment of the article. In forgings from finely-grained steel and heat resistant alloys at a depth up to 150-200 mm, it is usually possible to detect flaws with areas not smaller than 3-8 mm^2; as the depth of flaw location is increased the sensitivity of the method is reduced. When inspecting aluminum alloy blanks the sensitivity is slightly lower, since the main defects of these alloys, which are oxide films, have a reduced reflecting ability. If the blanks are produced on a small scale it is expedient to inspect them by the contact version of the ultrasonic echo method. For an appreciable output volume it is more expedient to use the immersion version. Coordinates of flaws which are detected are determined by depth gages, with which general-purpose contact-echo flaw detectors (UDM-1M, V4-7I, UZD-7N, UZD-14, etc.) are usually equipped. When working with longitudinal waves the distance to the flaw is found directly on the depth gage scale by comparing the time mark with the corresponding echo signal. The measurement error does not exceed 2-5%. When using other

types of waves the finding of the flaw coordinates is slightly more complex and the error is greater. Dimensions of small- and medium-size flaws are estimated by comparing the amplitudes of the echo signals bounced off the flaw and comparison reflectors which are located at various depths in standard specimens which are made from the same material as the product which is inspected. Having selected in the standard specimen a reflector which lies at the same (or approximately the same) depth as the flaw and which gives the same signal as the latter, the dimensions of the flaw are estimated by dividing the area of the comparison reflector by the detectability factor $K < 1$. This factor depends on the type of product which is inspected and on the kind of the flaw; it is found experimentally by statistical analysis of results of area measurements of detected flaws. Dimensions of large flaws are determined by the magnitude of the area at the surface of introduction of ultrasonic waves at which the echo signals are observed. Blanks of intricated shape can be checked by the ultrasonic echo method only with difficulty. Surface flaws of shaped blanks with a finished surface can be detected by etching or by capillary methods (color and luminescent), and also by the eddy current method and by the ultrasonic echo method using surface waves.

References: Defektoskopiya metallov [Flaw Detection in Metals]. Collection of articles, edited by D.S. Shrayber, Moscow, 1959; Nondestructive testing handbook, Vol. 2, N.Y., 1959.

Yu.V. Lange

FLAW DETECTION IN METAL CERAMICS PRODUCTS. Internal and surface flaws (cracks, blow holes, porosity, foreign inclusions) in semifinished and finished products from dense poreless metal ceramics (for example, material such as SAP) are detected by methods used for the detection of flaws in metal products (see Ultrasonic Flaw Detection, X-Ray Flaw Detection, Capillary Flaw Detection). The possibility of finding flaws is here the same as in inspection of metal products. Blow holes and looseness zones in products from porous metal ceramics are detected by the x-ray method. This same method is used for detecting cracks the direction of which coincides with the direction of irradiation or is close to it. Zones in which the bound between the frictional metal ceramics layer and the steel base is absent are detected by the ultrasonic shade method (see Flaw Detection in Multilayered Discs).

Yu. V. Lange

FLAW DETECTION IN MULTILAYERED DISCS. Brake and clutch discs are usually made in the form of a 2- or 3-layer design consisting of a steel base and friction elements from metal ceramics or plastics from one or both sides; the friction elements are connected to the base by diffusion sintering. The main defect which sharply impairs the operating characteristics of discs or individual segments from which the discs are assembled, is the disturbance of the bound between the friction elements and the steel base, which result in local overheating of the disc in service, its jamming and failure. Detection of zones with defective binding can be performed by the ultrasonic shade method in the immersion version (see Ultrasonic Flaw Detection). The fact that ultrasound is substantially attenuated in ceramics makes it necessary to use ultrasonic vibrations with a frequency not above 1-2 megacycles, which limits the sensitivity of the method and makes it impossible to detect flaws with an area smaller than 5-8 mm^2. Scanning is done along a spiral, for which purpose the disc being inspected is rotated about its axis, and the generating and receiving search heads, which are rigidly and concentrically fastened on a fork, are moved along the disc's radius. The disc of the recording device, with electrothermic paper on which the flaw detector readings are recorded fastened to it, which reproduces the shape and dimensions of the disc and the defective zones in it, is seated on the same axis with the disc being inspected.

D.S. Shrayber

FLAW DETECTION IN PLASTIC PRODUCTS. Blow holes, bubbles, foreign inclusions are detected by the x-ray method. This method is also good to use for detecting cracks which are oriented in the direction of radiation incidence or at moderate angles to this direction. X-ray apparatus which give soft (10-60 kv) radiation, for example the RUM-7 device, are used for inspection. Flaws filled with gas are also satisfactorily detected by this method, provided that their length in the direction of radiation incidence exceeds 3% of the total product thickness. Cleavages with a small opening which are oriented in a direction perpendicular to the irradiation, cannot be detected by the x-ray method. Flaws in transparent and semi-transparent plastics (organic glass, etc.) are detected by the visual method.

In the simplest case the product is illuminated by a simple incandescent lamp; here flaws (certain cleavages, zones with a lower content of binding resin in glass plastics, etc.) are recorded on a lighter background in the form of dark spots. Instead of the visual evaluation of the product quality use is sometimes made of a system with photoelements, which record the intensity of light which passes through the product in each of the inspected cross sections, which makes it possible to automate the inspection process.

Internal flaws in products whose shape is not complicated (sheets, bodies of revolution, etc.) made from nontransparent plastics which can be immersed in a fluid are detected by the immersion version of the ultrasonic shade method (see Ultrasonic Flaw Detection). A shade flaw detector which operates at a frequency of 160 kc is used to detect

flaws with an area larger than 1 mm^2. The inspection results are recorded by a loop oscillograph; the productivity is up to 0.58 m^2/min. Flaws which emerge at the surface of the product are detected by the color and luminescent methods of capillary flaw detection. Cleavages in laminated plastics are detected by acoustic flaw detection methods. The impedance method makes it possible to detect cleavages, for example, in glass plastics at a depth up to 4.5 mm, but not deeper than a half of the cross section, for which reason the product must be checked from both sides for complete inspection. The IAD-1 and IAD-2 flaw detectors can be used for the impedance method inspection. The resonant vibrations method detects cleavages at a greater depth, but even in this case the product must be inspected from both sides. If the plastic material is cemented to a more rigid base, then acoustic methods make it possible to detect cleavages over the entire cross section of the plastic material. Flaws which cause local reductions in the dielectric strength or products (cracks, grooves, etc.) can be exposed by methods of electrostatic flaw detection.

Yu. V. Lange

FLAW DETECTION IN PLYWOOD – is used primarily for detecting zones of plywood cleavage. Cleavages are detected by acoustic flaw detection methods. The method of free vibrations is used in the simplest form with estimating the result by ear (rapping) or by using apparatus with objective indicators (for example, the ChIKP-2 flaw detector). It is also possible to use the impedance method; it is inferior to the method of free vibrations with respect to the feasibility of detecting flaws at a large depth, but at the same time it is superior to it with respect to convenience and productivity of inspection. Flaws in plywood sheets with thickness of up to 20 mm can be detected by the immersion version of the ultrasonic shade method (see Ultrasonic Flaw Detection) using low ultrasonic frequencies (67 kcps). A magnetostriction-type emitter and receiver are used, the emission is pulsating; an electron-ray tube serves as the indicator.

References: Bergman, L., Ul'trazvuk i yego primeneniye v nauke i tekhnike [Ultrasound and its Application in Science and Technology], translated from German, Moscow, 1956.

Yu. V. Lange

FLAW DETECTION IN PRESSWORKED, ROLLED AND DRAWN SEMIFINISHED PRODUCTS. Characteristic flaws in bars, shapes and pipes are nonmetallic, slag and oxide inclusions, extrusion defects, internal cleavages, internal and surface cracks, subsurface blow holes, hair cracks, surface films, laps, etc. In addition, a defect in pipes is deviation from the specified wall thickness, and defects of certain types of shapes are transverse surface cracks (for example, in shapes with expanded ends) or cleavage in the longitudinal seam in closed-type shapes, which were extruded through a reed-type female die. In pressworked and drawn semifinished products the material is highly deformed for which reason the metallurgical flaws, as a rule, are flattened out and stretched out in the direction of shaping. Hence, the x-ray and gamma-ray flaw detection methods are ineffective; they can be used in individual cases, for example for detecting cracks in steel pipes (primarily in service). A mandatory method for inspection of semifinished products of all types is visual inspection, using the naked eye as well as optical means. The visual method is used to detect surface flaws (laps, films, bubbles, inclusions, etc.) on bars and on the external surfaces of shapes and pipes. Similar flaws on the internal surfaces are detected by periscope-type optical instruments equipped by miniature lighting devices which make it possible to inspect (with a moderate magnification) the internal surface of pipes and closed-type shapes with a length up to 10-15 m. In individual cases the detection of cracks which emerge onto a surface accessible to visual inspection is made easier by using methods of capillary flaw detection. Bars, pipes and shapes from ferromagnetic alloys

are most expediently inspected by magnetic flaw detection methods (usually using circular magnetization); here the locations of various surface and subsurface flaws (including hair lines and cracks) are detected by the settling of magnetic powder particles. Inside surfaces are inspected by optical devices similar to those mentioned above. Bars, shapes and pipes are also inspected by electric induction flaw detection methods, which are based on the use of eddy currents and make it possible to detect surface and subsurface cracks, blow holes and inclusions as well as to measure the wall thickness. These methods are most suitable for inspection of serially-produced articles of the same type, since they can be easily automated.

Methods of ultrasonic flaw detection are quite effective for inspection of bar stock, pipes and shapes. Using the contact and immersion versions of the resonance, shade and echo method, and utilizing the various types of ultrasonic waves, measurements are taken of the wall thickness of shapes and pipes (including shapes and pipes with variable cross section), and various surface and internal flaws are also detected. Bar stock with a sufficiently large diameter (40-50 mm and more) are inspected by longitudinal waves, which are introduced through the end surface and are directed parallel to the bar stock axis (here the search unit is moved along the entire end surface). If the damping of ultrasound in the bar stock material is moderate (for example, in a press-worked aluminum bar stock), then this method can be used to inspect bar stock with a length of up to 8-10 m. Ultrasonic waves can also be introduced through the side surface of bar stock. If then the longitudinal waves are directed along a plane perpendicular to the bar's axis, then very small flaws, primarily in the core zone of the bar stock are effectively detected by the echo method. The annular zone of the bar cross section which is situated beneath the surface at a depth of up to

[illegible] mm is a "dead zone" and this kind of inspection cannot be used to detect flaws in it. This zone can be inspected by using the shade method as well as by introducing the ultrasonic ray in the diametral plane at a sharp to the normal. In the latter case (as a result of refraction) shear waves which are propagated in the diametral plane of the bar under a sharp angle to its axis are excited in the bar's body. Under the above arrangements of irradiation the bar stock is rotated about its axis, and the search head is moved along the generatrix. The ultrasonic ray, scanning along a cylindrical spiral, will thus intersect its entire volume, which makes it possible to reliably detect boundaries of extrusion defects, internal and surface cracks, cleavages and other flaws. Shapes are usually also inspected by using shear waves which form as a result of transformation of longitudinal waves, which are introduced into the metal through a layer of contact lubricant or through an immersion medium. Since the shape usually has flat side faces, it is impossible to rotate it and scan it along a spiral, for which reason scanning is usually done by short strokes with the search head moving rectilinearly back and forth along the profile and being displaced through a specified distance (scanning pitch) in the transverse direction after each short stroke is completed. When a shape is of intricated form it may be found that it is impossible to sound through its individual zones with the orientation of the search head in space remaining unchanged, since, as a result of refraction, the ray may not reach the zone. In these cases programmed scanning is performed, which ensures the introduction of ultrasound at any place at an optimum angle. Such scanning can only be performed in complex, mechanized and automated immersion-type installations. Using surface waves it is possible to detect cracks which form at surfaces of special shapes (with expanded ends) in the process of manufacture or machining (twisting,

straightening). This inspection is performed by the contact version of the echo method, using a special search head with an adjustable angle of ultrasound introduction. Ultrasonic methods can also be used to inspect pipes with different wall thickness and cross-sectional shape. The most expedient inspection that based on the introduction of longitudinal ultrasonic waves (through an immersion or jet contact) into the pipe body in a plane perpendicular to the pipe axis, but outside the diametral plane, at a sharp angle to the normal. So-called shear and, for particular angles of incidence (usually for a small wall thickness of not more than 3-4 mm) so-called normal or Lamb's waves are excited in the pipe cross section as a result of refraction. The shear waves, which are multiply reflected from the external and internal pipe surfaces, travel over its entire cross section and, upon encountering a flaw in the path of their propagation, they are reflected also from it, giving an echo signal which is visible on the instrument's screen under the echo method, or reducing the amplitude of the passing signal in inspection by the shade method. Normal waves are propagaged through the pipe cross section in the same manner as in a wave guide, for which reason any changes in the pipe cross section (internal or surface flaws, changes in the wall thickness) produce a reflection of the ultrasound energy, which can be recorded either by the appearance of the echo signal or by a reduction in the energy which has emerged through the defective zone. In this kind of pipe inspection the ultrasound is introduced in a single point and does not require rotation of the pipe. For this reason scanning reduces only to moving the search head along the generatrix, which substantially simplifies the achieving of acoustic contact and makes inspection highly productive with a high sensitivity. The flaw detector readings can be recorded by a special recording device on a strip from electrothermal paper.

FLAW DETECTION IN PROTECTIVE COATINGS – inspection of the thickness and continuity of coatings. Methods given in the table are used for testing the thickness of protective coatings. The basic methods are the electrical induction and magnetic methods. Capillary and electrostatic methods are used for checking the continuity of certain kinds of coat-

TABLE

Methods for Checking the Thickness of Coatings

1 Метод	2 Область применения
Магнитный отрыв, магнитная индукция 3	Немагнитные металлические и неметаллические покрытия на магнитном металле; никелевые покрытия сталей 4
Электропроводящий 5	Неэлектропроводные покрытия на немагнитном металле; немагнитные металлические покрытия на немагнитном металле при условии различной электропроводности материала покрытия и основы 6
Термоэлектрический 7	Металлические покрытия на металле при условии различной величины термоэлектродвижущей силы материала покрытия и основы 8
С применением радиоактивных веществ 9	Покрытия и основа, различные по атомному номеру 10

1) Method; 2) field of application; 3) magnetic break-off, magnetic induction; 4) nonmagnetic metallic and nonmetallic coatings of magnetic metals, nickel coatings of steels; 5) electrical induction; 6) nonelectrically conducting coatings of nonmetallic materials, nonmagnetic metallic coatings of nonmagnetic materials provided that the electrical conductivities of the coating and base metals differ; 7) thermoelectric; 8) metallic coatings of metals provided that the thermal emf of the coating and base metals differ; 9) based on the use of radiation of radioactive compounds; 10) coatings and bases which differ by their atomic number.

ings (see Capillary Flaw Detection, Electrical Induction Flaw Detection). Cracks, pores and other flaws in lacquer and paint coatings of metals are detected by the LKD-1, GIPI-4 and similar flaw detectors, the opera-

tion of which is based on an integrated use of the electrical resistance and capillary methods. Flaws in thick, for example, heat-protective coatings are detected by the acoustic and ultrasonic methods (see Acoustic Flaw Detection, Ultrasonic Flaw Detection).

G. Yu. Sila-Novitskiy

FLAW DETECTION IN RIVETED JOINTS. The most dangerous and most frequently encountered flaws of riveted joints are radial cracks. These cracks start underneath the rivet heads and, propagating, can cover the distance between rivet holes in the sheet without emerging at the surface. Slitting of the rivet body is also sometimes encountered.

Radial cracks in sheets and slitting of rivets are detected by the ultrasonic echo method (see Ultrasonic Flaw Detection), which makes it possible to inspect riveted joints without removing the rivets. It is possible to use type UDM-1M, V4-71, UZD-7N pulse flaw detectors or other similar instruments. The inspection is usually performed at a frequency of 2.5 megacps using angle search units. Sometimes small-size search units are used, since they should fit freely between rivet heads. The angle of incidence of ultrasonic waves and the position of the search unit in the article are selected so as to subject to the waves the zone of the most probable crack appearance (Fig. 1); in this position the search unit is moved around the rivet. The slitting of rivets can

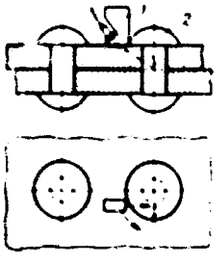

Fig. 1. Ultrasonic inspection of a riveted joint. 1) Search unit; 2) rivet.

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...ted by using straight search units of a special shape, which ensures reliable acoustical contact with the rivet head; the ultrasonic waves are then made to impinge in the direction of the rivet axis. The surface of the sheet or the rivet head is cleaned by an abrasive disc to remove boiler scale, rust and rough irregularities, whereupon it is lubricated by avtol-6 oil, etc. If a crack is present, the ultrasonic wave is reflected from it and gives a signal in the shape of a peak on the flaw detector screen. The instrument is calibrated by the reflection of a sound wave from an artificial flaw (undercut) which imitates a crack in a standard specimen. The quality of the flaw detector operation is checked by reflection of the ultrasonic wave from the edge of the rivet hole.

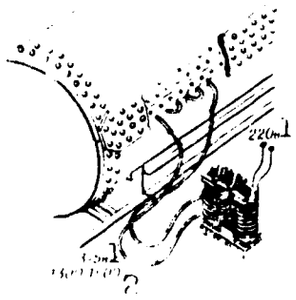

Fig. 2. Inspection of the riveted joint of a boiler drum by magnetic particle inspection. 1) v; 2) amps.

Radial cracks in steel riveted constructions can also be detected by magnetic particl inspection, but this requires removal of the rivets. A cable (Fig. 2) through which alternating current with the force of up to 1500 amps flows is passed through the rivet holes. As a result of this a circular magnetic field is formed around the hole. Simultaneously the inspected section of the article is covered by a magnetic suspension, particles of which settle on the zone in which cracks are to be detected and scattered magnetic fields arise over them. Sometimes another magnetization method is used in which electric contacts ("stoppers") are placed in neighboring rivet holes; in this case the electric current flows directly through the article.

References: Sokolov, V.S., Defektoskopiya materialov [Flaw Detection in Materials], Moscow-Leningrad, 1957; Bogoslovskiy, Yu.V., Ul'trazvukovoy defektoskop UZD-7N [The UZD-7N Ultrasonic Flaw Detector], Moscow, 1957.

I.N. Yermolov

FLAW DETECTION IN ROLLED PLATES. External and internal flaws in rolled metal plates are detected by the shade and echo ultrasonic flaw detection methods. Elastic vibrations (usually longidtudinal) are introduced into the plate, most frequently through a thick fluid layer (immersion contact). Flaws in hot-rolled steel plates with a thickness above 10 mm and width up to 2800 mm can be detected by the LETI automated ultrasonic shade installation. To increase the productivity, it uses 288 pairs of search heads. Emitting and receiving units are placed on a stationary traverse on different sides of the plate which moves in a water bath with a speed of up to 10 m/min. The elastic waves are radiated in pulses with a carrying frequency of 1.3 megacycles. The productivity of this installation is up to 28 m^2/min. The plates are inspected in the as-received state without additional machining of the surface. The inspection results are recorded on a diagram which shows the dimensions, shape and the location of the flaws in the plan to a reduced scale. Ultrasonic installations which use the echo method primarily with immersion contact are also used for flaw detection in light-alloy rolled plates (see Ultrasonic Flaw Detection, Flaw Detection in Forgings and Stampings). Quantity inspection is performed in immersion baths using automated installations which are equipped with systems for signalizing and recording the results, which ensure high produc-

Fig. Specimen of recorded cleavages in a 40 mm thick and 2.3 m wide steel plate.

[illegible]ivity. In those [illegible] instances, it is more convenient to use [illegible] for creating the immersion contact (the [illegible] fluid flows out through the clearance between the head and the product). Elastic waves are introduced into the plate from the bottom or top. It is also possible to use the contact version of the echo method, however, this increases the requirements to the quality of the plate's surface finish. The echo method is also used for flaw detection in rolled plates from ferrous metals. The advantage of plate inspection by this method is the high sensitivity, while the disadvantage is the presence of a dead zone.

References: Merkulov, L.G. [et al.], Avtomatizatsiya ul'trazvukovoy defektoskopii listovogo prokata s polucheniyem izobtazhenii vnutrennykh defektov [Automation of Ultrasonic Flaw Detection in Rolled Sheets with Attendant Obtaining of Images of the Internal Flaws], Moscow, 1961 (Peredovoy nauchno-tekhnicheskiy i proizvodstvennyy opyt. Tema 10, [Advanced Scientific-Technological and Industrial Experience. Topic 10], No. M-61-139/11); "Iron and Steel," Vol. 30, No. 4, pages 130, 149, 1959.

Yu.V. Lange

FLAw DETECTION IN RUBBER PRODUCTS. Blow holes, bubbles, and other gas-filled flaws whose length in the direction of irradiation comprises not less than 4-6% of the total thickness of the product are detected by the x-ray method. This method can also be used for detecting foreign (for examale, metallic) inclusions in the rubber. X-ray examination is performed by apparatus with soft radiation (for example, RUM-7). Breaks in the rubber, peeling of rubber of the cord and other flaws in automobile and aircraft tires are detected by the ultrasonic echo method (see Ultrasonic Flaw Detection). The tire to be inspected is submerged in a bath with liquid (usually water) and rotated about the axis. Ultrasonic waves, propagating from a generating device placed at a fixed position inside the tire, pass through the layer of the liquid and the product and are received by receiving heads which are placed at the outside of the tire. If a flaw is present in the path of the ultrasonic wave, the intensity of the wave field in the zone of the corresponding receiving head is reduced, which is recorded by the apparatus. The ShD-1 domestic [Soviet] tire flaw detector has 18 receiving heads and is equipped by an automatic recording device for recording the inspection results. The working vibration frequencies which are used in the instrument comprise 50 kcps and 150 kcps, the emission is continuous. The instrument reliably detects flaws with an area of 10 cm^2 and greater.

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"ZL," Vol. 26, No. 11, pages 1244-47, 1960.

Yu. V. Lange

FLAW DETECTION IN SEAMLESS PIPES – see Flaw Detection in Pressworked, Rolled and Drawn Semifinished Products.

FLAW DETECTION IN SHAFTS. Shafts (including crankshafts), as well as columns, axles, piston rods and similar, primarily steel, machine components can contain internal casting flaws, as well as surface cracks, i.e., quenching, grinding and fatigue cracks. X-ray and gamma-ray irradiation is used for detection of internal volume flaws in shafts up to 200-250 mm in diameter. Similar defects in shafts up to 500 mm in diameter are detected by betatron radiation. Fluoroscopy using these methods is possible provided that free access exists to the component to be inspected, hence it is most effective for the inspection of shafts in the process of production, and is very limited during use, since in the majority of cases this involves removal of the shaft from the rest of the assembly. Capillary flaw detection or magnetic flaw detection can be used to detect external cracks, inspect cylindrically-shaped components 6-7 meters long and up to one meter in diameter. Magnetization of a shaft requires passing through it current of up to 10,000-12,000 amps through a bar placed inside (which is not always possible) or directly through the shaft (for which purpose use is made of "soft" contacts which eliminate "burn-on" of the surface). This method is suitable only when free access to the shaft is possible. When magnetizing crankshafts, the magnetic field intensity at individual surface sections of the shaft is found to be different due to differences in cross-sectional dimensions and shape complexity which brings about sharp changes in the magnetic field direction. It is therefore possible, at sections with a higher magnetic field intensity, to record inexistent flaws (resulting from the magnetic inhomogeneity of the metal), which

camouflage cracks which can thus remain undetected. After magnetic inspection is performed, the shaft must be thorough demagnetized, which is quite complex task which limits the feasibility of flaw detection in shafts without removal of the shaft from the rest of the assembly. Internal and surface flaws in steel and nonferrous alloy shafts can also be detected by the ultrasonic echo method, introducing ultrasonic vibrations at various angles from the end and through the surface of the crankshaft journal. The reliability of flaw detection in shafts can be improved by using several inspection methods, the selection of which is determined by specific conditions, such as the shape and overall dimensions of the shaft, possibility of free access to the cross section to be inspected, etc.

D.S. Shrayber

FLAW DETECTION IN SHAPES – see Flaw Detection in Pressworked, Rolled and Drawn Semi-Finished Products.

FLAW DETECTION IN SHEETS. Surface defects of sheets (primarily metallic) can be detected by capillary flaw detection methods, and sometimes also by the visual method. The shade and echo methods of ultrasonic flaw detection are usually used for detection of internal and surface flaws. The immersion version is used primarily in case of utilization of the shade method for which purpose the sheet is immersed in a bath with a fluid; the contact version using longitudinal waves is used rarely. To increase the productivity the shade installations have several pairs of generating and receiving heads (Fig. 1). The UKL-2 in-

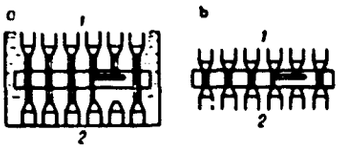

Fig. 1. Schematic diagram of the inspection of sheets by the ultrasonic shade method using axial ultrasonic waves. a) The immersion version; b) the contact version; 1) Generating unit; 2) receiver of elastic vibrations.

stallation is used for flaw detection in sheets with a thickness from 1 to 15 mm (with a length up to 1.5 m and width up to 1.0 m). The installation has 10 pairs of heads and works at a frequency of 2.8 megacycles; pulsating signals are used. The minimum size of a flaw which can be detected is 2.5 mm^2; the productivity is 0.2 m^2/min. Light and sound signals and an automatic stopping device which stops the feeding of the sheet upon discovery of a defect are available. Another shade installation for inspection of sheets and plates thicker than 10 mm has a productivity up to 28 m^2/min and is equipped by a system for recording flaws which are detected. The echo method is sometimes used for flaw de-

tection in sheets more than 2-3 mm thick. Longitudinal ultrasonic waves are introduced along the normal to the sheet surface by means of a combined-type head. In the absence of flaws, multiple reflections from boundaries are observed on the flaw detector screen, which, for sheets thicker than 4-6 mm, are visible in the form of individual pulses and for thinner sheets they combine into a single signal. The presence of a flaw produces a reduction in the number of images and a reduction in the distance between neighboring pulses, and in the inspection of thin sheets it reduces the duration of the signal which is formed by the

Fig. 2. Schematic drawing of sheet inspection by the contact version of the ultrasonic shade method using normal ultrasonic waves. 1) Wave generator; 2) receivers of elastic vibrations.

multiple reflections in the sheet. Longitudinal ultrasonic waves are used primarily to detect flaws which are oriented parallel to the planes of the sheet. Defects of any orientation are detected by using normal waves (or Lamb's waves), which are particularly effective for inspection of thin (less than 5 mm) sheets. In the shade method of flaw detection in sheets using normal waves (Fig. 2) the generating and receiving heads of the flaw detector are placed a distance of 20-50 cm from one another. The flaw reduces the ultrasonic field intensity in the zone where the receiving head is located. An installation is used in the FRG which makes it possible to operate three pairs of heads simultaneously. The sheet is not controlled completely, but rather in zones in the shape of 30 cm wide parallel strips (the distance between the generating and receiving heads of a single pair). Neighboring strips are removed 50 cm from one another. The lubrication of the sheet surface at points of its contact with the heads, pressing of heads (to the

sheet) and feeding of the sheet at a rate of from 0.1 to 1 m/sec is automatic. The installation uses continuous vibrations with frequencies of 2.8, 3.0 and 3.2 megacycles; a device is available for signalling about the presence of a defect.

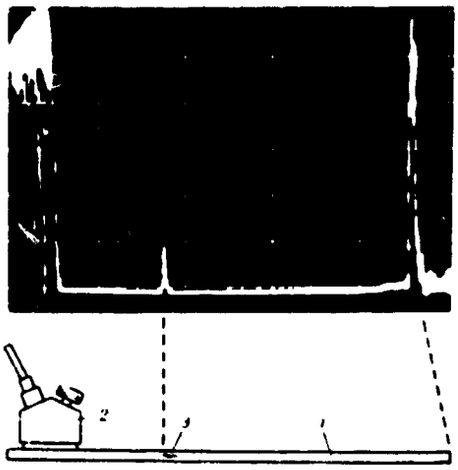

Fig. 3. Schematic drawing of the echo method using normal waves. 1) The sheet being inspected; 2) head which makes possible to adjust the angle at which the ultrasonic vibrations are introduced; 3) flaw.

An effective means of flaw detection in sheets is the echo method using normal waves which are introduced by the contact (Fig. 3) or immersion (Fig. 4) methods. The criterion for the presence of a flaw is an echo signal reflected from it. When using normal waves it is possible to obtain a higher productivity of single pair of heads in the shade method or of one head in the echo method as compared with the use of longitudinal waves. The ultrasonic beam of normal waves penetrates a strip along the sheet to a distance of several tens of cm, while a beam of longitudinal waves, which is directed perpendicular to the sheet surface, embraces an area which is approximately equal to the area of the generating head. Hence, for example, in inspecting sheet cards by the echo method using normal waves it is not necessary to move the head

over the entire surface of the sheet, and it is frequently sufficient to place it in the center of the card and to revolve it over 360°.

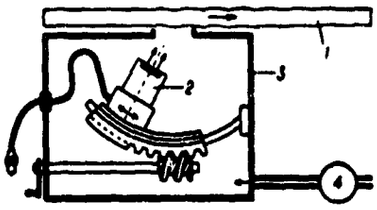

Fig. 4. Schematic drawing of sheet inspection using the immersion version of the ultrasonic echo method with use of normal ultrasonic waves. 1) The sheet being inspected; 2) head with adjustable angle of ultrasonic vibration direction; 3) housing filled with an immersion fluid; 4) pump.

The thickness of metal sheets accessible from one side is measured by ultrasonic methods. Thicknesses of up to 10-15 mm with an error of 1-3% are measured by the ultrasonic resonance method, while greater thicknesses are measured by the echo method whose error comprises 2-5%. Certain ultrasonic echo flaw detectors (for example, the USIP-9 of the West German company, Krautkrämer) are equipped with special extensions for measuring thicknesses within the limits of 4-60 mm (for steel) with an error of 2-3%. It is also possible to measure thicknesses by the magnetic thickness measurement and the electric resistance methods, as well as by the contactless methods of gamma-ray thickness measurement and eddy currents. Contactless methods also make it possible to measure the thickness of a moving sheet (in certain cases heated to a high temperature).

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cow, 1961 (Peredovoy nauchno-tekhnicheskiy i proizvodstvenny opyt. Tema 10, [Advanced Scientific-Technological and Industrial Experience. Topic 10], No. M-61-139/11).

Yu. V. Lange

FLAW DETECTION IN SLIDING BEARINGS. Zones where the antifriction layer peels off, oxide films, porosity, cleavages in the base metal, etc., are detected primarily by the shade and echo versions of the ultrasonic method (see Ultrasonic Flaw Detection). The UZDR-60 domestic [Soviet] ultrasonic flaw detector detects flaws in sliding bearings using the contact and immersion versions of the echo and shade methods. The shade method is used in the standard as well as in the mirror version, under which it is sufficient to have one-sided access to the article. In the UZDR-60 flaw detector the flaws are noted by switching on light and sound signals. In another domestic installation for inspection of large-size bearing liners use is made of the immersion version of the ultrasonic shade method. The generating and receiving heads of the flaw detector are situated in a fluid at the external and internal sides of the product. The heads are moved relative to the liner by mechanical means which takes place along a spiral line with a lead of 8 mm for rotating velocity of 19 rpm. Zones where the antifriction layer peels off and where cleavages exist in the base material are detected if their area is 0.3-0.8 cm^2 and greater.

References: Bogatyrev, V.G. and Semenov, R.A., Avtomatizirovannaya ustanovka dlya kontrolya vkladyshey ul'trazvukovym metodom (iz opyta Kolomenskogoteplovozostroitel'nogo zavoda). Soveshchaniye po voprosam kontrolya nerazrushayushchimi metodami (Defektoskopiya). Konspekty dokladov [An Automated Installation for Inspection of Liners by the Ultrasonic Method (from the experience of the Kolomna Diesel Locomotive Building Plant). Conference on the Problems of Nondestructive

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Yu. V. Lange

FLAW DETECTION IN SOLDERED JOINTS. Zones of disturbance of soldered joints in multilayered products with parallel opposite surfaces are detected by the ultrasonic methods – resonance, shade or echo method (see Ultrasonic Flaw Detection). If the joint is sound, the ultrasonic waves, propagating perpendicular to the joint surface, pass through it without perceptible reflection. A flaw produces strong reflection of the elastic waves which is recordeo by the apparatus. The resonance and echo methods are used when the article is accessible from one side, the shade method usually requires access from both sides. Ultrasonic methodd make it possible to detect flaws with an area of 0.5-1.0 cm^2. Defects of soldered joints between a thin (up to 0.8-1.0 mm for steel) skin and the more rigid internal element are detected by the impedance method (see Acoustic Flaw Detection), which is particularly effective for the thinnest skins and in the case when the product to be inspected has curvilinear surfaces, when the use of ultrasonic methods is difficult. Flaws of soldered joints which are oriented perpendicular or at large angles to the surface of the product can be detected by x-ray fluoroscopy (see X-Ray Flaw Detection) or by the echo method (usually using transverse waves). Flaw detection in soldered joints between the skin and the honeycomb filler is performed by the impedance method (for steel skins up to 0.7-0.8 mm thick), the immersion version of the ultrasonic echo method, the electric contact and x-ray methods, methods based on the effect of the flaw on heat transfer (heat-sensitive paints, determination of the thermal relief of the skin surface by infrared rays) etc. For flaw detection of soldered joints of honeycomb panels automat-

ic installations were developed which make it possible to record the inspection results. The figure shows a specimen of such a recording which was obtained on an installation (USA) using the immersion version of the ultrasonic echo method.

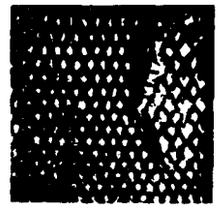

Fig. Specimen of recording of flaws in a soldered joint between the skin and honeycomb fillers.

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Yu. V. Lange

FLAW DETECTION IN STAMPINGS – see Flaw Detection in Forgings and Stampings.

FLAW DETECTION IN WELDED JOINTS. The quality of welded joints is inspected primarily by irradiating the seam by x-rays and gamma-rays, and by magnetic, capillary and ultrasonic flaw detection methods. Magnetic flaw detection methods are used to inspect welded joints from ferro magnetic materials. Here defects which emerge at the welded seam surface are detected. When the seam reinforcing bead is removed it is possible to detect subsurface flaws which lie at a depth of not more than 2 mm. The magnetographic method is used to detect flaws in thin butt-welded joints (not more than 12 mm thick).

Luminescent flaw detection and the color flaw detection method are used primarily for detecting flaws in welded joints from ferromagnetic and nonferromagnetic materials which emerge at the surface.

Control of quality of welded joints by x-ray and gamma-ray irradiation as well as by betatron radiation (for steel thicker than 200 mm) makes it possible to detect internal flaws in the welded seam and in the region near the seam: gas inclusions (pores, gas pockets), slag inclusions, lack of penetration, cracks. X-ray and gamma-ray fluoroscopy does not guarantee detection of small cracks which lie in a plane making an angle of more than 5° with the direction of the passing rays, and lack of penetration in the form of tight adhesion of the metal (lack of fusion without a gas or slag interlayer). The following mutual relationship between the positions of the emitter, inspected article and radiation detector must be observed in x-ray and gamma-ray fluoroscopy of welded joints of various types: a) butt joints with the joint faces cut straight and with space for the filler metal are inspected

with the center ray directed perpendicular to the seam (Fig. 1a); b) angular seams in lap joints are inspected with the center ray directed at a 45° angle to the plane of the sheet (Fig. 1b); it is also permis-

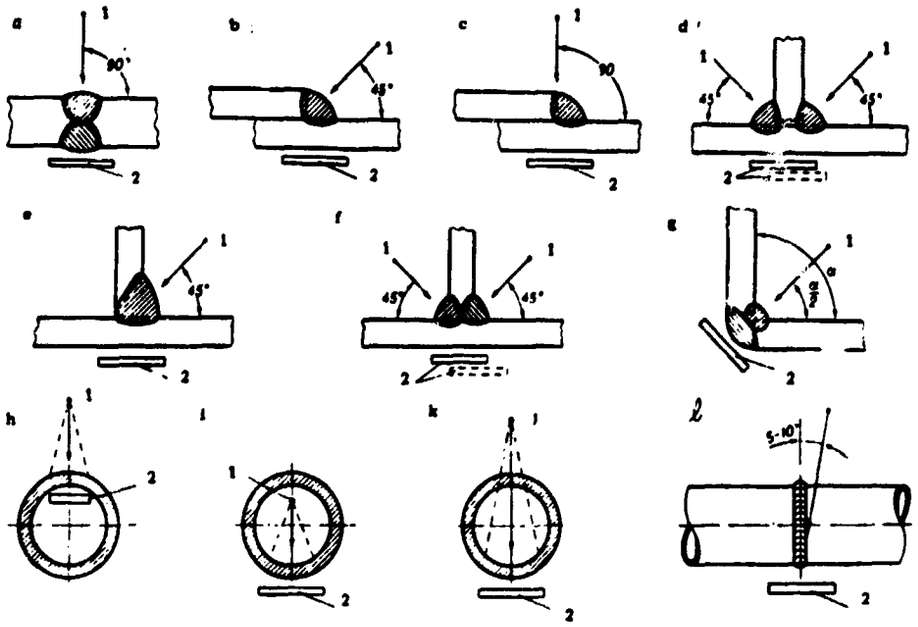

Fig. 1. Relative positions of the emitter, welded joint and radiation detector for inspection by penetration radiation. I) Emitter; D) detector; (α) angle of inclination of the center ray to the product surface. 1) I; 2) D.

ible to make inspection with the rays directed perpendicular to the plane of the sheet (Fig. 1c); c) seams in T joints without space for the filler metal are inspected with the center ray directed at an angle of 45° to the flange of the T (Fig. 1d); d) seams in T joints with the end faces cut at an angle in one or two directions are inspected with the center ray directed at a 45° angle to the T flange (Fig. 1e and f); e) seams in angle joints are inspected with the center ray directed along the bisector of the angle between the welded elements (Fig. 1g); f) annular and longitudinal seams in cylindrical or spherical products (pipes, boilers, vessels) can be inspected by placing the source inside the product (Fig. 1i) or outside the product (Fig. 1h) with the center ray directed perpendicular to the seam direction; g) annular and longi-

tudinal seams in products (pipes, vessels, etc.) whose shape makes it impossible to place the radiation source or the detector inside of them, are inspected by placing the detector from the outside of the seam at an angle to the product's axis (Fig. 1k and 1) in such a manner that the images of two oppositely-located sections should not be superimposed on one another.

Quality control of welded joints by ultrasonic flaw detection methods is, as a rule, performed by the pulse echo method using refracting search heads which are located at a certain distance from the weld reinforcement bead (Fig. 2). The angle β between the direction of propagation of the center ray in the metal and the normal to the surface at which the vibrating device is placed, is called the refraction angle or the angle of ray introduction. Welded seams are inspected by search coils with the ray introduction angle from to 40 to 70°. Butt joints from 10 to 25 mm thick are inspected by a ray singly refracted from the opposite surface of the metal (Fig. 3a), seams from 25 to 50 mm thick are inspected by refracted as well as direct rays; seams more than 50 mm thick are, as a rule, inspected by a direct ray. Angle and T joints

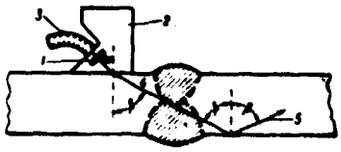

Fig. 2. Inspection of a welded joint by a direct ultrasonic ray. 1) Piezoelectric element; 2) body (prism) of the search head; 3) hose connecting the search head and the ultrasonic flaw detector; 4) inclined ray of ultrasonic shear vibrations which enter the product being inspected at angle β; 5) ray reflected from the opposite wall of the product.

are inspected by a reflected ray (Fig. 3b). The ultrasonic vibration frequency should be selected by taking into account the seam thickness and the magnitude of damping of ultrasonic vibrations in the seam metal. For example, inspection of welded seams from perlitic steels should be

performed by frequencies given in the Table.

Inspection of welded seams of austenitic steels is extremely difficult due to extensive damping of ultrasonic vibrations in the seam material, and it is sometimes practically impossible. Ultrasonic inspec-

TABLE

Frequency of Ultrasonic Vibrations for Inspection of Seams of Perlitic Steels

Толщина шва 1 (мм)	Оптимальная 2 частота (Мгц)
10—25	2.5—3.5
25—100	1.8—2.5
100—500	1.2—1.8

1) Seam thickness (mm); 2) optimum frequency (megacps).

tion makes it possible to detect thin films, cracks and lack of weld penetrations which are not detectable by other flaw detection methods.

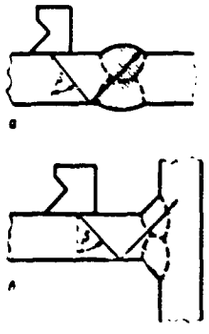

Fig. 3. Inspection of a welded seam. a) By a singly-reflected ray in the case of a welded butt joint; b) by a singly reflected ray in the case of a T joint.

When inspecting the entire cross section of a welded seam the search head is moved within certain limits in a direction perpendicular to the seam. The limits within which the search coil is moved depend on the geometric dimensions and the type of the welded joint, on the angle at which the ray is introduced and are determined from nomograms which are appended to instructions. Use is made frequently of mechanical devices which ensure the specified limits of search coil movement. For reliable acoustic contact it is most expedient to use the immersion version of the echo method, which makes it possible to automate the process of inspection of certain welded joints (longitudinal seam of welded pipes, welded

possible, using experience accumulated in inspecting such joints and theoretical considerations, to construct a system of standards and graphs, which make it possible to determine the dimensions of flaws with an accuracy sufficient for practical purposes.

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A.S. Matveyev

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FLAW DETECTION IN WELDED PIPES – see Flaw Detection in Welded Joints.

FLAW DETECTION IN WIRE. Cracks in the surface layer and other flaws, primarily those oriented along the wire are detected, the chemical composition, structural state and electrical conductivity of the material are inspected and the wire diameter is measured by methods of electrical induction flaw detection. The inspection is performed at a rate of 0.5-2.0 m/sec in flaw detectors with pass-through coils. Flaws are more effectively detected by the ultrasonic echo method using normal waves which propagate along the wire; in this case flaws are detected regardless of their orientation and position along the wire cross section. The rate of inspection is ~ 1 m/sec using a pulse-type echo flaw detector with a simple attachment and can be easily automated.

G. Yu. Sila-Novitskiy

FLAW DETECTION METHOD BY MEANS OF IRON PROBES – is a method based on the application of magnetical-susceptible elements, the iron probes, which measure weak magnetic fields or the gradients of these fields. The iron probes are used to detect the scattering caused by a disturbance of the continuity or homogeneity, of magnetic fields on the flaws of metallic objects.

Flaw detection by means of iron probes is very sensitive (up to 10^{-5} oersted per 1 degree of the scale) and permits the use of very small-sized pickups (up to 0.1 mm in diameter and 1 mm in length). The testing process may be easily automatized for simple-shaped objects. Flaw detection by means of iron probes is used to test the magnetic characteristics of materials exposed to high or low temperatures or aggressive media, to test the thickness of furnace linings or of hermetically sealed vessels, etc., because the pickup may be placed at a distance which is greater than the size of the heater.

Flaw detection by means of iron probes is very efficient in the detection of ferromagnetic particles and also of separated electromagnetic phases in objects or semifinished products made from nonmagnetic or weakly magnetic materials. This method is widely used to test the degree of demagnetization of parts (after the magnetic particle inspection, for example). It is efficiently used to measure the thickness of nonmagnetic coatings applied on a ferromagnetic basis, and also to measure the thickness of pipes made from nonmagnetic materials.

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S.M. Rozhdestvenskiy

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[Transliterated Symbols]

1563 ВИНИТИ = VINITI = Vsesoyuznyy nauchno-issledovatel'skiy institut nauchno-tekhnicheskoy informatsii = = All-Union Scientific Research Institute for Scientific-Technical Information

FLAWS IN ALUMINUM CASTINGS. The frequently encountered flaws in aluminum castings are: coarsely-grained structure, shrinkage cavities and porosity, cracks, gas porosity and slag inclusions (see Aluminum), warping, castings rejected after the heat treatment. Coarsely-grained structure reduces the mechanical properties of castings (particularly the plasticity). The main cause of coarse structure formation is overheating of the alloy during pouring or slow crystallization of the liquid metal in the mold. To obtain finely grained structure it is necessary to ensure sufficiently low temperature of the alloy before pouring. Adjustment of the moisture content of the molding sand (casting into sand molds) and the chill mold (chill casting) also makes it possible to establish an optimum casting regime.

Depending on the nature of the alloy and the crystallization time, concentrated shrinkage cavities or fine shrinkage porosity may form in castings. Large shrinkage cavities in points which solidify latest are usually formed in castings from alloys with a short crystallization time. Pores uniformly situated in the body of castings are formed on solidification of castings from alloys with large crystallization times. The appearance of shrinkage cavities and pores is due to unsatisfactory gating of the casting. The casting flaws in massive parts of castings should be eliminated by accelerating the crystallization process: when pouring into sand molds by installing cooling devices, in chill molding by adjusting the chill mold temperature. The use of a vertical-slot gating system has a beneficial effect. In addition, additional vents should be installed.

Cracks may be of two kinds: hot and cold. Hot cracks are formed in a casting on crystallization in cooling up to shaking out of the mold. Cold cracks are formed after the component has been removed from the mold. By their external appearance, hot cracks differ from cold cracks by the presence of oxides in the fracture. Hot cracks form as a result of shrinkage stresses, which develop at those points in the casting where the mold interferes with free shrinkage. The possibility of appearance of shrinkage cracks is the greater the greater is the alloy's tendency to shrink. Hence, the main means for combating this flaw is the proper selection of the alloy. In addition, it is necessary to plan a smooth, gradual transition from massive to narrow cross sections of the casting, to place cooling devices at massive parts of castings and to select the composition of core mixtures in a manner such that the pliability of the core should compensate for the shrinkage stress.

In chill mold casting the mold should be designed in such a manner as to make it possible to remove certain cores immediately after pouring of the component. This will make it possible for the casting to contract freely, without formation of cracks. For the same purpose it is possible to remove castings from the chill mold at a higher temperature.

Cold cracks form as a result of differences in the rates of cooling of thin and massive parts of castings and of the appearance of internal stresses at points of transition or in thin cross sections. This phenomenon should be combated by using smooth junctions at corners, slow cooling after solidification, avoiding sharp transitions of casting cross sections, etc.

The following forms of rejects are frequently formed in heat treatment: warping of castings, incomplete hardening, nonuniform hardening, cracks and burning. Warping can be due to nonuniform and rapid heating, sharp cooling in quenching or nonuniform distribution of the weight of

parts of the component on stools when placing in heat treatment furnaces. In addition, it can be the result of deformation due to prolonged action of residual stresses. Warping of components is eliminated by using appropriate stools.

To combat warping of intricately-shaped components, transverse stiffeners or reinforcing ribs, which are easily removed after heat treatment, are added attendant to pouring. To prevent the appearance of internal stresses, quenching is performed in water (90-100°) or oil (40-60°), if the strength of the casting remains within the required limits. Incomplete hardening can be due to insufficient holding or low heating temperature, as well as by a reduced cooling rate.

Nonuniform hardening is a result of nonuniform heating and nonuniform cooling of components. Here high mechanical properties are observed in thin cross sections, while reduced mechanical properties are observed in thick-walled sections. To eliminate this kind of defect the casting should be heat treated again. Thermal cracks in cast components depend on many factors. The nature of the alloy, intricacy of shape, difference of component wall thickness result in the appearance of cracks upon rapid heating of components for hardening purposes as well as when using a high cooling rate. In addition, cracks in components can appear as a result of internal stresses upon artificial aging.

The following steps should be taken to eliminate the formation of cracks in castings: a) uniform and slow heating of components to be hardened; b) if the difference in wall thickness is great, the thin places should be lubricated by asbestos paste; c) aging should be induced at the highest permissible temperature. Burning is brought about by increasing the homogenization temperature above permissible limits, which results in the fusing of the eutectic and, as a result, in a reduction in the strength and, particularly, in the material's plasticity.

To prevent burning it is necessary: to periodically measure the temperature in all zones of the furnace (the maximum difference in zones should not be higher than ±3-5°); components of intricate shape should be heated slowly, at a rate of 3° per minute, so as to ensure uniform heating and uniform progress of diffusion processes in all parts of the component.

References: Kolobnev, I.F., Krymov, V.V. and Polyanskiy, A.P., Spravochnik liteyshchika [The Foundry Man's Handbook]. Fasonnoye lit'ye iz aluminiyevykh i magniyevykh splavov [Intricately-Shaped Castings from Aluminum and Magnesium Alloys], Moscow, 1957; Kolobnev, I.F., Termicheskaya obrabotka aluminiyevykh splavov [Heat Treatment of Aluminum Alloys], Moscow, 1961.

M.B. Al'tman

FLAWS IN MAGNESIUM CASTINGS – defects which arise in the casting process and on the solidification of the molten metal in the mold. Defects may be allowable and inallowable, which require the castings to be rejected. Flaws in magnesium castings are divided into external, i.e., those which are visible on inspection, and internal, i.e., hidden. The main defects are: nonconformance to technical specifications with respect to the chemical composition and microstructure, with respect to physical properties (airtightness, etc.), with respect to configuration, dimensions and surface finish; slag inclusions, oxide and foam films, blow holes, burning fo the casting which is due to interaction of the alloy with gases and moisture; external and internal shrinkage cavities, porosities and microporosities; hot and cold cracks; warping, gray spots (reverse liquation), which form due to shrinkage of the alloy on solidification; cleavage, misruns, failure to cover the casting walls with metal, which are due to changes in the fluidity of the alloy; sand and flux inclusions, which are due to the falling of foreign substances into the alloy.

In accordance with technical specifications, single blow holes, slag inclusions, impurities, and other flaws the average diameter of which does not exceed 4 mm and with a width up to 3 mm, but not exceeding 1/3 of the wall thickness may be permissible on casting surfaces not subject to machining, provided that such defects do not exist on the opposite side at the same place; groups of blow holes with a diameter of 1.5-2 mm and depth of 1-1.5 mm in quantities of 3-10 per 100 cm^2 of area if they are held within the norms specified in Table 1.

Point blow holes with a diameter up to 1.5 mm and depth of 0.5-1.0 mm and scabs in accordance to standards established for each case, gray

TABLE 1

Permissible Blow Holes On Casting Surfaces Not Subject to Machining

Отливки 1	2 Площадь отливки ($см^2$)	3 Единичные раковины		Групповые раковины 4
		кол-во в площади 100 $см^2$ 5	на 6 отливке	кол-во групп 7
8 Мелкие	9 До 1000	3	3	2
10 Средние	1000—6000	3	7	3
11 Крупные	6000—8000	3	12	5

1) Castings; 2) casting surface (cm^2); 3) single blow holes; 4) groups of blow holes; 5) number in an area of 100 cm^2; 6) on a casting; 7) number of groups; 8) small-size; 9) up to; 10) medium-size; 11) large-size.

spots (products of reverse liquation); marks of the contact parts of the mold and ejectors, which penetrated the casting body to a depth of not more than 0.5 mm, or which protrude from the surface by not more than 1 mm, are permissible. Blow holes with a depth not exceeding 1/3 of the casting's thickness, in amounts shown in Table 2, are permissible on surfaces subjected to machining.

Internal flaws are permissible in castings of the following form: of nonmetallic inclusions, i.e., slag inclusions, oxide films, the character and dimensions of which are established by standards; of microporosities (blackness in the fracture), i.e., of sections with pores and pore chains of microscopic size (0.025-0.12 mm and less), which are located along the grain boundaries of the solid solution. Microporosity forms on cooling and solidification of the casting as a result of shrinkage and liberation of gas dissolved in the alloy, as well as in poorly saturated sections which solidify last. The more gas is contained in the molten metal, the more intensive the microporosity. The tendency of magnesium alloys to microporosity is shown in Table 3.

On x-ray radiographs microporosity is visble in the form of darkened sections of various shape and size or most frequently – in the

TABLE 2

Permissible Blow Holes on Casting Surfaces Subjected to Machining

1 Отливки	2 Площадь отливки ($см^2$)	Единичные раковины 3			Групповые раковины 4			
		диаметр 5	глубина 6	7 Количество штук	5 диаметр	6 глубина	8 количество штук в группе	количество 9 групп, не более
		(мм) 10			(мм) 10			
11 Мелкие	12 До 1000	4	4	5	1.5–2	1.5	3	2
13 Средние	1000–6000	4	5	5	1.5–2	1.5	3	2
14 Крупные	6000–8000	6	4	8	1.5–2	1.5	3	2

1) Castings; 2) casting area (cm^2); 3) single blow holes; 4) groups of blow holes; 5) diameter; 6) depth; 7) number of pieces; 8) number of pieces in a group; 9) number of groups, not more than; 10) (mm); 11) small-size; 12) up to; 13) medium-size; 14) large-size.

form of streaked strips. Microporosity is accompanied by liquation of the low-melting-temperature component (Mg_4Al_3) from the defective point

TABLE 3

Formation of Microporosity in Magnesium Castings When the Alloy Contains 30 cm^3 of Hydrogen per 100 g

Сплав 1	Балл микропористости 2	Склонность к микропористости 3	Группа склонности 4
5 МЛ2 5 МЛ16	0 0	6 Нулевая	1
5 МЛ11 5 МЛ10 7 ВМЛ3 5 МЛ9 5 МЛ17	9.5 10 12 13.5 15	8 Низкая	2
5 МЛ6 5 МЛ12 5 МЛ5	24 30 40	9 Средняя	3
5 МЛ4	70	10 Высокая	4

1) Alloy; 2) microporosity scale number; 3) tendency to microporosity; 4) tendency group; 5) ML; 6) zero; 7) VML3; 8) low; 9) average; 10) high.

to points with normal density; coloring of the fracture (in a black, yellowish-brown color) as a result of the high-temperature interaction

of the alloy's components with atmospheric oxygen which penetrates the casting through pores, with attendant formation of spinel-type compounds

TABLE 4

Average Mechanical Properties of Castings From the ML5 Alloy with Various Microporosity Intensity

1 Толщина стенки отливки (мм)	Без микропористости 2		С микропористостью слабой интенсивности 3		С микропористостью средней интенсивности 4		С микропористостью интенсивной 5	
	σ_b (кг/мм²) 6	δ (%) 6	σ_b (кг/мм²) 6	δ (%)	σ_b (кг/мм²) 6	δ (%)	σ_b (кг/мм²) 6	δ (%)
7 Более 30	18	4.5	12.5	1.7	11.5	2	10.5	1.7
30—20	19	5.2	16.5	3.5	15	3.2	12.5	2.2
20—10	20	6.6	17.5	5	16	3.8	14.5	3.1
10—4	21.5	7.5	18.5	5.5	18	4	16.5	3.5

1) Casting wall thickness (mm); 2) without microporosity; 3) with low-intensity microporosity; 4) with average-intensity microporosity; 5) with intensive microporosity; 6) (kg/mm^2); 7) more than.

[$Mg(AlO_2)_2$]; the intensity of the fracture coloring also increases after heat treatment; by losses in air tightness and mechanical properties. When microporosity is highly developed in nonheat treated castings from the ML4, ML5 and ML6 alloys, the ultimate strength is reduced by 40-45%, while in heat treated alloys it is reduced by 50-60%, the elongation is reduced by a factor of 3 and more, the yield strength decreases by 20--25%; the endurance limit and impact ductility are sharply reduced. The mechanical properties of specimens cut out from castings at locations with microporosities are lower than the properties of specimens cut out in the perpendicular direction by ~25%. In intricately-shaped castings from the ML4, ML5 and ML6 alloys it is impossible to completely eliminate the microporosity. However, in the most highly loaded parts it is possible to prevent this defect by using special production process procedures: installation of cooling devices and risers during casting, changing the location of the metal supply to the mold. For the most extensively used ML5 alloy a scale has been worked out showing the dependence of the ultimate limit and relative elongation of castings of

various types on the microporosity (Table 4).

Castings which do not conform to technical specifications by their chemical composition and microstructure, by dimensions, surface finish, mechanical properties and which have castings defects (cold shuts, cracks, through blow holes, flux inclusions) are rejected. In certain cases impermissible defects are removed by cleaning (within the limits of machining allowances), straightening in the cold and heated state, welding up, placing of studs, soldering, impregnation with 101/19 lacquer and AOG, secondary heat treatment. Hidden flaws (porosities, microporosities, slag and flux inclusions, blow holes, cracks) are detected by x-ray flaw detection, luminescent flaw detection, capillary flaw detection (see Flaw Detection in Castings).

A.A. Lebedev

FLAWS IN METALS, flaw detection - incompleteness of structure, which reduces the strength and effects other properties of metals and alloys (for example, electric conductivity, magnetic permeability, density, plasticity). Among the flaws in the fine structure of metals are dislocations, i.e., linear flaws in the crystal lattice which disturb the orderly alternation of atomic planes. Less fine flaws in metals are submicroscopic cracks which form along the boundaries of crystal blocks and on their surfaces. Even less fine micro-and macroscopic flaws are formed in metals as a result of imperfection of metal technology and the low technological effectiveness of multicomponent layers, which require particularly precise conformance to regimes at each stage of their fabrication and processing.

Defects which are encountered in metal articles and semifinished products differ by their dimensions and location as well as by their nature and origin. They form in the process of melting and casting of the metal, pressworking, heat treatment, casehardening, electrochemical processing, machining, joining of metals (welding, riveting, soldering, cementing). In addition, flaws in semifinished and finished products can arise during storage, transportation and service. By their character, flaws can be: local (various continuity disturbances such as pores, blow holes, cracks, cleavages, flakes, creases, laps, etc.); distributed over limited zones (liquation accumulations, zones of incomplete hardening, corrosion affected zones, local workhardening); distributed over the entire volume of the product or over its surface (nonconformance of the chemical composition, structure, quality of machining).

TABLE

Main Kinds of Metals

Stage of Flaw Formation	Kind of Flaw	Causes of Flaw Formation	Brief Characteristic of Flaw	Methods of Detecting the Flaw	Remarks
Melting and casting	Deviation from the specified chemical composition	Error in calculating the furnace charge; improper conduct of the melting operation, which resulted in partial burning out of individual elements	Nonconformance of the content of individual elements to values specified in the GOST or TU	On-the-spot chemical and spectral analysis, in individual cases inspection by thermo- and triboelectric and electric induction methods	Irremediable defect, which is a basis for rejecting the heat or ingot
	Nonmetallic, slag and flux inclusions	Poor purification of the molten metal surface before pouring; removal of slag or flux during pouring; poor preparation of casting sand; inaccurate molding	Inclusions of steel deoxidation and alloy refinement products of various size and shape; manganese and iron oxide, silicon dioxide, manganic sulfate, as well as slags, flux, refractory material particles, graphite electrodes, molding sand, etc.	X-ray and gamma-ray fluoroscopy, ultrasonic echo method	In the process of subsequent shaping of the material at high temperatures the inclusions are elongated in the shaping direction into continuous lines or small broken lines (Fig. 1) depending on their plasticity (MnS) or brittleness (Al_2O_3, SiO_2) and can sub-

				sequently serve as a failure source;
Oxides, scabs, skins	Penetration of oxide film into the casting as a result of insufficiently thorough removal of it before pouring or due to oxidation of metal by by air which is captured by the molten metal stream during pouring	Thin, usually hard and brittle interlayers, which disturb the metal's continuity	Ultrasonic echo method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
Cold shuts	Interruption of the stream and inaccurate removal of slag on pouring; "cold cut" metal; insufficient static metal pressure when filling the mold	Thin interlayers, which disturb the continuity of the metal;	Visual method, ultrasonic echo method, electrical induction method.	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
Shrinkage cavities	Insufficient gating of the casting in the crystallization process; absence of conditions for creating directed crystallization	Voids of various size and irregular shape, with highly oxidized precipitations and nonmetallic inclusions (Figs. 2, 3)	X-ray and gamma-ray fluoroscopy, ultrasonic echo method	That part of the ingot which contains the shrinkage cavity should be removed before further processing. Unremoved remainders of a

				shrinkage cavity are not welded together by pressworking and become various continuity disturbing flaws which reduce the strength of the metal
Shrinkage porosity	Insufficient gating of the casting in the process of crystallization	Thin, developed interdendritic voids, most frequently in the axial zone of the ingot	X-ray and gamma-ray fluoroscopy, ultrasonic echo method, capillary methods	In the shaping process the flaws may not weld together and result in the formation of continuity disturbances in the shaped metal
Gas porosity	Evolution of gases dissolved in the molten metal, with retarded mobility of these gases in the crystallizing casting	Fine gas pores spread over the ingot volume	X-ray and gamma-ray fluroscopy	In the process of pressworking the metal the pores are frequently welded up
Gas holes	Accumulation of gas pores which have precipitated from the molten metal into larger-size formations, with sufficient mobility in the crystallizing casting, for example,	Larger-size gas accumulations, which frequently concentrate in the underskin layer of the ingot	X-ray and gamma-ray fluoroscopy	In the pressworking process bubbles located in the core of the ingot and having a nonoxidized surface are

	when it is cooled slowly			welded up; underskin bubbles are usually only pressed down, but are not welded up, since the gas or the oxide film interferes with this (Fig. 4). When a thin sheet is heated, the pressed-down bubble usually blow up (Fig. 5) and makes the product defective.
Dendritic liquation	High rate of cooling of the molten metal, which crystallizes over a wide temperature interval	Nonhomogeneity of the chemical composition within the grain	X-ray and gamma-ray fluroscopy	The flaw can be eliminated to an appreciable extent by prolonged annealing (homogenization). Deformation of metal with perceptible dendritic liquation results in the formation of a fibreous structure

Liquation by specific weight	Poor intermixing of molten metal before pouring; retarded crystallization	Enrichment of the bottom part of ingot by components with greater and the upper part of ingot by components with lower specific gravity	X-ray and gamma-ray fluroscopy	Irremediable flaw, which results in differences in behavior of various parts of the ingot in the further processing
Zonal liquation	Movement of the molten mother solution enriched by low-melting-temperature components in the dendritic space of the crystallized skeleton of the alloy, which crystallized over an appreciable temperature interval	Increased concentration of low-melting-temperature components of the alloy in the center zones of the ingot (direct liquation) or in the peripheral layers (reverse liquation)	X-ray and gamma-ray fluoroscopy	Homogenization does not eliminate zonal liquation. Liquation segregations, by orienting themselves in accordance with the shaping of the metal, can subsequently serve as a failure source
Hot cracks	Destruction of the crystallized skeleton of the alloy under the action of thermal and shrinkage stresses at relatively high temperatures (Fig. 6)	Cracks of intercrystalline character with highly oxidized surfaces. In alloys with a high content of the eutectic phase the crack void is usually filled by the liquid eutectic phase	X-ray and gamma-ray fluoroscopy, ultrasonic echo method, electrical induction and capillary methods	Since the oxidized surfaces of cracks usually do not weld up, they bring about further destruction of the metal on processing

		Fins	Break through of molten metal from the internal zones onto the surface through external crystallized layers	Fused on metal on the ingot surface	Visual method	They are flattened out on pressworking, forming thin, easily removable scabs on the metal surface
		Cold cracks	Destruction of the ingot or casting due to the action of thermal and shrinkage stresses at relatively low temperatures, when the alloy's plasticity is low	Cracks of transcrystalline character with light, monoxidized surfaces	Visual method, x-ray and gamma-ray fluroscopy, ultrasonic echo method, electrical induction and capillary methods	Can weld up when the ingot is pressworked, intricately shaped castings can be corrected by welding
	Pressworking	Surface and internal cracks	Cracks in the ingot which failed to weld up; substantial stresses in the metal during shaping	Individual cracks or a network of cracks situated at various depths or at the surface	Visual method, x-ray and gamma-ray fluoroscopy, ultrasconic echo method, electrical induction and capillary methods	Irremediable flaw (Fig. 7). If, under conditions of subsequent processing, the defective zone is not removed, then the blank should be rejected

		Cleavages	Unremoved and unwelded remainders of shrinkage cavity or porosity zone	Internal disturbances of continuity, oriented along the fiber direction	Ultrasonic method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
	Presswork-king	Extrusion "pipe"	Forward flow of internal layers of bar stock of shape in the process of its extrusion	Taper-shaped disturbance of continuity in the center zone of a pressworked bar, near its end face	X-ray and gamma-ray fluoroscopy, ultrasonic echo method	Irremediable defect (Fig. 8). That part of the blank which contains the extrusion defect should be removed
		Cleavage in a longitudinal seam	Nonconformance to regimes (temperature, pressure) in pressworking shapes with intricately-shaped cross sections, which results in incomplete welding up of the oxidized surfaces of the metal, which is cut up by a reed-type female die in the extrusion process	Complete or partial disturbance of continuity in panes where halves of the shape's cross section meet	Ultrasonic echo method	Irremediable defect. If subsequent machining is not intended to remove the defective zone and the dimensions of continuity disturbances exceed the permissible values, the shape is rejected

Tears	Insufficient metal plasticity (nonconformance between the temperature and the degree of deformation); nonuniform rate of extrusion of internal and external layers of the metal in pressworking	Rough tears at edges of the rolled or surface of the press-worked and drawn blanks	Visual method	Irremediable defect. The rolled blank can be cut off along the width, the press-worked or drawn blanks should be rejected
Internal tears	Nonconformance of the rate of extrusion of internal layers of metal or pressworking or drawing; substantial tensile stresses in the internal layers of the metal	Rough failures in the axial zone of press-worked and drawn blanks, oriented in the longitudinal direction; forging cracks in forgings with square cross section, oriented along the diagonals of the square	Ultrasonic echo method	Irremediable defect (Fig. 9). The blank should be rejected
"Pigeon holes"	Opening up of thermal cracks of flakes in the process of hot working under the action of compressive stresses which are oriented along the parting surface	Voids of various dimensions and shape with smoothed out internal walls	Visual method, x-ray and gamma-ray fluoroscopy, ultrasonic echo method	If the defective zone is not slated for removal by subsequent machining, the blank should be rejected
Creases	Flattened folds which are formed on the surface of the metal during forging	Disturbance in the continuity at the workpiece surface which penetrates to a moderate depth	Visual method, ultrasonic echo method, magnetic method	In the process of subsequent treatment of the metal the disturbance of continuity is retained

					and can serve as a failure source
	Laps	Pressed in and rolled out folds and burrs which form on the metal surface during rolling, frequently due to improper adjustment of the rolls (Fig. 10);	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
	Dents	Depressions at the surfaces of forgings, stampings or rolled semifinished products, which are due to foreign solid particles on the hammering surface of the hammer, die or roll	Local depressions of various area	Visual method	The defect can be removed by cleaning, if this will not reduce the blank size to below the minus tolerance
	Notches	Grooves, passing along the external or internal surfaces of pressworked or drawn semifinished products, which are due to solid foreign particles on the female or mandrel surfaces	Grooves of various depth, which sometimes pass along the entire length of the blank	Visual method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source

Variance in the sheet thickness	Improper placing of rolls of the rolling mill, change in the gap in the rolling process	Deviation from nominal dimensions	Ultrasonic resonance method, electrical induction method, magnetic ferroprobe method, magnetic thickness gaging	Irremediable defect. Depending on the magnitude of deviation and on the intended service of the sheet it may be regarded as a cause for rejection
Difference in the walls of press-worked or drawn semi-finished products in the cross section	Improper placing of the pin of the press or the drawing machine mandrel with respect to the die	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	Irremediable defect. Depending on the magnitude of deviation and on the intended service of the blank it may be regarded as a cause for rejection
Thinning out or thickening of pipe walls, and webs of shapes in the longitudinal direction	Improper placing of the press pin or mandrel in the longitudinal direction, nonuniformity in the pull of the drawing machine	Same as above, particularly in pipes and shapes with variable cross section	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	Irremediable defect, as a rule it is a cause for rejection

Hair cracks	Deformation of gas bubbles, nonmetallic inclusions	Thin marks on the surface and at various subsurface depths (are exposed by stepped turning) of steel blanks	Magnetic method	Depending on the number of hair cracks, the blank can be rejected, since the hair crack may become a failure source
Scabs	Deformation of fins and metal splashes which adhere to the ingot surface	Thin, rolled out or forged flat films, which adhere tightly to the metal surface, but are easily separated from it	Visual method	Can be usually removed by cleaning
Flakes	Thin cracks, which form in certain steel brands with an excessive hydrogen content	Thin, winding cracks, which are light roundish-shaped spots in the fracture ("flakes"), frequently oriented along the direction of liquation precipitations in the cross section of forged blanks (Fig. 11)	Magnetic method, ultrasonic echo method	Despite the fact that in the process of subsequent deformations flakes can in certain cases weld up, they are causes for unconditional rejection for articles performing particularly critical functions, since they can form anew

Heat treatment, casehardening, and electrochemical processing	Coarsely-grained structure	Exceeding the specified heating temperature in heat treatment	Coarsely-grained structure, which is exposed in the metal fracture on the etched section	Ultrasonic echo method, electrical inductance method, magnetic inspection of structure	Can be corrected by appropriate heat treatment (for example, normalization)
	Overheating	The same as above, but to a greater extent	Oxide and sulfide precipitations along the grain boundaries are observed alongside with the coarse-grained structure	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	The defect can, in certain cases, be corrected by complicated heat treatment
	Burning	The same as above, but to an even greater extent	Fusing of precipitations along grain boundaries is observed alongside with coarse-grained structure	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	Irremediable defect
	Nonconformance with the specified structure	Improper heating or cooling regime dur- heat treatment	The alloy structure and properties do not conform to specifications	Electrical induction method, magnetic inspection of structure	Usually can be remedied by additional heat treatment

Coarsely-grained structure	Soft spots	Insufficient heating before quenching or insufficient rate of cooling of surface sections (for example, due to steam bubbles which adhere to the surface of the quenched component	Sections with reduced hardness are encountered on the surface of the quenched component	Electrical induction method, thermoelectric method	The defect can be corrected by secondary heat treatment
	Thermal cracks, including quenching cracks	High rate heating of cooling; nonuniform volume change due to the shape of the product; tendency of the alloy to crack formation	Single or group thin cracks, which start at the surface and extent to various depths (Fig. 12)	Magnetic method, electrical induction method, magnetic structure inspection	Irremediable defect
	Nonconformance of the thickness on the hardened layer in surface (high-frequency) hardening	Improper regime of high-frequency hardening	Improper distribution of specified properties and structural components along the cross section of the hardened component	Thermoelectric method, electrical induction method, magnetic structure inspection	Can be corrected by secondary hardening
	Decarbonization	Heating of steel products in furnace whose atmosphere contains water vapor, carbon dioxide or hydrogen	Burning out of carbon in the surface layers which results in a number of cases in reduction of the steel's strength	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	Irremediable defect

Carbonization	Heating of steel products in furnaces whose atmosphere contains excess carbon dioxide	Saturation of surface steel layers with carbon which increases the brittleness and tendency to crack formation	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
Peeling away cracks	Change in the sign of stresses in a thin surface layer, for example, upon grinding of a hardened product	Peeling of the surface layer of a steel component due to careless grinding	Magnetic method, ultrasonic echo method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as a failure source
Hardening microcracks	Brittle failure, for example, in martensite "needles" due to 2nd kind stresses	Internal microcracks, which frequently pass along the boundaries of former coarse autenite grains	Magnetographic method, ultrasonic echo method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source

Hydrogen cracks	Brittle failure of the surface layer of steel as a result of hydrogen saturation	Surface, quite thin cracks in steel components which are subjected to the effect of alkalis and acids and which were not subjected to dehydrogenation tempering (Fig. 13)	Magnetic method, ultrasonic echo method, capillar methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
Nonconformance of the thickness of the casehardened or electrochemically treated layer to specifications	Deviation from the regime of treatment (cementation, nitriding, oxidation, etc.) resulting in changing the rate of diffusion processes	Change in the depth of cementation, nitriding, oxidation, which are demonstrated in changes of hardness, fatigue and anticorrosion characteristics	Thermoelectric method, magnetic structure inspection, electrical induction method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
Nonconformance of the thickness of the electrodeposited layer to specifications	Nonuniform distribution of the current due to the intricate shape of the component; deviation from the processing regime	Nonuniform distribu- of the protective coating metal over the component's surface	Magnetic thickness gaging, electrical induction method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source

Machining	Finishing cracks	Destruction of the metal in the surface layer which has been welded on in the process of finishing operations (for example finish turning, grinding	Surface microcracks, which subsequently develop when the component is subjected to loads, particularly at elevated temperatures	Capillary methods, magnetic method, electrical induction method, ultrasonic echo method	The defect in a number of cases can be corrected by removing the damagned surface layer by electrolitic polishing
	Burn-ons	Sharp heating of individual sections of the component's surface in the grinding process	Hardened sections with a moderate area, which can serve as sources of brittle failure	Magnetic method, thermoelectric method	Irremediable defect
	Grinding cracks	Sharp heating of the surface layer of a component on grinding	A network of quite thin cracks on the component's surface	Magnetic method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
Straightening, installation	Straightening and installation cracks (press fitting, bolt connections, etc.)	Failure of metal as a result of application of appreciable stresses during installation or straightening of warped articles or components	Surface cracks oriented across the direction of maximum tensile stresses applied during assembly or straightening	Magnetic, method, ultrasonic echo method, electrical induction method, capillary methods; x-ray and gam-ma-ray fluoroscopy	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source

Joining of metals (welding, soldering, riveting, cementing)	Coarse-grained zone near the welded joint seam	Overheating of metal in the zone adjoining the seam	Coarse grain in the zone in which the seam exerts a thermal effect	Ultrasonic echo method	For particularly critical components and products it can serve as a cause for rejection
	Metallurgical flaws in a welded seam	Blow holes, pores, nonmetallic and slag inclusions in the seam as a result of deviation from the welding regime	Seam flaws of various size and shape, which constitute continuity disturbances	X-ray and gamma-ray fluoroscopy, ultrasonic echo method, magnetographic method	Irremediable defect
	Lack of weld penetration	Deviation from the welding regime	Absence of welding in a part of the joint seam	X-ray and gamma-ray fluoroscopy, ultrasonic echo method, magnetographic method	In a number of cases can be corrected by additional welding
	Welding cracks	Action of thermal and structural stresses in the process of cooling of the welded joint	Cracks in the seam or at the boundary of thermal influence zone	Magnetic method, x-ray and gamma-ray fluoroscopy, ultrasonic echo method	For particularly critical components and products it usually serves as a cause for rejection. In individual cases it can be corrected by additional welding with providing space for the filler metal and drilling down of the ends of the crack

	Cracks in riveted joints	Destruction of the metal as a result of application of substantial stresses in the riveting process	Cracks in the rivet body or in the metal adjoining the rivet	X-ray and gamma-ray fluoroscopy, ultrasonic echo method	Irremediable defect
	Lack of solder penetration	Insufficiently thorough cleaning of the surfaces being soldered or deviation from the temperature regime for soldering	Sections of various areas which are not soldered to one another	Acoustic impedance method, ultrasonic echo method or shade method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
	Poor cementing	Insufficiently thorough cleaning of surfaces being cemented or deviation from the temperature regime for cementing	Sections of various areas which are not cemented to one another	Acoustic impedance method, method of free vibrations, ultrasonic echo method or shade method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
Joining of metals (welding, soldering, riveting, cementing	Disturbance of diffusion bond	Insufficiently thorough preparation of surfaces, deviation from the temperature regime	Sections with various areas in multilayer designs (brake discs, bearings) in which there is no bonding	Ultrasonic shade method	In the process of subsequent treatment of the metal the disturbance of continuity is retained

					and can serve as failure source
Storage, transportation of semifinished and finished products	Mechanical damage to surfaces	Improper arrangement, shocks, scratching, rubbing of semifinished and finished products against one another	Nicks, dents, tears, damage to protective coatings and the cladding layer	Visual method	In certain cases can be corrected by cleaning if this will not cause the applicable dimensions of the semifinished or finished product to go below the minus tolerance
	Atmospheric surface corrosion	Destruction of metal at the surface under the action of moist atmosphere	Damage to metal over the entire surface (uniform corrosion) or at individual surface sections (local corrosion)	Visual method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
	Intercrystalline atmospheric corrosion	Destruction of metal under the action of moist atmosphere, which extends into the depth of the product primarily along grain boundaries	Failure of metal resulting in the loss of metallic properties in the corrosion zone	Visual method, ultrasonic echo method, electrical induction method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can

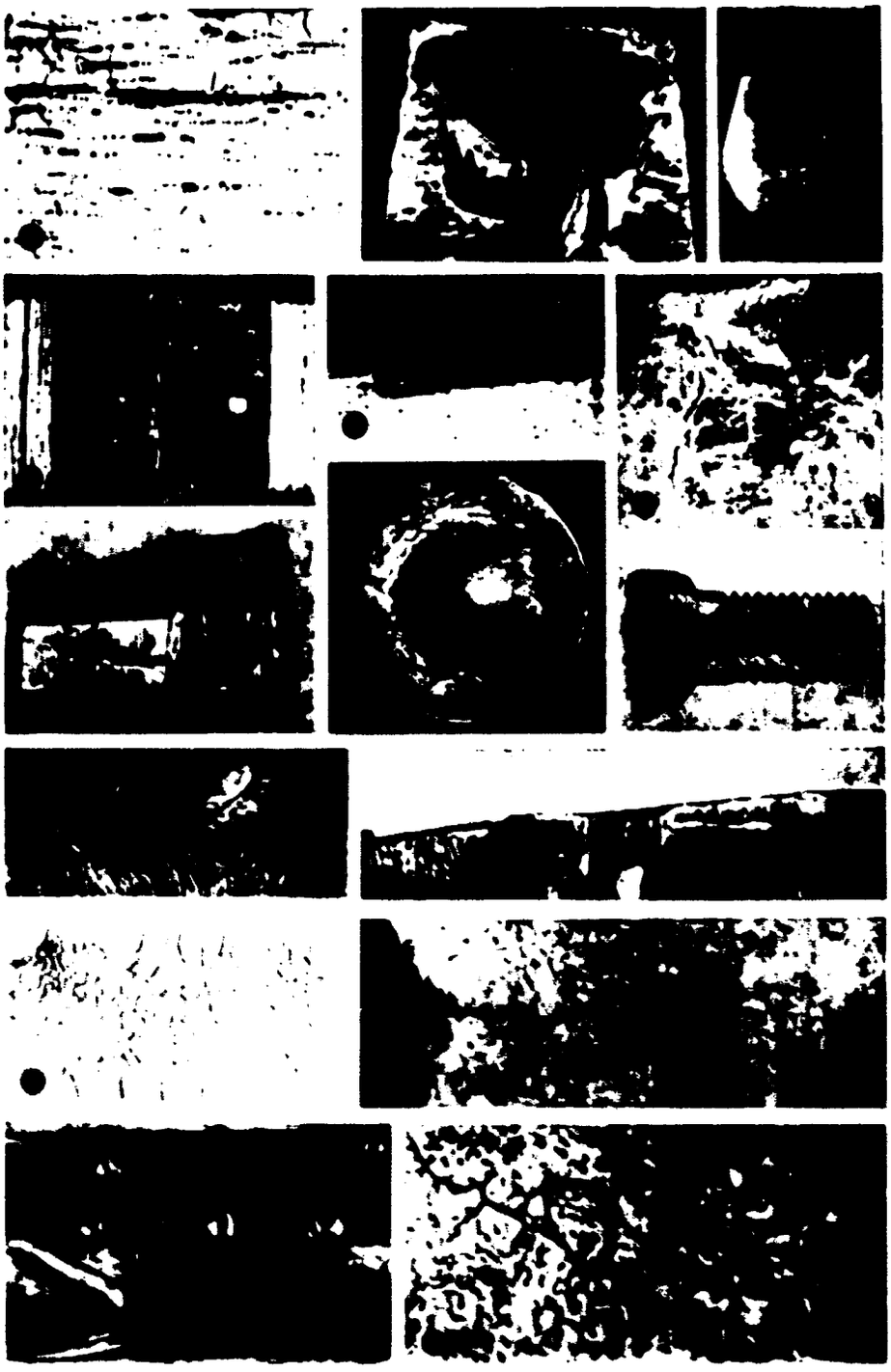
					serve as failure source
	Cracking during storage	Brittle failure of metal at the surface under the action of thermal and mechanical tensile fatigue stresses, and also of external loads, particularly when a moist or aggressive medium is acting	Thin surface cracks which usually arise in stress concentration zones	Visual method, ultrasonic echo method, electrical induction method, magnetic method, capillary methods	Nonconformance with the specified structure
Service	Fatigue cracks	Failure of metal, primarily in the zone where various stress raisers are situated, which takes place due to the repeated loads	Thin surface or internal cracks, which develop in the process of the component's functioning and which usually pass along the grain	Visual method, magnetic method, ultrasonic echo method, electrical induction method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
	Thermal fatigue cracks	Brittle failure of metal due to repeated temperature variations of substantial amplitude, particularly upon simultaneous application of mechanical loads	Thin surface cracks which for near the boundaries of zones with different temperatures or in the zone of stress concentrations, which develop in the process of the component's functioning and which pass first along grain boundaries and, as they de-	Visual method, ultrasonic echo method, electrical induction method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source

			velop, they pass along the boundaries or along the grain [proper], depending on the character of the load		
	Creep cracks	Failure of metal due to prolonged duration mechanical stresses	Thin cracks which arise at the surface in stress concentration zones, which develop in the process of the component's functioning and which pass in many cases along grain boundaries	Visual method, ultrasonic echo method, electrical induction, magnetic and capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
	Contact cracks	Surface cracks which form in loaded metallic products, for example on contact with molten metals	Surface cracks which arise in components subjected to loads under the action of molten solder or antifriction alloy (Fig. 14)	Visual method, x-ray fluoroscopy, magnetic method, ultrasonic echo method, electrical induction method	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
	Surface corrosion	Failure of metal at the surface under the effect of aggressive media	Damage to metal at the surface under the action of moist atmosphere	Visual method, capillary methods	In certain cases can be corrected by cleaning, if this will not cause the pertinent dimensions to go out of tolerance limits

Intercrystalline corrosion	Failure of metal under the effect of aggressive media, which extends into the product primarily along grain boundaries	Failure of metal resulting in the loss of metallic properties in the corrosion zone	Visual method, ultrasonic echo method, electrical induction method, capillary methods	Irremediable defect
High-temperature gas corrosion	Brittle failure of metal under the action of aggressive gases, primarily at high temperatures	Cracks which develop from the component's surface in heated zones and which usually pass along grain boundaries	Visual method, ultrasonic echo method, electrical induction method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source
Corrosion cracking under stress	Brittle failure of metal as a result of simultaneous effect of an aggressive medium and tensile mechanical stresses	Cracks in brass products, in riveted joints of boiler drums, etc., which develop during service (Fig. 15)	Ultrasonic echo method, electrical induction method, capillary methods	In the process of subsequent treatment of the metal the disturbance of continuity is retained and can serve as failure source

Local flaws which are localized in a limited volume can be point, line, plane and volume [flaws]. By their location they are divided into external (surface and subsurface) and internal (depth). Depending on the shape, dimensions and orientation with respect to prevailing stresses these defects can be more or less sharp stress raisers.

Flaws in the applied, engineering meaning should be considered such deviations from the normal quality, provided for in standards, which impair the working characteristics of the metal or product and result in reducing their grade or in rejection. However, not each flaw in metals is a defect in a product; deviations from the normal quality of the metal which are of no substantial importance to the functioning of the given product, should not be considered as defects for this product. Moreover, deviations from normal quality, which are defects for articles functioning under one set of conditions (for example, under fatigue loads) may be of no significance under other operating conditions (for example, under static loads). Consequently, the quality of the metal and of a product rationally manufactured from it can be improved upon complete removal of the most dangerous flaws (cracks, blow holes, cleavages, flakes, etc.) and reducing other flaws, which present a smaller danger under specific conditions of the product's operation, to a certain minimum. The level of "safe minimum" which determines the quality of the product is a function of the extent of intensity of conditions under which it operates; as the intensity is increased, it is reduced. High quality of metal and of products made from it can be ensured in two ways: refinement of the production process used in processing in order to make it impossible for a flaw to appear and by refining methods of metal quality control in order to detect the flaws and rejecting defective blanks, semifinished and finished products.



To the article, Flaws in Metals. Fig. 1. Slag inclusions in malleable cast iron (magnification factor 130). Fig. 2. Shrinkage cavity in the upper part of a steel ingot. Fig. 3. Shrinkage cavity in steel which was the cause of failure of a steel erector hook. Fig. 4. Gas-filled bubbles which have not welded up upon shaping of the metal. Fig. 5. Subsurface bubble, which was blown up on heating of steel metal (magnification factor is 90). Fig. 6. Hot cracks in the center zone of an ingot. Fig. 7. Cracking of the axial zone of a steel forging. Fig. 8. Extrusion defect in an aluminum alloy bar stock. Fig. 9. Internal tears in cold-drawn steel. Fig. 10. Lap in a steel blank. Fig. 11. Flakes in steel. Fig. 12. Tempering cracks at the surface of steel. Fig. 13. Hydrogen crack in the threading of cadmium plated pull rod. Fig. 14. Cracks in a steel pipe

which formed under the action of molten solder. Fig. 15. Cracks in steel which formed as a result of corrosion under stress (magnification factor is 100).

Usually the more reliable and radical practical solution of the problem is refinement of the production process. However, with the development of physical methods of nondestructive materials quality control (see Flaw Detection) their role in the fight for high quality of products increases continuously. The main defects which are encountered in metal blanks, semifinished and finished products at various processing stages, as well as in storage, transportation, and service are shown in the Table on pages .

Study of changes in the physical characteristics of metals and the detection of various flaws based on it is performed by using physical methods of nondestrutive testing which are shown in the Table. In finally deciding the problem of quality of a blank or product it is necessary to consider not only the quantity, dimensions, location and character of detected flaws, but also the specific conditions of the product's loading in service.

D.S. Shrayber

FLAWS IN STEEL CASTINGS – flaws which arise in the casting process and on solidification of the molten steel in the mold. Flaws can be permissible without correction, permissible with correction (by welding, straightening, etc.) and unallowable (final rejection). The permissibility of flaws in steel castings is determined by requirements put to its quality, the intended service of the cast component, kind and magnitude of loads (static, repeated, dynamic or vibration), kind and location of flaws, etc.

In comparison with casting from gray pig iron, from light and certain nonferrous alloys, steel castings exhibit a greater tendency to the formation of casting defects which is a result of peculiarities of steel as a casting material: high melting temperature, substantial crystallization interval, poor castability, high volumetric and linear shrinkage. The terminology and classification of flaws in steel castings are given in GOST 4009-48. The main flaws are: blow holes, sand inclusions, shrinkage cavities, hot and cold cracks, cold shuts [sic], short runs, warping, dimensional nonconformance.

Blow holes are open (external) or closed (internal) voids in the body of the casting (single, cluster and in the form of a rash) usually with a clean and smooth surface, which is sometimes covered by oxides. Small blow holes elongated in shape with a smooth surface located at a depth of 2-3 mm and which open to the casting's surface through tiny channels are called pinhole porosity (hydrogen blow holes). Blow holes are formed as a result of unsatisfactory quality of molds, cooling devices, cores, as well as gas saturation and poor deoxidation of the steel.

Sand inclusions are open or closed voids in the body of the casting, partially or completely filled with the molding material. Causes for the appearance of sand inclusions are improperly cleaned and unsturdy mold, presence of sharp angles in the mold, impact by the metal stream, low pouring temperature and presence of sharp angles in the mold, impact by the metal stream, low pouring temperature and presence of thin sections in the component's design.

Shrinkage cavities are open voids, sometimes in the form of a pipe on the surface of the casting, or closed voids in the casting's body. Shrinkage cavities usually have a rough surface and are located in thicker parts and at points of transtion from a thicker to a thinner casting cross section. Local accumulation of small and sometimes even microscopic shrinkage cavities is called friability or porosity. Causes for its appearance can be improper design of the cast component, improper use of risers and cooling devices or their absence, nonconformance to proper direction of metal solidification in the mold, high pouring temperature, etc.

Hot cracks are through or blind discontinuities in the body of the casting with walls covered by an oxide (scale) layer. Causes of formation are resistance of the mold and cores to shrinkage of metal, improper design of the cast component, improper gating system, use of metal with a high content of harmful admixtures (sulfur, gases) and poor deoxidation of the metal.

Cold cracks are through or blind discontinuities in the body of the casting with a granular fracture and clean surface, sometimes temper colored. They arise at temperatures not above 650°. Causes of formation are internal stresses which exceed the ultimate limit of the steel; external effects (shocks and local heating); presence of stress raisers in the casting's design, excessive content of carbon and phos-

phorus in the steel and poor deoxidation; reduction of the thermal conductivity of the steel by high alloying.

Cold shut is nonmonolitic fusion of metal streams which has the appearance of a seam with rounded-off edges, which passes into the body of the casting. It is a metal-covered surface oxide film which passes inside the casting body and gradually tapering off. Causes for formation may be improper design of the component, low melting temperature and slow filling of the mold by a thin or discontinuous stream, improper gating system, insufficient castability of the metal and formation of oxide films on the surface of the flowing metal.

Short run is any incomplete filling of the mold by metal which is expressed in the fact that the casting's contour is not clearly outlined or in the presence of holes (slots) in it. Short runs can be due to excessively thin casting walls, insufficient supply of molten metal, interruption of the stream when pouring into the mold, insufficient cross section of the gating system's elements, as well as to low temperature and insufficient castability of the metal.

Warping is the bending of the casting due to internal stresses, which results in nonconformance of its shape to the drawing. The main causes of warping in castings are: thermal retardation of shrinkage, i.e., stresses which are produced by resistance of the mold to the metal's shrinkage; stresses which arise on rapid cooling of the casting due to nonsimultaneity of phase transformations in the region of elastic deformations in steel which has critical points, which are due to the increase in volume. As a result of phase transformation in different parts of the casting, i.e., in thick and thin parts, which pass through critical points at different times, the direction of stresses can coincide with thermal and shrinkage stresses, which will be instrumental in warping and even failure of the component.

Dimensional nonconformance of castings to drawing dimensions takes place as a result of improperly made mold, erros in calculating the percentage of shrinkage, improper assembly of the mold, spreading apart of the mold, etc.

Casting as well as other flaws have the most substantial effect on the strength of a component if the stresses are uniformly distributed (without a high concentration) and if they act repeatedly, particularly in the case when the flaws extend across the direction of the greatest tensile stresses. For example, the flexural stresses in the turbine bucket blade are nonuniformly distributed. The entering and leaving edges, as well as the bucket back, being most highly stressed in flexure, should be free of flaws. In nonuniformly stressed components, particularly in the presence of concentrations, flaws are dangerous only in the most highly stressed zones of the component, which usually occupy an insignificant part of the surface and an even lesser part of the component's volume. For example, in components such as the crank shaft, gears, etc., even a rough flaw which is distant from the point of maximum stress, does not affect the component's strength.

Measures for combating flaws in steel castings can be design and production process refinements (see Flaw Detection in Castings).

References: Nekhendzi, Yu.A., Stal'noye lit'ye [The Casting of Steel], Moscow, 1948; Kontrol', preduprezhdeniye i ispravleniye braka fasonnogo lit'ya [Inspection, Prevention and Correction of Intricately-Shaped Casting Rejects], Moscow, 1949.

N.M. Tuchkevich

FLEXIBILITY – ability of a material to deform under flexure, which depends on the shape and dimensions of the cross section. When a compressed bar is subjected to a buckling load, the elasticity (λ) is numerically equal to the ratio of the bar length to the radius of inertia of its cross section.

S. I. Kishkina-Ratner

FLINT is a rock consisting of chalcedoyn (fibrous quartz) with a more or less significant admixture of opal, clay particles, carbonates, iron oxides and other minerals. Flint is encountered in nature in the form of lamina, nodules, irregular deposits or rounded pebbles. Colors are gray, yellowish gray, brown, black. In engineering, flint is often termed silex. The hardness on Mohs' scale is 7, the specific weight is 2.60, fracture is conchoidal, cleaves on impract into sharp-angled fragments. The average index of refraction is 1.537-1.540. The SiO_2 content varies from 85 to 98%. Flint has high strength and resistance to abrasion. Young's modulus is $7.45 \cdot 10^{11}$ dyne/cm^2, shear modulus is $3.45 \cdot 10^{11}$ dyne/cm^2, Poisson coefficient is 0.08. Resistance to crushing is more than 3350 kg/cm^2. Abrasion (emery powder No. 3) on a Bauschinger table with a load of 0.5 kg/cm^2 amountsto 0.015-0.004 g/cm^2. Surface area is 2200 cm^2/g. The dielectric constant of flint at 100 Hz is 8.2, at 10^7 Hz it is 4.4.

The use of flint in industry is based primarily on the utilization of its hardness, toughness and capability during grinding to cleave into particles having sharp cutting edges with high abrasive capability. The primary applications of flint are: lining of ball and roller mills and in the fabrication of balls for these mills in the cement, ceramic, paint and other branches of industry; the production of polishing discs in the ground form as a nonplastic additive in place of quartz in fine ceramics, in the production of artificial grindstones, for the preparation of Dinas refractories. The demands of industry on flint vary somewhat as a function of the field of application. The most severe demands

are made by the ceramics industry, particularly with regard to the content of iron oxides (not over 0.10-0.15%). The flint for lining ceramic mills must have a high hardness (no lower than 7 on the Mohs scale), good resistance to abrasion (less than 0.015 g/cm^2), high resistance to crushing (over 3000 kg/cm^2) and low iron oxide content. Moreover, the flint must work well and give the possibility of making plates no smaller than 20 x 12 x 8 (cm). The flint pebble for ceramic mills must have diametral dimensions of 3 x 7 (cm), rounded form and a smooth surface. Smaller pebble is used in the mills for the lacquer and paint industries. The cement industry can utilize flint of a lower quality.

References: Trebovaniya promyshlennosti k kachestvu mineral'nogo syr'ya [Industry Demands on Quality of Mineral Raw Material], 18th ed.; Tumanskiy A.L., Kremen' [Flint], M.-L., 1946.

V.I. Fin'ko

FLOW AREA – see Flow projection.

FLUIDS FOR HIGH-VACUUM UNITS – are fluids with a low vapor pressure at room temperature. Vacuum oils (VM) and mercury are the fluids which are most frequently used in vacuum engineering. Vacuum oils are mainly used as a working fluid in steam-jet pumps, as a sealing medium in mechanical vacuum pumps, and also as a lubricant. Vacuum oils are produced by vacuum distillation of a mixture of high-boiling natural or synthetic fluids, for example, relatively heavy petroleum fractions (vaseline oil, etc.). The working fluids (RZh) of steam-jet pumps must have a minimal vapor pressure at room temperature and a maximal one at the working temperature of the pump, and also have a high thermal stability and chemical inertness to air oxygen and to the exhausted gases. Mercury is used as a working fluid in steam-jet pumps, vacuum manometers and vacuum valves, and also in pumps (of Toepler type) for the pumping-over of gases. The properties of the most important fluids for high-vacuum units are quoted in the Table (page 300).

References: Jackel R., Polucheniye i izmereniye vakuuma [Generation and Measurement of Vacuum], translated from German, Moscow, 1952; Dashman S., Nauchnyye osnovy vakuumnoy tekhniki [The Scientific Principles of the Vacuum Engineering]; translated from English, Moscow, 1950; Vakuumnoye oborudovaniye i vakuumnaya tekhnika [Vacuum Equipment and Vacuum Engineering], edited by A. Gootry and R. Wakerling, translated from English, Moscow, 1951; Korolev B.I., Osnovy vakuumnoy tekhniki [Principles of Vacuum Engineering], 4th edition, Moscow-Leningrad, 1958.

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TABLE

Properties of Fluids for High-Vacuum Units

1 Жидкости	2 Назначение	3 Химический состав	4 Уд. вес при 20°	5 Упругость пара при 20° (мм рт.ст.)	6 Предельный вакуум без охлаждения ловушек по ионизац. манометру (мм рт.ст.)	7 Тип насоса	8 Место производства жидкости
Д-1А 9	РЖ пароструйных высоковакуумных насосов	Минеральное масло, смесь углеводородов	—	$4\cdot10^{-6}$—$2\cdot10^{-5}$	Не хуже $2\cdot10^{-6}$	Стеклянный насос СДН-1	СССР 14
15 Д-1В	То же 16	То же 16	—	$4\cdot10^{-6}$—$2\cdot10^{-5}$	Не хуже $3{,}5\cdot10^{-6}$	То же 16	»
17 Апиезон В	»	»	0,92	—	12 $4\cdot9\cdot10^{-8}$	Разгоночные металлич. насосы 18	Англия 19
20 Лейбольд Е (Н)	»	»	—	—	$1{,}7\cdot10^{-6}$	Стеклянные насосы	Германия 22
23 Майван 20	»	»	0,853	—	10^{-6}	— 21	США 24
25 Октойл S	»	Сложный эфир 26	0,910	$1\cdot10^{-6}$	$2\cdot10^{-6}$	Металлич. насосы 27	СССР 24
25 Октойл	»	То же 16	0,980	$2\cdot10^{-7}$	$5\cdot10^{-6}$	Стеклянные насосы	США 24
Наркойл 28	РЖ пароструйных высоковакуумных и бустерных насосов 29	Хлорированные углеводороды 30	1,54	—	$1\cdot10^{-6}$	Стеклянные насосы 21	СССР, США 24
Арохлор 31	РЖ пароструйных высоковакуумных насосов 10	То же 16	—	—	$8\cdot10^{-6}$	—	США 24
32 Трикрезил фосфат	То же	—	—	—	$2—5\cdot10^{-6}$	33 —	»
ВКЖ-94А 34	» 16	Кремнийоргинич. масло, смесь этилполисилоксанов 35	— 36	Не выше $5\cdot10^{-5}$	$5\cdot10^{-6}$ Не хуже $2\cdot10^{-5}$	Разгоночные насосы	Германия 22
38 ВКЖ-94Б	»	То же 16	—	$5\cdot10^{-6}$—$1\cdot10^{-5}$	$2\cdot10^{-6}$—$1\cdot10^{-5}$	Стеклянный насос СДН-1 37	СССР 14
39 Силикон ДС-703	»	» 40	1,09 (при 25°)	—	$5\cdot10^{-6}$ 41	То же	»
Силикон ДС-702 42	»	» 40	1,07 (при 25°)	—	$1\cdot10^{-7}$ 21	Разгоночные стеклянные насосы	США 24
ПФМС-2 43	»	Кремнийоргинич. масло, смесь метилфенилполисилоксанов	—	$5\cdot10^{-6}$—$7\cdot10^{-7}$	Не хуже $2\cdot10^{-6}$ 45	Стеклянные насосы	»
Масло «Г» 46	РЖ пароструйных бустерных насосов 47	Минеральное масло, смесь углеводородов 11	—	$5\cdot10^{-6}$—$1\cdot10^{-5}$	10^{-6} 48	Металлич. насос ТЦКЛ-100	СССР 14
Лейбольд 20	То же 16	То же 16	—	—	$5\cdot10^{-5}$ 49	Бустерный насос БН-3	»
Майван КВ 23	»	»	—	—	10^{-6} 57	Металлич. бустерный насос	Германия 22
Бутилфталат 52	РЖ пароструйных эжекторных насосов 50	—	—	—	10^{-6} 49	Металлич. эжекторный насос	США 24
ВМ-4 53	РЖ пароструйных бустерных насосов 47	11 —	1,047	$1\cdot10^{-6}$	—	Металлич. бустерный насос	СССР, США 24
Голь крест С 55	Масло для механич. (форвакуумных) насосов 54	Минеральное масло, смесь углеводородов	—	$4\cdot10^{-6}$—$1\cdot10^{-5}$	—	—	СССР 14
Мак Миллан 56	То же 16	То же 16	—	—	—	—	США 24
Сюкони 57	»	»	—	—	—	—	»
58 Ртуть	»	»	13,55	—	—	—	»
	РЖ пароструйных высоковакуумных насосов; вакуумных манометров и затворов 59						—
Вольфрамородистый кадмий 60	РЖ для манометров 61	»	—	—	—	—	—
Жидкие сплавы Ga—In—Sn 62	Вакуумные затворы 63	—	—	—	—	— 14	СССР, США 24

1) Fluids; 2) purpose; 3) chemical composition; 4) specific gravity at 20°; 5) vapor pressure at 20° (mm mercury column); 6) limit vacuum without cooling the traps, measured by ion meter (mm mercury column); 7) type of the pump; 8) country where the fluid is produced; 9) D-1A; 10) working fluid for steam-jet high-vacuum pumps; 11) mineral oil, mixture of hydrocarbons; 12) not higher than; 13) SDN-1 glass pump; 14) USSR; 15) D-1B; 16) the same; 17) Apiezon; 18) metallic distillation pumps; 19) Great Britain; 20) Leibold; 21) glass pumps; 22) Germany; 23) Myvan; 24) U.S.; 25) Octoil; 26) ester; 27) metallic pumps; 28) Narcoil; 29) working fluid in stream-jet high-vacuum and booster pumps; 30) chlorinated hydrocarbons; 31) Arochlor; 32) tricresyl phosphate; 33) distillation pumps; 34) VKZh-94A; 35) organosilicon oil, a mixture of ethyl polysiloxanes; 36) not higher than; 37) SDN-1 glass pump; 38) VKZh-94B; 39) Silicon DS-703; 40) at 25°; 41) glass distillation pumps; 42) Silicon DS-702; 43) PFMS-2; 44) organo-silicon oil, a mixture of methylphenyl polysiloxanes; 45) TsVL-100 metallic pump; 46) "G" oil; 47) working fluid for steam-jet booster pumps; 48) BN-3 booster pump; 49) metallic booster pump; 50) working fluid for steam-jet ejector pumps; 51) metallic ejector pump; 52) butyl phtalate; 53) VM-3; 54) oil for mechanical (rough exhaust) pumps; 55) Golf Crest C; 56) McMillan; 57) Sucony; 58) mercury; 59) working fluid of steam-jet high-vacuum pumps; vacuum gauges and vacuum valves; 60) cadmium borotungstate; 61) working fluid for manometers; 62) liquid Ga-In-Sn alloys; 63) vacuum valves.

Ye.N. Martinson

FLUORINE-CONTAINING RUBBER (fluororubber) – is the product of copolymerization of non-saturated fluorinated hydrocarbons in emulsion. Trifluorochloroethylene, hexafluoropropylene, vinylidene fluoride, and also esters on basis of perfluoroglycols and perfluorodicarboxylic acids (perfluorobutyl acrylate, perfluoroalkoxy dihydroalkyl acrylates) are used as the initial monomers for fluororubbers. Fluororubber is produced in a relatively small degree under the trademark SKF (USSR), Kel-F, Vytene (U.S.). The specific gravity of the fluororubber is 1.85. Fluororubbers are completely saturated compounds containing a high quantity of polar fluorine atoms; they are characterized by an exclusively high resistance to aging, weathering, strong oxidizers, oils, solvents, fuel, and high temperatures. Fluororubbers are nonburning and resistant to microorganisms. Fluororubbers on basis of nonsaturated fluorohydrocarbons can operate at 300°, and for a short time even at 350°. Fluororubbers on basis of perfluoroalkyl acrylates are resistant to temperatures up to 200-220°. Some mechanical properties of fluororubbers are listed in Table 1; Tables 2 and 3 give their resistance to the action of some aggressive media.

TABLE 1

Mechanical Properties of Fluororubbers

1 Прочность на разрыв (кг/см²)	130–260
2 Относительное удлинение (%)	330–550
3 Модуль при 300%-ном удлинении (кг/см²)	55–155
4 Твердость по ТМ-2	52–78
5 Сопротивление раздиру (кг/см)	26–70
6 Эластичность по отскоку (%)	8–18

1) Tensile strength (kg/cm^2); 2) relative elongation (%); 3) modulus at 300% elongation (kg/cm^2); 4) TM-2 hardness; 5) tear resistance (kg/cm); 6) resilience (%).

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Aging of fluororubbers under diverse conditions has given the following results: the mechanical properties and the surface do not change

TABLE 2

Swelling of Fluororubber on Basis of Fluoroolefines at 20° After Immersion for 24 Hours

1 Среда	Изменение объема (%) 2
Четыреххлористый углерод 3	1.3
4 Бензол	19.6
5 Этиловый спирт	1.7
Анилин 6	3.0
7 Трикрезилфосфат (при 150°)	24.0
Масло минеральное 8	0
9 Ацетон	271.0
Газообразный хлор 10	1.5
11 Бензин	0.8
Силиконовое масло 12	0
Хлорированный парафин 13	1.0
14 Фреон-113	180.0
Натриевая щелочь 15	2.1
Вода (при 100°) 16	2.7
Серная кислота (дымящая) 17	4.8
Фтористоводородная кислота (48%-ная) 18	4.8
Уксусная кислота (ледяная) 19	61.6
Азотная кислота (дымящая) 20	16.0

1) Medium; 2) change in volume (%); 3) carbon tetrachloride; 4) benzene; 5) ethanol; 6) aniline; 7) tricresyl phosphate (at 150°); 8) mineral oil; 9) acetone; 10) gaseous chlorine; 11) gasoline; 12) silicon oil; 13) chlorinated paraffin; 14) Freon-113; 15) sodium hydroxide; 16) water (at 100°); 17) sulfuric acid (fuming); 18) hydrofluoric acid (48%); 19) acetic acid (glacial); 20) nitric acid (fuming).

after aging for 7 days at 75° and 21 atm in an oxygen cylinder; the mechanical properties and the surface remain unchanged for 6 hours in an

TABLE 3

Swelling of Fluororubbers on Basis of Perfluoroalkyl Acrylates After Immersion For 336 Hours

Среда 1	2 Температура (°C)	Изменение объема (%) 3
4 Изооктан: толуол (70:30)	25	17
Изооктан 5	та же	8
6 Бензол	»	96
Ацетон 7	»	91
Метилэтилкетон 8	»	86
9 Этилацетат	»	100
Масло минеральное	100	0
Гидравлическая 11 жидкость углеводородная	»	3
Полигликолевое машинное масло 12	177	3

1) Medium; 2) temperature (°C); 3) change in volume (%); 4) iso-octane: toluene (70:30); 5) iso-octane; 6) benzene; 7) acetone; 8) methylethylketone; 9) ethyl acetate; 10) mineral oil; 11) hydraulic hydrocarbon fluid; 12) polyglycol machine oil.

atmosphere containing 0.013% ozone (after a preliminary stretching by 30%); the action of ultraviolet rays for 100 hrs insignificantly increases the tensile strength, and does not change the relative elongation and hardness; exposition to the atmosphere for one year does not effect the mechanical properties.

Fluororubbers are heat resistant in air and do not become degradated at the following temperatures: 204° for 2400 hours; 232° for 1000 hours; 260° for 250 hours, and 315° for 24 hours; compressed to 25% after aging at 121° for 70 hours, they restore the initial volume by 90-97%; the specific volume resistivity is $1.2 \cdot 10^{13}$ ohm·cm; the tangent of the loss angle is 0.025; the dielectric constant is 7.0; the breakdown voltage is 53 kv/mm.

The insufficient frostproofness (in the range of -20° for certain types) is an important disadvantage of the fluororubbers. The copolymers of hexafluoropropylene have a frostproofness up to -40°. Some types of fluororubbers on basis of fluorinated esters are frostproof up to -50°, -55°, but their reduced heat resistance permits a working below 200-230° only. Fluororubbers are vulcanizable by polyamines and organic peroxides combined with metal oxides, due to their saturated structure. Compounds vulcanized by organic peroxides prove the highest chemical stability. The vulcanization with peroxides is carried out stepwise: at 110° for 30 min in a press, and a following final vulcanization at 150° in a thermostat. The vulcanization time depends on the thickness of the product, it is 1 hr for 0.25 mm, 5 hrs for 1 cm, and 8 hrs for 2 cm thick objects. Compounds vulcanized with amines prove a lower residual deformation after compression, and an elevated frostproofness. Such compounds have a tendency to scorch; compounds with hexamethylene tetramine prove the lowest tendency to scorch. The best results are obtained by combining amines with di-isocyanates. Rubbers

vulcanized with isocyanates prove the highest oilproofness. Salts of hydroxides or oxides of bivalent metals, combinations of the hydrates of metal oxides, especially of the hydrate of calcium oxide, with sodium metasilicate, and, finally, polyamines, which are the most effective vulcanizing agents for this type, are taken for the vulcanization of fluororubbers on basis of perfluoroalkyl acrylates. Application of active fillers (carbon blacks and fine-disperse grades of silica) considerably increases the strength and the other mechanical characteristics of fluororubbers. Precipitated silica and metal silicates are the most used ones, especially for rubbers destined for working at elevated temperatures. Application of certain special grades of fine-dispersed silica treated with silicon compounds, increases the tensile strength of fluororubbers up to 300 kg/cm^2. Fluororubbers are poorly combinable with other rubbers. The working of fluororubber is carried out on the common equipment of rubber plants. Fluororubbers are characterized by a difficult behavior in the production, they are poorly miscible with ingredients; stocks of fluorine rubbers are difficult to extrude and to calendar. It is not recommended to store raw compounds of fluororubbers for a long time. Ketones and ethers are used as solvents for the production of adhesives from fluororubbers. The complex of valuable technical properties, first of all the high resistance to heat and to diverse aggressive media, decide the fields of their application. Diverse sealing and packing rings, diaphragms and membranes for working at high temperatures and in aliphatic or aromatic fuels, lubricating oils, silicon- and working fluids, concentrated acids and alkalis, hoses for the pumping over of every kind of hot aggressive fluids, vessels for fuel storage, shafts being in contact with every kind of chemical media, chemically stable shoes and clothes, fireproof partition walls, different pieces working under atmospheric effects, and protecting gloves are

produced from fluororubbers. Fluororubber is also used for the insulation of wires and cables which are exposed to the effect of high temperatures and contact with corrosion-active media under the operating conditions.

References: Novyye kauchuki. Svoystva i primeneniye [New Rubbers. Properties and Application], a Collection of translations, Moscow, 1958.

I.V. Borodina

FLUORITE (fluorspar) – is a mineral with the chemical formula CaF_2. The specific gravity is 3.18; the mineral is brittle, and perfectly cleavable along the octahedral planes; the Mohs hardness is 4; fluorite is usually stained in diverse colors: yellow, green, blue, violet, sometimes black-violet; colorless crystals are rare. It contains usually insignificant impurities like Ce, rare earths, uranium, etc., and also inclusions of gases and fluids. The color disappears upon heating and returns upon irradiation with x-rays. The crystal system is cubic; the dimension of the unit cell is a = 5.450 A; the Ca ions are placed on the vertices and in the center of a great cube, and the F ions in the centers of 8 small cubes which compose, as it were, the great cube determined by the situation of the Ca ions; each Ca ion is surrounded by 8 F ions, and each F ion by 4 Ca ions. A structure of this type is termed a fluorite structure. Fluorite crystals are found as formed cubic crystals, rarer as octahedral or dodecahedral ones, the cube faces are usually smooth, those of the octahedron, however, dull. Twins along {111} occur frequently. The pure fluorite crystals are highly transparent for ultraviolet and infrared light, they luminesce intensely in cathode rays and in ultraviolet light and also under heating (thermoluminescence). Fluorite occurs in nature as a result of hydrothermal processes; it is an accessory mineral in many occurrences of nonferrous and rare metals. Synthetic crystals are obtainable from the melt. Fluorite is mainly used in metallurgy to obtain low-melting slags. In chemical industry, synthetic cryolite and certain fluorine compounds are prepared from fluorite; in ceramics, it serves for the

manufacture of enamels and glazes. Transparent and colorless crystal varieties are used in optics for the preparation of lenses. It was found that fluorite crystals containing rare-earth elements and also Fe may be used in lasers.

References: Betekhtin, A.G., Kurs mineralogii [Course of Mineralogy], 3rd Edition, Moscow, 1961.

V.P. Butuzov

FLUOROPLASTICS – are fluorine derivatives of the ethylene: fluoroethylene-3 (the polymer of the trifluorochloroethylene), and fluoroethylene-4 (the polymer of the tetrafluoroesthylene). Fluoroethylene-3 is produced as a fine loose powder, from which a semitransparent colorless or brown hornlike material is obtained by pressing. Fluorethylene-3 is easily machinable; tendency to cold flow is almost absent; heating involves crystallization and increases the brittleness; objects made from fluoroethylene-3 cannot be applied, therefore, at temperatures higher than 70°. Fluoroethylene-3 is chemically inert, it resists all acids and alkalis, it is insoluble when cold in all solvents; it does swell, however, in certain organic substances; it becomes decomposed at high temperatures under the action of molten alkali metals and of elemental fluorine. Fluoroethylene-3 is used for the manufacture of linings working in aggressive media at a pressure of 32 kg/cm^2 and a temperature within –40 and +50°; of valve parts working at a pressure of 150-200 kg/cm^2; of membranes, and of various electrical insulating parts. The fluoroethylene-3M is a new modification of the fluoroethylene-3 in which the tendency to a rapid crystallization is eliminated. The static bending strength of fluoroethylene-3M is 350 kg/cm^2, the relative breaking elongation is 200-250%. The other properties of fluoroethylene-3M are very similar to those of the fluoroethylene-3, the former being, however, softer and more elastic.

Fluoroethylene-4 is obtained in the form of white grains; its chemical stability surpasses that of all known materials including gold and platinum, it is resistant to almost all mineral and organic acids, to

alkalis, organic solvents, oxidizing agents and other aggressive media; it does not swell. It becomes decomposed only by molten alkaline metals and elementary fluorine; it is not wettable by water. Cold yield increasing at rising temperature, a considerable residual deformation occurring at specific loads of 30-50 kg/cm^2, and transition into the flow region under pressures of the 200-250 kg/cm^2 range are the shortcomings of the fluoroethylene-4. The main method of the manufacture using fluoroethylene-4 is the compacting of the fine-disperse powder in the cold at a pressure of 300-350 kg/cm^2, sintering at 375 ± 10° of the objects formed in the cold state, and subsequent cooling. The high heat resistance, the chemical stability and the dielectric properties of fluoroethylene-4 enabled its widespread application for the manufacture of packing parts (linings, packings of stuffing boxes, cups, bellows, etc.); of electric and radio-engineering objects (plates, discs, rings, cylinders, insulating film); of chemically resistant parts (pipes, beakers, valves, cocks, membranes, pumps, etc.), and of porous materials. Profiled objects (pipes with very small cross sections and an inside diameter of 0.3 mm, an outside diameter of 0.7 mm) are manufactured by extrusion of fluoroethylene-4D, a modification of the fluoroethylene-4. An aqueous suspension of the fluoroethylene-4D is used for the production of impregnated fabrics, textolites, and (anti-frictional, anti-adhesive and electrical insulating) coatings on metals, and also for the impregnation of various porous materials. The properties of the fluoroplastics are quoted in Table 1.

The mechanical properties of the fluoroethylene-4 are listed in Table 2 as a function of the temperature.

An electrical insulating film in the form of an oriented or non-oriented white or slightly gray tape, transparent in thin layer, is prepared from fluoroethylene-4. The fluoroethylene-4 film possesses

high dielectric properties which remain almost invariable at different frequencies in the temperature range from −60 to +250°, it is extremely chemically resistant to aggressive media, it does not burn and is nontoxic; it is used as an electrical insulating material, especially in the high-and superhigh-frequency engineering, it is used for the insulation of coils, of the grooves of electric engines, and to braid wires and cables. The length of the film is 250 m, but it is available also in a shorter length. The application of the fluoroethylene-4 electric insulating film has made possible the manufacture of heat resistant conducting wires and cables working under bending between −60 and +250°. The main properties of the film are: specific gravity 2.1-2 2; temperature of decomposition 400°; temporary tensile strength (kg/cm^2, not less than) 300 for the oriented, and 100 for the nonoriented film; relative elongation (%, not less than) 30 for the oriented, and 100 for the nonoriented film; electric strength tested by d-c (kv/mm, not less than) 100 for the oriented, and 40 for the non-oriented film; width of the film 12-90 mm, thickness (in μ) 20-100 for the oriented and 40-200 for the non-oriented film.

TABLE 1

Properties of Fluoroplastics

	Свойства А	В Фторопласт-4	С Фторопласт-3
D	Удельный вес	2,1—2,3	2,09—2,16
E	Температура плавления кристаллов (°С)	327	208—210
F	Температура стеклования аморфной фазы (°С)	—120	— 55
G	Максимальная рабочая температура при эксплуатации (°С)	260	100
H	Минимальная рабочая температура при эксплуатации (°С)	—269	—195
I	Теплопроводность (кал/см·сек·°С)	$5.9 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$
K	Удельная теплоемкость (кал/г·°С)	0.25	0.22
L	Теплостойкость по Мартенсу (°С)	—	70
M	Водопоглощение за 24 часа (%)	0.00	0.00
N	Предел прочности (кг/см²):		
O	при растяжении	140—200 [1])	350—400 [1])
P	при изгибе	110—140	600—800
Q	при сжатии	—	500—570
R	Относительное удлинение при разрыве (%)	250—500	2[illegible]—10[illegible])
J	Остаточное удлинение (%)	250—350 [2])	90—180 [2])
T	Модуль упругости при изгибе (кг/см²):		
U	при +20° С	4700—8500	11 600—14 500
	при —60° С	13 200—27 800	26 000
V	Удельная ударная вязкость (кг см/см²)	100	20—160
W	Твердость по Бринеллю (кг/мм²)	3—4	10—13
X	Удельное объемное электрическое сопротивление (ом·см)	$1 \cdot 10^{17}$ (до $1 \cdot 10^{20}$)	$1.2 \cdot 10^{16}$
Z	Удельное поверхностное электрическое сопротивление (ом)	$1 \cdot 10^{14}$	$1 \cdot 10^{14}$
a	Электрич. прочность (по пл)	25—27 [3])	13 [4])
b	Диэлектрическая проницаемость при:		
	50 гц, С	1.9—2.2	3.0
	10⁶ гц, С	1.9—2.2	2.8
	10⁸ гц	1.9—2.2	2.5—2.7
d	Тангенс угла диэлектрич. потерь при:		
	50 гц	0.0002—0.0003	0.015
	10⁶ гц	0.0002—0.0003	0.024
	10⁸ гц	0.0002—0.0003	0.019
e	Прочность (сек.)	250	360
f	Показатель преломления	—	1.43
g	Горючесть	Не горит	Не горит
h	Температура разложения (°С)	415	315

1) Non-hardened specimens. 2) Hardened specimens. 3) At a thickness of 4 mm. 4) At a thickness of 2 mm.

A) Properties; B) fluoroethylene-4; C) fluoroethylene-3; D) specific gravity; E) melting point of the crystals (°C); F) vitrification point of the amorphous phase (°C); G) maximum working temperature in serve (°C); H) minimum working temperature in service (°C); I) heat conductivity (cal/cm·sec·°C); K) specific heat (cal/g·°C); L) heat resistance according to Martens; M) water absorption for 24 hours (%); N) maximum strength (kg/cm²); O) tensile strength; P) bending strength; Q) compression strength; R) relative breaking elongation (%); S) residual elongation (%); T) modulus of elasticity on bending (kg/cm²); U) at; V) specific impact resilience (kg·cm/cm²); W) Brinell hardness (kg/mm²);

X) specific electrical volume resistance (ohm•cm); Y) up to; Z) specific electrical surface resistance (ohm); a) electric strength (kv/mm); b) dielectric constant at; c) cps; d) tangent of the loss angle at; e) arc-resistance (sec); f) refractive index; g) combustibility; h) does not burn; i) temperature of decomposition (°C).

TABLE 2

Mechanical Properties of Fluoroethylene-4 as a Function of the Temperature

1 Температура (°C)	Модуль упругости при сжатии (кг/см²) 2	Модуль упругости при изгибе (кг/см²) 3	Предел прочности при растяжении (кг/см²) 4	Относительное удлинение при разрыве (%) 5
−60	18000	27800	—	—
−40	17000	23900	350	70
−20	15000	23300	325	100
0	11000	18100	300	150
20	7000	8500	200	470
40	4500	5100	180	650
60	3300	4800	—	—
80	2400	3800	135	600
100	1700	—	115	540
120	—	2450	—	—

1) Temperature (°C); 2) modulus of elasticity on compression (kg/cm^2); 3) modulus of elasticity on bending (kg/cm^2); 3) tensile strength (kg/cm^2); 4) relative breaking elongation (%).

References: Chegodayev, D.D., Naumova, Z.K., Dunayevskaya, Ts.S., Ftoroplasty [Fluoroplastics], 2nd Edition, Leningrad, 1960; Losev, I.P., Trostyanskaya, Ye.B., Khimiya sinteticheskikh polimerov [Chemistry of Synthetic Polymers], 2nd Edition, Moscow, 1964.

FLUOROSILOXANE RUBBER – is the product of the joint hydrolysis of fluoropropyl methyl dichlorosilane and dimethyl dichlorosilane in a 1:1 ratio. It is characterized by resistance to oils, fuels and solvents. Fluorosiloxane rubbers are equivalent to dimethyl siloxane rubbers with respect to all basic mechanical qualities and heat resistance, but they surpass the latter in the resistance to oils, fuels and solvents. A comparison of the properties of fluorosiloxane and dimethyl siloxane (KD) rubbers is given in the Tables 1, 2, 3 and 4.

TABLE 1

Comparison of the Properties of Fluorosiloxane and Dimethyl Siloxane (KD) Rubbers

Каучук 1	Прочность на разрыв (кг/см²) 2	Относительное удлинение (%) 3	Темп-ра хрупкости (°С) 4	Остаточная деформация после сжатия при 50° в течение 22 час (%) 5
К.Ф. . . 6 . .	55	170	—74	62
КД . . . 7 . .	60	210	—74	64

1) Rubber; 2) tensile strength (kg/cm^2); 3) relative elongation (%); 4) brittleness point (°C); 5) residual deformation after compression at 50° for 22 hrs (%); 6) fluorosiloxane rubber; 7) KD.

The resistance of the fluorosiloxane rubber to oils and fuels depends on the content of trifluoropropyl methyl siloxane groups.

Fluorosiloxane rubbers become degradated when operating in absence of air at elevated temperature; they are unstable to abrasion, and show an increased viscosity under the joint action of temperature and load.

TABLE 2

Resistance of Fluorosiloxane Rubbers with Different Fluorine Content to the Action of Fuels and Oils

	Масла 1	
	топливо ASTM 2	турбинное масло 3
Продолжительность и 4 темп-ра испытания . .	5 70 час. 25°	70 час. 176°
% набухания для резин на полимеров типа: 6		
$(CH_3)_2SiO$ 0% F	150	40
$CH_2CF_2CH_2CH_2SiO$ 36,5% F	21	9
$CH_2CF_2CF_2(CH_3)_2SiO$ 46,1% F	25	7
$CH_2CF_2(CF_2)_3(CH_3)_2SiO$ 52% F	21	5

1) Oils; 2) ASTM fuel; 3) turbine oil; 4) time and temperature of the test; 5) hrs; 6) swelling of rubbers from the polymers of the type.

TABLE 3

Resistance of Fluorosiloxane and Dimethyl Siloxane (KD) Rubbers to the Action of Solvents at Room Temperature for 72 Hours

Каучук 1	% набухания 2					
	3 в изооктане	4 в ксилоле	5 в четыреххлористом углероде	6 в этиловом спирте	7 в ацетоне	8 в бутилацетате
9 К ф.	15	18	21	5	150	150
КД 10	150	150	150	2	15	150

1) Rubber; 2) swelling, in %; 3) in iso-octane; 4) in xylene; 5) in carbon tetrachloride; 6) in ethanol; 7) in acetone; 8) in butyl acetate; 9) fluorosiloxane rubber; 10) KD.

The formulae for the compounds, the working and vulcanization methods of fluorosiloxane rubbers are the same as that of KD.

Fluorosiloxane rubber is delivered in the USSR in the grade SKTF 100, in the U.S. as Silastic ZS-53. The latter rubbers are more resistant to oil. Another type of oil-resistant siloxane rubber is the nitrile-siloxane rubber which is cheaper than the fluorosiloxane rubber.

The nitrile-siloxane rubber is equivalent to the fluorosiloxane and KD rubber with regard to all the basic properties, but it is in-

TABLE 4

Resistance of Fluorosiloxane, KD and Nitrile-Siloxane Rubbers to Thermal Aging at 200 and 250°

1 Каучук	2 Прочность на разрыв (кг/см²)	3 Относительное удлинение (%)	Свойства 4 после старения в течение: 5 30 суток при 200°		10 суток при 250°	
			прочность 2 на разрыв (кг/см²)	относительное 3 удлинение (%)	прочность 2 на разрыв (кг/см²)	относительное 3 удлинение (%)
6 КД	60	220	40	150	30	100
7 К.ф.	55	170	37	120	35	150
8 Нитрилсилоксановый	47	160	35	50	9 Хрупкие	

1) Rubber; 2) tensile strength (kg/cm^2); 3) relative elongation (%); 4) properties after aging for; 5) ... days at ...; 6) KD; 7) fluorosiloxane rubber; 8) nitrile-siloxane; 9) brittle.

ferior to the latter in resistance to thermal aging in air at 200-250°.

Fluorosiloxane and nitrile-siloxane rubbers are used in diverse branches of the national economy for the production of diverse packing parts, owing to their increased resistance to oil.

F.A. Galil-ogly

FOAM ALUMINUM – aluminum or aluminum alloys saturated with hydrogen (85-90% H) in order to form a cellular (porous) structure.

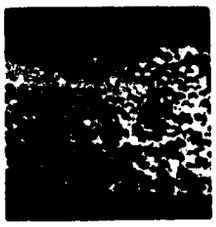


Fig. Cellular structure of foam alluminum.

Hydrogen saturation is carried out by adding titanium hydride or zirconium hydride, which has a high elasticity of dissociation, to the molten metal at temperatures higher (by 20-30°) than the melting point of aluminum. A metastable supersaturated solution of hydrogen in aluminum is formed when the hydride decomposes and is fixed by rapid cooling. As a result, solid foam aluminum consists of gas-filled metal cells (Fig. 1). If the cells are closed the foam aluminum is gas- and water-impermeable and has good buoyancy. Its characteristics depend to a considerable extent on the specific gravity and properties of the initial alloys (see Table). Round and rectangular ingots and strips can be fabricated from foam aluminum; shaped blanks can be produced by casting in metal or sand molds.

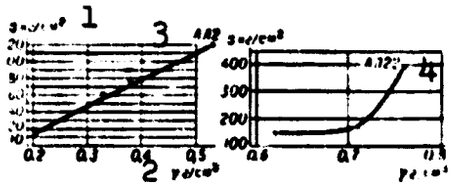


Fig. 2. Compressive strength of AL2 and AL22 alloys as a function of specific gravity. 1) kg/cm^2; 2) g/cm^3; 3) AL2; 4) AL22.

II-24P-2

Certain Characteristics of Foam Aluminum

γ (g/cm³) 1	2 Исходные сплавы							
	3 сплав АЛ2				7 сплав АЛ22			
	σ_{-b}	E	$a_н$	λ 6	σ_{-b}	E	$a_н$	λ
	(кг/см²) 4		(кг·см/см²) 5	(кал/см·сек·°С)	(кг/см²)		(кг·см/см²)	(кал/см·сек·°С)
0,3	49	18500	2,54	0,011	50	23100	1,8	0,0052
0,4	83	30800	3,3	0,029	87	23900	2	0,01
0,5	115	34000	5,1	0,039	130	38700	2,3	0,015
0,6	160	42000	7,8	0,052	160	51060	2,6	0,019

1) g/cm³; 2) initial alloys; 3) AL2 alloy; 4) kg/cm²; 5) kg·cm/cm²; 6) cal/cm·sec·°C; 7) AL22 alloy.

Fig. 3. Impact strength of AL2 alloy as a function of specific gravity. 1) kg·cm/cm²; 2) g/cm³; 3) AL2.

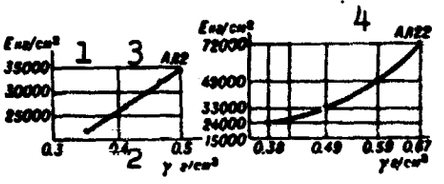


Fig. 4. Compressive modulus of elasticity of AL2 and AL22 alloys as a function of specific gravity. 1) kg/cm²; 2) g/cm³; 3) AL2; 4) AL22.

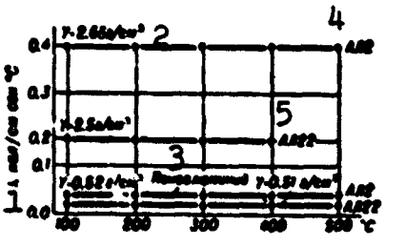


Fig. 5. Coefficient of thermal conductivity of AL2 and AL22 alloys as a function of temperture. 1) cal/cm·sec·°C; 2) g/cm³; 3) foam aluminum; 4) AL2; 5) AL22.

The specific gravity of foam aluminum varies from 0.23 to 0.75 g/cm^3, depending on the number of gas bubbles per unit volume. The compressive strength of this material is directly proportional to its specific gravity (Fig. 2). The same relationship exists between impact strength and specific gravity (Fig. 3) and modulus of elasticity and specific gravity (Fig. 4). The modulus of elasticity has a rather high value. Their specific gravities being equal, the strength of different types of foam aluminum increases with the characteristics of their initial alloys. Foam aluminum is distingiushed by a low thermal conductivity, which is also attributable to the structure of the metal and depends on the conductivity of the initial alloy (Fig. 5). Thermal conductivity increases with specific gravity. Foam aluminum is a corrosion-resistant, hermetic material and can withstand hydraulic pressures of up to 100-130 atm. It is readily machined, soldered, and welded. Welding raises its thermal conductivity (in the welded joints). Its low specific gravity, low thermal conductivity, high corrosion resistance, and comparatively high modulus of elasticity enable us to regard foam aluminum as a promising structural material for machine building, ship building, construction, and other branches of technology.

M.B. Al'tman

FOAM CERAMICS – mineral-based sintered materials with a cellular-foam structure. They consist of bubbles of air (or some other gas) surrounded by thin membranes that form an unusual type of framework. Foam ceramics are generally produced from highly dispersed mineral powders and liquid foams. Such foams are colloidal systems with a liquid surface of separation; the dispersion medium is a liquid and the dispersed phase is a gas in the form of bubbles separated by liquid films. In contrast to other dispersed systems, the medium also becomes a dispersed phase in foams. The size of the bubbles and the gas content of the foam may vary within wide limits.

Being dispersed systems with a substantial interphase surface, foams are thermodynamically unstable. Special additives (stabilizers) are used to increase their stability and thus strengthen the film framework, since pure liquids do not form sufficiently stable foams. Many organic surface-active agents and certain other substances have a stabilizing action on foams. Addition of a highly dispersed mineral powder, which is wetted by the liquid phase, leads (on mixing) to formation of a three-phase foam. The solid particles are distributed throughout the film and the bubbles are then surrounded by two-phase membranes.

When such a mass is dried the liquid phase evaporates and a two-phase (solid) foam is formed. The weak bonding between the mineral particles in the cellular-foam framework thus produced explains the low mechanical strength of the dried mass. Foams are hardened by ordinary annealing, during which the organic constituents (stabilizers) of the

liquid foam undergo decomposition (pyrolysis) and the material is sintered, retaining the structure inherited from the initial foam. The size of the bubbles and the concentration ratio of the gaseous and solid phases (and thus the bulk weight and other characteristics of the foam) may vary within wide limits. They depend on the composition of the liquid foam, the chemical-mineralogical nature and specific surface of the powder, the amount of powder in the three-phase mass, and the conditions under which the latter is prepared. Thus, a foam produced from a given mineral powder can be given the requisite characteristics by varying the ratio of the phases (solid, liquid, and gaseous) in the mass, i.e., by regulating its phase composition.

TABLE 1

Ultimate Compressive Strength of Foam Ceramics

Тип пенокерамики 1	2 Пористость общая (%)	3 Объемный вес (г/см³)	4 σ сж (кг/см²)
На основе Al_2O_3 5	30 75 80 85	1.2 1 0.8 0.6	200 130 51 21
На основе ZrO_2 6	51 72 75 83	2.36 1.7 1.47 1	246 151 80 45

1) Type of foam ceramic; 2) total porosity (%); 3) bulk weight (g/cm^3); 4) kg/cm^2; 5) based on AL_2O_3; 6) based on ZrO_2.

TABLE 2

Characteristics of PK-1 Foam Corundum

1	2	3	4	5	6
0.5	160	20	0.8	$2 \cdot 10^{-2}$	0.22	0.85

1) Bulk weight (g/cm^3); 2) kg/cm^2; 3) kcal/m·hr·°C; 4) temperature conductivity (m^2/hr); 5) kcal/kg·°C; 6) coefficient of blackness.

All other factors being equal, the characteristics of foam ceramics depend on the structure of the framework, i.e., the number of bubles, their size, the manner in which they are distributed in the material, and the ratio of bubble size to membrane thickness. The tinner the membranes in comparison with the bubbles, the higher are the thermophysical and mechanical characteristics of the foam and the stronger are the membranes. Table 1 presents data on the compressive strength of foam ceramics based on Al_2O_3 and ZrO_2 as a function of porosity.

The ultimate tensile strength of a foam ceramic based on Al_2O_3 (PK-1 foam corundum) having a bulk weight of 0.8 g/cm^3 is 37 kg/cm^2, while its ultimate bending strength is 148 kg/cm^2. The thermal conductivity of foam ceramics decreases as their porosity increases. The thermal conductivity of foam oxides drops as the temperature rises, since the conductivity of sintered oxides is reduced by heating. Table 2 shows certain characteristics of PK-1 foam corundum.

Since sintered aluminum oxide is a heat-resistant material, PK-1 foam corundum can function in many aggressive media. In contemporary structures foam ceramics are employed principally as heat insulation intended to function for long periods with high temperatures on the hot side. The higher the temperature and the longer the period for which the insulation is exposed, the higher should be the heat-resistance of the foam ceramic. Foam-ceramic materials based on high-melting metal oxides (Al_2O_3, MgO, BeO, ZrO_2, etc.) satisfy the most rigid requirements. In many cases sintered foam oxides are more resistant to aggressive media and severe temperature gradients.

References: Guzman, I.Ya. and Poluboyarinov, D.N., Legkovesnyye ogneupory iz okisi alyuminiya [Light-Weight Refractory Materials of Aluminum Oxide], Ogneupory [Refractory Materials], 1959, No. 2.

I.D. Abramson

FOAMED MAGNESIUM is a porous material with volumetric weight 0.1--0.5 g/cm^3. Foamed magnesium consists of gas-filled cells with thin walls. The ultimate strength with volumetric weight of 0.15 g/cm^3 is equal to 1.8-2 kg/mm^2. With increase of the volumetric weight the ultimate increases proportionately, reaching 25 kg/mm^2 for cast foamed magnesium iwth volumetric weight 1.8 g/cm^3. The cellular structure of foam magnesium provides high stiffnes.. The ultimate strength may be increased to 20-22 kg/mm^2 with a volumetric weight of 0.8 g/cm^3 by deformation. Foamed magnesium can be machined, bolted, riveted. A drawback is the difficulty of production and working. Foamed magnesium is produced by introducing a foaming agent (hydrides of titanium, zirconium lithium and others) into molten magnesium under an inert gas. Decomposing on heating, the foaming agent causes the molten metal to froth and it is quickly cooled with water before the foam collapses.

A.A. Lebedev

FOAM MATERIALS – gas-filled materials with a solid as the dispersion medium and a gas as the dispersed phase; in foams, as in gas-filled materials in general, the gaseous phase constitutes more than 50% of the total volume of the substance and the diameter of individual pores is no less than 1 μ. We can distinguish foams of organic and inorganic (based on SiO_2 and combinations of SiO_2 with metal oxides, aluminosilicates, and other substances) origin.

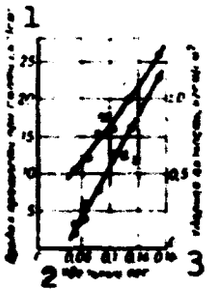


Fig. 1. Mechanical characteristics of plastic foam based on an epoxy resin as a function of specific gravity (up to $\gamma = 0.18$ g/cm^3): α – impact strength, σ_{-b} – ultimate compressive strength. 1) Ultimate compressive strength, kg/cm^2; 2) specific gravity; 3) impact strength, kg-cm/cm^2.

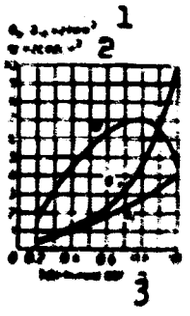


Fig. 2. Mechanical characteristics of plastic foams as a function of specific gravity at $\gamma > 0.2$ g/cm^3): σ_b – ultimate tensile strength, σ_{-b} – ultimate compressive strength, α – impact strength. 1) kg/mm^2; 2) kg-cm/cm^2; 3) specific gravity.

The most common foams are those based on polyvinyl chloride, polystyrene, phencl-formaldehyde, and other high-molecular synthetic resins. The general characteristics of foams include low specific gravity (0.01-0.2 g/cm^3 in the majority of cases), good heat- and sound-insulating characteristics, high dielectric properties, buoyancy, and good cutability and glueability. Most foam materials, however, are combustible and have a comparatively low heat resistance. The mechanical characteristics of foams depend to a great extent on their specific gravity (Figs. 1 and 2). These characteristics are sufficiently high for foams to be used as structural materials in order to increase the specific strength, rigidity, and vibration resistance of structural components.

The foam structure of these materials is formed by: 1) mixing a resin with the inorganic gas-forming agents $NaHCO_3$ and $(NH_4)_2CO_3$ (frothing agents or porophores) and then heating the mixture, which causes the porophores to decompose and liberate gases. Organic gas-forming agents (azo compounds, azides, nitroso compounds, etc.) are more widely employed, their decomposition generally being accompanied by liberation of nitrogen; individual granules of the composition are frothed and then sintered (cemented) into a monolithic foam by heating under slight pressure; 2) saturation of a resin with gases under pressure followed by a sharp reduction in pressure (sometimes combined with heat treatment), which leads to liberation of gases into the resin mass in the form of extremely small bubbles (the autoclave method); 3) irradiation of a resin with γ-rays or neutrons followed by heating; the destruction of the resin molecules during irradiation produces substances that decompose and liberate gases. This method is employed to produce foams based on polyacrylic resins; 4) mechanical dispersal of a gaseous product in a liquid polymer. Equipment with mechanical mixers or air-

bubbling devices is used in this case; the process is carried out in the presence of surface-active agents. Materials such as mipor are produced by this method; 5) evaporation of readily volatilized liquids added to the initial composition, this being the method employed in the manufacture of stiropor; 6) self-frothing, which is based on deliberation of gaseous products during the chemical interaction of the substances participating in formation of the resin. This method is used to produce foams from polyurethane and epoxy resins.

Fig. 3. Mechanical characteristics of FK plastic foam as a function of rubber content: α – impact strength, σ_b – ultimate tensile strength. 1) kg/cm^2; 2) kg-cm/cm^2; 3) rubber content, parts by weight.

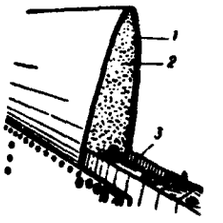


Fig. 4. Use of plastic foam in the construction of an aircraft wing: 1) Glass textolite; 2) plastic foam (filler); 3) metal longeron.

Foams based on polyvinyl chloride and polystyrene resins have similar properties. The former (PKhV-1, PKhV-E, etc.) have a higher resistance to organic solvents, but may corrode aluminum- and magnesium-alloy components in contact with them. Polystyrene foams (PS-1, PS-4, stiropor, stirophor, etc.) are inert with respect to metals, but dissolve more easily in organic solvents. They have better mechanical characteristics at normal temperatures than other foams, but have a low heat resistance. Their dielectric characteristics are somewhat higher

than those of polystyrene foams. A number of new foams have also been developed on the basis of polystyrene. For example, PS-18 has a fine cellular structure, a bulk weight of 0.03 g/cm^3, a coefficient of thermal conductivity of 0.02 kcal/m·hr·°C, a tangent of dielectric-loss angle of 0.0005 at 10^{10} cps, and a dielectric permeability of 1.036 at 10^{10} cps. Mipor, which is widely used as a heat- and sound-insulating material, has a high heat resistance (a working temperature of 110°). Foams based on phenol aldehyde and polysiloxane (silicoorganic) resins are still more heat-resistant. Foam of types FF and K-40 can withstand temperatures of 150-200° or more. The strength and heat-resistance of these foams can be raised by addition of powdered aluminum, ground quartz, and other substances. Nitrile-based rubber is added to reduce the brittleness of type FF foam; type FK foam with the desired combination of strength and impact strength can be obtained by adding sulfur and a hardening agent to the initial mixture and vulcanizing it (Fig. 3).

Polyurethane foam has good physicochemical and technological characteristics. It can be produced at the consumer plant by self-frothing. For this purpose a mixture of two components containing isocyanate and carboxyl or hydroxyl radicals is poured into appropriate molds. A diisocyanate and a polyester are used in practice, their interaction causing simultaneous formation of a polyurethane resin and frothing as a result of liberation of carbon dioxide. The foam formed fills the mold and, after the heating necessary for final setting, it acquires the necessary characteristics. A more elastic material is obtained when there is an excess of polyester.

A number of foams capable of hardening when they react with polyamines or other compounds containing labile hydrogen atoms have been developed on the basis of polyepoxy resins. Epoxy (polyepoxy) foams are

distinguished by exceptionally high adhesion and set without liberation of by-products, which makes it possible to produce them directly in structures without pressing or use of glues. Their other advantages include stability in acids, alkalis, and organic solvents, good dielectric characteristics, and high heat-resistance.

Inorganic foams are obtained by frothing compositions based on silicon dioxide and then annealing them at high temperatures. These materials include glass foam, foam concrete, foam silicate, foam ceramite, etc.

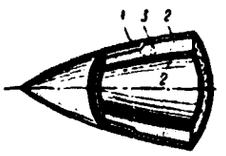


Fig. 5. Use of plastic foam in deflectors for aircraft antennas: 1) Metal tip; 2) glass-textolite housing; 3) plastic-foam filler.

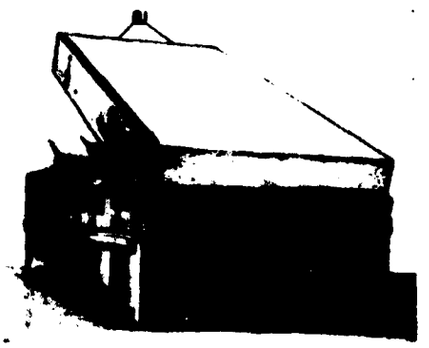


Fig. 6. Plastic-foam panel blocks.

Foam materials are widely used as light fillers in sandwich panels or reinforced structures with metal or plastic facings. They have also come into wide use in aircraft building (Fig. 4) and in the oxygen, refrigeration, and furniture industries. Such "sandwich" structures have a higher specific strength and rigidity than unfilled structures. Foam materials (especially those based on polystyrene) have proved to be

Fig. 7. Plastic-foam heat-insulating pipe.

Fig. 8. Plastic-foam life preservers.

Fig. 9. Plastic-foam life belt.

very effective in the construction of radar components, including mirors, emitters, reflectors, and especially antenna deflectors (Fig. 5). Such deflectors are strong, light, and radio-transparent. As a result of their low thermal conductivity foam materials can be successfully used in the manufacture of heat-insulating panels, partitions, slabs (Fig. 6), etc., for the construction of residences and polar stations and as heat-insulating materials for coolers, refrigerators, and piping (Fig. 7). Their lightness and gas-impermeability make foams suitable for use in the production of various difficult-to-submerge articles, such as life preservers (Fig. 8), life belts (Fig. 9), pontoons, buoys, and other floating devices, serving as a replacement for cork. Soft, elastic foams of the porolon type are used in the production of shock-absorbers, sponges, carpets, soft chairs, mattresses, etc. Inorganic foams are used principally in the manufacture of heat-resistant, heat-insulating panels for prefabricated construction of commercial and residential buildings.

References: Penoplastmassy [Plastic Foam], collection of articles,

edited by A.A. Moiseyev et al., Moscow, 1960; Berlin, A.A., Sverkhlegkiye i konstruktsionnyye plastmassy [Ultralight and Structural Plastics], Moscow, 1959; Idem, Osnovy proizvodstva gasonapolnennykh plastmass i elastomerov [Principles of the Production of Gas-Filled Plastics and Elastomers], Moscow, 1954; Kitaygorodskiy, I.I., Keshishyan, T.N., Penosteklo [Glass Foam], Moscow, 1953; Spravochnik po mashinostroitel'nym materialam [Handbook of Machine-Building Materials], edited by G.I. Pogodin-Alekseyev, Vol. 4, Moscow, 1960.

B.K. Vul'f

FOAM-SLAG SITALL – see Sitalls.

FORTISAN – is a hydrated cellulose fiber obtained by drawing acetate fiber (100% degree of draft) in an atmosphere of superheated steam (pressure about 2.5 atm) under simultaneous saponification of the acetyl groups by a 1% solution of NaOH containing 15% CH_3COONa. Fortisan is the most highly oriented hydrated cellulose fiber with a high strength. The specific gravity of fortisan is 1.52; the moisture percentage is 9.6 at 20° and a relative moisture of 65%. The chemical stability is the same as that of cotton and of viscose rayon, the colorability is poor and considerably lower than that of cotton and viscose rayon. The breaking length is 63-80 km. The loss in strength is about 30% in wet state and 38% in a loop. The specific tensile strength is 95-121.5 kg/mm^2. The initial modulus of elasticity is 2080-2500 kg/mm^2. Fortisan is used for technical purposes: production of transmission belts, conveyor belts, hoses, etc.

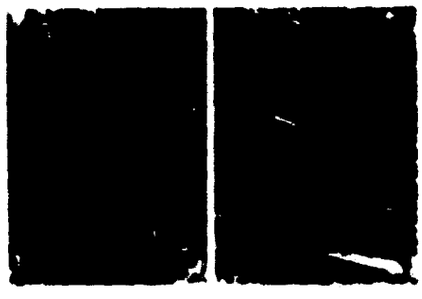
References: Serkov, A.T., Konkin, A.A., Kotomina, I.N., "Khimicheskiye volokna," 1959, No. 1, page 15; Moncriff, R.U., Khimicheskiye volokna [Synthetic Fibers], translated from English, Moscow, 1961, page 207; Sherman, J.V., Sherman, S.T., The New Fibers, N.Y., 1946, pages 279-294.

L.S. Galbraykh

FRACTOGRAPHY – is the examination of the surface of mechanical destructions (fractures) of specimens and parts carried out usually by means of an optical or electron microscope combined with a visual inspection at low magnification. The fracture surface must not be previously pickled or ground. To be able to investigate the "weak points" of the destructed specimens or parts in the same state in which the destruction occurred is an advantage of the fractography. Fractography helps to explain the surface structure of the fracture, the course of the development of the fracture, the role of the various structural components, the change in their state under a load, etc. The orientation of the investigated part of the fracture surface with respect to the optical axis of the microscope is the main methodical problem of the fractography. A hinge-joint on the stage of the metal microscope is used to carry out the orientation. The fractography is carried out in direct light, the fracture surface being slightly inclined. The microrelief of the surface becomes detectable in this way.

Fractography by means of optical microscopes is limited by the shadowing of the inner surface sections by the protruding edges, wherefore usually only the microsections near to the border of the fracture can be investigated, and is also limited by the necessity that at least small plane sections of the fracture must be present (sections with crystalline structure, for example); this exigency encumbers the investigation of fibrous fractures. Fractography by means of electron microscopes with a magnification of ten thousand has clarified new details of the fracture structure which are not detectable at lower mag-

nifications: the origin of the fractures on the carbide inclusions existing on the grain boundaries (Fig.) in the case of a ductile destruction; the formation of steps with strongly deflected sharp edges on the shear surfaces in the case of brittle destruction, etc. These facts show that a considerable plastic deformation between parallel cracks takes place at the end of a brittle destruction. The greater sharpness is the depth of the pattern and the possibility to investi gate small sections of distorted surfaces are the advantages of the electron microscope fractography in comparison to that of optical microscopes. The necessity, in some cases, of dissolving the metal of the specimen for the preparation of a replica (a copy of the surface) is disadvantage of the electron microscope fractography. There exist also other methods of fractography: photometrical fractography which measures the relfectance of fracture surfaces, x-ray diffraction and electron-diffraction study of surface layers, differential staining, and the investigation of the microgeometry of the fracture surfaces by means of profilographs. Many of the peculiarities of the structure of fractures made apparent by fractography are not yet explained.



Electron micrographs of break surfaces in low-carbon steel: a) Viscous fracture, 12,000x; b) brittle, 5000x (after L.G. Orlov and L.M. Utevskiy).

References: Fridman, Ya.B., Gordeyeva, T.A., Zaytsev, A.M., Stroyeniye i analiz izlomov metallov [Structure and Analysis of Metal Fractures], Moscow, 1960.

Ya.B. Fridman

FRACTURE – the breaking of a body into pieces on application of a mechanical load, sometimes in conjunction with thermal, corrosive, and other factors. In the majority of materials fracture is accompanied by simultaneous elastic and Plastic deformation and strict delineation of these processes is difficult. Fracture is classified as insipient (formation and development of cracks) or complete (breakage of the body into two or more pieces); as brittle (without substantial plastic deformation) or plastic (viscous); as fatigue, prolonged, or Delayed fracture, etc.

Ya.B. Fridman

FRACTURE STRENGTH – the greatest stress required to fracture a specimen; we can distinguish resistance to brittle fracture, or Rupture strength, and resistance to viscous fracture, or Sheer strength. In tensile tests the fracture strength S_k is determined from the load at the instant of complete fracture related to the final cross-sectional area. For brittle materials fracture under tension occurs at the instant when the greatest load is reached and the fracture strength (rupture strength) is thus virtually identical to the ultimate strength: $S_k \simeq \sigma_b$. For plastic materials, which neck during extension, the fracture strength can be roughly calculated from the formulas: $S_k = \sigma_b (1 + 1.35\ \psi_k)$ at $\psi_b \leq 0.15$ and $S_k = \sigma_b(0.8 + 2.06\ \psi_k)$ when $\psi_b > 0.15$, where ψ_k is the final and ψ_b the uniform reduction in cross-sectional area.

References: Fridman, Ya.B., Mekhanicheskiye svoystva metallov [Mechanical Properties of Metals], 2nd Edition, Moscow, 1952.

N.V. Kadobnova

FREE-CUTTING STAINLESS STELL is stainless steel which is improved for working on automatic and semiautomatic machines; additions of sulfur, selenium, and phosphorus provide for good machinability. Sulfur or selenium, and sometimes phosphorus as well, in the structure of the free-cutting stainless steels have the form of finely granulated nonmetallic inclusions – sulfides, selenides, and phosphides (Fig. 1) which, located between the metal particles, provide for easier separation of the chip from the surface of the part being worked. Most often the addition of sulfur to 12%-chrome free-cutting stainless steel is performed together with the addition of 0.5% Mo in the form of molybdenum sulfide, which aids in improved distribution of the sulfides and facilitates hot working of the steel. Sometimes for this same purpose zirconium is added along with the sulfur, which in the steel structure has the form of zirconium sulfides. The chemical composition of the most typical free-cutting stainless steels is presented in Table 1, and the tempering temperature is shown in Fig. 2. The presence of a large amount of nonmetallic inclusions is reflected in the mechanical properties of the free-cutting stainless steel, giving it marked anisotropy. However, in specimens cut from the material along the direction of rolling the effect of sulfur content to 0.25% on the mechanical properties of 12%-chrome steel is hardly noticeable, while the fracture resistance and the relative elongation vary little in comparison with steel not containing sulfur. The chrome-nickel austenitic free-cutting stainless steels have in their composition selenium or tellurium (analogs of sulfur), since these additives improve the pressure

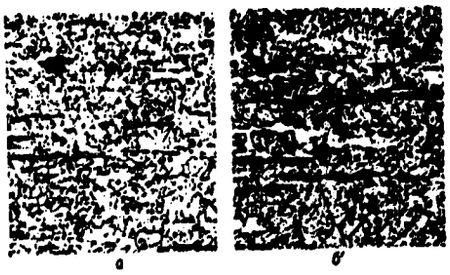


Fig. 1 Microstructure of stainless 12%-chrome steel with addition of sulfur: a) After annealing at 843°, furnace cooling (HB = 150 kg/mm^2); b after quench from 982° in oil and tempering (HB = 375 kg/mm^2).

TABLE 1

Chemical Composition of Free-Cutting Stainless Steel

Сталь по ГОСТ 1	2 Содержание элементов (%)							3 другие элементы
	C	Si	Mn	Cr	Ni	S	P	
4 Х14 (ЭИ241)	<0,15	<0,7	<0,7	13—15	—	0,2—0,4	<0,035	—
5 ЭИ474	0,2—0,3	<0,5	0,8—1,2	12—14	1,5—2,5	0,15—0,25	0,08—0,15	—
6 Х18Н10Е (ЭИ453)	<0,12	<0,8	1—2	17—19	9—11	<0,02	<0,035	Te или Se 0,18—0,35 7

1) Steel per GOST; 2) content of elements (%); 3) other elements; 4) Kh14 (EI241); 5) EI474; 6) Kh18N10E (EI453); 7) Te or Se.

TABLE 2

Mechanical Properties and Heat Treatment of Free-Cutting Stainless Steel

Сталь 1	2 Термическая обработка	3 Твердость	4 σ_b (кг/мм^2)	δ (%)
5 Х14 (ЭИ241)	Состояние поставки (прутки) 6	$HB(d_{отп})$ 3,6—4,2 мм	—	—
8 ЭИ474 (МПТУ 4157-53)	Состояние поставки (прутки) 9	$HB(d_{отп})$ 3,6—4,2 мм	70—100	—
10 То же	Отжиг 11	RC 23—25	85	10
» 12	Закалка с 1030—1050° на воздухе, отпуск при 180—240°	RC 42—52	165	3
» 13	Закалка с 1030—1050° на воздухе, отпуск при 240—280°	RC 53	162	5
Х18Н10Е (ЭИ453)	Закалка с 1050° в воде	HB 140—223 кг/мм^2	55 ($\sigma_{0,2}$=20)	40 (ψ=40)
14	15	16		

1) Steel; 2) heat treatment; 3) hardness; 4) σ_b kg/mm^2; 5) Kh14(EI241); 6) as delivered (rods); (rods); 7) $HB(d_{otp})$; 8) EI474 (MPTU 4157-53); 9) as delivered (rods); 10) same; 11) anneal; 12) air quench from 1030-1050°, temper at 180-240°; 13) air quench from 1030-1050°, temper at 240-280°; 14) Kh18N10E (EI453); 15) water quench from 1050°; 16) HB 140-223 kg/mm^2.

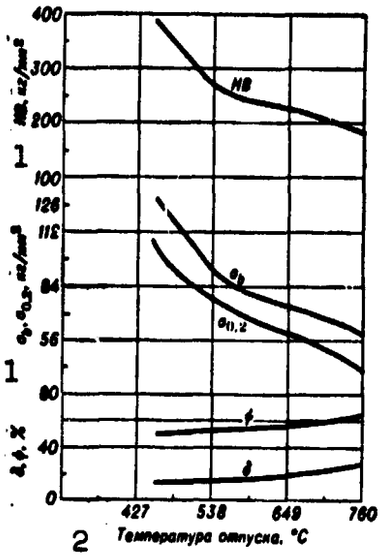


Fig. 2. Variation of mechanical properties of steel with 0.11% C, 13% Cr and addition of sulfur, as a function of tempering temperature (soak for 5 hours, air cooled). 1) HB kg/mm^2; 2) tempering temperature, °C.

workability of the steel in the hot condition. The corrosion resistance of the free-cutting stainless steels is somewhat lower in comparison with the usual grades of these steels. In atmospheric conditions the free-cutting stainless steels have about the same corrosion rate as ordinary stainless steel; the resistance to oxidation deteriorates with increases temperature.

Applications: steel Kh14 – for parts requiring high wear resistance (bolts, nuts, gears and other threaded details); EI474 steel – for instrument components with high hardness (trunnions, gears, transmission shafts, etc.): Kh18N10E steel – for components of medium hardness which are machined on automatic machine tools.

References: Khimushin F.F., Nerzhaveyushchiye stali (Stainless Steels), Moscow, 1963: Watkins S.P., "Metal Progr.", 1941 v. 39, No. 4, p. 452; No. 6, p. 710.

F.F. Khimushin

FRICTION CAST IRON — is a cast iron used for parts of braking devices. It is characterized by a high friction coefficient, a high wear resistance and by the fact that no seizing takes place within the wide temperature range caused by the friction during braking. In service, friction cast iron must well resist thermal cracking under the high stress caused by the great temperature difference between the friction surface and the underlying layers; it must have a high heat conductivity to remove quickly the heat formed on the surface of the friction joint, and a sufficiently high strength at normal and higher temperatures.

Chemical Composition of Friction Cast Iron

Область применения	Содержание элементов (%)							
	C	Si	Mn	P	S, не более	Cr	Ni	др. элементы
Авиастроение . .	3,25	2,4	0,70	—	—	—	0,75	0,75 Mo
То же	3,4—3,8	2—2,5	0,6—1	⩽0,4	0,1	0,2—0,5	0,8—1,4	0,2—0,5 Mo
То же	3,5—3,8	1,4—2,2	0,6—0,9	⩽0,1	0,12	0,3—0,6	0,5—2	0,7—0,9 Mo
То же	3,7—3,9	1,45—1,65	—	—	—	0,3—0,4	1,35—1,55	0,3—0,4 Mo
Автомобилестроение, МАЗ . . .	3,25—3,5	2,2—2,5	0,6—0,8	⩽0,2	0,12	0,25—0,6	—	0,15—0,35 Cu, 0,03—0,06 Ti
То же, ГАЗ . . .	3,55—3,8	1,9—2,15	0,6—0,9	0,2—0,3	0,13	⩽0,2	—	—
То же, ЗИЛ . . .	3,2—3,4	1,9—2	0,5—0,8	0,15—0,2	0,12	0,25—0,35	0,25—0,35	—
Тормоза Кировского з-да . . .	2,9—3,5	1,7—2,3	1,7—2,3	0,3—0,6	0,15	⩽0,3	⩽0,3	—
Тормоза спец. назначения . . .	2,9—3,45	1,25—1,53	1,85—2,45	0,45—0,75	—	⩽0,2	—	0,06—0,1 Ti
Ж.-д. тормоза . . .	3,6—3,8	1,1—1,3	0,6—0,8	—	—	—	—	0,5 Mo
То же	2,9—3,3	1,2—1,6	до 0,8	1—1,4	0,15	—	—	—
То же (ГОСТ 6921—54) . . .	3—3,4	1—1,5	1—1,5	0,2—0,4	0,2	—	—	—

1) Field of application; 2) percentage of elements; 3) not more than; 4) other elements; 5) aircraft construction; 6) the same; 7) automobile industry, industry, MAZ; 8) the same, GAZ; 9) the same, ZIL; 10) brakes of the Kirov Plant; 11) brakes for special purposes; 12) railroad brakes; 13) the same (GOST 6921-54); 14) up to.

Nonalloyed and low-alloy gray irons with pearlitic base are used for parts of braking devices; their chemical composition is quoted in the Table.

Gray cast iron with an increased carbon content (3.6-3.8%) has a lower tendency to crack thermally and tc seize. Phosphorus increases the wear resistance and the friction properties of gray iron, but it promotes the cracking. Nickel and molybdenum increase the rigidness of pearlite and, therefore, increase the strength and wear resistance.

Owing to the brittleness of gray iron and its tendency to crack thermally which frequently causes a breakage of the braking devices, the latter are manufactured by a bimetallic method; by welding the cast iron on a steel frame. This combination guarantees a high toughness of the part and the high resistance characteristic for gray iron, and avoids also a disintegration of the part in the cause of breakage. The gray-iron layer is welded on the steel frame during the casting; the liquid gray iron is overheated to 1570°. Cast iron for bimetallic brakes is founded in cupola furnaces or in other founding units.

In the automobile industry, brake shoes of pearlitic or pearlite-ferritic malleable iron are also used. Brake shoes of graphitized steel (see Graphitization of steel) with a content of 1.5% free graphite give satisfactory results. High-alloy iron with a composition similar to that of the Ni-Resist grade ZhChNDKh15-7-2 (see Scale-resistant cast iron) is used for the brakes of windlasses which work in sea water.

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lit'yu [Handbook on Iron Casting], 2nd Edition, Moscow-Leningrad; Larin, T.V., Devyatkin, V.P. and Tarasenko, A.Ya., Puti povysheniya friktsionnykh svoystv i iznosostoykosti tormoznykh kolodok podvizhnogo sostava zheleznykh dorog [Methods to Increase the Friction Properties and the Wear Resistance of the Brake Shoes of Railroad Rolling Stock], in the book: Trudy 3 Vses. konferentsii po treniyu i iznosu v mashinakh [Transactions of the 3rd All-Union Conference on Friction and Wear in Machines], Vol. 2, Moscow, 1960; Hall, A.M., Nikel' v chugune i stali [Nickel in Cast Iron and Steel], translated from English, Moscow, 1959.

A.A. Simkin

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[Transliterated Symbols]

1648 МАЗ = MAZ = Moskovskiy avtomobi'nyy zavod = Moscow Automobile Plant

1648 ГАЗ = GAZ = Gor'kiyevskiy avtomobil'nyy zavod = Gor'kiy Automobile Plant

1648 ЗИЛ = ZIL = zavod imeni Likhacheva = Likhachev Plant

FRICTION CERMET is an alloy metals (iron, copper, lead, chromium, nickel and others) with nonmetallic additives – asbestos, graphite, barite, sulfides, oxides and others, prepared using the powder metallurgy method and intended for components operating under frictional conditions. Friction cermet is produced in the form of various bimetallic products in which the cermet frictional layer is sintered onto a steel base. Depending on the chemical composition and the product usage, the friction layer is in the range of 0.8-5 mm. Two types of friction cermets are produced – using iron and copper bases. The iron-base cermets are used primarily for operation under conditions of dry friction, while the copper-base are used in an oil medium.

TABLE 1

Chemical Composition of Friction Materials (%)

1 Тип фрикц. металлокерамики	Fe	Cu	Pb	Графит 2	Барит ($BaSO_4$) 3	Кремнезем (SiO_2) 4	Асбест 5	Сульфид меди 6
7 На железной основе	Основа	10–15	–	5–9	2.5–3	0–3	0–3	0.5–7
9 На медной основе	0.2–	Основа	5–15	4–8	–	0.3–0.5	0.3–0.5	–

1) Type of friction cermet; 2) graphite; 3) barite ($BaSO_4$); 4) silica (SiO_2); 5) asbestos; 6) copper sulfide; 7) iron-base; 8) base; 9) copper-base.

The chemical composition of the cermet fricition materals produced in the USSR is given in Table 1. In addition to the materials listed in the table, a friction cermet is produced in small quantities in the USSR whose base (iron) is alloyed with Ni, Cr and W. This cermet has high wear-resistance performance but less stable characteristics of its friction properties (see Tables 2, 3). The figure shows a view of a

cermet friction brake disc.

TABLE 2

Basic Properties of Friction Cermets

1 Свойства	2 Единица измерения	3 Фрикционная металлокерамика: 4 железная основа	5 медная основа
6 Плотность	7 г/см³	6,65—6,7	5,4—5,8
НВ	8 кг/мм²	60—80	18—25
9 $\sigma_{в}$ срез	10 кг/мм²	6,8—7	6—7
σ_{-1}	10 кг/мм²	16,5—17	25—28
$\sigma_{б}$	10 кг/мм²	3—5	2—4
$a_{н}$	11 кгм/см²	0,06—0,07	—
12 λ в интервале 20—500°	13 $\frac{кал}{ом \cdot сек \cdot °C}$	0,062—0,072	0,095—0,1
14 $\alpha \cdot 10^{6}$ в интервале 20—500°	1/°C	11,5—18	17,6—22
15 Коэфф. трения по стали:			
16 при сухом трении	—	0,5—0,45	0,28—0,3
17 в масляной среде	—	0,1—0,12	0,1—0,12
18 Коэфф. стабильности	—	0,891—0,895	—
19 Эффективность торможения	—	$7,36 \cdot 10^{-4}$	—
20 Износ за одно торможение по чугуну ЧНМХ	мм	0,053—0,06	—

1) Property; 2) unit of measurement; 3) friction cermet; 4) iron-base; 5) copper-base; 6) density; 7) g/cm^3; 8) kg/cm^2; 9) $\sigma_{b\ srez}$; 10) kg/mm^2 11) kgm/cm^2; 12) λ in range 20-500°; 13) cal/ohm-sec-°C; 14) $\alpha \cdot 10^6$ in range 20-500°; 15) friction coefficient on steel; 16) with dry friction; 17) in oil medium; 18) stability coefficient; 19) braking effectiveness; 20) wear per single stop on ChNMKh iron.

TABLE 3

Areas and Conditions of Application of Friction Cermets

1 Тип металлокерамики	2 Типичные условия применения	3 Основные области применения
На железной основе 4	5 Сухое трение. Рабочее давление 20—30 кг/см². Скорость торможения 20—25 м/сек. Поверхностная рабочая темп-ра 900—1200°. Объемная рабочая темп-ра 300—400°	6 Тормозные диски авиационных самолетов, тормозные узлы экскаваторов
7 На медной основе	8 Масляное трение. Рабочее давление 5—10 кг/см². Скорость торможения 10—15 м/сек. Поверхностная рабочая темп-ра 70—80° (объемная рабочая темп-ра 35—40°)	9 Узлы трения шкур автомобилей, экскаваторов, тракторов

1) Type of cermet; 2) typical application conditions; 3) basic areas of application; 4) Iron-base; 5) dry friction. Working pressure 20-30 kg/cm^2. Braking speed 20-25 m/sec. Surface operating temperature 900-1200°.

Bulk operating temperature 300-400°; 6) brake discs for jet airplane wheels, brake components for excavators; 7) copper base; 8) fluid friction. Operating pressure 5-10 kg/cm^2. Braking speed 10-15 m/sec. Surface operating temperature 70-80°. Bulk operating temperature 35-40°; 9) hydraulic clutch components for trucks, excavators, tanks.

References: Rakovskiy V.S. and Saklinskiy V.V., Metallo-keramkia v mashinostroyenii (Cermets in Machine Construction), M., 1956; Samsonov G.V., Plotkin S.Ya., Proizvodstvo zheleznogo poroshka (Production of Iron Powder), M., 1957; Bal'shin M.Yu., Poroshkovaya metallurgiya (Powder Metallurgy), M., 1948.

V.S. Rakovskiy

FROST-RESISTANT RUBBER – rubber which retains its elastic properties at low temperatures and is capable of undergoing large reversible formations over a wide temperature range. As the temperature drops polymers and rubbers based on them lose their flexibility and behave like solids (glass). This is manifested external in a loss of elasticity, which destroys the usefulness of rubber articles.

TABLE 1

1 Показатели	2 Температура (°С)			
	20	−40	−60	−[illegible]
3 Предел прочности при разрыве (кг/см²)	150	—	—	600
4 Относительное удлинение (%)	200	120	60	12
Твердость по ТМ-2 5	60	80	90	100
Восстанавливаемость после сжатия (%) 6	95	60	30	5

1) Characteristic; 2) temperature (°C); 3) ultimate tensile strength (kg/cm^2); 4) relative elongation (%); 5) hardness in TM-2 apparatus; 6) restoration after compression (%).

TABLE 2

Каучуки 1	Температура стеклования (°С) 2	Каучуки	Температура стеклования (°С)
3 Натуральный	−65	Дивинилнитрильные: 12	
4 Дивинильные:		СКН-18	−18
6 СКД 5	−105	СКН-26 13	−26
СКБ 7	−45	СКН-40 14	−21
8 Дивинилстирольные: СКМ	−70	15 Бутильные	−65
9 СКС-30	−65	16 Хлоропреновый	−10
СКС-10 10	−75	Силоксановый 17	−55
		Фторсодержащий 18	−30

1) Rubber; 2) vitrification temperature (°C); 3) natural; 4) divinyl; 5) SKD; 6) SKB; 7) SKBM; 8) divinyl styrene; 9) SKS-30; 10) SKS-10; 11) divinylnitrile; 12) SKN-18; 13) SKN-26; 14) SKN-40; 15) butyl; 16) chloroprene; 17) siloxane; 18) fluorine-containing.

The elasticity of a rubber is also affected by crystallization. Natural, chloroprene, isoprene, siloxane, butyl, and isobutylene rubbers and butadienpolymers with a regular structure are crystallized polymers. Divinylstyrene (SKS, SKMS) and divinylnitrile (SKN) rubbers, divinyl rubbers with an irregular structure (SKB, SKBM), etc. are uncrystallized rubbers. Freezing of a rubber, i.e., the transition from an elastic to a solid state, is accompanied by an increase in strength, hardness, and modulus of elasticity and a decrease in elongation and elastic restoration after removal of the deforming stress.

Table 1 presents data on the change in the properties of rubber based on the frost-resistant divinyl styrene gum SKMS-10 as the temperature drops.

The frost resistance of a rubber is essentially determined by that of the gum on which it is based.

Table 2 presents data on the vitrification temperatures of various gum rubbers.

TABLE 3

Количество пластификатора (вес. ч. на 100 вес. ч. каучука) 1	Коэфф. восстанавливаемости при −60° 2	Предел прочности при разрыве (кг/см²) 3	Твердость по ТМ-2 4
0	0.11	200	68
10	0.27	183	73
20	0.31	165	80
30	0.32	149	85
50	0.36	110	94

1) Amount of plasticizer (parts by weight per 100 parts by weight of gum); 2) coefficient of restoration at −60°; 3) ultimate tensile strength (kg/cm²); 4) hardness in TM-2 apparatus.

SKMS-10, SKBM, and SKD gums are used for rubber components which must operate in air over a temperature range of ±60°, while NK, SKS-30, SKN-18, and SKB gums are used for components which must function at −40° to −50°. SKN-18 is employed for petroleum-oil media over the temperature range ±50°, while SKN-26 gum is used for temperatures of −35°

to −40°. Addition of frost-resistant synthetic gums to gums with a low frost resistance increases the resistance of the latter. In practice, this makes it possible to produce rubbers with a high frost resistance and no loss of strength.

The frost-resistance of a rubber mixture is influenced by the following ingredients:

a) Vulcanizers have no material effect on the freezing temperature of rubbers; a few vulcanizing agents promote production of rubbers with a coarser structure (i.e., fewer bonds between the rubber molecules). Such rubbers are somewhat more susceptible to deformation at low temperatures, which in practice leads to a drop of 3-5° in the freezing temperature. These vulcanizing agents include tetramethyl thiram disulphide (in a proportion of 2-3 parts by weight to 100 parts by weight of gum) at a sulfur content of no more than 0.5 parts by weight, as well as certain other accelerators that do not require the mixture to contain sulfur for vulcanization.

b) Fillers have a varying influence on the freezing temperature of rubbers. In the case of vitrified rubbers increasing the amount of fillers, especially reinforcing fillers, reduces their frost-resistance and increases their vitrification temperature; in the case of crystallizable rubbers fillers hamper regrouping of the molecules from the random to the ordered state, so that crystallization becomes more difficult. The filler content of rubber mixtures varies from 50 to 150 parts by weight per 100 parts by weight of gum, depending on the hardness, durability, resistance to various aggressive media, etc., required of the rubber.

c) Softeners, provided that they combine well with the gum and themselves have a low freezing temperature, are capable of substantially reducing (by 10-15°) the freezing temperature of rubber mixtures. Such

softeners are referred to as plasticizers or antifreezes. Chemically, they are basically complex ethers of multibasic aliphatic and aromatic acids (e.g., the dibutyl or dioctyl ether of phthalic acid, the dibutyl ether of sebacic acid, and the tricresol ether of phosphoric acid). The amount of plasticizers used in a rubber mixture is usually 15-30 parts by weight per 100 parts by weight of gum.

Addition of a plasticizer improves the frost resistance of rubbers, increases their coefficient of restoration, and shifts their vitrification temperature toward lower temperature; however, it reduces their ultimate tensile strength, hardness, and durability, a phenomenon which must be taken into account in developing formulas for rubbers which must combine other properties with frost resistance.

Table 3 presents data on the variation in the coefficient of restoration (K_v), strength, and hardness of rubbers based on SKN-18 as a function of plasticizer (dibutylphthalate) content.

The frost resistance of a rubber is determined from its coefficient of frost resistance (GOST 408-53), its embrittlement temperature (GOST 7912-56), its coefficient of elastic restoration (TU MKhP 1161-58), etc.

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of the Physical Chemistry of Polymers], Moscow, 1960; Nemetallicheskiye materialy i ikh primeneniye v aviastroyenii [Nonmetallic Materials and Their Application in Aircraft Building], edited by I.P. Losev and Ye.B. Trostyanskaya, Moscow, 1958.

F.Ye. Fradkina

FTORLON – is a synthetic fiber developed in the USSR. A fluorine polymer soluble in acetone is the raw material. Ftorlon is manufactured from acetone solutions by the wet method. The specific properties of Ftorlon are: high resistance to aggressive chemical reagents (concentrated nitric acid, hydrogen peroxide, etc.), at temperatures up to 120°; high strength, high initial modulus, and lightproofness; incombustibility and flameproofness, water-repellency, high specific gravity, and a relatively low heat resistance (up to 120°). The fiber is produced in the form of a noncolored or colored filament thread with diverse general and elementar numbers. Details see Fiber from fluorine-containing polymers.

References: Zasulina, Z.A., Yakovleva, I.I. and Rogovin, Z.A., "Nauchno-issled. tr. Mosk. tekstil'n. in-t" [Scientific Research Transactions of the Moscow Textile Institute], 1956, Vol. 18; Zazulina, Z.A., Martsinkovskaya, R.N., Rogovin, Z.A., "Tekstil'naya promyshlennost'," 1957, No. 5; Dodonov, N.T., Zasulina, Z.A., "Khimicheskaya promyshlennost'," 1960, No. 4.

Z.A. Zasulina

FUNGUS RESISTANCE – see Biological Resistance.

FURFURAL-FURYL RESINS – are thermosetting resins obtained from furfural or furyl alcohol, possessing a high heat resistance, incombustibility and waterproofness. The furfural-furyl resins cure at higher temperatures and possess a higher heat resistance and alkaliproofness than the phenolic thermosetting plastics.

The furfural-acetone resin is one of the basic furfural-based resins, Furfural-acetone monomer is a high-boiling dark cherry-red liquid which forms a solid thermosetting resin at normal and raised temperatures under the effect of acid curing agents. Benzenesulfonic acid, phosphoric acid, etc., are used as curing agents. Furfural-acetone monomer is totally soluble in acetone; the Ostwald viscosity is not higher than 30 centipoises; the moisture content is not higher than 2%, the rate of polymerization with 3% benzenesulfonic acid at 170-180° is 30-110 sec; the specific gravity is not lower than 1.08. Furfural-acetone monomer is used for the production of heat resistant varnishes and impregnations, of noncombustible wood and of plates made from wood shavings, and also for the production of mineral-organic cement-less concrete (plastic concrete).

The solid furfural-acetone resin FA-15 (drop point 80-120° according to Ubbelohde) is a regulator of the curing rate of phenol-formaldehyde novolac resins.

The liquid furfural-phenol resins FM-3 and FM-4 possess good adhesive properties, heat resistance, and resistance to alkaline emulsions; they are used as a binder in the manufacture of abrasive cloths.

TABLE 1

Properties of Adhesives

Свойства 1	2 Марка			
	ФЛ-1 3	ФЛ-4 4	Ф-10 5	6 ФЛ-4с
7 Сухой остаток (%)	35—45	25—30	40—45	45—50
8 Вязкость по Форду — Энглеру (сек.)	30	20	30—40	Не менее 20
9 Эластичность пленки по шкале НИИЛК (мм)	10—15	3—5	—	Не более 1 мм
10 Сопротивление сдвигу (дюраль с дюралем, кг/см²): при 20° ; 11 ; 12	100—130	150—175	140—145	100—130
при 100°	—	—	100—110	—

1) Properties; 2) grade; 3) FL-1; 4) FL-4; 5) F-10; 6) FL-4s; 7) dry residue (%); 8) Ford-Engler viscosity (sec); 9) elasticity of the film according to the scale of the NIILK (mm); 10) shearing strength (Dural-Dural joints, kg/cm^2); 11) at ...°.

TABLE 2

Electric Insulating Properties of FL-4 and F-10 Films

Свойства 1	2 ФЛ-4			3 Ф-10		
	4 при 20°	5 после выдержки в воде в течение 24 час.	4 при 115°	4 при 20°	4 при 250°	6 после 48 час. в условиях гигроскопической влажности
7 Удельное поверхностное электросопротивление (ом)	1,1—2,5·10^{14}	1,5—3,4·10^{14}	4,6—4,9·10^{12}	1,7·10^{14}	7,8·10^{8}	9,0·10^{14}
8 Удельное объемное электросопротивление (ом·см)	4—5,5·10^{14}	1,6—5,4·10^{14}	0,1—2·10^{13}	1,2·10^{14}	8·10^{8}	2,3·10^{14}
9 Тангенс угла диэлектрич. потерь при частоте 50 гц	0,01—0,022	0,012—0,015	—	—	—	—
10 То же при частоте 10^6 гц	—	—	—	0,024	0,016	0,033
11 Диэлектрич. постоянная при частоте 50 гц	10,7	7,2	—	—	—	—

1) Properties; 2) FL-4; 3) F-10; 4) at ...°; 5) after being kept in water for 24 hours; 6) after being exposed to hygroscopic moisture for 48 hrs; 7) specific electrical surface resistance (ohm); 8) specific electrical volume resistance (ohm·cm); 9) tangent of the loss angle at 50 cps; 10) the same at a frequency of 10^6 cps; 11) dielectric constant at 50 cps.

The modified and nonmodified FL-2, FL-1, FL-4, F-10, and FL-4s furyl alcohol-base resins are used as varnishes for anti-corrosion coatings, for the preparation of hot-drying cements (for metals, concrete, and other materials), and also of hot-curing anti-corrosion adhesives.

FL-2 is used as a binder in the manufacture of electric carbons; FL-1, FL-4, and F-10 are used as anti-corrosion adhesives or, with and

without fillers, as coatings. Graphite, asbestos, and other materials are used as fillers. The furfural-phenol-formaldehyd resins cure on heating at 150-160°, or in the cold with addition of acid catalysts. These adhesives adhere well to metal, glass, concrete, wood, and plastics; they are resistant to water, kerosene, gasoline, oils, solutions of mineral salts, and to a number of organic solvents; they resist bases containing fluorine in low concentrations, but they do not resist oxidizers. The FL-1 adhesive and coatings based on it are stable in weakly alkaline and in acid media; FL-4 is stable in alkaline and in weakly acid media, F-10 in acid and weakly alkaline media. The furyl adhesives FL-1 and FL-4 retain their applicability for a long time in the working temperature range of −60° to +100°.

Films of the FL-4 and F-10 adhesives possess good electrical insulating properties, they virtually do not change in moist atmosphere and at temperatures of the order of 100°, they are highly waterproof and may be used under water.

FL-4s adhesive readily runs, and is used to tighten adhesive and electric spot-welded steel and aluminum joints which undergo a subsequent anodization; the adhesive does not swell during curing in thick layers, it resists acid and alkaline anodization media, and it is used at temperatures between ±60° and also for bonding metals and nonmetals. The properties of the adhesives are quoted in Table 1, and those of the films in Table 2.

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M.S. Krol'

Manuscript Page No.	[Transliterated Symbols]
1661	ФА = FA = furfurol'-atsetonovaya = furfural-acetone
1662	НИИЛК = NIILK = Nauchno-issledovatel'skiy institut lakokrasochnoy promyshlennosti = Scientific Research Institure of the Paint and Varnish Industry

GAGARIN'S PRESS – universal machine for tension, compression and flexure testing. It is distinguished by a screw-type loading mechanism and a lever-type force-measuring device. The maximum load of the press is 5000 kg. A peculiar feature is an automatic diagram apparatus that draws curves in the "absolute deformation-load" coordinates on a large scale. The values of the ultimate strength determined by the Gagarin's press diagram and from the indications of force-measuring devices of other testing machines are in good agreement. The error in determining the yield strength by the Gagarin's press diagram can reach for certain materials (for example, high-strength strength steel, various copper alloys, etc.) quite substantial values (10-20%). With the appearance of Gagarin's press use was first made of small (so-called Gagarin) specimens 3-6 mm in diameter for mass testing. At present Gagarin's press is replaced by more modern machine (for example, IM-4, IM-12 designed by the TsNIITMash). Gagarin's press was designed by the Russian engineer A.G. Gagarin in 1896 and was awarded a gold medal at the International Exposition in Chicago (1906).

References: Shaposhnikov, N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Testing of Metals], 2nd edition, Moscow-Leningrad, 1954.

I.V. Kudryatsev, D.M. Shur

GALENA – (lead glance) – a mineral, lead sulfide PbS, contains admixtures of Ag, Zn, Cd, Sb, Bi, Cu, In, Tl, Au, Pt, etc. Crystallizes in the cubic system. Is encountered in the form of coarsely crystalline and fine grained masses, frequently in the form of cubic, less frequently in the form of octahedral crystals. Structure of the type of common salt. Color lead gray, metallic luster. Mohs hardness 2-3, specific gravity 7.4-7.6, complete cleavagebility along the cube. Is soluble in nitric acid, t°_{pl} 1112°. The electric conductivity of galena increases with an increase in temperature, but at temperatures above 300° it drops sharply. It is diamagnetic, exhibits positive and negative photoelectric effects. Galena is found primarily in hydrothermal deposits: Altay, North Caucasus, Kazakhstan, Eastern Siberia (USSR), the state of Missouri (USA), Broken Hill (Australia), etc. Galena is a major lead ore from which silver is extracted concurrently. It is partially processed for obtaining white lead pigments, glaze, etc. Detectors are made from galena crystals which give a negative photoeffect.

References: Mineraly [Minerals]. A handbook, Vol. 1, edited by F.V. Chukhrov, Moscow, 1960; Betekhtin, A.G., Mineralogiya [Mineralogy]. Moscow, 1950.

T.K. Sukhushina

GAMMA-RAY FLAW DETECTION – inspection of products by gamma-ray irradiation. It is used in shipbuilding, metallurgy, construction of petroleum and gas pipelines, etc. Artificially-produced radioactive isotopes are used as gamma-ray sources. Gamma-ray flaw detection has in a number of cases substantial advantages over other method of nondestructive testing, but it requires protection from the harmful biological effect of the radiation. The gamma-radiation source is placed at a specified distance (focal distance) from the article being inspected, while a device for recording this radiation is placed at its other side. Gamma-ray flaw detection is based on the dependence of gamma-radiation attenuation on the density of the absorbing medium. Section of the product being inspected (of the density disturbance type) attenuate the radiation flux to a lesser extent than sections without flaws. The change in the intensity of radiation which passes through the different sections of an article is recorded by an intensity indicator, which makes it possible to judge about the quality of the article. Depending on the type of indicator used, a distinction is made between: gamma-ray radiography (where the indicator is a special x-ray film), xeroradiography (xerox plate, which loses its electrical charge due to the radiation effect), visual method (a screen which luminesces due to the radiation), ionization method (various electrical indicators which transform the

Fig. 1. Gamma radiograph of a welded seam section with poor penetration, slag inclusions and pore accumulations.

intensity into electrical signals proportional to it). See: Xerographic X-Ray and Gamma-Ray Flaw Detection, Visual Method of X-Ray and Gamma-Ray Flaw Detection.

Fig. 2. Gamma radiograph of an assembled switch (a break in a current-feeding wire can be seen).

References: Tatochenko, L.K. and Medvedev, S.V. Promyshlennaya gamma-defektoskopiya [Industrial Gamma-Ray Flaw Detection], Moscow, 1955; Sokolov, V.S. Defektoskopiya materialov [Flaw Detection of Materials]. 2nd edition, Moscow-Leningrad, 1961; Rumyantsev, S.V. and Grigorovich, Yu.A., Kontrol' kachestva metallov gamma-luchami [Quality Control of Metals by Gamma-Rays]. Moscow, 1954; Rumyantsev, S.V., Primeneniye radioaktivenykh izotopov v defektoskopii [The Use of Radioactive Isotopes in Flaw Detection]. Moscow, 1960.

L.K. Tatochenko

GARNET – mineral of the orthosilicate group with isolated SiO_4 tetrahedra in the crystal structure. It occupies the seventh place with respect to natural prevalence. The general formula is $R''_3R''_3[SiO_4]_3$, where R''_3 is Mg, Fe", Mn" and Ca, and R''_2 is Al, Fe", Cr, Ti. Usual admixtures are Na_2O, K_2O, P_2O_5, V_2O_3, ZrO_2, sometimes Se, less frequently others. Luster oily, glassy to adamandine, white streaks, uneven fracture. Garnet is frequently present as a neogene in crystal shales. Can be also obtained artificially. The main forms of garnet are a part of two isomorphous series: adamandite and andradite (Table).

TABLE

Main Forms of Garnet

Изоморфный ряд 1	Название минерала 2	Формула 3	Уд. вес 4	Твердость по Моосу 5	Цвет 6	Показатель светопреломления 7	Растворимость в HCl 8
Альмандиновый 9	Альмандин 10	$Fe_3Al_2[SiO_4]_3$	4.25	7,5–8	Красный, фиолетовый, бурый 11	1.830	Растворяется после прокаливания 12
13 То же	Пироп 14	$Mg_3Al_2[SiO_4]_3$	3.51	7,0–7,5	Кроваво-красный 15	1.705	То же 13
»	Спессартин 16	$Mn_3Al_2[SiO_4]_3$	4.18	7.0	Светло-желтый до коричневого 17	1.800	»
Андрадитовый 18	Гроссуляр 19 (эссонит, гессонит)	$Ca_3Al_2[SiO_4]_3$	3.53	6,5–7,0	Бледно-зеленый, коричневый 20	1.735	»
13 То же	Андрадит 21	$Ca_3Fe_2[SiO_4]_3$	3.75	6,9–7,0	Светло-зеленый до черного 22	1.895	»
»	23 Шорломит	$Ca_3(Al, Fe, Ti)_2 \times$ $\times (Si, Ti)O_{12}$	3.88	7.0	Черный 24	2.00	»
»	Уваровит 25	$Ca_3Cr_2[SiO_4]_3$	3.52	7,0–7,5	Изумрудно-зеленый 26	1.870	Не растворяется 27

1) Isomorphous series; 2) name of mineral; 3) formula; 4) specific weight; 5) Mohs hardness; 6) color; 7) light refraction index; 8) solubility in HCl; 9) adamandite; 10) adamandine; 11) red, violet, brown; 12) is soluble after calcining; 13) same as above; 14) pyrope; 15) blood red; 16) spessartine; 17) light-yellow to cinnamon brown; 18) andradite; 19) glossularite (essonite, hessonite); 20) pale-green, cinnamon brown; 21) andradite; 22) light-green to black; 23) shlorlomite; 24) black; 25) uvarovite; 26) emerald green; 27) is not soluble.

Among the intermediate varieties we find: rhodolite, demantoid, chrysolite, melanite, topazolite, aplome, allochroite, romantsovite,

colophonite, polydelphite, etc. The main user of garnet (primarily of adamandite, less frequently of rhodolite, spessartine and andradite) is the abrasives industry (sandpaper for polishing of wood, leather, rubber, plastics and powders for glass polishing). Transparent, intensely colored, flawless, pure crystals of pyrope, adamandite, melanite, uvarovite, hessonite and chrysolite are used in the making of jewelry. The same almandite and pyrope crystals are used in nonprecision instrument making as industrial jewels, replacing the more expensive sapphire and ruby, in the production of ceramic floor tiles. It has a new use in electronics (synthetic garnet) as an effective replacement of titanates in radar and other microwave installations.

References: Betekhtin, A.G. Kurs mineralogii [A Course in Mineralogy], 3rd edition, Moscow, 1961; Chernosvitov, Yu.L., Granat [Garnet] in the book Nemetallicheskiye iskopayemyye SSSR [Nonmetal Minerals of the USSR], Vol. 5, Moscow-Leningrad, 1941; Trebovaniya promyshlennosti k kachestvu mineral'nogo syr'ya [Industrial Requirements Put to the Quality of Mineral Raw Materials], Issue 3; Chernosvitov, Yu.L. Granat [Garnet], Moscow-Leningrad, 1962; "Electronics," Vol. 30, No. 6B, 1957.

Yu.L. Chernosvitov

GAS CORROSION OF METALS. The majority of gases and gaseous media in technology interact with metal and alloys at high temperatures. The interaction of metals and alloys with atmospheric oxygen is most extensively studied. Below we consider the effect of gaseous media on the corrosion of the iron group of metals, and of stainless and high-temperature oxidation resistant steels and alloys. The corrosion of Ti, Nv, V, Mo, W and other metals is considered in articles about these metals.

Gas corrosion in an atmosphere of oxygen. Figure 1 shows oxidation

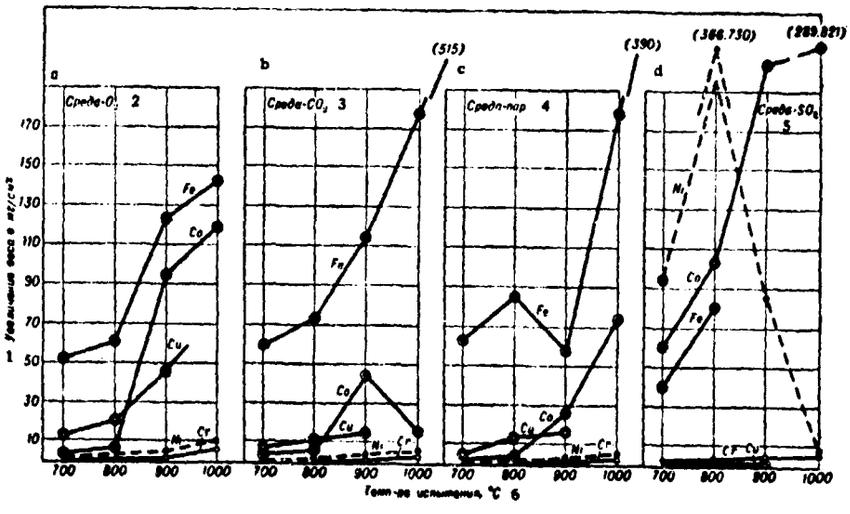

Fig. 1. High-temperature corrosion resistance of iron, nickel, cobalt, chromium and copper at different temperatures. a) In oxygen; b) in carbon dioxide; c) in water vapor; d) in sulfur dioxide. 1) Increase in weight in mg/cm^2; 3) medium – O_2; 4) medium – steam; 5) medium – SO_2; 6) test temperature, °C.

curves for pure Fe, Ni, Co, and also for Cr and Cu in various gaseous media at high temperatures. They attest to the fact that all the above metals, with the exception of Cr and Ni, are intensely oxidized at high

temperatures in oxygen, carbon dioxide, water vapor and sulfur dioxide atmospheres. The introduction of chromium into iron, nickel, cobalt or steel increases their resistance to oxidation; here the high-temperature corrosion resistance of steels is the higher, the higher their chromium content. Steel with 10-13% Cr is oxidation resistant up to 750°, with 17% Cr it is up to 800-900° and with 25% up to 1100°.

A similar effect is exerted by aluminum and silicon, the addition of which to chromium and chromium-nickel steels increases their high-temperature corrosion resistance even more. The high-temperature corrosion resistance of steel and alloys depends on the chemical composition and the protective effect of the oxide films which are formed on the metal surface in the process of oxidation, that is, on the melting temperature of the oxides, the ratio of the oxide volume V_{mo} to the metal volume V_{me}, which was used up in oxidation.

When $V_{mo}/V_{me} > 1$, very dense films, which reliably protect the metal from further oxidation, may form on its surface. The rate of oxidation of the metal in this case is most frequently governed by the parabolic law: $x^2 = Kt$ ($\underline{x}$ is the film thickness, $\underline{t}$ is the time and K is a constant). If the volume ratio is less than unity, the the films which are formed on the metal surface do not possess protective properties, they are very loose and porous. The rate of oxidation of metals in this case is very high and is frequently governed by the linear law, that is, $x = Kt$.

The formation on metal and alloy surfaces of refractory oxide films which cling tightly to the metal and which interfere with two-directional diffusion of metal and oxygen atoms, promotes increasing the high-temperature corrosion resistance. The majority of metals: Fe (to 570°), Cr, Ni, Al and others, form nonvolatile oxides which cling tightly to the metal surface and reliably protect the metal from further oxidation

(Fig. 2). However, a number of elements exist which act negatively on the high-temperature corrosion resistance of chromium and chromium-nickel steels. The high-temperature corrosion resistance is reduced most highly by V, Mo and B (Fig. 3). The negative effect of these elements begins to be felt starting with a certain concentration of the above in steel, which is due to the formation of unstable oxide films or low-melting-temperature and volatile oxides on the steel surfaces. Thus, for example, addition of Mo to steel aids in the formation on the metal surface of volatile oxides (MoO_3, melting temperature 790°), which disturb the continuity of protective oxide films and aid in ac-

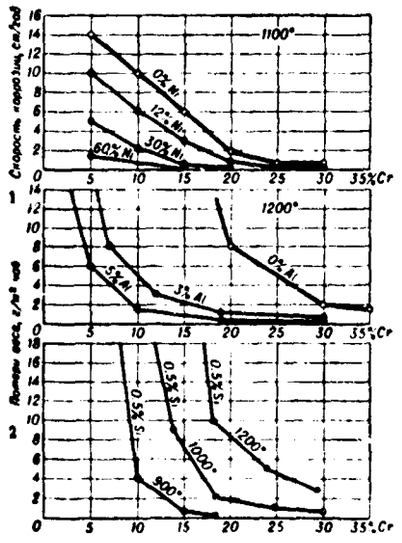

Fig. 2. Effect of nickel, aluminum and silicon on the high-temperature corrosion resistance of the iron-chromium alloy at various temperatures. 1) Corrosion rate, cm/year; 2) weight losses, g/m^2-hour.

Fig. 3. Effect of vanadium on the high-temperature corrosion resistance of chromium-nickel steel of type 20-20 at 1000° and test duration of 50 hours.

celerated oxidation of the alloy. In the presence of V low-melting tem-

perature oxide films are formed (V_2O_5, melting temperature 790°), which promote accelerated transfer of the metal and oxygen atoms through the oxide film, that is, accelerated oxidation of the metal. Boron also forms low-melting temperature oxide films on the surface of steel.

Several oxides are formed on the surface of multiple-component alloys. Certain data on the melting and sintering temperatures of the oxide are given in Table 1.

Iron oxides, which have a relatively low sintering temperature, have a high affinity to self-diffusion and to diffusion of elements through them. In conjunction with this, they poorly protect the metal from oxidation at higher temperatures.

TABLE 1

Density, Melting Points and Sintering Temperatures of Individual Oxides and Silicates

Формула [1]	γ [2] (г/см³)	Точка плавления (°С) [3]	Начало спекания (°С) [4]
FeO	5.9	1377	720
Fe_3O_4	5.2	1527	810
Fe_2O_3	5.2	1565	840
Cr_2O_3	5.2	2275	1260
SiO_2	2.2—2.6	1700	880
Al_2O_3	3.9	2050	1160
$2FeO \cdot SiO_2$	—	1205	615
$MnO \cdot SiO_2$	—	1270	655

1) Formula; 2) g/cm^3); 3) melting point (°C); 4) onset of sintering (°C).

It was established by study of the structure of oxide films of high-temperature corrosion resistant steels, containing Cr, Al or Si, that protective oxides of these elements are contained primarily in the internal layer of the scale, which is in direct contact with the steel surface. The transition layer between the oxide layer and the metal ensures reliable binding of the metal with the scale and increases the high-temperature corrosion resistance. Study of films of high-temperature corrosion resistant steels and alloys has established that most

frequently these films are formed in the form of double oxides with the structure of spinels such as $FeO \cdot Me_2O_3$ or $Fe_2O_3 \cdot MeO$. Films with this structure have high protective properties, particularly in the case when the alloying element which they contain has a smaller ionic radius and thus reduces the lattice parameters of the oxide. Oxides with a densely packed lattice exert a greater resistance to the diffusion of elements with a larger radius of oxygen and metal ions and thus reduce the oxidation rate. According to investigations by Dankov and Kornilov, the oxide film which is in direct contact with the surface of high-chromium steels, has a structure of a spinel such as $FeO \cdot Cr_2O_3$, while the external layer consists of a solid solution of $(FeCr)_2O_3$ oxides of the α-modification.

Wuestite (FeO) provides a poorer oxidation protection of the metal surface, since it has a defective lattice, due to which the diffusion

TABLE 2

Crystal Lattice Periods for Spinel-Type Oxide Phases

1 Тип окисла	Окисные фазы 2	Параметр решетки (Å) 3	1 Тип окисла	Окисные фазы 2	Параметр решетки (Å) 3
Чистые 4 окислы металлов	Fe_2O_3	8.32	На основе FeO 5	$FeO \cdot Cr_2O_3$	8.35
	Al_2O_3	7.90		$FeO \cdot Al_2O_3$	8.10
	Cr_2O_3	7.74		$FeO \cdot V_2O_3$	8.40
				$FeO \cdot Fe_2O_3$	8.38
На основе 6 Fe_2O_3	$MnO \cdot Fe_2O_3$	8.57	Окислы др. металлов 7	$CoO \cdot Cr_2O_3$	8.32
	$TiO \cdot Fe_2O_3$	8.50		$NiO \cdot Cr_2O_3$	8.31
	$CuO \cdot Fe_2O_3$	8.44		$MgO \cdot Al_2O_3$	8.07
	$CoO \cdot Fe_2O_3$	8.37			
	$NiO \cdot Fe_2O_3$	8.34			

1) Oxide type; 2) oxide phases; 3) lattice parameter (A); 4) pure oxides of metals; 5) with FeO as a base; 6) with Fe_2O_3 as a base; 7) oxides of other metals.

of iron or oxygen atoms is accelerated. The introduction of alloying elements into iron alloys reduces the formation of wuestite-type structure oxides on their surface and aids in the formation of spinel-type structure oxides.

Gas corrosion in an atmosphere of nitrogen. It is known that dilution of oxygen by nitrogen reduces the rate of oxidation of metals, although nitrogen also interacts with iron, stainless steels and high-temperature corrosion resistant alloys at high temperatures. However, the rate of interaction between metals and nitrogen in the air is substantially lower than the rate of interaction with oxygen. Alloys containing Cr, Al, Ti and Be form nitrides at high temperatures (500° and above) which is extensively utilized in the nitriding of products. Admixtures of Mo, V and Ti have a favorable effect on nitrogen absorption by steel, while admixtures of Ni have the opposite effect.

This peculiar feature of high-nickel steels is used extensively in the making of nitriding furnace fittings, since high resistance to nitrogen saturation is needed to prevent brittle failure of apparatus during extended operation. At moderate temperatures atomic nitrogen reacts strongly with the metal, while the molecular atmospheric nitrogen is inactive and, as a rule, it is not absorbed by the majority of alloys. A different situation is observed at higher temperatures, when the nitrogen becomes more active. For example, type 15-35, 25-20 and 18-20 chromium-nickel steels which are quite inert to nitrogen absorption at moderate temperatures, when heated to above 1000° absorb nitrogen which forms nitrides in them. Increasing the chromium content in iron increases the nitrogen absorption capacity. The formation of nitrides reduces the Cr content in the solid solution and reduces the oxidation resistance of the alloy. Nitrides of Cr, which have a different linear expansion coefficient than the solid solution and which frequently are located along the grain boundaries, sharply reduce the high-terperature corrosion resistance of the alloy, particularly when the components work under conditions of frequent temperature changes. In iron-chromium alloys, the nitrogen, penetrating the alloy, precipitates acicular ni-

trides the appearance of which is followed by the formation of austenite fields.

Gas corrosion in an atmosphere of furnace gases. Gaseous media which are formed on combustion of various kinds of coal, liquid and gaseous fuels (oil, gasoline, producer gas, lighting gas) always contain carbon dioxide, water vapor, oxygen and sulfur dioxide. In incomplete combustion of fuel carbon monoxide, carbohydrates, hydrogen sulfide and other carbon compounds (in the form of carbohydrates) are also present in addition to carbon dioxide and water vapor. The high-temperature corrosion resistance of metals depends on the gas composition (Fig. 1). Chromium has the best resistance to gas corrosion at high temperatures in the above media. Co and Ni exhibit a very low corrosion resistance in sulfur dioxide; here the corrosion maximum for Ni ensues at 800°. At 700° and above pure iron is highly destroyed by gas corrosion in all media. High-alloy chromium and chromium-nickel steel exhibit a higher resistance to corrosion in all media; here no great difference was discovered in these steels with respect to the composition of the gaseous medium. Nickel steels and Nichrome have showed a sharp drop in corrosion resistance in sulfur dioxide; here, unlike nickel the corrosion resistance decreases with an increase in temperature. The atmosphere of a furnace which contains an appreciable amount of water vapor and carbon dioxide or sulfur dioxide, acts more intensely than a pure air atmosphere.

When fuel is burned, sulfur burns, in an oxidizing atmosphere it is contained in the products of fuel corbustion in the form of sulfur dioxide while in a reducing atmosphere it may be in the form of hydrogen sulfide. Sulfur has a particularly strong effect on Ni, Co and alloys containing these elements. Ni and its alloys, absorbing sulfur from the furnace atmosphere, become entirely brittle as a result of

formation of low-melting-temperature sulfides along the grain boundaries, which weaken the bond bond between them (Fig. 4). Many sulfides

TABLE 3

Melting Temperature of Sulfur Compounds of Metals

Соединение 1	$t_{пл.}$ (°C) 2	Соединение 1	$t_{пл.}$ (°C) 2
La_2S_3	2100	Na_2S	978
Ce_2S_3	2000	NiS	810
ZnS	1800	NiS_2	787
MnS	1325—1620	K_2S	471
FeS	1197	As_2S	305
MoS	1185	MnO — MnS	1340
CuS	1130	FeS — MnS	1181
PbS	1112	FeO — FeS	940
CoS	1100	Fe — FeS	985
Al_2S_3	1100	Ni — NiS_2	625—645

1) Compound; 2) t_{pl}, (°C).

Fig. 4. Destruction of type 18-25 chromium-nickel steel (2.5% Si) by sulfur corrosion after being heated for 200 hours at 1000° in an atmosphere of products of combustion of lighting gas with an admixture of 2% of SO_2.

of metals, which are contained in high-temperature with the exception of nickel sulfides. However, the melting temperature of these sulfides can decrease sharply should they interact with the metal or its oxides (Table 3) with attendant formation of low-melting-temperature eutectics. These eutectics are precisely responsible for the reduction of corrosion resistance of alloys at high temperatures. The melting temperature of iron sulfide, which is 1197°, drops to 985° attendant to the formation of an eutectic from iron and iron sulfide. The eutectic from iron oxide and iron sulfide melts at 940°. A low-melting-temperature eutectic, consisting of nickel and nickel sulfide, melts at about 645°.

The corrosion resistance of chromium-nickel high-temperature corrosion-resistant steels in sulfur dioxide atmospheres depends highly on

the Cr:Ni proportion in the steel. When the Ni content in the steel is higher than that of Cr, it is susceptible to destruction by gas corrosion along the grain boundaries due to formation of a sulfide eutectic. Sulfur-containing gases exert a lesser influence on the high-temperature corrosion resistance in an oxidizing medium than they do in a reducing medium. Dense protective films may form in the oxidizing medium, which to a certain extent interfere with the formation of sulfides, while in a reducing medium such films are not formed and for this reason direct and faster formation of sulfides and their eutectics is observed. Increasing the content of Cr in its alloys with Fe or Ni increases their resistance to gas corroion in a sulfur-containing atmosphere. It is thought that the protective effect of an alloy of Cr with Fe in a hydrogen sulfide atmosphere is not effective at high temperatures, since a low-melting temperature eutectic from iron oxides and iron sulfide, which melt at 940°, appears. The protective effect of aluminum is substantially higher than that of chromium. At 400° and 450° an increased content of Al in steels increases the resistance to hydrogen sulfide. At higher temperatures this effect is not unique. First the resistance is reduced, and then when more than 4% of aluminum

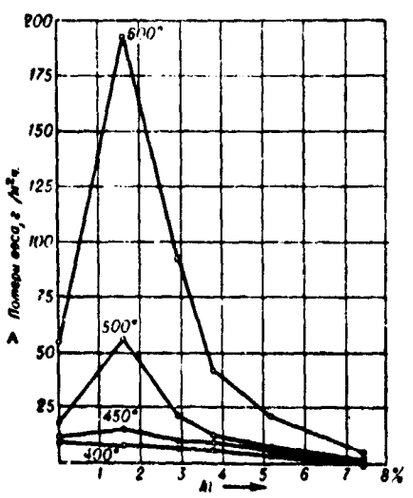

Fig. 5. Effect of aluminum on the corrosion resistance of iron in

hydrogen sulfide at 400-600°. A) Weight loss, g/m^2 hour.

is added, a substantial increase is observed (Fig. 5). Adding of aluminum to iron above 800° does not have a beneficial effect. Sulfide corrosion in this case is frequently amplified. Silicon also increases the corrosion resistance of high-temperature corrosion resistant steels (Fig. 6).

It is noted that carburization has a negative effect on the corrosion resistance in a sulfur-containing atmosphere. High-temperature hydrogen sulfide corrosion is a serious problem in the use of carbon and low-chromium (6% Cr) steels in the hydrogenation and dehydrogenation of petroleum, which take place under a high pressure and at high temperatures. Corrosion due to hydrogen sulfide and hydrogen is accompanied by the formation of scaly products of corrosion, which frequently peel off quite easily. The rates of corrosion failure depend on the steel compositions and on the hydrogen sulfide concentration and become higher with an increase in temperature and pressure. Specimens from type 18-8-Ti, 25-12 and 25-20 chromium-nickel steels yielded very good results without showing signs of scale formation. Good resistance to hydrogen sulfide corrosion was exhibited by submersion-aluminized carbon steel and 7% chromium steel.

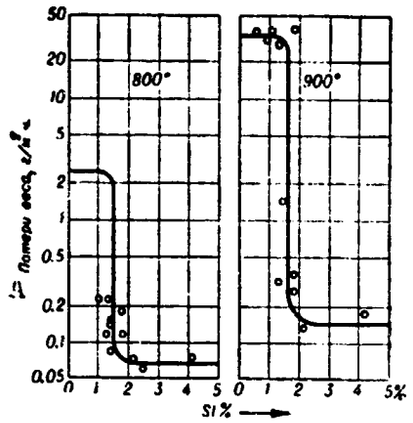

Fig. 6. Effect of silicon on the corrosion resistant of 6% chromium steel in hydrogen sulfide at 800° and 900°. A) Weight loss, g/m^2 hour.

Gas corrosion at high temperatures in water vapor. The reduction effect of hydrogen can become an oxidizing effect if an insignificant

amount of water vapor is added together with the hydrogen. The equilibrium conditions of reduction and oxidation of iron as a function of the temperature in the hydrogen-water vapor mixture have been studied in sufficient detail. Above 800° the oxygen of dissociating water vapor is particularly aggressive, and frequently failure is observed primarily along the grain boundaries. High-alloy chromium-nickel steels and alloys are very intensely oxidized by water vapor, which at high temperatures is partially dissociated into hydrogen and oxygen. At the average operating temperatures of steam power installations from 200° to 500°, at which the water vapor still does not dissociate, the superheated water vapor, just like hydrogen, has a strong effect on metals, making them brittle.

It was noted that stresses aid in the appearance of steam brittleness, particularly in the interval of 400-500°. Such steam brittleness was observed in Monel metal, in nickel and also in type 35-20 nickel-chromium steel, which is used at elevated temperatures and high water vapor pressures. Iron and low-alloy steels at 600° in superheated steam are oxidized by approximately a factor of 2 more intensely than in heated air.

Study of gas corrosion of metals in a water vapor atmosphere makes it possible to establish that the greatest oxidation takes place during the first 500 hours (Fig. 7); here about 70% of all the losses is devolved upon weight losses during the first 100 hours of a 2000 hour test. Chromium has a favorable effect on the resistance of steels to oxidation in a water vapor atmosphere.

It is noted that, scale film which forms in steam power installations due to gas corrosion is more loose than that formed by oxidation in air. The protective layer under water vapor conditions becomes due to the sintering process only at 700° and 800°.

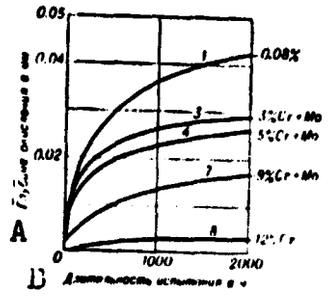

Fig. 7. Effect of the test duration (in hours) on the depth of oxidation of carbon (1, 0.08% C) and chromium (3, 4, 7, 8) steels with different chromium content tested in a water vapor temperature at 595°. A) Depth of oxidation in mm; B) test duration in hours.

Gas corrosion at high temperatures in neutral and protective atmospheres. The presence of gases containing hydrogen and carbon and also their mixtures with nitrogen is of significance for heating in a protective atmosphere. A distinction must be made between gases which act as oxidizers, which include carbon dioxide, and gases which act as reducing agents, which include carbon monoxide and hydrocarbons. As the temperature is increased, carbon dioxide has an increasingly higher oxidation effect.

Stainless and heat resistant steels and alloys which contain chromium exhibit an entirely different character of interaction with carbon dioxide. While for iron, at the constant ratio of partial pressures P_{CO}/P_{CO_2}, the oxidation region is replaced by a reducing region with a decrease in temperature, for chrome a reduction in temperature means replacement of the reducing region by an oxidizing region. It follows from this that the oxidation of chromium or chromium steel with Cr_2O_3 films depends primarily on the carbon dioxide which is thus formed. This points to the fact that an atmosphere from $CO - CO_2 - N_2$ is not suitable for oxidation-less heating of high-chromium steels.

Hydrogen has a high reducing capacity and can thus serve as an excellent protective gas. Furnaces with hydrogen atmosphere for bright annealing with iron heating elements can operate for very long periods

of time at 1100° and 1200°, if care is taken that the heating elements be cooled in a hydrogen atmosphere. Hydrogen which does not contain water vapor can also be used as a protective gas for bright annealing of stainless chromium-nickel steels and alloys.

Prevention of chrome oxidation by water vapor requires that the ratio of hydrogen and water vapor be very high. These ratios become larger with a decrease in temperature. The more hydrogen in the gas and the less water vapor, less is the chromium oxidized. Hydrogen protects chromium from oxidation at 750-850° only when its water vapor content is of the order of 0.01% and less, that is for H_2:H_2O ratios of the order of 10,000 (Fig. 8). Dissociated ammonium must be dried even more extensively. Cases are known when a bright surface could not be obtained when annealing brand 1Kh19N9 steel in moist electrolitic hydrogen. Pro-

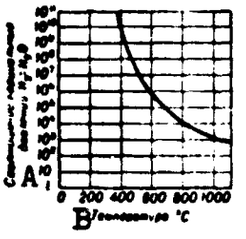

Fig. 8. Curve of equilibrium between chromium and a mixture of hydrogen with water vapor. A) Ratio of partial pressures H_2:H_2O; B) temperature, °C.

tective atmospheres which consist of a mixture of dissociated ammonium and hydrogen (75% H_2 and 25% N_2), upon deep drying, are being used for bright annealing of chromium-containing steels.

Carbon contained in gases acts the stronger, the greater is the reducing capacity of the gaseous mixture. This is utilized in practice for cementation of steels. Producer, water and lighting gases or pure hydrocarbons above 600° have a highly carbonizing effect on chromium-containing heat resistant steels and alloys with attendant formation of chromium carbides. However, if the steels contain other elements, which

have a high chemical affinity of carbon, such as for example, titanium niobium, then more stable carbides of these elements are formed as well as chromium carbides (depending on the temperature and composition). C Carburization of heat resistant steels and alloys is a detrimental factor. The presence of carbides has a negative effect on the mechanical properties, on the electric resistivity of heating elements, etc.

Study of the effect of protective atmospheres in heat treatment of highly heat resistant brand EI437B, EI617, EI867 and EI929 brand alloys makes it possible to establish that the best results are obtained when use is made of very highly purified and dried neutral gases (argon and helium). In this case no extensive changes are observed in the chemical compostion of surface layers and the alloy retains high service characteristics and a sufficiently bright surface. When industrial gases are used changes are observed in the surface layers which are due to the oxidizing effect of residues of oxygen, water vapor and carbon dioxide, which is detrimental to the aforementioned characteristics of the alloy. When using protective atmospheres consisting of nitrogen with an excess of hydrogen (with water vapor and other components removed) comparatively moderate changes are observed in the surface layers (for example at a depth of 0.07-0.1 mm in the EI437B alloy), which should be removed by grinding. When heating multi-component alloys (EI617, EI867, etc.) in an oxidizing atmosphere (air) more extensive changes in the surface layers are observed (Fig. 9), which is due to depletion of their Cr, Ti and Al which turn into scale, with the result that the heat-resistant characteristics of products are sharply impaired. For this reason a substantially greater layer (1.5-3 mm) is removed from the surface. It is expedient to heat treat heat resistant alloys in a well purified atmosphere of inert gases. Work-hardening produced by machining should be removed by additional heat treatment.

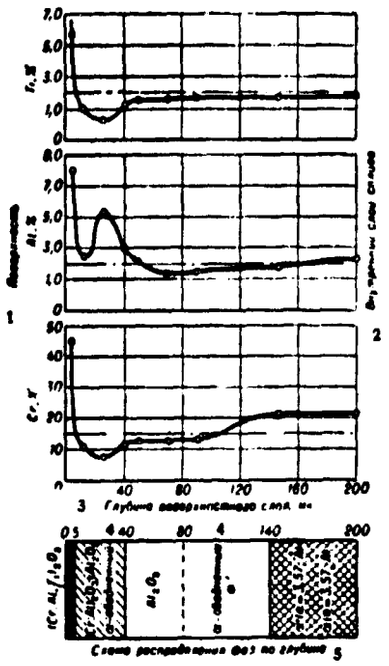

Fig. 9. Effect of heating at 1000-1300° during 200 hours on the change in structure of the EI617 alloy in surface layers. 1) Surface; 2) internal layer of the alloy; 3) depth of surface layer; 4) α-poor; 5) schematic of phase distribution in the depth.

Gas corrosion in hydrogen at elevated temperatures and high pressures. Hydrogen-containing gas media which operate under high pressures and at elevated temperatures, are extensively used in technology for t the production of synthetic ammonium, hydrated coal in obtaining synthetic gasoline and in other processes in the chemical petroleum, food and other branches of industry.

Hydrogen diffuses easily through the metal and reacts with oxides with attendant formation of water; with carbon, more precisely with cementite, with attendant formation of methane, with sulfur, phosphorus and a number of other elements with attendant formation of the corresponding compounds. If the reaction products which are thus obtained (for example, water vapor) as a result of oxidation, or hydrocarbons (for example, methane), as a result of interaction between hydrogen and iron carbide, have a substantially poorer diffusion ability, then this

results in the appearance of stresses, in loosening of the alloy structure, reduction of its strength and breakdown. The reaction of hydrogen with carbon steel is accompanied by decarbonization of the metal.

Figure 10 shows the effect of the hydrogen temperature and pressure on the resistance of two carbon steels with 0.76% and 0.22% C in tests of various length. The negative effect of hydrogen is felt strongly

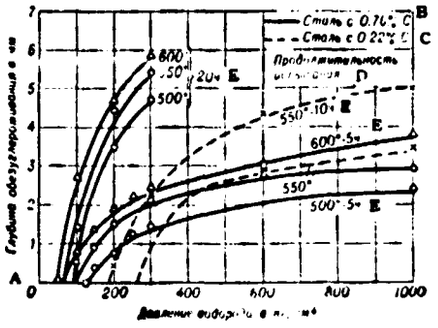

Fig. 10. Decarbonization of steel in a hydrogen atmosphere as a function of the pressure in test of varying duration at 500, 550 and 600°. A) Depth of decarbonization in mm; B) steel with 0.76%C; C) steel with 0.22% C; d) test duration; E) hours.

above 350° and, apparently, it depends little on the carbon content. At 300° and 1000 atm no detrimental effect of hydrogen for the given test duration was observed. Experience acquired in using carbon steel in high pressure ammonium-synthesis apparatus shows that carbon steel with properly removed oxygen worked beautifully for many years up to 200° and of the order of 800 atm. However, it failed very rapidly when the temperature was raised to 250-260°. Alongside with the reduction in strenth, plasticity and hardness, a sharp reduction in the steel's carbon was observed in the internal wall material.

Alloying of carbon steel with attendant formation of special chromium, vanadium and titanium carbides instead of cementite eliminates the harmful influence of hydrogen. This is due to the fact that not all the carbides are decomposed by hydrogen, as this takes place in cementite by the reaction $Fe_3C + 4H = Fe + CH_4$, and therefore, when the formation

of cementite in steels is prevented, hydrogen corrosion does not take place and alloyed steels exhibit high resistance to the destructive ef-

TABLE 4

Effect of the Hydrogen Pressure on Mechanical Properties of Carbon Steel at 400° and a Test Duration of 100 Hours

Давление водорода 1 (atm)	σ_b	$\sigma_{пц}$ 2	$\sigma_{0,2}$	δ (%)
	(кг/мм²) 3			
0	49.8	24.9	26.3	23.3
150	31	25.4	—	6.4
450	20	—	—	1.5
600	10	—	—	0.0

1) Hydrogen pressure (atm);
2) σ_{pts}; 3) (kg/mm^2).

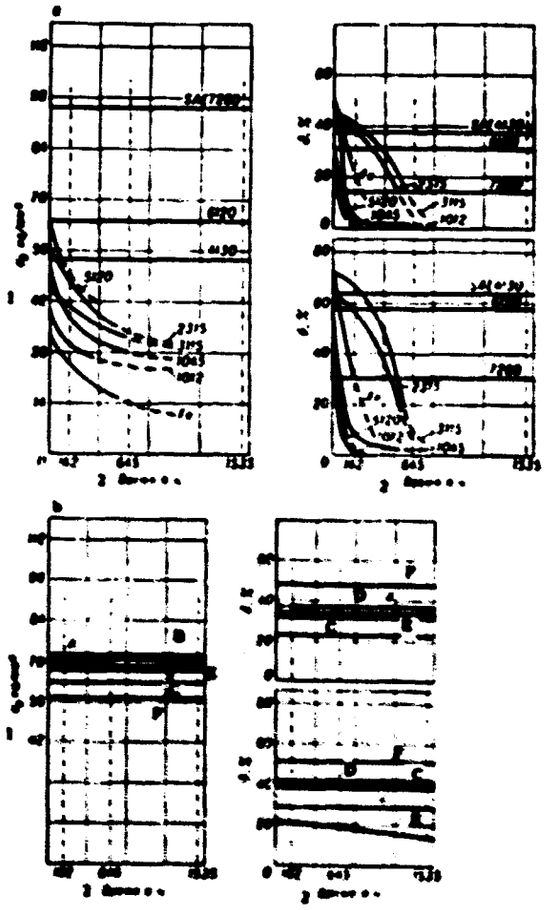

Fig. 11. Variation in the mechanical properties of steels as a function of the time the specimens were held in a nitrogen-hydrogen mixture at a pressure of 1000° and temperature of 500° (according to Maxwell). a) 1012 denotes steel, containing 0.12% C; 1045 denotes steel containing 0.45% C; 2315 denotes steel with 0.15% C, and 3.5% Ni; 3115 denotes

steel with 0.15% C, 1.25% Ni and 0.6% Cr; 4130 denotes steel with 0.3% C, 0.65% Cr and 0.2% W; 5120 denotes steel with 0.2% C and 0.75% Cr; 6120 denotes steel with 0.2% C, 0.9% Cr and 0.15-0.18% V; 7260 denotes steel with 0.6% C, 0.75% Cr and 0.75% W. b) A) Steel with 17% Cr; B) ATV-3; C) ATV-1; D) Midvalloy 25-20 (25% Cr and 20% Ni); E) NCT3 (25% Cr and 20% Ni); F) Resisteel 2600 (18% Cr, 20% Ni, 0.15% C). 1) σ_b, kg/mm^2; 2) time in hours.

fect of hydrogen (Fig. 11).

Ammonium synthesis apparatus which operates up to 600° and up to 300 atm is made from steel with 3-6% Cr and with an admixture of 0.40% of Mo or Mo + V, while at 500-550° and 600-1000 atm use is made of chromium nickel austenitic steel which have a higher creep resistance. A certain reduction in the impact ductility in austenitic steels is observed as a result of hydrogen absorption, which was noted in testing these steels after holding them for 120 hours in hydrogen at 600° and 1000 atm. This brittleness can be eliminated by adding tungsten and molybdenum. Among the postive qualities of chromium-nickel austenitic steels at these temperatures we should count the high resistance to nitriding and crack formation. Copper admixtures have a negative effect. In a number of cases both copper and copper-containing steel as well as copper-nickel steels fail rapidly.

The creep strength of steels drops more rapidly in a hydrogen atmosphere than in a nitrogen atmosphere, and the more intensely, the less is the steel alloyed. The best resistance was shown by EI559B steel, followed by EI559 while 30KhMA has the poorest resistance.

The effect of pressure and temperature on changes of the mechanical properties of the Hypernik alloy and 10% chromium steel with 0.15% C, smelted in vacuum (Table 5) was studied.

It follows from these data that 10% chromium steel has a sufficiently high resistance to hydrogen corrosion under the specified test conditions. The strength reduction at 500° is brought about by soften-

ing of the steel due to tempering. Tubular specimens were observed to fail under hydrogen pressures of 2000 atm, while oil filled tubes of the same size withstood a pressure of 4000 atm.

Methods for reducing gas corrosion. 1) Addition of special alloying elements (Cr, Ni, Al, Si) which impart high resistance to gas corrosion in the respective medium, to alloys. All the corrosion resistant and heat resisting alloys must contain Cr in a given quantity, and in a number of cases also Ni, Al, Si, etc. The addition of W, Mo and V

TABLE 5

Mechanical Properties of Steel (10% Cr, 0.15% C) After Being Held in Hydrogen Under Pressure at 400° and 500°

1 Условия испытания			2 Механические свойства		
P (атм) 3	Темп-ра (°С) 4	Длительность (час.) 5	σ_b 6 (кг/мм²)	δ (%)	ψ (%)
1000	400	168	117	11	36
7 контрольное	400	168	118	11	35
1000	450	168	103	9	43
1000	500	168	116	8	15
2000	500	120	67	15	54
2000	500	120	68	16	56

1) Test conditions; 2) mechanical properties; 3) (atm); 4) temperature (°C); 5) duration (hours); 6) (kg/mm^2); 7) control.

reduces the oxidation resistant of heat resisting alloys. 2) Electrolitic or chemical nickel plating, cladding by high-temperature oxidation resisting alloys or enamel plating. 3) Casehardening of components by diffusion saturation of the product surface by chromium, aluminum, silicon, beryllium. 4) Heat treating in inert protective media. 5) To ensure high service stability of products from heat resisting alloys it is necessary to remove (mechanically, chemically, by hydraulic abrasion or electrolytic methods) surface layers of metals which were depleted of a number of elements, after heat treatment or performing it in neutral media. 6) The use of chromium-nickel alloys with a high nickel

content or of alloys with a high silicon content (type 25-20 chromium-nickel steel with 3% Si or type 20-35 with 2% Si) is recommended for work in a highly carburizing reducing media. 7) The use of steels with a higher chromium content and a lower nickel content (type 28-4 chromium-nickel steels, high-chromium steels and pig irons) is recommended for work in media with a high sulfur content.

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F.F. Khimishin

GAS FILLED PLASTIC MATERIALS - see Foam Materials.

GAS-FILLED PLASTICS – ultralight plastics obtained from various synthetic polymers. A special feature of these materials is the nonuniformity of their physical structure, which resembles that of a hardened foam. Gas-filled plastics are distinguished by low specific gravity and high heat-, sound-, and electrical-insulating properties. The chemical and mechanical characteristics and thermostability of these plastics depend to a considerable extent on the characteristics of the initial polymers, while their insulating characteristics depend on their physical structure. Gas-filled plastics can be produced from all presently known polymers.

We can distinguish gas-filled plastics with a closed-cellular structure (plastic foam) and with an open-porous structure (porous plastic), in which the elementary cells or pores communicate with one another and with the surrounding atmosphere. Either plastic foam or porous plastic can be obtained, depending on the production method employed and the physicochemical characteristics of the initial polymers. The majority of gas-filled plastics (polyvinyl chloride foam, polystyrene foam) produced from thermoplastic polymers by pressing are plastic foams; porous plastics can be obtained from the same polymers by appropriate changes in the initial composition and frothing method. Plastic foams and porous plastics can be produced by the same chemical reaction of the initial components (e.g., so-called self-frothing compositions of the polyester urethane type), depending on the qualitative and quantitative composition of the initial substances. Gas-filled plastics can be classified both by structure and by elastic properties (rigid, semi-

rigid, and elastic). These materials are used commercially: 1) for producing light, rigid fillers for load-bearing structural elements, insuring high long-term resistance to thin metal facings, and to reduce the weight of finished products; 2) in the manufacture of critical radio and electronic components that must combine high radio transparency with good insulating properties, comparatively low weight, and sufficient mechanical strength and atmosphere-resistance; 3) in the manufacture of light, strong fillers for heat-insulating structures, insuring low temperature conductivity when heated on one side; 4) in the production of light nonsubmersible components and elements of floating structures that must function in various liquid media (water, gasoline, kerosene, oil, etc.) and have sufficient strength.

Gas-filled plastics are also widely used as damping materials to increase the fatigue strength of structures subjected to long-term vibration loads, as well as in the manufacture of products that must have high elastic characteristics (seats for automobiles, aircraft, etc.); they are also used in construction technology (as composite structures intended to muffle noise) and in the manufacture of household articles.

Gas-filled plastics are produced serially in the form of semifinished products, slabs, and molded articles.

For brief descriptions of the principal characteristics and applications of the most widely employed and promising gas-filled plastics see the articles entitled Foam materials, Silicoorganic plastic foam, Polyvinyl chloride foam, Polystyrene foam, Polyurethane foam, Phenol-formaldehyde plastic foam, and Reinforced plastic foam.

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V.A. Popov

GAS FLAME COATINGS – coatings applied to the surfaces of products by the gas flame method. Material in the form of wire, rod or gaseous powder jet, is heated when it passes through a flame and it is sprayed onto the surface to be coated by a compressed gas stream. Gas flame coatings are made from materials with melting temperatures from 50-60° to 3000°, and when plasma burners are used materials with higher melting temperatures are applied. Gas flame coatings may be continuous and porous. Porous metallic gas flame coatings are compacted by glazing or thermal diffusion roasting, treating by chemical reagents, impregnation by high-polymer materials; porous gas flame coatings from ceramic materials are compacted by impregnation. The figure shows the classifica-

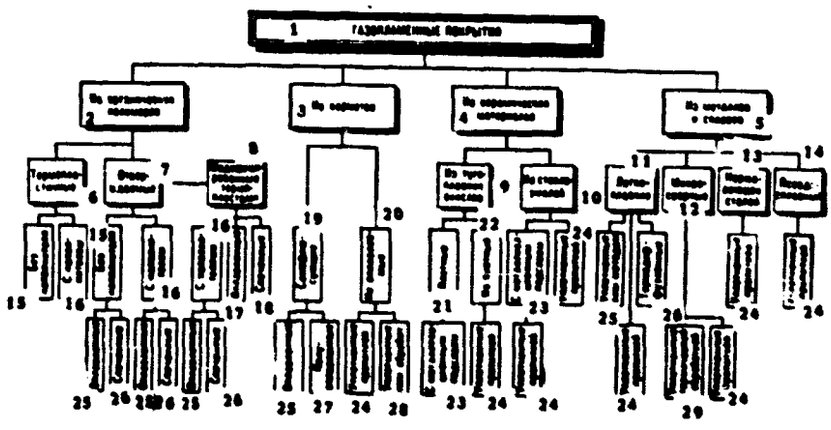

Fig. Classification of gas flame coatings by composition and the industrial application process. 1) Gas flame coatings; 2) from organic polymers; 3) from cermets; 4) from ceramic materials; 5) from metals and alloys; 6) thermoplastic; 7) hardenable; 8) modified by thermoplastics; 9) from refractory oxides; 10) from glass enamels; 11) low-temperature melting; 12) microweldable; 13) stainless steels; 14) pseudo-alloy; 15) without a filler; 16) with a filler; 17) glazed; 18) sintered; 19) self-fluxing; 20) nonglazable; 21) dense; 22) noncontinuous; 23) with a metallizing sublayer; 24) compacted by impregnation; 25) compacted by chemical means; 26) thermodiffusion; 27) half-glazed; 28) compacted by chemical treatment; 29) compacted by heat treatment.

tion of gas flame coatings by composition and the process of industrial application. Polyethylene, copolymers of ethylene with propylene, high-strength polystyrene, polyvinylbutiral, polyarylic resins, polycaprolactam and shellac are used as nonmetallic gas flame coatings. The optimum thickness of thermoplastic coatings is 0.2-0.3 mm, increasing the thickness of coatings reduces their adhesion properties, overheating upon increasing the thickness impairs the physicomechanical and chemical properties. Hardenable polymers (phenoladehide, alkyd, organic silicon, epoxy) are applied with a thickness of several mm without glazing of the successively applied layers; they are compacted by sintering or upon heating the coatings thus applied for the purpose of hardening. To prevent cracking, coatings from hardenable polymers are modified by thermoplastic materials which have elastic properties and by fillers. The physicomechanical properties of gas flame coatings from high polymers are determined by instruments used in testing of lacquer and paint coatings, and in the case of coatings of substantial thickness this is done by typical plastic testing instruments. The resistance of gas flame coatings to various media at temperatures up to 60° is given in Table 1. The physicomechanical indicators of certain thermoplastic gas flame coatings are given in Table 2, and of phenolaldehide resin are given in Table 3.

Polymeric gas flame coatings are used for restoring the dimensions of metal models, making of electric surface heaters, preventing icing of aircraft, protection of erosion wear and avitation of hydraulic turbine buckets and ship's propellers, electrical insulation of tool handles, corrosion protection of electroplating shop equipment, etc.

The composition and physicomechanical properties of metal and alloy gas flame coatings differ from the composition of properties of metals and alloys which are used for their application. The hardness of

metallizing gas flame coatings is higher than the hardness of the starting metals, they are capable of lubricant absorption and are character

TABLE 1

Resistance of Gas Flame Coatings to Various Media at Temperature up to 60°*

Среда 1	Концентрация раствора (%) 2	Полиэпоксиламид 3	Полиэтилен 4	Поливинилбутираль 5	Поливинилхлорид 6	Тиокол 7	Битум 8
HNO_3	10	R	0	R	0	Д	R
HCl	10	Д	0	Д	0	0	Д
H_2SO_4	10	Д	0	Д	0	0	Д
CH_3COOH	3	Д	0	Д	0	0	Д
H_2O	—	Д	0	Д	0	0	Д
C_2H_5OH	—	Д	0	Д	0	0	Д
C_6H_6	—	Д	0	Д	0	0	Д
CH_3COCH_3	—	Д	0	Д	0	0	Д
H_2SO_4	20	R	0	Д	0	0	Д
H_2SO_4	30	Д	0	Д	0	0	Д
HCl	30	Д	0	Д	0	0	Д
HNO_3	30	Д	0	Д	0	0	Д
H_2O_2	30	Д	0	Д	0	0	Д
NaOH	50	Д	0	Д	0	0	Д
KOH	50	Д	0	Д	0	0	Д
HCOOH	20	R	0	Д	0	Д	Д
CH_3COOH	20	Д	0	Д	0	0	Д
Бензин 11	—	0	0	0	0	0	0
Раст. и животные масла 12	—	0	0	R	0	0	0
CCl_4	—	0	0	R	0	0	0
NaCl	10	0	0	R	0	0	R

* 0 — has no effect.
** D — has a partial effect.
R — it breaks down.
*** — is applied by the gas flame method from solutions in plastifiers.

1) Medium; 2) solution concentration (%); 3) polycaprolactam; 4) polyethylene; 5) polyvinylbutirol; 6) polychlorovinyl; 7) Thiocol; 8) bitumen; 9) R; 10) D; 11) gasoline; 12) vegetable and animal fats.

ized by high wear resistance. Table 4 shows the properties of metallizing gas flame coatings from certain metals.

The uses and major properties of metallizing coatings. Zinc gas flame coatings for cathodic protection of steel structures and vessels from atmospheric, underground and sea erosion are not damaged by the periodic freezing and melting of water on their surfaces, are effective in media with pH of 6-11 even if the coatings are quite porous; in sea

water they are compacted by the zinc chlorate which then forms. They are also used as priming coats for paint and varnish coatings with

TABLE 2

Physicomechanical Indicators of Certain Thermoplastic Gas Flame Coatings

1 Покрытия	2 Полиэтилен низкого давления	3 Поливинилбутираль	4 Капрон	5 Сплав этилцеллюлозы с монтанским 40:60	6 Шеллак	7 Битум ухтинский	8 Эпоксидная смола Э-41Т
9 Прочность связи с подложкой (кг/см²)	20—40	до 100 10	Удовлетворительная 11	Удовлетворительная 11	Удовлетворительная 11	Удовлетворительная 11	Удовлетворительная 11
12 Прочность на удар на приборе У-1 по покрытию 13	10—35	20	50	3	4	5	4
по подложке 14	30	2	7	3	4	2	3
Эластичность (мм) по Эриксену 15	0.8—1.5	0.5—1.0	1.25	0.8	0.95	0.9	0.85
Твердость на маятниковом приборе МИ-3 16	0.25—0.35	0.82—0.95	0.54	0.73	0.94	0.22	0.65

1) Coatings; 2) low-pressure polyethylene; 3) polyvinylbutiral; 4) capron; 5) an alloy of ethylcellulose with montan wax 40:60; 6) shellac; 7) Ukhta bitumen; 8) E-41T epoxy resin; 9) strength of bound with the base layer (kg/cm^2); 10) up to 100; 11) satisfactory; 12) impact strength measured by the U-1 instrument; 13) for the coating; 14) for the base layer; 15) Ericksen elasticity (mm); 16) pendulum hardness measured on the MI-3 instrument.

TABLE 3

Physicomechanical Properties of a Coating From Modified Phenolaldehide Resin

Прочность на растяжение (кг/см²) 1	Модуль упругости (кг/см²) 2	Относит. удлинение при разрыве (%) 3	Прочность при изгибе (кг/см²) 4	Удельная ударная вязкость (кг·см/см²) 5	Теплостойкость по Мартенсу (°С) 6
110—150	26700	0.2—0.6	303.0	2.1	5[illegible]

1) Tensile strength (kg/cm^2); 2) modulus of elasticity (kg/cm^2); 3) elongation at break (%); 4) flexural strength (kg/cm^2); 5) specific impact ductility ($kg \cdot cm/cm^2$); 6) Martens heat resistance (°C).

vinyl, alkyd, etc., resins as a base. Aluminum gas flame coatings are used for cathodic protection of steel structures in media with pH 2.5-3.0, for protection from the effect of sulfur dioxide; protection from temperature effects up to 1000° requires glazing or thermodiffusion

sintering of the coatings. Steel gas flame coatings are used for restoration of worn machine components; shaft journals are metallized by steel with a high carbon content, seats of ball and roller bearings and stationary seats in general are coated by low-carbon steel. The hardness of coatings from 45 steel is 223-285 kg/mm^2, the hardness of coatings from U8, and U10 steels is 285-320 kg/mm^2. Stainless steel gas

TABLE 4

Properties of Certain Metallizing Gas Flame Coatings

1 Металл или сплав	2 Предел прочности при растяжении (кг/мм^2)	3 Предел прочности при сжатии (кг/мм^2)	4 Твердость по Роквеллу
5 Сталь 15	15.8	69.7	147
6 Сталь 45	15.5	73.8	240
7 Сталь У8	—	—	—
8 Латунь Л-62	5.2	24.4	63
9 Алюминий А-99	5.0	13.1	25
10 Цинк (Ц-1)	3.2	19.7	29
11 Медь (М)	5.4	32.0	44

1) Metal or alloy; 2) ultimate tensile strength (kg/mm^2); 3) ultimate compressive strength (kg/mm^2); 4) Rockwell hardness; 5) 15 steel; 6) 45 steel; 7) U8 steel; 8) L-62 brass; 9) A-99 aluminum; 10) Zinc (Ts-1); 11) copper (M).

flame coatings are used to restore worn components. The coating hardness is 270-285 kg/mm^2; a coating containing: 2% Mo, 1% Si, 0.1% C, 18% Cr, 12% Ni with the balance consisting of iron is recommended for restoration of worn bronze and stainless steel components. Iron-aluminum coatings (1:1 by weight) are used as antifriction coatings instead of bronzes and Babbit metals; the friction coefficient is 0.04-0.045. Molybdenum gas flame coatings are antifriction and wear resistant coatings of the working surface of machines, in the production of all-aluminum diesel and automotive engines (the steel coating is applied over a thin molybdenum layer which covers the aluminum casting), are used for repair of large dies, restoration of worn crankshafts, protection of polishing machine spindles. Properties of molybdenum gas flame coatings:

specific weight 8.6 g/cm^3; melting temperature 2620°, porosity (total) 14%, thermal expansion coefficient $4.82 \cdot 10^{-6}$, oxygen content in the form of oxides up to 0.2%, capture cross section for thermal neutrons 2 barns, Rockwell hardness 88, adhesion to steel 2.7 kg/mm^2, high wear resistance, excellent machinability. Permissible operating temperature: under atmospheric conditions not above 400°, in a reducing medium up to 2500°. Surfaces do not have to be machined, it can be applied on steel, aluminum, graphite, ceramics, glass. Nickel-based gas flame coatings with chromium and silicon borides protect structures from the effect of molten metallic sodium, aluminum, bismuth, mercury and molten glass; are resistant to the effect of ammonium sulfide and ammonium sulfate, phenols, hydrogen sulfide, boric, naphthene, acetic, phosphorus, chromium, nitric and hydrofluoric acids, hydrogen peroxide, acid and neutral salts. Wear resistance and antifriction gas flame coatings from iron silicoborides resist sulfuric acid of any concentration as well as the effect of tetraethyl lead. Nickel-based gas flame coatings from chromium borides are also used as binders for the application of tungsten carbide coatings on drilling equipment. The properties of these gas flame coatings are: specific gravity 7.55-7.69, they are not porous, thermal expansion coefficient $14.5\text{-}16.2 \cdot 10^{-6}$, Rockwell hardness from 30-35 to 62, depending on the composition, ultimate tensile strength 4550-5250 kg/cm^2, friction coefficient 0.18-0.20, coating thickness 0.1--0.3 mm.

Gas flame coatings from metal oxides are used as wear and temperature resistant coatings for metals and graphite, as electric insulation high-temperature coatings and as thermal barrier coatings. The properties of commercial type metal oxide coatings are presented in Table 5.

Gas flame coatings from oxides of rare-earth metals are used for coating of pistons and heads of internal combustion engine cylinders to

prevent the formation of scale on chambers and rings.

TABLE 5

Properties of Metal Oxide Coatings

	1 Материалы покрытия		
	Al_2O_3	ZrO_2	2 Циркон (силикат циркония)
3 Химический состав	98.6%	4 Стабилизованная окись	ZrO_2 65% SiO_2 34%
5 Объемный вес (g/cm^3)	3.2	5.2	3.8
6 Удельный вес	3.6	5.7	4.15
7 Удельный вес γ-формы	3.77	—	—
8 » » α-формы	4.0	—	—
9 Общая пористость	8—12	8—12	8—12
10 Коэф. теплового расширения в пределах темп-р 21—1399° 10^{-6} на 1°	7.18	11.51	6.18
11 Теплопроводность при темп-ре ок. 815° (ккал/м·час·°C)	2.356	0.992	1.88
12 Коэф. черноты	0.3—0.4	0.3—0.4	0.3—0.4
13 Темп-ра плавления (°C)	1982	2482	1850
14 Цвет	15 Белый	16 Рыжевато-коричневый	16 Рыжевато-коричневый
17 Твердость по Кнупу	2000	1000	750
18 Временное сопротивление изгибу (kg/cm^2)	28—25	—	—
19 Модуль упругости (kg/cm^2)	0.24—0.46·10^{-6}	—	—

1) Coating materials; 2) zircon (zirconium silicate); 3) chemical composition; 4) stabilized oxide; 5) specific weight (g/cm^3); 6) specific gravity; 7) specific gravity of the γ-modification; 8) specific gravity of the α-modification; 9) total porosity; 10) thermal expansion coefficient in the temperature interval from 24 to 1399°, 10^{-6} per 1°; 11) thermal conductivity at a temperature of about 815° (kcal/m·hour·°C); 12) blackness coefficient; 13) melting temperature (°C); 14) color; 15) white; 16) redish-brown; 17) Knoop hardness; 18) ultimate flexural strength (kg/cm^2); 19) modulus of elasticity (kg/cm^2).

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A.L. Kozlovskiy

GAS-IMPERMEABLE RUBBER – rubber whose permeability to various gases varies from 0.06 to $5 \cdot 10^{-8}$ ml·cm Hg/sec·cm^2·mm. This type of rubber is widely used in the manufacture of balloon materials, certain types of flexible piping, packing components, porous shock absorbers, automobile and bicycle inner tubes, etc.

The impermeability of a rubber is basically governed by that of the caoutchouc and depends on the nature of the gas.

The impermeability of vulcanizate containing up to 2% bonded sulfur is equivalent to that of gum rubbers. Impermeability increases with sulfur content and becomes selective with respect to various gases; for example, the permeability of ebonite (which contains 32% bonded sulfur) to helium is 1/3 of that of caoutchouc, while its permeability to hydrogen is approximately 1/40 and to nitrogen is no more than 1/2000 of that of caoutchouc.

Rubbers containing fillers are less permeable to gases than gum rubbers. The greatest decrease in permeability is achieved by adding fillers with fat particles, such as ground mica or powdered aluminum.

The gas permeability of rubber is reduced by thermal aging.

Permeability to gases is evaluated from the permeability constant P, the diffusion constant D, and the sorption content σ, which are related by the equation $P = D\sigma$. Knowing or having experimentally determined two of these constants, the third can be found from the aforementioned equation. The Table shows the permeability of various natural and synthetic rubbers to nitrogen.

Indices of Gas Permeability for Natural and Synthetic Rubbers

Каучук 1	Наполнитель 2	Содержание наполнителя (объем %) 3	$P \cdot 10^{-3}$ мл·атм / см·сек·см 4	$D \cdot 10^{-6}$ см²·сек 5	$\sigma \cdot 10^{-2}$ мл·см³ / см·атм 6
НК 7	Ламповая сажа 14	5	4,4	0,46	9,5
		20	2,7	0,35	7,9
	Каолин 15	5	5,2	0,44	11,8
		20	2,6	0,30	8,6
	Молотая слюда 16	5	3,0	0,32	9,3
		20	1,4	0,21	6,9
СКВ 8	Ламповая сажа	5	4,4	0,40	10,0
		20	3,9	0,38	11,0
	Каолин	5	4,4	0,52	8,5
		20	3,0	0,40	7,2
	Молотая слюда	5	3,0	0,25	12,0
		20	1,5	0,15	10,0
СКС-30 9	Ламповая сажа	5	3,2	0,24	13,3
		20	2,9	0,25	11,6
	Каолин	5	2,8	0,26	10,7
		20	1,4	0,20	7,0
	Молотая слюда	5	2,1	0,17	12,3
		20	0,9	0,13	6,6
СКС-10 10	Ламповая сажа	5	4,8	0,43	11,1
		20	4,5	0,41	10,8
	Каолин	5	4,5	0,38	11,8
		20	3,0	0,30	10,0
	Молотая слюда	5	2,6	0,20	13,0
		20	1,50	0,15	10,0
СКН-26 11	Ламповая сажа	5	0,90	0,12	7,5
		20	0,77	0,08	9,5
	Каолин	5	0,45	0,14	3,2
		20	0,25	0,06	4,1
	Молотая слюда	5	0,37	0,072	5,1
		20	0,12	0,026	4,6
Хлоропрен 12	Ламповая сажа	5	0,70	0,06	11,6
		20	0,53	0,05	10,6
	Каолин	5	0,76	0,053	14,3
		20	0,43	0,043	10,0
	Молотая слюда	5	0,45	0,040	10,5
		20	0,20	0,025	8,2
Полиизобутилен 13	Алюминиевая пудра	5	0,11	0,010	10,0
		20	0,11	0,023	5,0
	Каолин	5	0,20	0,050	4,0
		20	0,10	0,055	1,9

1) Caoutchouc; 2) filler; 3) filler content (% by volume); 4) $P \cdot 10^{-3}$ (ml·atm/cm·sec·cm); 5) $D \cdot 10^{-6} \cdot cm^2 \cdot sec$; 6) $\sigma \cdot 10^{-2} \cdot ml \cdot cm^3 \cdot atm$; 7) NK; 8) SKB; 9) SKS-30; 10) SKS-10; 11) SKN-26; 12) chloroprene; 13) polyisobutylene; 14) lamp black; 15) kaolin; 16) ground mica.

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N.K. Pankova

GASOLINE- AND OIL-RESISTANT LACQUER AND PAINT COATINGS are coatings which are resistant to the attack of liquid fuels and mineral oils.

For the protection of metallic vessels (containers) intended for the storage and transportation of various grades of gasoline containing up to 40 percent aromatic hydrocarbons, and also the mineral oils, use is made of the following gasoline- and oil-resistant lacquer and paint coatings: enamel No. 55, having high resistance to the action of the hydrocarbons and the mineral oils (up to 50°), good elasticity, resistant to hot water and water vapors; applied in two coats on surfaces pre-primed using the FL-03K or FL-03Zh primers; primer dried at 180° for 30 minutes, each coat dried at 180° for 1 hour, solvent used to bring the enamel to working consistency.

Enamel 60T (new grade is VL-515) is used with temperature of petroleum products to 60-80°, is resistant to hot water and water vapor. To obtain a gasoline- and oil-resistant coating the enamel is applied in 3-4 coats without primer. Each coat is dried at 120° for 1 hour. A mixture of ethyl spirit and ethyl cellosolve (1:1) is used to bring the 60T enamel to the working consistency (18-20 seconds on the VZ-4 viscosimeter).

The gasoline-resistant enamel UBE-1 is applied on a surface which has been pre-primed using the gasoline-resistant primer UBT-1. A more uniform and continuous coating is obtained if the primer and enamel are heated to 30-40° before application. A primer coat and 2-3 enamel coats are applied to obtain a high-quality coating. Each coat is first air-dried for 30 minutes and then dried for 1-1.5 hours at 120-140°. Sol-

vent, xylene or RKB-1 thinner is used to bring the primer and enamel to the working consistency (25-28 seconds on the VZ-4).

The FL-75 enamel is used for the protection of the interior surfaces of automobile gasoline tanks and other containers, and is applied on surfaces which have been preprimed using the gasoline-resistant FL-04 primer. The coatings based on these materials have exceptionally high gasoline resistance and good resistance to the other petroleum products. The primer and enamel are applied by spraying or pouring of single coats. Drying of each coat is performed at 180° for 30 minutes. The primer and enamel are brought to the working consistency (18-20 seconds on the VZ-4) using xylene or a mixture of xylene with white spirit (1:1).

The AO lacquer is intended primarily for the protection of aluminum and magnesium details operating in a medium of gasoline, kerosene and lubricating oils; to provide reliable protection it is applied on previously anodized or oxidized surfaces. The coating based on the AO lacquer has high resistance to gasoline and kerosene. The lacquer is applied without primer in two combined layers with a drying interval of no more than 3 minutes between layers. Then it is dried at 15-25° for 2 hours and at 80-90° for 1 hour. After the hot drying there are again applied two caots of lacquer with the same drying interval between coats and a final drying of no less than 1 hour at 15-25° and 4 hours at 115-120°. The AO lacquer is brought to the working consistenc, using the R-6 thinner (12-14 seconds on the VZ-4).

For the protection of articles which are periodically in contact with liquid fuels, mineral oils and which require a decorative finish, use can be made of several lacquer and paint materials. The NTs-11 (GOST 9198-59) automobile nitro-enamels and the gray nitro-enamels of the types MV-8 and MV-108 have satisfactory gasoline and oil resistance.

The nitro-enamels are applied over the 138 or FL-03K primer in 2-4 coats with drying of each coat for no less than 2 hours at 18-20°. The RDV thinner is used to bring the enamels to the working consistency (22-25 seconds on the VZ-4). The coatings based on the type A glyptal and pentaglyptal enamels (TU MKhP 2556-51) have quite good oil resistance; they are used for the protection of agricultural machines and various equipment which comes into contact with mineral oils during operation. Drying of the coatings at 90-110° for 3-4 hours improves their resistance to oil. The enamels are applied to a surface which is pre-primed using the 138, FL-03K, FL-03Zh and other primers. Wide usage is also made of the instrument enamels: PU-281, PF-28 black, 1425F protective and the FSKh (GOST 926-52) grade enamels for agricultural machines, and others. In those cases when it is not possible to dry the coatings at elevated temperature, for the protection of articles from periodic exposure to gasoline and the mineral oils use can be made of the enamels based on the copolymer of vinyl chloride and vinylidene chloride, for example, VKhE-4001 white, VKhE-4023 gray, the VKhGM and VKhG 4007 primers. The enamels are applied in 2-3 coats using the forementioned primers, and also can be applied over the FK-03K or FL-03Zh primers. The enamels are applied in 2-3 coats using the foremention ed primers, and also can be applied over the FK-03K or FL-03Zh primers. It is best to apply the type VKhE enamels using paint sprayers. Thinning of the enamels to working consistency (12 seconds on the VZ-4) is accomplished using the R-4 or R-5 thinners.

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I.I. Denker

GASOLINE-KEROSENE-OIL RESISTANCE – the ability of polymer materials to withstand the action of petroleum products.

Many polymers (resins, plastics, synthetic fibers, etc.) partially dissolve and some swell in petroleum products. Swelling reduces the mechanical characteristics of polymers as a result of the decrease in intermolecular interactions; partial dissolution washes out the additives to the chain (antioxidants, plasticizers, etc.). Petroleum products also have a chemical influence on the oxidation and aging of polymers because of their participation in conjugate oxidation, which leads to decomposition of polymers. Destructive processes often predominate when swollen polymers are oxidized, since structuring processes are hampered in such systems. Polymers whose molecules contain polar substitutes (polynitrilacrylic acid and copolymers of this acid and divinyl [nitrile rubber], polychloroprene rubber, polysulfide and fluoroorganic polymers, etc.) are gasoline-kerosene-oil resistant. Materials based on such polymers swell little in saturated hydrocarbons. Selection of plasticizers plays a material role. Gasoline-kerosene-oil resistance can be increased by adding inorganic fillers, carbon black, or vulcanizing agents, as well as by such substances in combination with many synthetic resins. The gasoline-kerosene-oil resistance of polymer materials depends on their purity, impurities often accelerating oxidation. This index is usually evaluated under "controlled" conditions, by placing the material or assembled unit in an appropriate medium kept at high temperature in a heater.

N.N. Lezhnev

GAS PERMEABILITY – capacity of materials to pass gases through themselves in the presence of a pressure drop; is characterized by the value of the gas permeability coefficient, which depends on the structure of the body, the nature of the gas and the temperature. In the case of isothermal stationary flow we have the relationship:

$$i = P[(p_1 - p_2)/d]$$

where $\underline{i}$ is the gas flux density, P is the gas permeability coefficient, (p_1-p_2) is the partial gas pressure drop, and $\underline{d}$ is the thickness of the membrane through which the gas passes. The gas permeability coefficient is expressed in cm^3 of gas (under standard conditions) which passes through cm^2 of a membrane 1 cm thick per second under a gas pressure drop of ~1 atm. Depending on the structure of the body and the gas pressure, the mechanism of gas permeability can be regarded as a diffusion flux, molecular diffusion, viscous flow and flow out of holes. Diffusion flux is characterized by transfer of particles of the diffusing substance through interatomic or intermolecular spaces in a solid body. Gas permeability in this case is regarded as successive dissolution of the gas in the body's boundary layer, its diffusion through the body and generation of gas at the other side of the body.

If the dissolution in the body follows Henry's law, and the diffusion process is governed by Fick's law, then the gas permeability coefficient for diffusion flux is equal to $P = D\sigma$, where D is the diffusion coefficient and σ is the coefficient of solubility of the gas in the material. In the case of diffusion flux gas permeability increases sharply with the temperature. Molecular diffusion takes place when the

gas passes through a porous body with pores whose diameter is small in comparison with the molecular mean free path of the gas. The quantity

TABLE

Gas Permeability of Polymer Films ($cm^2/sec \cdot atm \cdot 10^8$).

	Темпера-тура (°С)	Газы 2			
		N_2	O_2	H_2	CO_2
3 Силоксановый каучук	20	188	380	390	1635
4 Натуральный каучук	20	5.9	15.9	34.6	90
5 Бутадиеновый каучук	20	3.8	11.9	27.0	66.5
6 Бутадиенстирольный каучук (СКС-30)	30	4.6	18.5	25.2	116
7 Полихлоропреновый каучук	20	0.69	2.4	8.1	15.3
8 Полиэтилен низкой плотности	20	1.08	2.6	5.9	12.5
9 Поликарбонат	20	0.23	1.4	10.5	5.8
10 Полиамид	30	0.008	0.035	0.70	0.22
11 Поливинилхлорид (непластифицированный)	20	0.006	0.035	—	0.10
12 Полиэтилентерефталат	20	0.0037	0.030	0.51	0.14
13 Поливинилиденхлорид (непластифицированный)	25	0.0006	0.002	0.06	0.012

1) Temperature (°C); 2) gases; 3) siloxane rubber; 4) natural rubber; 5) butadiene rubber; 6) butadiene styrene rubber (SKS-30); 7) polychloroprene rubber; 8) low-density polyethylene; 9) polycarbonate; 10) polyamide; 11) polyvinyl chloride (nonplasticized); 12) polyethyleneterepthalate; 13) polyvinylidene chloride (nonplasticized).

of gas that passes through a body by molecular diffusion increases with an increase in temperature in proportion to $\sqrt{T}$. Viscous flow describes gas permeability in porous materials with pores whose diameter exceeds the molecular mean free path of the gas. As the temperature is increased, the rate of viscous flow is slightly reduced. When the pore diameter is substantial, gas permeability is governed by the general law of outflow of gas from holes. The gas permeability coefficient of various materials varies within wide limits, decreasing successively in the series fabrics – leather – polymer films – nonorganic glass – metals. The gas permeability of polymers decreases with an increasing packing density, molecular forces and rigidity of the polymer's chain

moleculaes. The highest gas permeability is peculiar to rubber-like polymers; organic glass, crystalline and space-structure polymers are characterized by a low gas permeability (see Table).

Gas permeability is of great significance in the development of packaging materials, hermetizing gaskets, pneumatic chambers (tires, blow-up designs), anticorrosion coatings, in foundry practice (flasks), in the light industry (gas permeability of shoes, clothing, parachutes), in construction (gas permeability of concrete, ceramics, construction materials) and in other branches of technology.

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S.A. Reytlinger

GEOMETRIC SIMILARITY – constancy of the shape of figures regardless of their dimensions. In similar figures the angles between two similar sides are equal, while the ratio of similar segments is constant and equals the similarity coefficient. The areas of closed similar figures are proportional to the squares of their similarity coefficients, while the volumes of solids are proportional to the cubes of their similarity coefficients. Observation of geometric similarity is not sufficient to insure that mechanical characteristics will be independent of dimensions. See Scale effect and Law of similarity.

Ya.B. Fridman

GENERAL-PURPOSE LUBRICANTS – plastic lubricating materials (lubricant greases, konstalin, etc.) used in various mechanisms operating at temperatures of from –30 to +65° (rolling-contact and sliding bearings, gear, worm, and chain transmisions bearing low and moderate loads, universal joints, etc.).

Lubricant greases are obtained by thickening medium industrial oils of types 20, 30, 45, etc. with calcium soaps of synthetic fatty acids (synthetic lubricant greases) or natural fats (aliphatic lubricant greases). These greases are insoluble in water and have satisfactory protective properties. Their service life in friction units ranges from several days to several months. The permissible container-storage time is 5 years or more.

Synthetic lubricant greases are produced in three varieties (GOST 4366-56): general-purpose USs is medium-melting; automobile USs is prepared from purified synthetic fatty acids, has better operational characteristics, and is employed in critical units; USs-1 is a press grease with a low thickener content, which increases its usefulness at low temperatures and improves its compressibility in friction units, and is used principally for lubricating the friction units of automobile chaisis; USs-2 is the most widely used general-purpose all-weather lubricant for various mechanisms, naval equipment, tractors, agricultural machinery, etc.

Aliphatic lubricant greases (GOST 1033-51) are produced in types US-1 (a press grease), US-2 (L), and US-3 (T). Their characteristics are similar to those of synthetic lubricant greases of the correspond-

ing types. At temperatures above 55-65°, 1-13s (TU NP-5-58), YaNZ-2 (GOST 9433-60), 1-13 aliphatic (GOST 1631-61), and konstalin aliphatic (GOST 1957-52) lubricants, which are based on sodium and sodium-calcium soaps of synthetic acids, are used instead of lubricant greases. These lubricants are used in the bearings of electrical machinery, the hubs of automobile wheels, etc. Type 1-LV lubricant (TU NP 21-58), which consists of 1-13 lubricant containing an antioxidant (diphenylamine), is employed in the journal boxes of railroad cars. The recommended temperature range for these lubricants runs from −15 to +110°. Heating thickens 1-13s and YaNZ-2 lubricants and their use at temperatures above 80-90° is consequently not recommended. YaNZ-2 lubricant is distinguished by better low-temperature serviceability. Aliphatic lubricants are more heat-resistant than synthetic lubricants. The aforementioned materials are all water-soluble, so that they cannot be used under conditions where they will be exposed to moisture. At the same time, they are better in a moderately moist environment than lubricant greases, protecting metallic surfaces against corrosion. Lubricants of the konstalin and 1-13 types are usually employed in friction units where the speed of the rotating components does not exceed 2-3000 rpm. Type 1-LZ lubricant ensures that railroad cars will run for 120 thousand km. The lubricant in the bearings of electric motors must be replaced after several thousand hours of operation. All these lubricants can be stored for 2-3 years in air-tight containers.

V.V. Sinitsyn

GETINAKS – laminated electric insulation material which is obtained by pressing together of parallel-placed layers of paper impregnated by synthetic resins. Getinaks is produced as sheets and plates of various thickness from 0.2 to 50 mm. Sulfate cellulose paper is used for electrical engineering Getinaks. Various synthetic resins are used as Getinaks binders, primarily phenolformaldehide (phenolaldehide, cresolaldehide, xylenolaldehide), and less frequently epoxy-phenolanilinoformaldehide, melaminoformaldehide. Getinaks has a quite high mechanical strength and good electric insulation properties. Since the mechanical properties of paper are not the same in all the directions, paper-base Getinaks has various properties. The properties of Getinaks are: ultimate tensile strength along the filler layers 1600, across the filler layers 1050 kg/cm^2, the tensile modulus of elasticity along the filler layers 14.800, across the filler layers 108,000 kg/cm^2, Martens heat resistance 150-180°, thermal conductivity $3.5 \cdot 10^{-4}$ kcal/m·hour·°C, fatigue strength after 10^7 loading cycles in flexure 350-490, in tension and compression 580 kg/cm^2, creep strength 1000 hours after load application 56% of the tensile strength. The physicomechanical and electric insulation properties of Getinaks depend to a substantial extent on the service conditions: moisture, temperatures and media. Getinaks is sensitive to moisture variations. Prolonged keeping of Getinaks at high moisture in water and at elevated temperatures is detrimental to its properties. The moisture absorption of Getinaks is reduced with an increase in the plate thickness.

Getinaks is produced of two types: for industrial current frequency

service and for high frequency work. In addition, the electrical and radio engineering industries use special brands of Getinaks. Low-frequency electrical engineering Getinaks is used for work at industrial current frequency. In a number of cases low-frequency Getinaks has strengthening fillers such as fabric or a metal mesh pressed into the material.

Low-frequency Getinaks is made of the following brands, depending on the intended use: A, B and E with a high electric strength for work in transformer oil, V for work in air and in transformer oil (has a high mechanical strength), V_s permeable to light, for work in air, G for work under high moisture conditions, D panel for work in air (has a high mechanical strength), GM for magnetic wedges with a metal mesh, which works under high moisture conditions, PGT facing with upper layers from phenolformaldehide resin impregnated fabric.

Brand E Getinaks has low electric losses and high electric strength, particularly along the layers. The electric strength along the layers in transformer oil at 90° and for a distance between electrodes of 50 mm is higher than 100 kv. In addition, brand E has lower variations of dielectric properties at elevated temperatures. Electrical engineering high-frequency Getinaks is used for work in high-frequency fields, its variety is sheet foil Getinaks from synthetic resin impregnated paper, faced on one or both sides by a red-copper electrolitic foil 0.05 mm thick. Depending on the intended service, high-frequency Getinaks is produced of the following brands: A_v for work in general purpose radio installations, B_v for work in telephone installations, V_v for work in high-frequency and telephone installations, G_v for work in high-frequency installations, D_v for panels of high-frequency installations, G_f-1, G_f-50 are foil-covered on one side, G_f-1-T is foil-covered from one side and heat resistant, G_g-2, G_v-50 which are foil covered

from two sides, G_f-2-G which is foil covered from two sides and heat resistant.

The physicomechanical and dielectric properties of foil-faced material are similar to those of Getinaks without foil facing. However, additional requirements with respect to binding of the foil and the Getinaks are presented to foil-faced material. The foil should not peel off the basic material when heated to 100-120°, after being held at high humidity (95-98%), when subjected to vibrations and at low temperatures. In addition, the foil should not peel off Getinaks after short duration (5 secs) submersion into solder at 270°.

The physicomechanical and electric insulation properties of high- and low-frequency Getinaks are given in GOST 2718-54.

The bulk of components made from Getinkas is produced by machining. Getinaks is used extensively in electrical machinery as high-voltage insulation, in transformers and other apparatus, in the production of telephone apparatus, radio engineering and other branches of industry. Due to the relatively low cost of Getinaks, it is used for making of all kinds of panels, covers, sleeves, pinions, washers and similar components.

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B.A. Kiselev

GETTERS (gas absorbing materials) – substances which are usually used in vacuum devices for absorption of gases and vapor which remains after the devices have been vacuumed by vacuum pumps, and also those which are generated during the operation of the devices. Getters are used, in addition, in inert-gas-filled instruments for removal of foreign admixtures from the filler gas and also in ionic sorption pumps. Atomizing and nonatomizing getters are used in vacuum technology. The former bind gases in the evaporation process with a metal surface which is formed on the instrument wall upon condensation of getters. Nonatomizing getters are usually applied in the form of thinly dispersed metal powders made from materials with gas absorbing properties. The main property of getters is their high absorptive ability with respect to oxygen, hydrogen, nitrogen, carbon dioxide, carbon monoxide, and other gases. The gas absorption is determined by the chemical activity of the substances and also by their ability to dissolve gases (absorption) or to hold at the surface (adsorption). The predominantly used atomizing getters are feba (ferrum-barium), bati (barium-aluminum-titanium), barium berylate, the active substance of which is barium. The active substances of nonatomizing getters are: tantalum, titanium, zirconium, barium, cerium, lantanum and niobium. The main characteristics of getters are given in the table.

TABLE

Degasing, Atomization and Gas Absorption Temperatures, Methods of Fields of Application of Main Gas Absorbing Materials

1 Газопоглотители	2 Температура (°С)			3 Способ применения	4 Преимущественное применение
	обезгажи-вания 5	газопогло-щения 6	распыления 7		
Феба 8	750—800	Не выше 200 9	900—1000	В виде отрезков бариевой проволоки в трубчатой железной оболочке 10	Генераторные лампы малой и средней мощности, приемно-усилительные лампы 11
Барий и его соединения 12	600—700	Не выше 200	900—1300	Проволочные таблетки в металлич. оболочке 13	Электронолучевые трубки, миниатюрные лампы, генераторные лампы средних размеров 14
Цето 15	800—900	200—600	—	Порошковое покрытие никелевой или железной подложки 16	Лампы, в к-рых нельзя применить распыляющиеся газопоглотители и нельзя воспользоваться температурой, необходимой для распыления 17
Торий 18	800—1000 на металлич. подложке; 1500—1600 на графитовой 19	400—500	—	Покрытие, нанесенное на аноды или специальные никелевые подложки 20	Лампы для сверхвысоких частот, генераторные лампы средней мощности 21
Цирконий 22	700—1300 (до 1700 для проволоки) 23	800 (до 1600 для проволоки) 24	—	В виде покрытия, нанесенного на аноды или сетки приборов, или в виде проволоки 25	Лампы генераторные мощные и средней мощности, приборы УКВ 26
Тантал 27	1600—2000	700—1200	—	Лист, порошок 28	Генераторные лампы средних размеров, мощные вакуумные и генераторные лампы 29
Алюминий—магний 30	400	Адсорбируют газы лишь в момент распыления 31	450—500	Покрытие порошком, намазка 32	Небольшие приемные лампы, лампы с оксидным катодом 33
Титан 34	—	—	1700—2000	В виде проволоки 35	В сорбционно-ионных насосах 36
Ниобий 37	1650	400—900	—	В виде проволоки и брикетов 38	Электровакуумные приборы 39

1) Gas absorbing materials; 2) temperature (°C); 3) method of utlization; 4) predominant utilization; 5) degasing; 6) gas absorption; 7) atomizing; 8) feba; 9) not above 200; 10) in the form of barium wire sections in a tubular iron shell; 11) low and medium capacity transmitting tubes, receiver amplification tubes; 12) barium and its compounds; 13) wire tablets in a metallic shell; 14) electron-ray tubes, miniature tubes, medium-size transmitting tubes; 15) Tseto [cesium-thorium]; 16) powder coating of a nickel or iron base layer; 17) tubes in which atomizing absorbers cannot be used and it is impossible to use the temperature needed for atomization; 18) thorium; 19) 800-1000 with a metal base layer, 1500-1600 with a graphite baselayer; 20) coating applied to anodes or over special nickel backing layers; 21) super high-frequency tubes, medium capacity transmitting tubes; 22) zirconium; 23) 700-1300 (up to 1700 for wire); 24) 800 (up to 1600 for wire); 25) in the form of a coating applied to anodes and grids of devices, or in the form of wire; 26) high and medium capacity transmitting tubes, UKV devices; 27) tantalum; 28) sheets, powder; 29) medium-sized transmitting tubes; high-capacity vacuum and transmitting tubes; 30) aluminum-magnesium; 31) adsorb gases only at the instant of atomization; 32) powder coating, smeared-on coating; 33) moderate-size receiving tubes, tubes with an oxidic cathode; 34) titanium; 35) in the form of wire; 36) in ionic sorption pumps; 37) niobium; 38) in the form of wire and pellets; 39) electric vacuum devices.

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E.N. Martinson

GLASS (inorganic) – a material obtained on cooling of a nonmetallic melt, taking the form of an amorphous, isotropic, brittle, more or less transparent body having the mechanical characteristics of a solid as a result of a gradual increase in its viscosity. The process by which the melt is converted from the liquid state to the solid vitreous state should be reversible.

The principal commercial types of inorganic glass and their chief vitrifying components are shown in Table 1.

TABLE 1

Виды стекол 1	Главные стеклообразующие компоненты 2
Силикатные 3	Двуокись кремния 12
Алюмосиликатные 4	Окись алюминия и двуокись кремния 13
Боросиликатные 5	Борный ангидрид и двуокись кремния 14
Бороалюмосиликатные 6	Борный ангидрид, окись алюминия и двуокись кремния 15
Борофторалюмосиликатные 7	Борный ангидрид, фтор, окись алюминия и двуокись кремния 16
Алюмофосфатные 8	Окись алюминия и фосфорный ангидрид 17
Алюмосиликофосфатные 9	Окись алюминия, двуокись кремния и фосфорный ангидрид 18
Силикотитанатные 10	Двуокиси кремния и титана 19
Силикоцирконатные 11	Двуокиси кремния и циркония 20

1) Type of glass; 2) principal vitrifying components; 3) silicate; 4) aluminosilicate; 5) borosilicate; 6) boroaluminosilicate; 7) borofluoroaluminosilicate; 8) aluminophosphate; 9) aluminosilicophosphate; 10) silicotitanate; 11) silicozirconate; 12) silicon dioxide; 13) aluminum oxide and silicon dioxide; 14) boron anhydride and silicon dioxide; 15) boron anhydride, aluminum oxide, and silicon dioxide; 16) boron anhydride, fluorine, aluminum oxide, and silicon dioxide; 17) aluminum oxide and phosphoric anhydride; 18) aluminum oxide, silicon dioxide, and phosphoric anhydride; 19) silicon dioxide and titanium; 20) silicon dioxide and zirconium.

The first four types of glass are particularly widely used.

In addition to vitrifying components, the majority of glasses also

contain various metal oxides (of lithium, calcium, potassium, sodium, magnesium, lead, iron, etc.). Inorganic glass does not have an ordered crystal structure and is characterized by an isotropic structure and high brittleness. It does not melt like a crystal on heating, i.e., does not have a definite melting point, but displays a certain softening range, which depends on its nature (composition). At temperatures above 1000° glass is found either in a dispersed liquid state or in a laminar vitreous melt, which is referred to as a vitreous mass. When the temperature is reduced the viscosity of this mass increases until it has completely hardened and passed into the brittle vitreous state, i.e., glass. The vitrification temperature (T_g), at which this transition occurs, corresponds to a viscosity of the order of 10^{13} poises; at the softening temperature T_f the viscosity of glass is approximately 10^9 poises. At T_f glass begins to exhibit the characteristics typical of its liquid state. The interval between T_g and T_f, which is called the softening interval, is a transition region within which glass exists in a highly viscous plastic state; the extent of this interval depends on the chemical composition of the glass and may vary from several tens to hundreds of degrees. The viscosity of ordinary commercial silicate glasses ranges from 10^2 to 10^{13} poises. The viscosity of glass is most greatly altered at 800-1100°. Articles are molded from the vitreous mass over the viscosity range 10^3-$4 \cdot 10^8$ poises.

The surface tension of the vitreous mass is approximately 3-4 times tha[illegible] water and is comparable to that of molten metals. The surface tension of the most common silicate glasses at 900-1300° is 200-350 dynes/cm; on cooling and transition to the brittle temperature range the surface tension rises sharply, to 1200 dynes/cm or more. In practice, crystallization of silicate glasses occurs only at temperatures above T_g. The temperature range 800-1100° is the most dangerous for

crystallization of commercial glasses. The specific gravity of glass usually ranges from 2.2 (for light borosilicate crown glasses) to 6.5 (for heavy flint glasses). The specific gravity of commercial plate glass is 2.5-2.6, while that of quartz glass is 2.3. The strength and elasticity of mass-produced glass vary within wide limits. Glass has an ultimate strength on compression σ_{-b} = 50-200 kg/mm^2, on extension σ_b = 3-7 kg/mm^2, and on bending σ_{izg} = 3-10 kg/mm^2, an impact strength α_n = 1.5-2.5 kg·cm/cm^2, a modulus of elasticity (Young's modulus) E = = 4500-8500 kg/mm^2, and a Poisson constant μ = 0.180-0.320. For commercial plate glass σ_b = ~60-70 kg/mm^2, σ_{izg} = 5-10 kg/mm^2, E = 6500-7200 kg/mm^2, and μ = 0.22-0.25. Quartz and alkali-free glasses have higher mechanical characteristics, while glasses with an elevated content of lead, sodium, and potassium oxides have lower characteristics. The technical tensile and bending strengths of ordinary commercial glasses are less than their theoretical strengths by a factor of 100-300, the latter equaling approximately 1000-1200 kg/mm^2. Glass is virtually incapable of undergoing plastic deformation and has an especially low tensile strength (less by a factor of 10-15 than its compressive strength). The brittleness of glass is very high in comparison with that of other materials.

Fracture of glass usually begins at the surface and is associated with development and propagation of superficial and internal cracks, which form so-called foci of brittle fracture. The surface strength of commercial plate glass on symmetric bending is 9-15 kg/mm^2. The strength of the internal layers of glass is 25-30 kg/mm^2; the ratio of the strength of the internal layers to that of the surface layer amounts to 2.5-3.5. The technical strength of glass is governed principally by the strength of its surface layer, since extremely dangerous superficial defects are generally concentrated in this layer. In addition, it

is the surface that is primarily subject to the action of the surrounding medium (moisture, gases) and during deformation by bending, which is the type of deformation most frequently encountered under operational conditions, the greatest stresses are at first set up at the surface, i.e., in that layer in which the majority of the initial cracks that eventually destroy the material are formed. The strength of glass consequently depends to a large extent on the method by which it is produced and processed. Strength characteristics vary within very wide limits and depend on the geometric shape, size (volume, thickness), and surface condition of the specimens (glass articles) being tested, as well as on the strength-determination method (the manner in which the specimens are loaded) and the loading time.

Fatigue is due chiefly to surface adsorption of water vapor and gases, which promote formation and propagation of superficial microcracks during mechanical fracture. In comparison with annealed glass, quenched glass (sheets 6 mm thick) have a higher resistance to static loads (by a factor of 3–4), a higher impact strength (by a factor of 5–7), and a lower modulus of elasticity (by 5–7%). The Mohs hardness of glass is 4–8; ordinary commercial glasses have a hardness of approximately 5, their microhardness ranging from 500 to 800 kg/mm^2. The heat capacity of glass rises slightly as it is heated to T_g and increases rapidly over the interval T_g–T_f. The heat capacity of various glasses ranges from 0.08 to 0.25 cal/g·°C at 15–100°; that of commercial plate glass is 0.20–0.22 cal/g·°C. The heat capacity of glasses with a high content of barium or lead oxides is materially reduced (to 0.08 cal/g·°C), but can be raised by increasing the content of boron, sodium, and lithium oxides. The thermal conductivity of glass is exceptionally low in comparison with that of other solids, the conductivity factor ranging from 0.0016 to 0.0032 cal/cm·sec·°C for various glasses. Quartz

and borosilicate glasses have the highest thermal conductivity, while lead and barite glasses have the lowest. The thermal conductivity of glass can be raised by a factor of approximately 2 by heating it to the softening-initiation temperature; it rises still further at temperatures above 800°, colorless (transparent) glasses having a considerably higher "thermal transparency" than colored glasses (especially those containing cobalt, chromium, iron, or manganese oxides).

The coefficient of linear expansion of glasses with different compositions varies from $5 \cdot 10^{-7}$ to $150 \cdot 10^{-7}$ over the temperature range 15-100°. Increasing the content of silicon, boron, titanium, zirconium, beryllium, and zinc oxides materially reduces the thermal expansion of glass; barium, lead, sodium, potassium, and lithium oxides considerably increase its thermal expansion. The coefficient of thermal expansion of quenched glasses is usually somewhat higher (by 2-5%) than that of well-annealed glasses. The heat resistance of commercial glasses is shown in Table 2. The overwhelming majority of glasses (especially thick glasses) have a low heat resistance.

TABLE 2

1 Вид стекла	Термическая стойкость (°С)
3 Промышленное листовое	60–80
4 Малощелочное 13-в	80–100
5 Термометрическое 600	100
6 Химико-лабораторное ТС-32	120
7 То же № 23	140
8 «Пирекс» (МКР-1)	150–200
9 Кварцевое	до 1000

1) Type of glass; 2) heat resistance (°C); 3) commercial plate glass; 4) low-alkali 13-v; 5) thermometric 600; 6) chemical-laboratory Ts-32; 7) the same, No. 23; 8) "Pyrex" (MKR-1); 9) quartz glass.

The chemical stability of glass depends on its composition, the reagent to which it is exposed, the temperature, its thermal history, and the condition of its surface. Chemical reagents can be divided into two groups in accordance with the nature of their action on glass: the

TABLE 3

1 Виды стекол	n_D	ν
2 Кварцевое	1,4584	67,8
3 Листовое	1,52—1,53	55—58
4 Свинцовый хрусталь	1,55—1,60	40—45
5 Оптические	1,49—1,96	20—71

1) Type of glass; 2) quartz; 3) plate; 4) lead crystal; 5) optical.

first group (humid air, water, acid solutions, solutions of neutral or acidic salts) participate in hydrolytic and ion-exchange reactions with the vitreous silicates to form a film consisting of the decomposition products of glass on the surface; as this film is formed it protects the surface from further decomposition. The second group [solutions of hydroxides (alkalies), carbonates (especially soda and potash), phosphates (especially H_3PO_4), and hydrofluoric acid] intensively decompose th silicon dioxide and silicates at the surface of the glass without forming a protective surf e layer. Chemical reagents can be arranged in the following order in accordance with the intensity of their destructive effect on glass: hydrofluoric acid → phosphoric acid → alkali solutions → solutions of alkali carbonates → acids → water. The loss in weight of glass amounts to 0.5-1.5% in alkaline media and 0.01-0.1% in acids. The chemical stability of glass can be materially increased by raising its content of silicon, zirconium, titanium, boron (to 12%), aluminum, calcium, magnesium, and zinc oxides or by partially replacing its sodium oxide with potassium oxide; its stability is markedly reduced when its content of lithium, sodium, potassium, barium, and lead oxides is increased. The decomposition of glass under the action of any reagent is greatly intensified when the temperature is raised; decomposition is increased by a factor of 1.5-2.5 for every 10° of rise in temperature (up to 100°). The most intensive decomposition of glass oc-

curs at temperatures above 100°, especially under elevated pressure (in boilers, autoclaves, etc.).

The electrical characteristics of glass mark it as a dielectric. The deep electrical conductivity of ordinary commercial glasses is quite low (from 10^{-10} to 10^{-17} $ohm^{-1} \cdot cm^{-1}$) at temperatures of up to 200°, so that many glasses (quartz, borosilicate, etc.) are good dielectrics and are used as insulators. Electrical conductivity increases by a factor of approximately 10^8–10^{10} at 200–400° and rises sharply above 600°, reaching 0.2–1.0 $ohm^{-1} \cdot cm^{-1}$ for molten glasses. Thus, for example, the deep conductivity of commercial plate glass is 10^{-13}–10^{-14} $ohm^{-1} \cdot cm^{-1}$ at room temperature and increases to 0.3–1.1 $ohm^{-1} \cdot cm^{-1}$ at 1400–1450°. The lowest dielectric permeability ε is displayed by quartz glass (3.7–3.8) and vitreous boron anhydride (3.1–3.2). As the content of alkali- and heavy-metal ions (especially those of lead and barium) is raised ε steadily increases to a value of the order of 15. The dielectric permeability of the majority of commercial glasses ranges from 5 to 9. It increases as the temperature is raised, this phenomenon being especially pronounced at temperatures above 200° and at low frequencies. As the electric-field frequency is increased from 10^3 to 10^9 cps ε is reduced by approximately 10%. In glasses with different chemical compositions the tangent of the angle of dielectric loss varies from 0 (for clear quartz glass) to $175 \cdot 10^{-4}$ (for sodium-calcium aluminosilicate glass). Quenching of glass makes its dielectric losses approximately 2 times as great as those of normally annealed glass of the same composition. The dielectric strength of certain commercial glasses ranges from 29 kv/mm (commercial plate) to 80.0 kv/mm (clear quartz glass) at ordinary temperatures and a frequency of 50 cps.

The optical characteristics of glass depend principally on its chemical composition, the condition of its surface, and the type of

heat treatment to which it has been subjected. The index of refraction and dispersion of glass characterize its ability to refract and scatter visible light rays. Optical constants are especially important for optical glass. Table 3 shows the maximum and minimum indices of refraction (n_D) and dispersion factors (ν) for different commercial glasses.

Increasing the content of silicon, phosphorous, aluminum, or fluorine oxides leads to a decrease in n_D and a rise in ν. When lead, titanium, antimony, and tungsten oxides are added n_D is greatly increased and ν is considerably reduced. Barium, calcium, zinc, and cadmium oxides also cause a sharp rise in n_D, but greatly reduce ν. Birefringence is determined from the path difference (in mμ/cm) or the difference in indices of refraction of the rays into which a light ray passing through birefringent glass is decomposed; in practice, a difference in indices of refraction of $1:10^{-6}$ corresponds to a path difference of 10 mμ/cm. The permissible residual internal stresses for well-annealed glass articles should not exceed 0.05, i.e., 5% of the ultimate tensile strength of the glass, which corresponds to a birefringence of 50-60 mμ/cm. The birefringence of quenched glass (automobile, etc.) reaches 1300-1600 mμ/cm.

TABLE 4

1 Отражающий материал	2 Показатель преломления	3 Коэффициент отражения света от одной поверхности
4 Вода	1.33	2
5 Промышленное листовое стекло обычного состава	1.53	4.3
6 Свинцовое стекло флинт (Ф)	1.60	5.3
7 Свинцовое стекло тяжелый флинт (ТФ)	1.65	6.1
8 То же	1.90	9.2
9 Алмаз	2.42	17

1) Reflective material; 2) index of refraction; 3) refraction coefficient for one surface; 4) water; 5) commercial plate glass of the usual composition; 6) lead flint glass (F); 7) heavy lead flint glass (TF); 8) the same; 9) diamong.

TABLE 5

1 Вид красителя в стекле	2 Окраска, сообщаемая стеклу	Вид красителя в стекле	Окраска, сообщаемая стеклу
NiO	3 Красно-фиолетовая (калиевые стекла) или желто-коричневая (натриевые стекла)	CrO	10 Желто-оранжевая
		CuO_2	Сине-зеленая 11 или зелено-ато-голубая
CoO	4 Синяя или фиолетовая	Cu	12 Рубиновая
MnO	5 Слабо-желтая	Fe_2O_3	Желтая 13
Mn_2O_3	6 Фиолетовая	FeO	Сине-зеленая 14
Cr_2O_3	7 Зелено-желтая	Au	Рубиновая
FeS	Желтая, различных оттенков	CdS—CdSe	От желтой до рубиновой 15 (через оранжевую)
Se	Розовая 9	UO_2	Желто-зеленая 16 флюоресцирующая

1) Type of stain in glass; 2) color imparted to glass; 3) red-violet (potassium glasses); or hellow-brown (sodium glasses); 4) blue or violet; 5) light yellow; 6) violet; 7) greenish-yellow; 8) yellow of varying hue; 9) reddish; 10) yellow-orange; 11) blue-green or greenish-blue; 12) ruby red; 13) yellow; 14) blue-green; 15) from yellow to ruby red (through orange); 16) fluorescent blue-green.

TABLE 6

1 Промышленные стекла	Коэффициент светопропускания 2	Коэффициент светопоглощения 3
	%	
4 Оптические (разных категорий)	91—90	0,4—1,5
5 Техническое листовое с высокой светопрозрачностью	90—89	1,3—2,4
6 Свинцовый хрусталь	88—86	1,5—2,5
7 Листовое для иллюминаторов и смотровых окон, водоуказательные (гладкие) для котлов	85	6—8,5
8 Промышленное листовое полированное, автомобильное и др.	84	
Листовое оконное 9	83—82	
Светотехническое глушеное (опаловое и молочное) 10	70—40	10—20

1) Commercial glasses; 2) light-transmission factor; 3) light-absorption factor; 4) optical glass (different categories); 5) technical high-transparency plate glass; 6) lead crystal; 7) plate glass for illuminators and inspection windows, water-gauge glasses (smooth) for boilers; 8) polished commercial plate glass, automobile glass, etc.; 9) window glass; 10) translucent glass for illumination engineering (opal and milk glass).

The refraction and scattering of light are governed by the index of refraction, the angle of incidence of the light rays, and the chemical uniformity and surface condition (processing quality) of the glass.

Table 4 shows the influence of index of refraction on reflection coefficient for light rays perpendicularly incident in air.

The refraction of light from a completely smooth, well-polished glass surface is minimal and optically regular (mirror reflection). Light scattering glasses usually have a high coefficient of diffuse refraction, that for glass with a mat finish being 10-20%, that for translucent glasses (opal glass) 20-30%, and that for milk glasses 30-40%. The qualitative and quantitative character of light absorption depends on the wavelength of the light rays passing through the glass, the chemical composition and color of the glass, and the length of the optical path traversed by the rays in the glass. Ordinary commercial plate glass (colorless) has the lowest absorption for visible light with a wavelength of 520-530 mμ, i.e., in the green portion of the spectrum; this is due specifically to the greenish tint of thick glass. The selective absorption exhibited by colorless glasses is especially pronounced in the invisible portions of the spectrum. As a rule, commercial colorless glasses containing 0.05-0.1% iron oxides intensively absorb rays in the ultraviolet and infrared portions of the spectrum, while glasses with a high content of lead and barium oxides intensively absorb x- and γ-rays. The ultraviolet absorption of glass is materially reduced when its content of silicon, boron, and phosphorous oxides is increased and when iron and titanium oxides are absent. Glass with a high content of lead, titanium, or antimony oxides intensively absorbs ultraviolet rays. Glass consisting of boron, beryllium, and lithium oxides absorbs virtually no x-rays. Presence of substantial quantities of ferric oxide greatly increases the absorptive capacity of glass in the infrared region of the spectrum. Quartz and chalcogenide glasses have a low infrared absorption. Selective absorption in the visible portion of the spectrum is especially pronounced in colored glasses con-

taining staining oxides or components. As a result of their nonuniform absorption of visible light with different wavelengths, such glasses have a varying spectral transmissivity and appear to be different colors in transmitted white light (Table 5).

Table 6 shows the average white-light absorption and transmission factors (per cm of ray path or glass thickness) for certain commercial glasses.

The transmissivity of sheet window glass 2 mm thick is 87%, while that of glass 6 mm thick drops to 84%.

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GLASS-CERAMIC MATERIALS – artificial stones combining vitreous and crystalline phases in different ratios. The characteristics of these materials depend on the properties, ratio, and relative distribution of the phases. Glass-ceramic materials are manufactured by both ceramic and glass-making techniques, this being due to the close relationship between glass and ceramics and between the processes involved in glass and ceramic production. Ceramic materials are formed by sintering the charge components, while glass is formed by fusing these components. Since a certain amount of liquid accumulates during sintering, ceramic materials contain glass as well as a crystalline phase. On the other hand, glass may crystallize to a greater or lesser extent. In order to produce glass-ceramic materials with the requisite characteristics by glass-making or ceramic methods it is necessary to employ special technological procedures that ensure the proper ratio and composition of the vitreous and crystalline phases and provide the correct material structure. In using the ceramic method one such procedure involves synthesis and preparation of the crystalline phase and addition of powdered glass with a specially selected composition to the sintered mixture. This procedure is called glass-cement binding and the materials obtained are called glass-cement ceramics (see Crystalline ceramics). Production of glass-ceramic materials by glass-making techniques consists in fabrication of glass articles by the usual methods and subsequent crystallization by heating under definite regimes. This process is based on the catalytic crystallization of glass, in which heating creates surfaces of phase separation, which promote formation of a large

number of crystallization centers throughout the entire glass mass. A large number of crystallization centers results in formation of a uniform fine-grained structure as a result of crystallization and consequently makes it possible to obtain high-quality materials. Surfaces of phase separation are formed during heat treatment of the glass, either as a result of introduction of additives (Cu, Au, Ag, Pt, etc.) that precipitate in finely dispersed form throughout the glass or as a result of selection of a glass composition capable of microliquation; the latter apparently serves both to create surfaces of separation and to form microphases with a high crystallization capacity. Finely dispersed particles not only set up surfaces of separation, but promote microliquation. Materials of diverse character can be obtained by varying the chemical composition of the glass and the heat-treatment temperature and time.

Glass-ceramic materials obtained by glass-making techniques and subsequent crystallization are called sitalls in the USSR (see Sitalls), pyrocerams in the USA, and vitrocerams in the German Federal Republic. Thus, these materials include glass-cement ceramics, which are obtained by the ceramic method, and Sitalls, which are obtained by glass-making techniques. Among the products fabricated from them are glass-cement abrasive disks, which are used for rapid machining of metals and yield 2-2.5 times better results in polishing glass than abrasive tools fabricated with other types of binders. Glass-ceramic materials also include electrical vacuum and high-frequency ceramics and aerial insulator holders, glasses or frits with special composition being used as binders for the latter. The Sitall method opens up broad prospects for the manufacture of various materials of this type. Glass-ceramic materials produced by this method are used for structural, sanitary-engineering, architectural-decorative, scultural, road-building, and sound- and

heat-insulating products, piping, machine-building, instrument, radio, and electronic components, economical high-hot-strength vessels and bottles for the home, etc. Glass-ceramic materials can be manufactured from slag and ash, rock, and nonmetallic minerals, as well as from chemical raw materials. The American pyrocerams 9605 and 9606 are produced in this manner and have the following characteristics: specific gravity – 2.62 and 2.60 respectively, softening temperature – 1350° and 1250°, coefficient of thermal expansion (20-300°) – $14 \cdot 10^{-7}$ and $57 \cdot 10^{-7}$, bending strength – 2590 and 2240 kg/mm^2, dielectric constant at 10^6 cps – 6.1 and 5.6, and loss factor – 0.010 and 0.014. The characteristics of glass-ceramic materials may vary within wide limits.

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Ts.N. Gurevich

GLASS CLOTH – see Fiberglass.

GLASS FIBER – fiber obtained from molten glass which has a smooth surface and strictly cylindrical shape over the entire length. The main forms of glass fiber are: continuous 20 and more kilometers long and staple from 5 to 50 cm [long]. Continuous glass fiber and products made from it in the form of threads, fabrics and nonwoven materials are used for power designs. By its external form glass fiber is similar to silk. and is processed on textile industry equipment. Materials from staple glass fiber (cotton and wool type) are used for filtration, thermal insulation and in noncritical structures. Continuous glass fiber has the smallest diameter of 3-9 microns, the staple fiber can be obtained with a diameter smaller than one micron (ultrathin) and 2-3 microns (superthin). The continuous and staple fibers differ by the glass composition (Table 1). The selection of the gas composition depends on the forming conditions, properties and intended service of the glass fiber. Modern t nology also makes use of nonorganic glass fiber which has a high melting temperature (1750-1800°) such as quartz (SiO_2 = 100%), silica

TABLE 1

Chemical Compositions of Glasses Used for Glass Fiber Production

Стекло 1	2 Вид волокна	3 Содержание окислов (%)								
		SiO_2	Al_2O_3	B_2O_3	CaO	MgO	Na_2O	F	K_2O	ZrO_2	Fe_2O_3
4 Бесщелочное алюмоборосиликатное	Непрерывное	54.0	14.5	10.0	16.5	4.0	0.7	0.3	–	–	–
6 Алюмомагниевое	7 То же	61.0	25.0	–	8.5	5.5	0.0	–	–	–	–
8 Натрийкальцийсиликатное	9 Штапельное	56.0	5.0	–	22.0	4.0	11.0	–	–	–	–
10 Натрийкальцийсиликатное № 20	Штапельное ультратонкое	61.0	2.0	3.0	8.0	–	23.0	–	1.0	3.0	1.0

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1) Glass; 2) kind of fiber; 3) content of oxides (%); 4) nonalkaline aluminum-borosilicate; 5) continuous; 6) aluminum-magnesium; 7) same as above; 8) sodium-calcium-silicate; 9) staple; 10) sodium-calcium-silicate No. 20; 11) staple, ultrathin.

(SiO_2 = 96-98%) and kaolin (SiO_2 = 50% and Al_2O_3 = 50%).

The high mechanical, heat resistant, dielectric and thermal insulating properties and the chemical stability of glass fiber and products made from it depend to a substantial extent on the fiber diameter and on the chemical composition of the glass.

The mechanical properties of glass fiber depend on the chemical composition and the homogeneity of the glass, the method of its production, on the surrounding medium and the temperature. Glass fiber from nonalkaline aluminum-borosilicate glass is the strongest. A high alkaline content of glass sharply reduces the strenth of glass fibers. The strength of glass fibers is effected by drawing conditions and the cooling rate (Table 2). The surface defects substantially reduce the strength of glass fiber; as the diameter is made smaller, the strength increases (Fig. 1). Crystallization of the glass and inhomogeneous inclusions reduce the strength by 25-30%; the strength of glass fibers

TABLE 2

Properties of Glass Fibers Obtained by Various Methods

1 Способ производства	2 Диаметр волокна (мк)	3 Прочность: 4 Разрывная длина (км)	3 Прочность: 5 Предел прочности (кг/мм²)	6 Удлинение при разрыве (%)
7 Фильерный (вытягивание волокна из расплава с большой скоростью 8 через фильеры)	6—7	80—92	200—250	3.6—5.1
9 Штабиковый (вытягивание из разогретого 10 конца штабика)	6—7.5	63—75	150—180	3.3—3.7
11 Дутьевой (полученне волокна раздувом струи стекла воздухом или паром) 12	6—8	38—45	90—110	2.5—2.9

1) Production method; 2) fiber diameter (microns); 3) strength; 4) rupture length (km); 5) ultimate strength (kg/mm²); 6) rupture elongation (%); 7) spinneret; 8) (drawing the fiber from the melt at a high rate through spinnerets; 9) mold; 10) (drawing from the heated end of a mold); 11) blown; 12) (fiber obtained by blowing a glass jet by air or steam).

increases in dry air and in nonpolar carbon liquids. In moist air, in water, water solutions of surface-active substances the strength of glass fibers is reduced to 50-60%, but is fully restored after drying. When a deforming force is applied for a long time, particularly in a wet medium, fatigue appears in glass fibers which disappears after it is made waterproof, for example, by organic si[illegible]icon compounds. After the load is removed the strength of glass fibers is restored. Glass fiber withstands multiple applications of a tensile force provided that this load is periodically removed and that the fiber is being deformed in a nonpolar hydrocarbon medium or in air with a low relative humidity. The mechanism by which the strength of glass fiber is reduced in water and in water solutions of surface-active substances is related to the adsorption effect of the medium. Molecules of substances which are being adsorbed on the glass fibers weaken forces which act between their surface elements, thus facilitating the formation of cracks in weak points of the surface layer, which result in destruction of the fibers. The complete reversibility of deformation after removal of the load, which is observed, is determined by the gradual spontaneous displacement of the adsorbed molecules of the medium from the surface microcracks of the fiber, and by the closing of these cracks under the action of the binding forces in the glass (Rebinder's effect). At standard temperature and under short duration loads glass fibers behave practically as perfect elastic-brittle bodies, being governed, up to rupture, by Hooke's law (Table 3). As the load duration is increased, an elastic aftereffect develops in the glass fibers alongside with the initial instantaneously elastic deformation; the magnitude of this aftereffect is small and it depends on the chemical composition of the glass and the relative humidity of the air (Fig. 2). The moisture also has a substantial effect on the flexure and abrasion resistance of

glass fiber.

The adsorption effect of moisture is eliminated at low and high temperatures which increases the strength of glass fibers. Heat treatment (heating to 400-500° and cooling) of glass fiber and products made from it reduces their strength by 50-70%. The composition of the glass exerts an important influence on the strength of fiber glass after heat treatment. Glass fiber from quartz glass and molten kaolin lose strength after heating and cooling only at 1100°, while asbestos fibers are destroyed completely as early as at 500-600° (Fig. 3). After heat treatment of glass fiber one may observe that they are compressed, their density and indices of refraction are increased.

Fig. 1. Dependence of the tensile strength (P) on the glass fiber diameter (d is in microns). 1) P, kg/mm^2.

The chemical stability of glass fibers is independent of their diameter, but the absolute solubility of thin fibers is substantially higher than the solubility of thick fibers. The resistance of glass fiber to chemical reagents depends on the glass composition; fibers from nonalkaline aluminum-borosilicate glass are water resistant but do not resist acids, articles from sodium-calcium-silicate glass are less water resistant, but resist acids and alkalis. Materials of quartz, silicon and kaolin composition resist water, high-pressure vapor and various acids (except for hydrofluoric and phosphoric acids).

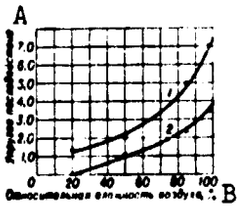

Fig. 2. Effect of relative humidity of air on the elastic aftereffect of glass fibers. 1) Fiber from sodium-calcium-silicate glass; 2) fiber from nonalkaline borosilicate glass. A) Elastic aftereffect; B) relative air moisture, %.

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The electrical properties of glass fiber and of products made from them depend on the chemical composition of the glass. The introduction of

TABLE 3

Comparative Data on the Modulus of Elasticity of Glass Fibers and Fibers of Natural Origin

Волокно (1)	Модуль упругости (кг/мм²) (2)
3 Стеклянное бесщелочное	7200—9000
4 Стеклянное щелочное . .	5000—6500
5 Хлопок	1200
6 Лен	5000
7 Натуральный шелк . . .	1300

1) Fiber; 2) modulus of elasticity (kg/mm^2); 3) nonalkaline glass; 4) alkaline glass; 5) cotton; 6) flax; 7) natural silk.

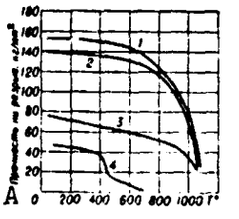

Fig. 3. Effect of the temperature on the strength of high-temperature resistant fibers. 1) Quartz fiber; 2) kaolin fiber; 3) silicon fiber; 4) asbestos fiber. A) Tensile strength, kg/mm^2.

TABLE 4

Effect of Air Humidity on the Specific Electric Resistivity (ohm·cm) of Glass Fabrics

Стекло (1)	Относительная влажность воздуха (%) (2)				
	20	40	60	80	100
Бесщелочное алюмоборосиликатное (3)	$2 \cdot 10^{15}$	$6 \cdot 10^{14}$	$7 \cdot 10^{13}$	$9 \cdot 10^{12}$	$3{,}4 \cdot 10^{11}$
Натриевокальциевосиликатное . . (4)	$4 \cdot 10^{13}$	$1{,}8 \cdot 10^{13}$	$7{,}5 \cdot 10^{11}$	$9{,}8 \cdot 10^{10}$	$2{,}8 \cdot 10^{9}$

1) Glass; 2) relative air humidity (%); 3) nonalkaline aluminum-borosilicate; 4) sodium calcium-silicate.

alkaline metal oxides into the glass reduces its electrical resistivity and increases dielectric losses. The electrical conductivity of glass

fabrics at room temperature is primarily a surface property and changes under the action of moisture, various hydrophobic coatings and temperature (Fig. 4.).

The dielectric permeability and the tangent of the dielectric losses angle for products made from quartz and silicon fibers do not change as the temperature is raised to 700°, which makes it possible to use them as good high-temperature resistant dielectrics. Glass fibers and articles made from them can have good semiconductor properties. This is achieved by changing the chemical composition of the glass, metallization and graphitization. The thermal conductivity of products from glass fibers, particularly of staple products (felt, wool, plates), is very low (0.03 kcal/m·hour·°C) due to their high volume porosity. The thermal conductivity coefficient of glass fabrics (0.04-0.05) changes little at higher temperatures, and that of thin fabrics is similar to the coefficient for glass wool, that is, 0.03 kcal/m·hour·°C. When the temperature is raised to 1000°, the thermal conductivity coefficient of materials made from silicon and kaolin glass fibers increases and comprises 0.2 kcal/m·hour·°C. Depending on the thickness, density and intertwining, glass fibers have high transmission factor (up to 65%), reflection factor (75-80%) and acoustical absorption factor (0.9 at sound wave frequencies of 500-2500 cps). Glass fibers and articles made from them are of great importance as a high-strength reinforcement for plastics (glass plastics). Glass plastics are good replacements for metals in aircraft construction, for air and gas pipelines, surface coating of vessels, machines and for other purposes (Tables 5 and 6).

The fields of utilization of glass fiber materials are given in Table 7.

Figure 4 (see page) shows kinds of glass fiber and products made from it.

TABLE 5

Electric Properties of Glass Fabrics and Articles (at 20°)

Стекло 1	Удельное объемное сопротивление (ом·см) 2	Тангенс угла диэлектрич. потерь при 10^6 гц 3	Пробивное напряжение (кв/мм) 4	
			без пропитки лаками 5	после пропитки лаками 6
7 Весщелочное алюмоборосиликатное	$2 \cdot 10^{15}$	$9 \cdot 10^{-4}$	4—5	40—45
8 Натриевокальцийсиликатное	$4 \cdot 10^{12}$	$28 \cdot 10^{-4}$	4—5	40—45
9 Кварцевое и кремнеземное	$3 \cdot 10^{17}$	$2 \cdot 10^{-4}$	4—5	40—45

1) Glass; 2) specific volume resistivity (ohm·cm); 3) tangent of dielectric losses angle at 10^6 cps; 4) breakdown voltage (kv/mm); 5) without lacquer impregnation; 6) after lacquer impregnation; 7) nonalkaline aluminum-borosilicate; 8) sodium-calcium-silicate; 9) quartz and silicate.

TABLE 6

Mechanical Properties of Glass Plastics Made from Different Glass Fiber Materials

Вид стекловолокнистого материала 1	Смола 2	Содержание смолы (%) 3	Предел прочности при растяжении для однонаправленных материалов (кг/см²) 4
5 Жгут несклеенный из нити $N_м$ 70—80 (5—7 мк), в 8 сложений	Эпоксидно-фенольная 6	20	13 000—15 000
7 Жгут склеенный из нити $N_м$ 70—80 (5—7 мк), в 8 сложений	То же 8	19.9	14 000—16 000
9 Жгут несклеенный из нити $N_м$ 22—26 (9—11 мк), в 10 сложений	»	18.5	14 000—16 000
10 Нить крученая $N_м$=10 (5—7 мк)	»	18.0	12 000—14 000
11 Лента нетканая узкая (6 мм) из нити $N_м$ 70—80 (5—7 мк)	» 13	24.0	13 000—15 000
12 Холст жесткий из рубленых стеклянных нитей (10 мк)	Полиэфирная ПН-3	58—60	2 800— 3 000
14 Холст из штапельного полокна	Фенольная 15	80.0, с минеральным наполнителем — гипсом 30—40 16	1 400— 1 800
Ткань стеклянная марки ТС-8/3-250 17	Эпоксидно-фенольная 18		7 000— 8 000

1) Kind of glass fiber material; 2) resin; 3) resin content (%); 4) ultimate tensile strength for unidirectional materials (kg/cm²); 5) uncemented clusters from threads with N_M 70-80 (5-7 microns), in 8 layers; 6) epoxy phenolic; 7) cemented clusters from threads with N_M 70-80 (5-7 microns), in 8 layers; 8) same as above; 9) uncemented clusters from thread with N_M 22-26

(9-11 microns). in 10 layers; 10) twisted thread with N_M = 10 (5-7 microns); 11) non-woven narrow strip (6 mm) from thread with N_M 70-80 (5-7 microns); 12) rough canvas from chopped glass theads (10 microns); 13) PN-3 polyester; 14) canvas from staple fiber; 15) phenol; 16) 80.0 with a mineral filler, that is, gypsum 30-40; 17) glass fiber of the TS-8/3-250 brand; 18) epoxy phenolic.

TABLE 7

Fields of Application of Glass Fiber Materials and Their Effectivness

Products from glass fiber.	Use.	Resin content.
Glass yarn, strips, fabrics, cord, hosiery.	Insulation of electric wires with round and retangular cross section, cables and various electric machinery.	Increases the power output of engines. In combination with heat resistant lacquers it makes it possible to obtain class "VS" insulation with an allowable working temperature of 170°, and, together with organosilicon lacquers, "S" with 250° and higher. Increases the working temperature, reduces the overall dimensions and weight of electric machinery.
Mica glass fiber (glass micanites).	Insulation of stator windings.	Replaces highly scarce mica and increases the strength and breakdown voltage.
Glass fiber wastes in the form of alkaline-composition packing materials.	Packing materials for packing glands in acid pumps, stopcocks and communications through which the aggressive medium passes.	Increases the service life of equipment in aggressive media.
Glass fabrics.	Filter fabrics in the chemical industry.	Increases the service life of filters by a factor of 20-30 in comparison with standard textile materials. Makes it possible to filter hot acidic and alkaline solutions, hot gases and also to recover sediments, slag, etc.
Glass fabrics.	Special lighting apparatus, moving picture theater screens.	Ensures a high reflectivity coefficient and heat resistance.

Glass fabrics.	Drapes in radio studios, moving picture workshops, radio receivers, etc.	Ensure high acoustical properties and heat resistance.
Dyed glass fabrics.	Upholstery of aircraft, vessels, as decorative and camouflage material.	Is incombustible in addition to possessing all the properties of ordinary textile materials.
Glass felt, mats, wool.	Heat insulation of steam pipelines, railroad cars with isothermal cargo and in shipbuilding.	Yields high-quality insulation with a low weight and low thermal conductivity coefficient.
Same as above.	Filtering of air in air conditioning installations, gas purification in gas-generator fueled automotive vehicles and tractors.	Substantially increases the service life of these installations with an attendant reduction in their weight due to the high volume porosity and chemical stability.
	In battery cell separators.	Extends the service life of batteries by higher dielectric properties, chemical stability and volume porosity.
Ultrathin glass fiber.	Insulation of various engineering products (sound absorbers, etc.)	Ensures low thermal conductivity, low specific weight, high acoustical absorption factor and heat resistance.
Same as above.	Making of glass paper.	Makes it possible to obtain paper with good electric insulation properties and heat resistance.
Mixtures of glass fiber materials with plastics.	Materials of construction.	Makes it possible to obtain: substantially higher heat resistance than that of cotton fabric textolite, an electric strength higher by a factor of 4, moisture absorption lower by a factor of 5-6, strength up to 8000 kg/cm^2 for a specific weight of 1.6-1,75 and up to 12-14,000 kg/cm^2 for unidirectional clusters from cemented glas. threads.

Mixtures of glass fiber materials with plastics.	Insulation (by bitumen and resin impregnation) of pipes in the petroleum and gas industries.	Increase the service life of gas and petroleum pipelines.
Products from quartz, kaolin and silicon fiber.	High-temperature thermal insulation, electric insulation and heat protection.	Ensure thermal insulation of equipment up to 1200° in prolonged service and up to 2000° in short-term tests. Retain stable electric properties under temperature changes up to 700°. Have a low thermal conductivity at room temperature and in the temperature interval of 1000-1500°.
Metallized glass fiber and products made from it.	Semiconductor and current conducting materials.	Make it possible to obtain materials with semiconductor properties and with high reflectivity factors.

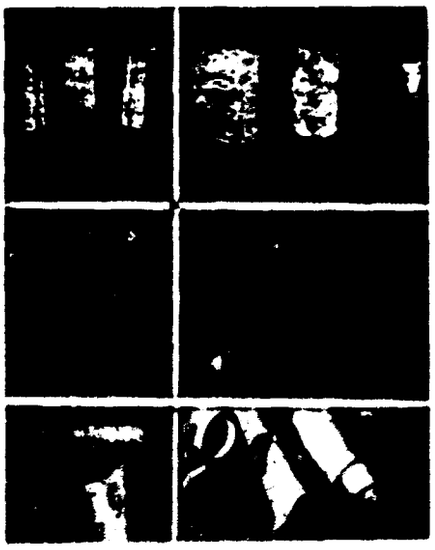

Fig. 4. Glass fiber and articles made from it. 1) Twisted thread; 2) staple yarn; 3) electrical insulation cord and strip; 4) conductors with glass fiber insulation; 5) glass fabric; 6) materials produced with glass fabrics as a base (glass textolite, glass micanite, rubberized glass fabric).

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[Glass Technology]. 3rd edition, Chapter 24, Moscow, 1961.

M. S. Aslanova

GLASS FIBER MAT AND STRIP - see Thermal and Sound Insulating Loose-Fiber Materials.

GLASS FILMS – flexible flat glass less than 100 μ thick. The flexibility of glass films depends on their thickness: films 10–15 μ thick are readily bent around drums 20 mm in diameter, while the maximum depth of curvature of ordinary glass does not exceed tenths or even hundredths of the length of the specimen tested. The mechanical strength of glass films substantially exceeds that of thick glass and is also governed by its thickness. The thinner the film, the higher is its mechanical strength. A similar relationship between breakdown strength and thickness is observed in electrical tests. The breakdown gradient rises by a factor of almost 3 as the thickness of glass films is reduced from 90 to 15 μ at room temperature, using glass of uniform composition. Films of low-alkali and alkali-free glass have an electrical strength equivalent to that of natural mica. Glass films are capable of withstanding severe local thermal transitions, from temperatures near the softening point of the initial glass to negative temperatures. As a result of their thinness, glass films have a high transparency. All the other physicochemical characteristics of such films depend on the composition of the initial glass.

The principal methods employed for producing glass films are drawing from a glass melt through various forming devices and drawing of a flat glass sheet by local heating to the softening point.

Glass films are used in the electronics industry for the manufacture of small high-frequency capacitors and targets for electron-beam tubes. The possible applications of these materials are very diverse. They can be employed for various electrical-insulating papers and flexi-

ble insulating materials. The consistent chemical composition of glass films permits them to be used as the basis for insulating materials with highly stable characteristics. Films and film-based materials with new technical indices can be produced by varying the chemical composition of the initial glass. The use of glass films in the manufacture of insulating materials has made it possible to partially replace expensive, hard-to-obtain natural mica. Glass films can be used as the basis for structural materials, in the form of glass-plastic sheets and piping of varying size and shape. Employment of glass plastics as a reinforcing material in the production of structural plastics increases their modulus of elasticity, strength, and rigidity. Structural glass plastics reinforced with glass films are distinguished by increased transparency. Ultrathin glass films (less than 1 μ thick) are of interest for research on the structure of glass.

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O.L. Al'takh

GLASS FOAM – a light, porous material obtained by sintering finely ground powdered glass and a frothing agent (coke, powdered marble, chalk, dolomite, pyrolusite, etc.). When it has set and cooled this material has high heat- and sound-insulating characteristics. Glass foam can readily be machined, glued to other materials, sawn, drilled with ordinary tools, or lathed. It can be heated to a temperature 200-250° above the softening point of the initial glass. The magnitude of this temperature difference is governed both by the chemical composition and thermal conductivity of the glass and by the linear dimensions of the article in question. The thicker the specimen being tested, the greater is the extent to which it can be heated. Its pores give glass foam a sound-absorbing capacity amounting to approximately 50% over the frequency range 500-4000 cps. The strength of glass-foam specimens subjected to 50 freezing-thawing cycles is reduced by 20-25%. This material is produced commercially with bulk weights of 200, 300, and 400 kg/m^3.

The characteristics of glass foam are shown in the table.

Glass foam is used for insulating subterranean heat-transfer pipes, as a buoyant material for life-saving devices and pontoon bridges, to increase the buoyancy of metallic structures, to protect ships against corrosion, and for insulating refrigerator cars. Glass foam with open pores is used in the manufacture of filters for acids and alkalis. This material can be employed as a substitute for natural pumice in grinding and polishing wood.

Characteristics of Glass Foam

1 Объемный вес ($кг/м^3$)	2 Коэффициент теплопроводности (ккал/м·час·°С) при 20°	3 Предел прочности при сжатии ($кг/см^2$)	4 Водопоглощение (объемные %)
100	0.031	8	6—9
200	0.052	20	6—9
300	0.071	35	6—9
400	0.090	60	6—9
500	0.110	90	6—9
600	0.130	110	6—9
700	0.150	130	6—9

1) Bulk weight (kg/m^3); 2) coefficient of thermal conductivity (kcal/m··hr·°C) at 20°; 3) ultimate compressive strength (kg/cm^2); 4) water absorption (% by volume).

References: Kitaygorodskiy, I.I., Keshishyan, T.N., Penosteklo [Glass Foam], Moscow, 1953.

G.G. Sentyurin

GLASS PLASTICS – plastic materials consisting of a fiberglass filler (elementary glass fiber, silica, quartz, basalt, or tuffonite fiber, glass cloth of varying structure, glass mats or canvas, etc.) and a binder (thermoreactive and thermoplastic polymers). The fiberglass materials give glass plastics high mechanical strength. The binder cements the fiberglass and should have a good wetting capacity, high adhesion to fiberglass, low shrinkage, and a high cohesive strength. Glass plastics can be arbitrarily divided into four groups in accordance with the type of filler and the technological characteristics of the material: glass textolites – plastics in which the filler is glass cloth (products with different characteristics can be obtained, depending on the structure of the cloth); glass voloknites – cast and pressed compositions consisting of a filler (chopped glass fibers, coarse cloth, or filaments) and powdered fillers, dyes, or pigments; oriented glass plastics, which are obtained by arranging glass fibers, threads, or filaments in parallel and simultaneously or subsequently applying a binder (synthetic resin); glass plastics or products based on preliminarily molded glass fiber or mats, chopped coarse cloth or filaments normally being employed.

The binder should make it possible to fabricate large articles from glass plastics; it should harden rather rapidly. The most widely used binders are those based on polyester, epoxy, phenol-formaldehyde, and silicoorganic resins. Halide-containing ingredients and special fillers are added to the binder to produce incombustible glass plastics. Special heat treatment or thermochemical processing of the fiber-

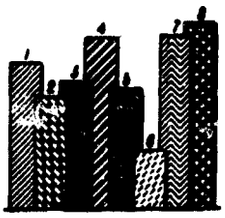

Fig. 1. Specific tensile strength of structural materials: 1) 30KhGSA steel; 2) D16 duralumin; 3) OT-4 titanium; 4) DRS pine; 5) DPS delta-wood; 6) PTK textolite; 7) EF32-301 glass textolite; 8) SVAM.

Fig.2. Specific strength of structural materials on compression: 1) 30KhGSA steel; 2) D16 duralumin; 3) OT-4 titanium; 4) DRS pine; 5) DSP delta-wood; 6) EF32-301 glass textolite; 7) SVAM.

glass filler improves the adhesion of the binder to the glass fibers and makes the physicomechanical and dielectric characteristics of the plastic more stable. Heat treatment at 200-300° reduces the content of filler lubricant (used during textile processing of the fiber) to 0.2-0.5%; this lubricant is completely removed by treatment at 400-450°. The characteristics of glass plastics can be made considerably more stable at elevated humidities by treating the filler with compounds that form chemical bonds with the filler glass and the binder (volan, which is a complex compound of the chromium salts of methacrylic and hydrochloric acids and chromium oxychloride, as well as silanes). When phenol-formaldehyde, melamine, or epoxy resins are used as binders the best results are obtained by treating the fiberglass filler with γ-aminopropyltriethoxysilane or other amine-containing silanes. The products obtained by reacting allyl or vinyl trichlorosilane with resorcine are general-purpose substances for treating the fiberglass filler. The water resistance of glass plastics and the stability of their char-

acteristics can be increased by adding similar active products to the binder. Glass plastics can be subjected to all types of machining, but the cutting regimes and tools differ somewhat from those usually employed, since the fiberglass filler has an abrasive action on the tool and these plastics have a low thermal conductivity. The use of glass plastics in various branches of industry is also due to the fact that components of these substances can be joined to one another and to other materials by gluing, riveting, or bolting. Glass plastics have high mechanical strength; the specific strength of glass textolite and oriented fiberglass plastics is equal to and sometimes even greater than that of steel or duralumin (Figs. 1 and 2). The principal drawback of glass plastics is their comparatively low rigidity.

The table shows the physicomechanical and dielectric characteristics of the principal types of glass plastics.

Physicomechanical and Dielectric Characteristics of Principal Types of Glass Plastics

Свойства 1	Тип пластика (наполнитель и связующее) 2			
	стеклотекстолит ЭФ32-301 на эпоксифенольном связующем 3	ориентированный стеклопластик СВАМ (структура 1:1 на эпоксифенольном связующем) 4	стеклосволокнит АГ-4В на модифицированной фенолформальдегидной смоле 5	пластик на стеклянного мата на полиэфирной смоле 6
Удельный вес 7	1.82—1.8	1.88—1.91	1.7—1.8	1.6—1.7
8 Модуль упругости при растяжении (кг/см²)	220000	до 350000	120000—150000	80000—100000
9 Предел прочности (кг/см²): при растяжении 10	4000	4500—4700	800—1200	1000—1800
вдоль слоев: при сжатии 11	2600	4200	1300—2000	—
12 при изгибе	4140	4100—4600	1500—2000	2000—3200
Удельная ударная вязкость (кг·см/см²) 13	140	290—310	50—100	70—80
14 Теплостойкость по Мартенсу (°С)	240	—	280	—
15 Водопоглощение за 24 часа (%)	0.28	0.1—0.3	0.03	0.2—0.5
16 Удельное объемное электросопротивление (ом·см)	$1.2 \cdot 10^{14}$	$5 \cdot 10^{14}$—$1 \cdot 10^{16}$	$4 \cdot 10^{13}$—$3 \cdot 10^{15}$	—
17 Диэлектрич. проницаемость при 10^6 гц	4.4—4.8	—	6.0	—
18 Тангенс угла диэлектрич. потерь при 10^6 гц	0.013—0.015	0.011—0.015	0.03	—
19 Коэфф. линейного расширения 21 по основе	$6.2 \cdot 10^{-6}$	—	7.0—$14.8 \cdot 10^{-6}$	15—$26 \cdot 10^{-6}$

1) Characteristic; 2) type of plastic (filler and binder); 3) EF32-301 glass textolite in epoxy phenolic binder; 4) SVAM oriented glass plastic (structure 1:1 in epoxy phenolic binder); 5) AG-4V glass voloknite in modified phenol-formaldehyde resin; 6) plastic consisting of glass mat in polyester resin; 7) specific gravity; 8) modulus of elasticity on extension (kg/cm^2); 9) ultimate strength (kg/cm^2); 10) on extension; 11) on compression; 12) on bending; 13) impact strength (kg·cm/cm^2); 14) Martens thermostability (°C); 15) water absorption over 24 hr (%);

16) deep resistance (ohm·cm); 17) dielectric permeability at 10^6 cps; 18) tangent of angle of dielectric loss at 10^6 cps; 19) coefficient of linear expansion; 20) along layers; 21) along base.

The mechanical characteristics of a glass plastic are governed by the type of filler and binder, the quantitative ratio of these two ingredients, and the technological processes by which it is manufactured and products are fabricated from from it. Glass textolites and oriented plastics based on epoxy and modified epoxy resins have the highest strength. These plastics are characterized by anisotropic characteristics and have the greatest long-term strength and dynamic durability. The long-term bending strength of glass textolites based on various binders amounts to 50-74% of their initial short-term strength after 1000 hr of loading. Their dynamic durability at 10^7 cycles amounts to 23-28% of their short-term static strength. The long-term strength of plastics based on fiberglass mats equals 49-67% of their initial strength, while their dynamic durability amounts to 18-25% of this strength. The mechanical characteristics of glass plastics depend on operational conditions and are noticeably reduced at high humidities and temperatures. Glass textolites and glass voloknites based on silicoorganic binders have the best electrical-insulating properties. Glass plastics have the highest heat resistance of any plastic material; they can function at temperatures of up to 400° and briefly withstand temperatures of up to 2000-2500°. Their thermal conductivity depends on their density and fiberglass content, ranging from 0.18 to 0.4 kcal/m·hr·°C.

The anisotropic synthetic synthetic fibrous materials SVAM and AG-4s are characteristic glass plastics. In order to produce SVAM the elementary fibers, drawn [illegible] an electric furnace, are coated with binder and arranged in parallel (or slightly inclined) turns on a rotating drum or special receiving device. The coiled structure (glass veneer)

is removed in the form of sheets or strips and fabricated into finished products after drying. The complete exclusion of all textile operations and the formation of a protective polymer-binder film on the fresh, undamaged fiber surface satisfies the prerequisites for maximum utilization of fiber strength. Two-strand twisted glass thread (used in the manufacture of glass cloth) or 10-strand braided glass is employed in the manufacture of AG-4s. The threads, arranged in parallel, are coated with binder and form a continuous strip, which is ready for processing after drying. Unpolymerized sheets or strips with a unidirectional structure are formed in the material, observing a predetermined ratio of longitudinal and transverse layers, i.e., giving a predetermined anisotropy of physicomechanical characteristics. Finished products are fabricated by pressing at appropriate temperatures and pressures, by vacuum forming, or by winding and subsequent setting in autoclaves or polymerization chambers. The processing regimes and equipment employed are governed by the type of binder and the character of the finished product. The method described above for production of SVAM is used to reinforce cylindrical casings in the radial direction, omitting the glass-veneer stage; in this case the entire technological process reduces to two operations, winding the fibers under tension on a rotating cylinder and simultaneous application of binder, followed by polymerization (this can be reduced to one operation for cold-setting resins).

Glass plastics are widely employed in various branches of technology. They are used as electrical-insulating materials in instruments and electrical machinery and equipment, considerably increasing their reliability and service life.

Glass-plastic piping can be widely employed in the gas and petroleum industries, while storage tanks for water, chemical reagents, etc., can be used in the chemical industry. In the automobile industry glass

plastics are used in the manufacture of light components, cabs, and hoods. These materials have come into especially wide use for the manufacture of small-series ambulances, trucks, and sports cars. They are employed as structural and radio-engineering materials in th aviation industry. Glass plastics are the principal material for the reflectors of radio-locating stations. They have also been successfully employed in the production of various types of rockets. In other nations they are employed in the production of railroad rolling stock. Glass-plastic boats do not rot, are not subject to corrosion, and are easily manufactured.

References: Kiselev, B.A., Stekloplastiki [Glass Plastics], Moscow, 1961; Morgan, F., Stekloplastiki [Glass Plastics], collection of articles translated from English, Moscow, 1961.

B.A. Kiselev

GLASS TEXTOLITE – a laminated structural material obtained by hot pressing of glass cloth cut to the dimensions of the press plates, assembled into a packet of the requisite thickness, and preliminarily impregnated with an organic or silicoorganic resin. Glass textolite has a smooth surface without cracks, swollen areas, deep folds, or foreign inclusions. A layer of cellophane can be pressed onto the sur-

TABLE 1

Thermophysical Characteristics of Glass Textolites

1 Показатели	2 Марки: 3 КАСТ-В	4 ЭФ32-301	5 СТ	6 СТУ	7 СКМ	8 СТК-41А	9 СТК-41Б	10 СТК-41/ЭП	11 СТЭФ	12 ПСК
13 Теплостойкость по Мартенсу (°С)	215–220	240	180	200	215–300	>250	>250	>250	>200	25 Повышенная теплостойкость
14 Нагревостойкость (°С)	–	–	130	130	250	>200	>200	>200	–	–
15 Допустимая рабочая температура (°С)	–	–	130	130	800	180	180	180	155	–
16 Коэффициент линейного расширения при температуре:										
17 от –60 до +20°	11.25×10^{-6}	–	–	–	–	–	–	–	–	–
18 от 20 до 100°	$6.3 \cdot 10^{-6}$	$6.2 \cdot 10^{-6}$	–	–	$6.1–8 \cdot 10^{-6}$	–	–	–	–	–
19 от 100 до 200°	$6.45 \cdot 10^{-6}$	–	–	–	–	–	–	–	–	–
20 Коэффициент теплопроводности (ккал/м²·ч·°С) при температуре испытания:										
21 от 20 до 100°	0.244	0.3–0.37	–	–	–	–	–	–	–	–
22 от 100 до 200°		0.37–0.33	–	–	–	–	–	–	–	–
23 Температуропроводность (м²/ч) при температуре испытания:										
от 20 до 100°	–	$0.5 \cdot 10^{-6}$	–	–	–	–	–	–	–	–
от 100 до 200°	–	$7.1–8.8 \times 10^{-6}$	–	–	–	–	–	–	–	–
24 Удельная теплоемкость (ккал/кг·°С) при температуре испытания:										
от 20 до 100°	–	0.23–0.25	–	–	–	–	–	–	–	–
от 100 до 200°	–	0.3–0.35	–	–	–	–	–	–	–	–

1) Characteristic; 2) type; 3) KAST-V; 4) EF32-301; 5) ST; 6) STU; 7) SKM; 8) STK-41A; 9) STK-41B; 10) STK-41/EP; 11) STEF; 12) PSK; 13) Martens thermostability (°C); 14) heat resistance (°C); 15) permissible working temperature (°C); 16) coefficient of linear expansion at temperature of: 17) from –60 to +20°; 18) from 20 to 100°; 19) from 100 to

200°; 20) coefficient of thermal conductivity (kcal/m^2·hr·°C) at test temperature of: 21) from 20 to 100°; 22) from 100 to 200°; 23) temperature conductivity (m^2/hr) at test temperature of; 24) specific heat capacity (kcal/kg·°C) at test temperature of; 25) elevated thermostability.

TABLE 2

Physicomechanical and Electrical Characteristics of Glass Textolites

	1 Показатели	2 Марки										
		3 КАСТ	4 КАСТ-В	5 СТ	6 СТУ	7 СТЭФ	8 ЭФ32-301	9 СКМ-1	10 СТК-41А	11 СТК-41В	12 СТК-41/ЭПС	13 ПСК
14	Удельный вес	1.8	1.8	1.7–1.8	1.7–1.8	1.7–1.8	1.6–1.8	1.77	1.67–1.70	1.56–1.70	1.7–1.8	1.6–1.8
15	Предел прочности (кг/см²):											
16	при растяжении по основе	3300	3200	1200	1500	2000–3000	4080	2100	2000	2000	1800–2500	>550
17	по утку	2100	2000	–	–	–	2250	1700	–	–	–	–
18	при сжатии вдоль слоев	–	1100	–	–	–	2600	610	–	–	–	
19	перпендикулярно слоям	–	3500	–	–	–	4200	–	–	–	–	–
20	при изгибе	–	1500	1200	1500	2500	4140	1400	1100	1100		1200
21	при сдвиге (скалывании) вдоль слоев	175	–	130	225	300	65	–	100	100	300	–
22	Модуль сдвига (кг/см²):											
23	по основе	–	40000	–	–	–	35000	–	–	–	–	–
24	под углом 45°	–	75000	–	–	–	104500	–	–	–	–	–
25	Модуль упругости при растяжении (кг/см²):											
	по основе	206000	200000	–	–	–	220000	–	–	–	–	–
	по утку	123000	110000	–	–	–	163000	–	–	–	–	–
26	Удельная ударная вязкость (кг·см/см²):											
	по основе	80	85	>50	>50	>150	148	80	>50	>50	>50	>25
	по утку	60	50	–	–	–	120	55	–	–	–	–
27	Коэффициент Пуассона:											
	по основе	–	0,115	–	–	–	0,203	–	–	–	–	–
	по утку	–	0,085	–	–	–	0,122	–	–	–	–	–
28	Удельное объемное электрическое сопротивление (ом·см)											
29	в нормальных условиях	10^{13}–10^{14}	10^{13}	10^{13}	–	10^{13}	–	$5\cdot10^{13}$	10^{14}	10^{14}	10^{14}	–
30	после пребывания в среде с 95±3% относительной влажности в течение 28 суток	–	10^{8}	10^{8}	–	–	–	–	10^{9}	–	10^{9}	–
31	то же в течение 24 час.	–	–	–	–	10^{13}	–	$6\cdot10^{11}$–10^{13}	10^{11}	–	10^{13}	–
32	Удельное поверхностное электрическое сопротивление (ом):											
	в нормальных условиях	10^{10}–11^{13}	–	10^{13}	–	10^{13}	–	1.2×10^{14}	10^{14}	10^{14}	10^{14}	–
	после пребывания в среде с 95±3% относительной влажности в течение 28 суток	–	–	10^{8}	10^{8}	–	–	–	10^{9}	–	10^{9}	–

33	Электрическая прочность (кв/мм)	–	–	15	14	30	–	11	18	8	20	–
34	Тангенс угла диэлектрических потерь (при 50 гц):											
	в нормальных условиях . . .	0,02–0,03	–	0,07	0,07	0,005	–	0,01	0,003	0,003	0,004	–
35	при температуре 200°	–	–	–	–	–	–	0,08	0,01	0,01	–	–

1) Characteristic; 2) type; 3) KAST; 4) KAST-V; 5) ST; 6) STU; 7) STEF; 8) EF32-301; 9) SKM-1; 10) STK-41A; 11) STK-41B; 12) STK-41/EP; 13) PSK; 14) specific gravity; 15) ultimate strength (kg/cm^2); 16) on extension along warp; 17) along woof; 18) on compression along layers; 19) perpendicular to layers; 20) on bending; 21) on shear (slip) along layers; 22) slip modulus (kg/cm^2); 23) along warp; 24) at angle of 45°; 25) modulus of elasticity on extension (kg/cm^2); 26) impact strength $kg \cdot cm/cm^2$); 27) Poisson's ratio; 28) deep electrical resistance (ohm·cm); 29) under normal conditions; 30) after being kept in an environment with a relative humidity of 95 ± 3% for 28 days; 31) the same, after 24 hr; 32) superficial electrical resistance (ohm); 33) breakdown strength (kv/mm); 34) tangent of angle of dielectric loss (at 50 cps); 35) at temperature of 200°.

face of glass textolite. Large quantities of glass textolites with varying characteristics are produced commercially. Table 1 shows the thermophysical characteristics of these materials, while Table 2 shows their physicomechanical and electrical characteristics.

Glass textolites can be subjected to all types of machining, gluing, and riveting, under regimes similar to those employed for metals (see Machining of plastics).

Glass textolites are used in the manufacture of various articles and structural components for electronics and radio engineering.

GLASS WITH AN ELECTRICALLY CONDUCTIVE SURFACE – glass whose surface has been coated with a thin film of metal oxides with semiconductive characteristics. These glasses are produced with oxides of tin, indium, titanium, cadmium, antimony, lead, and other metals, as well as various combinations of these oxides with small additives of copper, zinc, cobalt, etc., oxides. The thickness of the conductive film varies from several A to several μ, while its resistance (per unit surface area) ranges from several ohms to hundreds of thousands of ohms. The film is transparent to light in the visible portion of the spectrum, absorbing 1-20% and reflecting 10-12% of the light flux. The resistance of the film decreases and its light absorption increases as it becomes thicker.

TABLE 1

1 Метод нанесения пленок	2 Толщина пленок (Å)	3 Показатель преломления пленки n_D	Коэффициент отражения света пленкой 4 (%)	
			минимальный 5	максимальный 6
Гидролиз $SnCl_4$ при 500° 7	250	1.65	—	—
	500	1.78	4.2	12.6
	1000	1.80	4.2	14
	1300	1.82	—	—
Пиролиз $SnCl_4$ при 450° 8	300	1.83	4.2	—
	500	1.85	4.2	16
	1100	1.88	4.2	17
	2500	1.92	4.2	18
	3500	1.94	4.2	19.5

1) Method of applying film; 2) film thickness (A); 3) index of refraction n_D; 4) coefficient of reflection (%); 5) minimum; 6) maximum; 7) hydrolysis of $SnCl_4$ at 500°; 8) pyrolysis of $SnCl_4$ at 450°.

The following are the most common methods for producing electrically conductive films: 1) condensation on heated glass of the vapor produced by heating solid or liquid film-forming susbstances (the va-

TABLE 2

Вид оксидной пленки 1	Толщина пленки (Å) 2	Удельное поверхностное электросопротивление (ом) 3	Поглощение света пленкой (%) 4	Коэффициент отражения света пленкой (%) 5	Светопропускание стекла, покрытого пленкой (%) 6
SnO_2	200	10^6	0	4	90
	500	10^4	0	4	90
	1000	700	0	4	90
	5000	150	2	14	80
	10000	74	3	16	77
	20000	35	10	15	71
CdO	250	2000	2	6	88
	750	900	10	16	70
	1000	360	20	20	56
TiO_2	500	$4 \cdot 10^6$	3	8	85
	1000	$2 \cdot 10^6$	7	22	67

1) Type of oxide film; 2) film thickness (A); 3) superficial resistance (ohms); 4) light absorption (%); 5) coefficient of reflection (%); 6) transmissivity of film-coated glass (%).

porization or "smoking" method); 2) thermal diffusion of metal ions from within the glass to its surface and subsequent reduction of these ions in a hydrogen atmosphere at high temperatures (for glasses containing easily reduced oxides of lead, silver, copper, bismuth, and antimony); 3) surface treatment of heated glass with film-forming aerosols (dispersed with air under a pressure of 4-5 atm or with ultrasound). Films formed on hot glass (450-650°) have a higher transparency and a lower resistance than films produced on cooler glass (below 300°); in the latter case the film is often porous, nontransparent, and nonconductive. The initial materials for the latter two methods are generally halides of those metals whose oxides must be obtained at the surface of the glass; sulfates, nitrates, carbonates, and certain organic compounds are also employed. Conductive coatings of stannic oxide, which are distinguished by high mechanical strength and chemical stability, are the most common; they do not require hard-to-obtain materials.

Stannic oxide films are formed on glass at high temperatures by pyrolysis or hydrolysis of various tin compounds; alcohols, acetone, phenol hydrazine, etc., are used as reducing agents. Table 1 shows the

optical characteristics of coated glass as a function of the thickness of stannic oxide films obtained by pyrolysis or hydrolysis of $SnCl_4$.

Stannic oxide films have a very low absorption in the visible portion of the spectrum; they are most transparent at wavelengths of from 0.5 to 1 μ. Pronounced absorption begins at a wavelength of 370 mμ. Maximum transmissivity in the infrared portion of the spectrum occurs at a wavelength of 10 μ. The electrical conductivity of such films on glass is electronic in character and is distinguished by a comparatively low thermal coefficient (3-5% per °C), varying reversibly over the range 0-250°. Stannic-oxide films are sufficiently resistant to prolonged exposure to ac and dc currents with voltages of up · kv and densities of up to 15 amp/mm^2.

Table 2 shows the electrical and optical characteristics of stannic-oxide films in comparison with other conductive films on glass.

Table 3 shows the characteristics of conductive stannic-oxide films obtained by the aerosol method (with the glass heated to 640°).

High-resistance conductive films from 4000 to 6800 A thick can be produced on glass by evaporation of $SnCl_2$ in pure crystalline form or with BiOCl added. The superficial resistance of such a film ranges from 10^3 to 10^7 ohms, while that of tin-bismuth films (containing 10% Bi_2O_3) is 10^4-10^8 ohms. Such semiconductive films are resistant to heating at 380° for 15 hr; they do not lose their properties after cooling to -60° or prolonged storage at room temperature.

Films obtained by reduction of components in the surface layer of the glass are distinguished by an ability to withstand high stresses; their electrical resistance is uniform and remains virtually unchanged on storage at room temperature or heating to 200° in air. Such films have a negative thermal coefficient of electrical resistance ranging from 0.3 to 1% per °C. Special glasses containing readily reduced metal

oxides (Bi_2O_3, Sb_2O_3, As_2O_3, etc.) are used to produce these films. When the glass is heated and its surface treated with hydrogen the metal ions undergo thermal diffusion from within the glass to the surface and are there reduced. Table 4 shows the chemical composition of the glasses used and the superficial resistance of semiconductive films obtained by this method.

TABLE 3

1 Раствор, применяемый для образования пленки	2 Растворитель	Давление воздуха при образовании аэрозоля (атм) 3	4 Время обработки стекла аэрозолем (сек.)	Поверхностное электросопротивление квадрата пленки (ом) 5	Светопропускание стекла, покрытого пленкой (%) 6
50%-ный раствор $SnCl_4 \cdot 5H_2O$ 7	Этиловый спирт (ректификат) 11	5 5	10 5	1000 4500	81 82.5
	Вода 12	4. [illegible]	10 5	4000 6000	79 81.4
50%-ный раствор $SnCl_2 \cdot 2H_2O$ 8	Этиловый спирт (ректификат)	5.1 5.5	15 10	600 1000	78.5 81
	Вода	4.9 5.2	15 10	1000 3000	77.5 79
То же, с добавкой $TiCl_3$ 9	Вода	5.4 5.5	15 10	700 1500	80 82
То же, с добавкой $SbCl_3$ 10	Этиловый спирт (ректификат)	5. 4.8	15 10	40 60	77.5 79

Note: The transmissivity of the initial uncoated glass is 90%, while after treatment with $SnCl_4 \cdot 5H_2O$ it is 88.5%.

1) Film-forming solution; 2) solvent; 3) air pressure during aerosol formation (atm); 4) aerosol-treatment time (sec); 5) superficial resistance of square of film (ohms); 6) transmissivity of coated glass (%); 7) 50% $SnCl_4 \cdot 5H_2O$; 8) 50% $SnCl_2 \cdot 2H_2O$; 9) the same, with $TiCl_3$ added; 10) the same, with $SbCl_3$ added; 11) ethyl alcohol (redistilled); 12) water.

TABLE 4

Состав стекол (мольные проценты) 1					Удельное поверхностное сопротивление стекол (ом) после обработки в атмосфере водорода при темп-ре (°C) 2			
SiO_2	PbO	$BiO_{1.5}$	$SbO_{1.5}$	$AsO_{1.5}$	340	380	400	440
60	40	–	–	–	$>10^{10}$	$>10^{10}$	$>10^{10}$	$>10^{10}$
60	39	1	–	–	–	$5.6 \cdot 10^8$	$7.1 \cdot 10^8$	$1.3 \cdot 10^7$
60	38	–	1	–	$5.1 \cdot 10^7$	$4.3 \cdot 10^8$	–	$>10^{10}$
60	30	–	10	–	$1.5 \cdot 10^7$	$3.5 \cdot 10^7$	$1.3 \cdot 10^8$	$6.5 \cdot 10^8$
60	39	–	–	1	$7.5 \cdot 10^7$	$4.6 \cdot 10^8$	–	$>10^{10}$
60	30	10	10	–	$2.7 \cdot 10^8$	$7 \cdot 10^8$	$7.8 \cdot 10^8$	–

1) Composition of glass (cation percent); 2) specific superficial resistance (ohms) of glass after treatment in hydrogen atmosphere at a temperature of (°C).

Films obtained by treating these glasses with hydrogen for 4-6 hr at temperatures above 380° are nontransparent in the visible portion of the spectrum (at wavelengths of from 280 to 750 mμ).

Coatings based on indium and titanium oxides are widely used.

Indium-oxide films are obtained by spraying glass heated to 425-450° with indium trichloride in an atmosphere with a high relative humidity or by condensation of soft metallic indium on the glass at temperatures of 120-205°. The electrical resistance of a square of film obtained by spraying glass with indium trichloride dissolved in alcohol ranges from 25 to 500 ohms. Glass coated with an indium-oxide film passes approximately 85% of all visible light rays; such a film can withstand heating to 100°.

Cadmium-oxide films are applied by cathodic dispersion to the surface of cold glass, while gold films are applied by vacuum evaporation onto glass preliminarily coated with bismuth or zinc oxides.

Semiconductive films on glass usually have high mechanical strength, very good adhesion to the glass, and the requisite chemical stability; they can be removed from the glass only by polishing, dissolution in hydrofluoric acid, or treatment with atomic hydrogen. Electrical energy is generally supplied to the semiconductive coating with the aid of silver, copper, or silicate-silver contacts (busbars). The conductivity of these contacts should be 20 or more times that of the semiconductive coating itself.

Glasses with conductive surfaces are essentially open conductors, so that it is often necessary to provide reliable insulation for the conductive layer; this is done either by cementing the coated glass to uncoated glass, using an organic intermediate layer (to produce a three-layer glass of the triplex type with an internal conductive surface), or by applying clear film-forming insulating lacquers or other sub-

stances to the conductive surface. Such insulating coatings are generally produced with silicoorganic compounds, such as types K-44, K-47, and K-60 lacquer (depositing a polymer film 20-50 μ thick) or the corresponding chlorosilanes or oxysilanes; when these substances are hydrolyzed a film of SiO_2 is formed on the surface to be protected.

The practical applications of glasses with electrically conductive surfaces are very diverse. Electrically heated glass is widely employed in the manufacture of windows for various types of vehicles and buildings (self-defrosting glass), electrically heated glass panels, etc.

TABLE 5

1 Показатели	2 Стекло для транспорта и сооружений	3 Стеклянные панели (отопительные)	4 Зеркала (незапотевающие)
5 Габариты (мм)	14 1200×800	500×400	350—400
6 Толщина (мм)	7—10	4—6	8—11
7 Вид стекла	Закаленное трехслойное (триплекс)	Закаленное 15	Закаленное трехслойное (триплекс)
8 Температура нагрева (°С)	–	80—90	40—60
Продолжительность разогрева (мин.) 9	–	20	20—30
Удельная мощность (вт/см²) 10	0.02—0.09	0.06—0.08	0.025—0.045
11 Потребляемая мощность (вт)	–	100—150	60—100
Общее сопротивление (ом) 12	–	300—450	500—800
13 Рабочее напряжение (в)	40—250	110, 127, 220	220

1) Characteristic; 2) glass for vehicles and buildings; 3) glass panels (heating); 4) mirrors (nonsweating); 5) dimensions (mm); 6) thickness (mm); 7) type of glass; 8) heating temperature (°C); 9) heating time (min); 10) specific power (watts/cm^2); 11) power consumption (watts); 12) total resistance (ohms); 13) working voltage (v); 14) quenched 3-layer glass (triplex); 15) quenched glass.

Table 5 shows the characteristics of various types of electrically heated glass produced in the USSR.

The electrical resistance of the conductive layer remains unchanged on heating to 250°. Electrically heated glass is usually quenched to increase its heat resistance. With natural cooling the maximum load on the conductive layer should not exceed 1.5 watts/cm^2 (at a voltage of 220 v a 500·500 mm sheet of electrically heated glass can withstand a load of 2.5 kw).

Glass with a conductive surface is used in the manufacture of ves-

sels, instruments, and boilers for the household, the laboratory, and the chemical industry. All types of glass boilers are hygienic and resistant to chemical reagents and permit observation of the course of the process; they ensure uniform distribution of heat over the entire heated surface and have an efficiency reaching 96%, while that of the best metal boilers generally does not exceed 70%.

In addition, such glasses can be subjected to electrolytic surface deposition of zinc, cadmium, copper, nickel, and chromium. Semiconductive films on glass can be used as cathodes, for equilibrating the voltage gradient over the surface of glass bulbs in high-voltage vacuum devices (high-resistance films), for removing charges from the surface of electronic components, in the manufacture of stable high-value heat-resistant resistors (fixed or variable), and as transparent electrodes in the manufacture of photocells for various luminescent devices.

References: Grechanik, L.A., Solomin, N.V., Shpakova, I.V., Nauchno-tekhn. sbornik Nauchno-issled. in-ta elektrostekla (NIIES) [Scientific-Technical Collection of the Scientific Research Institute of Electrical Glass (NIIES)], 1959, No. 14; Ryabov, V.A., Borob'yeva, O.V., Yegorova, L.S., Steklo [Glass], Inform. byulleten' Vses. n.-i. in-ta stekla [Information Bulletin of the All-Union Scientific Research Institute of Glass], 1957, No. 1 (95); Frich. Ya., SiK, 1959, No. 11; Yanishevskiy, V.M., Zhukovskaya, Ye.A., Reznik, N.P., Ibid., 1960, No. 8; Botvinkin, O.K., Borob'yeva, O.V., Portnova, V.A., Ibid., 1961, No. 1; Wein, S., Glass Ind., 1957. November.

S.I. Sil'vestrovich

GLAUCONITE – group of hydromicaceous minerals which have a high covering and cation exchange capacity. The composition is not constant; on the average glauconite contains: 48-59% of SiO_2, up to 36% of Fe_2O_3 and FeO, up to 23% of Al_2O_3, up to 8% of K_2O, up to 4.5% of MgO and up to 15% of H_2O. Specific weight 2.2-2.8, Mohs hardness 2-3. The color of glauconite is green (from dark-green, almost black, to olive), sometimes yellow or grayish green. When heated to 150° glauconite gradually loses the adsorbed water, which is then restored within 24 hours, at a temperature of about 500° it loses all the hydroxyl water, at 925° glauconite becomes magnetic. Sintering temperature 1080°, t°_{pl} 1160°. When heated to 1500° it retains all the potassium. Sharp volatization of potassium which increases with temperature, takes place upon addition of $CaCl_2$ and $CaCO_3$. When heated with 15% HCl at a temperature of 80-100° it is completely leached out and loses its green color, it dissolves completely in H_2SO_4. It is resistant to alkalis, toxins and atmospheric agents. Glauconite has a high cation exchange capacity, which increases substantially upon stabilization by sodium silicate or aluminosilicate, after heating to about 400° the ion exchange capacity is reduced. With respect to hydrophily glauconite is close to quartz; the absolute wettability of glauconite is +1.0, the hysteretic wettability is 0.17 (it is 0.23 for quartz). The absorption capcity differs in glauconite of different age and which formed at different depths, with the highest capacity peculiar to deep-water glauconites, it is reduced after calcining. Peptization (formation of colloidal solutions) of glauconite is removed by heat treatment at 600-700°.

Glauconite is used as a cheap green paint, under the name neopermutite it is used as a hard water softener, primarily in high pressure boilers; as an adsorbent in bleaching substances, for the production of silicagel, refractory bricks, art ceramics; for the extraction of Al, Li and rare elements, for obtaining fast-hardening portland cement clinker, as a purifying adsorbent. Glauconite can also be used to determine the absolute age of sedimentary formations.

References: Betekhtin, A.G., Mineralogiya [Mineralogy]. Moscow, 1950; Kazakov, A.V., Glaukonit [Glauconite], in the book Mineralogicheskiye i fizikokhimicheskiye issledovaniya nekotorykh osadochnykh porod i poleznykh iskopayemykh [Mineralogic and Physio-Chemical Studies of Certain Sedimentary Rocks and Minerals[. Moscow, 1957 (Trudy Instituta geologicheskikh nauk AN SSR. Geologicheskaya seriya [Trans. of the Institute of Geological Sciences of the AN SSSR. Geological Series], Issue 152).

V. I. Magidovich

GOLD, Au – is a chemical element of the 1st group in Mendeleyev's Periodic System; atom number 79, atom weight 196.967. One stable isotope, Au^{197}, is known. Au^{195} is the most long-lived of the artificial radioactive isotopes. Its content in the earth's crust amounts to $5 \cdot 10^{-7}$% by weight. Gold is found in nature both in free state as nuggets and in form of telluric compounds ($AuTe_2$). Gold is a lustrous yellow metal which is very inert to the reaction of strong chemical reagents. The density is 19.32 g/cm^3, $t°_{pl}$ is 1063°, $t°_{kip}$ is 2947° (according to Aiken). Gold is only limitedly utilized in technology. The non-oxidizability, constancy in weight, and other physical properties of gold are important for construction purposes. Gold is widely used in jewelry and dentistry, as electrode in the electrochemical separation of some radioactive elements, for coating of shells of natural neutron sources and also for calibrating them, and for other purposes. The majority of gold is deposed in bank safes to standardize the currency. See Noble Metals.

O. Ye. Zvyagintsev

GRANITE – see Natural Acid-Resisting Materials.

GRAPHITE – mineral from the native elements group, one of the polymorphous varieties of carbon. Specific gravity 2.23 (from 2.21 to 2.26), t°_{pl} 3850°, t°_{kip} about 3900°. Color gray with a metallic luster. Specific heat from 0.187 (at 100°) to 0.452 kcal/g·degree at 2600°. Heat of melting (the evaporation heat being the same) about 120 cal/ /mole, linear expansion coefficient $2.5 \cdot 10^{-6}$. Specific resistivity 0.50 ohm·mm^2/m, that is by a factor of 2.5 lower than that of mercury. The electric conductivity of crystals perpendicular to the c-axis, that is, parallel to the lattice layers, is by a factor of 10^4 greater than along the c-axis. The electrical conductivity drops sharply when the temperature is increased. Has negative thermoelectricity. Graphite is magnetically anisotropic, that is, the permeability parallel to the lattice layers is equal to $0.5 \cdot 10^{-6}$ CGS magnetic units (is independent of the temperature), and perpendicular to the layers it is $22 \cdot 10^{-6}$ and varies upon heating. Average volumetric contraction coefficient (100-500 atm) $3.04 \cdot 10^{-6}$ per atm, at 5000 atm it is $1.98 \cdot 10^{-6}$ per atm. The ultimate compressive strength of graphite slabs is usually 150-300 kg/ /cm^2 and up to 840 kg/cm^2 for special service slabs, the ultimate tensile strength is 45-60 kg/cm^2 and the ultimate flexural strength is 100-150 kg/cm^2. The mechanical strength of slabs is increased at 1000-2000°. The coefficient of friction is very low; graphite is easily polished. The cleavage surface of graphite crystals is quite unsaturated by molecular attraction forces, which is responsible for the good adherance of graphite to solid surfaces. Graphite is acid resistant, is oxidized only at high temperatures, but is soluble in molten iron and

burns in molten saltpeter. Graphite is nontransparent even in thin plates.

Uses of graphite. In metallurgy: 1) crucibles for the smelting of metals (particularly, for the smelting of rare metals); 2) fireproof, chemically passive gaskets and ingot molds; 3) graphite nonstick "dusts" and casting mold lubricants; 4) graphite tubes, "boats" and other pyrochemical products (from artificial graphite); 5) graphite-ceramic smelting crucibles from coarse-scale graphite with a particle size of 0.2 mm. In electrical equipment: 1) graphite electrodes for electrolysis of molten media and solutions, in particular chloride, which do not allow the use of metallic anodes; 2) arc electrodes, graphite conductive covers, graphite-carbon tubes and other electric furnace components. Graphite powder is used for packing of electrical contacts between electrodes and their metal fittings; 3) sliding contacts for electrical machinery (electric brushes); 4) graphitized, depolarizing agglomerate for the positive poles of alkaline batteries and galvanic cells; 5) graphite anodes and grids in mercury rectifiers. For antifriction articles and lubricants: 1) "graphalloy," which is a conglomerate consisting of graphite, Al, Mg and Pb, for self-lubricating bearings and electrical machinery rings; 2) graphite liners for bearings, piston rod sleeves, packing rings for pistons, pumps and compressors; 3) graphite lubricant (graphite powder or greases and oil and water suspensions) are used for lubrication of heated parts of machines, autoclave screws, etc., as well as in the manufacture of all-drawn products. In nuclear engineering graphite in the form of rods and other components is used in reactors as a neutron decelerator. Artificial, very pure graphite is used for this purpose. In rocket technology it is used for nozzle throat liners and gas channels. Thinly milled graphite with a good covering ability is used in the manufacture of gray heat- and acid-resistant

paints. Boiler compounds, which are colloidal dispersions of graphite ("Aquadag" amd "Oildag") are put into steam boilers, evaporators, etc., to prevent scale formation. Chemically resistant graphite articles are used in chemical machine building when working with hydrofluoric acid, where neither metals nor ceramics can be used (facing tiles, pipes, heat transfer apparatus). In communication facilities graphite is used as resistances (graphite powder), plates (membranes), brushes (in communications apparatus and in radio apparatus). Graphite is used in arc welding apparatus (electrodes), in voltage regulators (graphite resistances and contacts), in the production of pencils (natural and artificial graphite).

Requirements put to the quality of graphite vary depending on its intended use; 25 GOSTs exist for different branches of industry.

References: Trebovaniya promyshlennosti k kachestvu mineral'nogo syr'ya [Industrial Requirements Put to the Quality of Mineral Raw Materials], Issue 3 - Veselovskiy, V.S. Grafit [Graphite], 2nd edition, Moscow, 1960; Mineraly [Minerals], Handbook, Vol. 1, Moscow, 1960.

V. V. Shcherbina

GRAPHITE IRON – is a porous antifriction cermet used in sliding bearings. The composition of graphite iron is: 95-98% iron and 2-5% graphite. The porosity lies in the range of 15-30%, the pores are filled with lubricating oil. The type of the structure, depending on the chemical composition and the operational conditions of the production, affects decisively the properties of graphite iron, especially the friction coefficient and the resistance to wear. Three types of structure are characteristics for graphite iron: the ferrite, pearlite, and cementite (iron carbide) structure.

The ferrite structure results at a low carbon content and low-temperature sintering; the pearlite structure ensues on a mean carbon content and ordinary sintering conditions (1050-1100°), and the cementite structure follows from a great carbon content, high sintering temperature and heat treatment (hardening, etc.). Graphite iron with pearlite structure is mainly used. Graphite iron with ferrite structure has a low resistance to wear, and such with pearlite structure shows an increased brittleness.

Graphite iron is widely used for the production of bearings and bushes in different assemblies of machines and mechanisms in a number of branches of the machine industry. Investigations were carried out which point at a very promising use of graphite iron in railroad bearings instead of babbitt bearings.

TABLE

Properties of Graphite Iron with Pearlite Structure

1 Свойства	2 Показатели свойств
3 Плотность (г/см³)	5,7—6,5
HB (кг/мм²) 4	40—50
σ_b (кг/мм²)	18—22
σ_{-b} (кг/мм²) 4	50—60
$\sigma_{изг}$ (кг/мм²) 5	30—32
$a_н$ (кгм/см²) 6	0,3—0,5
δ (%)	0,5—0,7
E (кг/мм²) 6	5000—7000
$\alpha \cdot 10^6$ (20—100°), 1/°C	8,0—11,0
7 Коэфф. трения по стали без принудит. смазки	0,01—0,02
8 Маслоемкость (%)	2,0—2,5
9 Макс. допустимая нагрузка кг/см²	75—80
10 t° допустимая, °C	150—200

1) Properties; 2) property indices; 3) density (g/cm^3); 4) kg/mm^2; 5) σ_{izg} (kg/mm^2); 6) kg·m/cm^2; 7) coefficient of friction on steel without forced lubrication: 8) ability to absorb oil (in %); 9) maximum permissible load, kg/cm^2; 10) permissible t°, in °C.

References: Rakovskiy, V.S., and Saklinskiy V.V., Metallokeramika v mashinostroyenii [Cermets in Machine Building], Moscow, 1956; Samsonov G.V., and Plotkin S. Ya., Proizvodstvo zheleznogo poroshka [Production of Iron Powder], Moscow, 1957; Moshkova A.D., and Uspenskiy Ya. V., Tekhnologiya proizvodstva i primeneniye poristykh podshipnikov [Technology of Production and Use of Porous Bearings], Moscow – Sverdlovsk, 1959.

V. S. Rakovskiy

GRAPHITIZATION OF STEEL – partial precipitation of carbon contained in the steel in the form of clustered accumulations, which is observed under specific conditions in carbon and alloy steels, most frequently when the carbon content is 0.5%. The fracture of steel in these cases is dark-gray in color (so-called black fracture). Graphitization of steel sharply impairs its mechanical properties, results in the breaking of products made from tool and leaf-spring steel. At the same time graphite, which has lubricating properties, improves the wear resistance of steel, in conjunction with which special wear resistant graphitized steel has been elaborated (EI293, EI366, etc.).

Graphitization of steel is aided by deoxidation of steel by aluminum and a high content of carbon, silicon, nickel and copper. Chromium, manganese, molybdenum, vanadium, titanium, niobium reduce the graphitization tendency of steel. Graphitization of tool and leaf-spring steel is aided by: forging at low temperatures, prolonged annealing at a temperature somewhat lower than the critical point A_c, or at 760-800°, slow cooling after annealing, and also stresses and work-hardening. Graphitization is sometimes developed in steels which do not contain chromium at the boundary of the thermal effect of welded joints of high-pressure pipes of steam pipelines after prolonged service. To eliminate this phenomenon, welded seams must be subjected to a high temper.

References: Gudremon, E, Spetsial'nyye stali [Special Steels], translated from German, Vols. 1-2, Moscow, 1959-60.

A.N. Minkevich

GRAPH PAPER (base) – paper produced from 100% bleached cellulose. The following types are manufactured, varying in the purpose for which they are intended (GOST 7717-55): D1 – for strip graphs, in spools and rolls, cut spools narrow in width (120, 140, 180, 230, 280, 310, 350, and 390 ± 0.5 mm); D-2, for disk and sheet graphs, in small-diameter

Показатели 1	Д-1 2	Д-2 3	Д-3 4
6 Вес 1 м² (г) 5	80	120	65
Объемный вес (г/см³, не менее)	0.9	0.9	0.9
7 Средняя разрывная длина по двум направлениям (м, не менее)	3500	3500	5000
8 Проклейка (мм, не менее)	2.0	2.0	1.5
9 Гладкость с сеточной и сетчатой сторонами (сек., не менее)	100	400	Машинная гладкость
10 Линейная деформация в поперечном направлении (%, не более) при изменении относит. влажности воздуха 30–80%	0.35	0.35	–
11 Зольность (%, не менее)	6	8	–
12 Просвечиваемость по просвечному методу — число дырочек (не менее)	– 7	– 7	10 7
13 Влажность (%)			

1) Index; 2) D-1; 3) D-2; 4) D-3; 5) weight of 1 m^2 (g); 6) bulk weight (g/cm^3, no less than); 7) average tearing length in two directions (m, no less than); 8) sizing, mm, no less than; 9) average smoothness on face and screen sides (sec, no less than); 10) linear deformation in transverse direction (%, no less than); with relative humidity varying from 30 to 80%; 11) ash content (%, no less than); 12) transparency by hatch test, number of sheets (no less than); 13) moisture content (%); 14) machine smoothness.

sheets for disk graphs (200, 250, and 300 mm), with margins for cutting to desired size; D-3 – transparent for special instruments in rolls 800 and 900 ± 2mm wide. Graph paper is water-impermeable and resistant to linear deformation. In order to increase their moisture resistance, D-1 and D-2 graph papers contain up to 6% melamine-formaldehyde resin.

This paper is suitable for ink writing, giving clear lines and hatching on graphs. The table shows the technological characteristics of the three types of paper.

In order to ensure clear ruling graph paper includes a filler (kaolin, talc, etc.), which improves its printing characteristics. The paper is sized with colophony glue and a solution of aluminum sulfate. A light-blue variety of D-3 is produced on request. Graph paper is used in automatic-recording instruments.

Z.I. Gruzdeva

GRAY BODY – a body having a continuous radiation spectrum similar to that of an Absolutely black body. The only difference between the spectra of a gray body and an absolutely black body lies in the fact that at a given temperature T and wavelength λ the radiation capacity of the former $E_c(\lambda, T)$ is always less than that of the latter $E_0(\lambda, T)$. From the similarity of their spectra it follows that the ratio $E_c(\lambda, T)/E_0(\lambda, T) = \varepsilon_{\lambda(T)}$ (the spectral blackness of the gray body) does not depend on the wavelength and is a constant less than unity for a given gray body. For the same reason, the blackness ε of the full radiation of a gray body is equal to its spectral Blackness ($\varepsilon = \varepsilon_\lambda$).

An absolutely gray body does not exist in nature, but the majority of technological materials (metals with an oxidized or roughened surface and structure, heat-insulating, etc. materials) have characteristics similar to those of gray bodies and are regarded as such in practice.

A.I. Kovalev

GRAY CAST IRON – is a cast iron with a gray-colored fracture, in which structure the whole carbon or the greatest part of it is precipitated in the form of free graphite, and structurally free carbides are absent. Depending on the founding technology, the content of alloying constituents and also the heat treatment, the castings of alloying constituents and also the heat treatment, the castings may contain precipitations of lamellar or spheroidal graphite, and the structure of the metal base may be purely pearlitic, pearlite-ferritic, ferrite-pearlitic, or purely ferritic (see Modified cast irons, Magnesium-ally cast iron, Pearlitic cast iron, Alloy cast iron, Heat treatment of cast iron).

Precipitations of the binary ($Fe-Fe_3P$) or tertiary ($Fe-Fe_3C-Fe_3P$) phosphite eutectic are usually present in the structure of nonalloyed cast iron, and precipitations of the tertiary phosphite eutectic $Fe-Cr_4C-Fe_3P$ are present in chrome-alloy cast iron.

In engineering technology, the term "gray iron" means a modified or nonmodified cast iron with lamellar graphite (Table 1). The gray iron with spheroidal graphite is termed magnesium-alloy or high-strength cast iron.

The mechanical properties of gray iron (Table 2) depend on the structure of its metal base and the type of the distribution of the precipitated lamellar graphite. The structure of the metal base depends on the content of combined carbon. The pearlitic base with most strength is obtained at 0.7-0.9% of the combined carbon; the presence of ferrite or cementite lowers the strength of the gray iron castings,

and the presence of cementite deteriorates, moreover, the machinability. Gray iron with a uniform distribution of lamellar graphite, possesses higher mechanical properties than cast iron with the same structure of the metal base, but an interdendritic distribution of the lamellar graphite (Table 3).

TABLE 1

Chemical Composition and Structure of Gray Iron Castings with Lamellar Graphite

1) Марка чугуна (ГОСТ 1412—54)	2) Толщина стенок отливки (мм)	3) Содержание элементов (%)						Структура 5
		C	Si	Mn	P	S	Cr	
					не более			
6) СЧ 00 и СЧ 12-28	8) до 10	3.2—3.8	2.4—2.7	7) 0.5—0.8	0.65	0.15	— 10	Феррито-перлитная, графит грубый
	10—20	3.2—3.8	2.3—2.6		0.5	0.13	—	
	20—30	3.1—3.6	2.2—2.5	—	—	—	—	
	свыше 30	3—3.5	2.1—2.4	—	0.5	0.13	—	
СЧ 15-32	до 20	3.2—3.6	2—2.4	7) 0.5—0.8	9) 0.65	9) 0.15	— 11	Перлито-ферритная, графит средней величины
	20—29	3.1—3.5	2—2.3					
	свыше 30	3—3.4	1.8—2.2		0.5	0.13	—	
СЧ 21-40	до 20	3.2—3.5	1.9—2.3	7) 0.5—0.8	9) 0.65	9) 0.14	— 12	Перлитная, небольшое количество феррита, графит средней величины
	20—30	3.1—3.4	1.9—2.2					
	30—40	3.1—3.4	1.8—2.1	0.6—0.9	0.4	0.12	до 0.15	
	свыше 40	3—3.3	1.8—2	0.7—1	0.3	0.12	до 0.2	
СЧ 24-44	до 20	3.1—3.4	1.8—2	0.7—1	0.2	7) 0.12	до 0.25	13) Мелкоперлитная или сорбитная, графит мелкий завихренный
	20—30	3—3.3	1.5—1.8	0.7—1	0.25		до 0.25	
	30—40	3—3.1	1.3—1.6	0.8—1.3	0.2		до 0.3	
	свыше 40	2.9—3.1	1.1—1.6	0.8—1.5	0.2		до 0.35	
СЧ 28-48	10—20	3—3.3	1.7—2	0.8—1.1	0.3	7) 0.12	0.2—0.3	То же
	20—30	2.9—3.2	1.4—1.8	0.8—1.2	0.25		0.2—0.4	
	30—40	2.9—3.2	1.2—1.5	0.8—1.5	0.2		0.3—0.5	
	свыше 40	2.9—3.2	1—1.5	0.8—1.5	0.2		0.3—0.5	
СЧ 32-52	20—30	2.8—3.2	1.4—1.8	1—1.4	0.35	7) 0.12	0.2—0.3	Сорбитная 15
	30—40	2.8—3.1	1.3—1.7	1.1—1.5	0.3		0.2—0.4	
	свыше 40	2.8—3	1—1.6	1.1—1.5	0.25		0.3—0.5	
СЧ 35-56	25—30	2.8—3.1	1.3—1.7	1—1.4	0.3	7) 0.12	0.2—0.3	То же 14
	30—40	2.7—3	1.2—1.6	1.1—1.5	0.25		0.1—0.4	
	свыше 40	2.7—3	0.9—1.6	1.1—1.5	0.2		0.3—0.5	
СЧ 38-60	30—40	2.7—3	1—1.6	1.1—1.5	0.2	7) 0.12	0.35—0.4	То же
	свыше 40	2.7—3	0.8—1.5	1.1—1.5	0.2		0.3—0.5	

1) Cast iron (GOST 1412-54); 2) thickness of the casting walls (mm); 3) percentage of elements; 4) not more than; 5) structure; 6) SCh; 7) and; 8) up to; 9) more than; 10) ferrite-pearlitic, coarse graphite; 11) pearlite-ferritic, mean-size graphite; 12) pearlitic, a small quantity of ferrite, mean-size graphite; 13) fine-pearlitic or sorbitic, fine, eddied graphite; 14) the same; 15) sorbitic.

TABLE 2

Mechanical Properties of Gray Iron Castings with Lamellar Graphite

Чугун (ГОСТ 1412–54)	σ_b	$\sigma_{изг}$	HB	f (мм)		Примечание
	(кг/мм²), не менее			600	300	
СЧ 00	испытание не производится					
СЧ 12-28	12	28	143–229	6	2	
СЧ 15-32	15	32	163–229	8	2,5	Чугун немодифицированный
СЧ 18-36	18	36	170–229			
СЧ 21-40	21	40	170–241			
СЧ 24-44	24	44	170–241			
СЧ 28-48	28	48	170–241	9	3,0	Чугун модифицированный
СЧ 32-52	32	52	187–255			
СЧ 35-56	35	56	197–269			
СЧ 38-60	38	60	207–269			

1) Cast iron (GOST 1412-54); 2) izg; 3) (kg/mm^2) not less than; 4) (mm); 5) note; 6) not tested; 7) nonmodified cast iron; 8) modified cast iron.

TABLE 3

Dependence of the Mechanical Properties of Cast Iron on the Structure of the Metal Base and the Distribution of Lamellar Graphite

Показатель механич. свойств и единица измерения	Ч. с. с равномерным распределением графита		Ч. с. с междендритным распределением графита	
	перлитная основа	ферритная основа	перлитная основа	ферритная основа
σ_b (кг/мм²)	18–45	12–18	15–30	10–15
E (кг/мм²)	7000–14000	5000–12000	10000–15000	8000–13000
$\sigma_{изг}$ (кг/мм²)	36–80	24–36	32–45	24–32
f_{600} (мм)	6–8	8–12	5–6	6–8
σ_{-1} (кг/мм²)				
σ_{-1} при изгибе (кг/мм²) без надреза	70–140	50–80	60–120	45–65
То же, с надрезом	8–18	6–9	8–18	6–9
$a_н$ (кгм/см²) без надреза	8–15	6–8	8–15	6–8
То же, с надрезом по Мезнагеру	0,5–1	1–1,5	0,3–0,5	0,5–1
Циклич. вязкость, J, при нагрузке $^1/_3$ σ_b	0,2–0,5	0,3–0,6	0,1–0,2	0,2–0,3
σ_b (%)	15–30	15–30	12–20	12–20
HB (кг/мм²)	180–350	100–140	180–350	100–140

1) Characteristics of the mechanical properties and units of measurement; 2) gray iron with a uniform distribution of graphite; 3) cast iron with interdendritically distributed graphite; 4) pearlitic base; 5) ferritic base; 6) kg/mm^2; 7) σ_{izg} (kg/mm^2); 8) σ_{-1} on bending (kg/mm^2) without notch; 9) the same, with notch; 10) a_H, (kgm/cm^2) without notch; 11) the same, with a Mesnager notch; 12) toughness, J, under an alternating load of $1/3\ \sigma_b$.

The following values of the main physical properties of gray iron with lamellar graphite may be taken at: $\alpha \cdot 10^6$ ($1/°C$) = 8-11 within 20-100°; λ ($cal/cm \cdot sec \cdot °C$) = 0.10-0.12; γ (g/cm^3) = 6.9-7.3; shrinkage = = 1%; ρ (microohm·cm) = 45-120; coercivity (oersted) = 3-10; residual magnetism (gauss) = 4000-6000; maximum magnetic permeability (gauss/

oersted) = 250-600. The gray iron castings are submitted to heat treatment in order to change their physicomechanical properties; the conditions of the heat treatment depend on the purpose. Gray iron of the SCh 00 and, partially, of the SCh 12-28 grades is used for low-duty castings in general machine building; SCh 15-32 and SCh 18-36 are used for a large number of castings in general machine building and machine-tool building, which work under s amll stress (stands, foundations, jackets, boxes, caps, etc.), and of such which work under a mean stress (carriages, supports, etc.), for thin-walled castings with a large size (parts of agricultural, textile, sewing, printing, and calculating machines), for castings working under a pressure of 10 to 30 atm (steam-, gas- and water pites, valves, fittings, valve boxes, etc.), and, at light-duty conditions, for antifriction parts (see Antifriction cast iron) instead of bronze (bearings, bushs, etc.), for low-duty castings in chemical machine building, for castings in electrical engineering (parts of generators, etc.), and also for the manufacture of chills, ingot molds for shaped iron castings, and for glass molds; SCh 21-40, SCh 24-44, SCh 28-48, and SCh 32-52 are used for high-duty castings submitted to high stress, vibrations and abrasion at high speed (cam gears, camshaft disks, carcasses, petroleum pumps, flywheels, frames, pistons, gear wheels, etc.); SCh 35-56 and SCh 38-60 are used for parts worn out by dry friction, great pressure and temperatures up to 500°, and also for parts exposed to flame, and, finally, for high-duty castings of metallurgical equipment.

References: Girshovich, N.G., Sostav i svoystva chuguna [Composition and Properties of Cast Iron] in the book: Spravochnik po chugunnomu lit'yu [Handbook on Iron Casting], Moscow-Leningrad, 1960.

A.A. Simkin

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[Transliterated Symbols]

1783 Cч = SCh = seryy chugun = gray iron

GRIFFIT'S THEORY – see Theory of Failure.

GUIGNET-PRESTONE ZONES – see Aging of Aluminum Alloys.

GUN METAL – tin-bronze containing approximately 10% Sn. It is used in the manufacture of various shaped castings and, in the past, was employed for casting cannon barrels.

O.Ye. Kestner

GYPSUM – mineral, dihydrate of calcium sulfate. Chemical composition ($CaSO_4 \cdot 2H_2O$), monoclinic, prismatic. Mohs hardness 2. Specific weight 2.317. Thermal conductivity (at 16-46°) 0.259 kca/m·hour·°C. Light refraction indices $n_g = 1.5305$, $n_p = 1.5207$. At 107° it is partially dehydrated passing into alabaster, $CaSO_4 \cdot 1/2\ H_2O$, which at 170--200° is transformed into the anhydrate $CaSO_4$. Sedimentary, metasomatic gypsum deposits and deposits in wind-eroded zones are known. It is relatively easily soluble. Transparent gypsum crystals are used in optics for the making of gypsum plates which are extensively used for microscopic investigations of transparent materials (in particular, in determining the optic signs of minerals). Raw fibreous gypsum (selenite) is used for inexpensive jewelry.

Gypsum is used in the production of portland cement, fertilizers, paints, dense grade paper (as a filler). Molds for precision casting of machine components are made from gypsum. Calcined gypsum is used extensively for castings and molds [gypsum casts (in medicine) bas reliefs, cornices, etc.], as well as cement for fastening of nonmetallic to metal components.

References: Trebovaniya promyshlennosti k kachestve mineral'nogo syr'ya [Industrial Requirements Put to the Quality of Mineral Raw Materials], issue 50. Pechurov, S.S. and Shneyder, V.E., Gips [Gypsum], 2nd edition, Moscow, 1959; Kurs mineralogii [A Course in Mineralogy], edited by A.K. Boldyrev (et al.]. Leningrad-Moscow, 1936.

V. V. Shcherbina

HADFIELD STEEL – steel with a high resistance to wear (abrasion) under high specific pressures or under impact loads. It is used in the form of intricate castings and also in the shaped state in the form of forgings, rolled stock and cold-drawn wire. Hadfield steel is a high-alloy manganese austenitic steel and is known under the brand name G12 in the shaped state and under the brand name G13L as casting [steel]. With respect to wear resistance under high pressures and impact loads Hadfield steel exceeds wear-resistant steels of other groups, for example, of the U10, U13, ShKh15, Kh12, Kh12M, Kh18 brands and graphitized steel.

TABLE 1

Chemical Composition of Hadfield Steel

1) Steel	2) Element content (%)							3) GOST
	C	Si	Mn	Cr	Ni	S	P	
4) G13L	0.9–1.3	0.5–1.0	11.5–14.5	≤0.5	≤0.5	≤0.05	≤0.12	2176–67
5) G12	1.0–1.3	≤0.5	11.0–14.0	≤0.3	–	≤0.03	≤0.03	–

1) Steel; 2) element content (%); 3) GOST; 4) G13L; 5) G12.

The isothermal transformation of austenite in steel containing 13% of manganese at 370° starts only after 48 hours; below 260° practically no carbide precipitation and phase transformations take place in the absence of deformation. Obtaining stable mechanical properties of castings requires that the ratio of the manganese to the carbon content be not less than 10. To obtain optimal casting properties they are heated up to 1020-1100° (here the carbides are entirel, dissolved) and are cold water quenched into austenite. When quenching thick walled casting care should be taken to provide intensive water circulation. Due to the

affinity to dehydrogenation, holding in the heating for quenching should not exceed 30-40 minutes.

TABLE 2

Physicomechanical Properties of Hadfield Steel

Сталь 1	Термич. обработка 2	$\sigma_в$ (кг/мм²) 3	$\sigma_{0,2}$ (кг/мм²) 3	δ (%)	ψ (%)	$a_н$ (кгм/см²) 4	E (кг/мм²) 3
Г13Л 5	Закалка с 1020—1100° в воде 6	80—100	35—40	40—50	35—45	20—30	20000

1) Steel; 2) heat treatment; 3) (kg/mm^2); 4) (kgm/cm^2); 5) G13L; 6) quenching from 1020-1100° in water.

The temperature interval for hot machining of the steel is 1150-900°. Preforging heating should be slow, in order to avoid the formation of internal cracks due to the low thermal conductivity and the high linear expansion. The forgings are air-cooled. Prolonged heating of steel quenched to austenite at above 300° or short-duration heating at 400° and above makes it brittle. Heating and cold shaping results in the breaking down of the austenite with attendant precipitation of carbides along the grain boundaries and slip planes and increasing the Brinell hardness to 500 kg/mm^2; here the steel becomes magnetic and very brittle (Fig. 1). Hence, under service conditions, it is not permissible to so heat castings from steel quenched to austenite. After water quenching the Brinell hardness is low (about 200 kg/mm^2), here

TABLE 3

Effect of the Temperature on the Mechanical Properties of Hadfield Steel

Темп-ра (°C) 1	$\sigma_в$ 2 (кг/мм²)	$\sigma_{0,2}$ 2 (кг/мм²)	δ (%)	ψ (%)
+100	105	43	55	55
+ 20	105	35	48	35
− 80	105	50	37	30
−110	96	52	25	22
−150	92	70	12	11
−196	90—92	85	4	3—5

1) Temperature (°C); 2) (kg/mm^2).

the steel is practically not machineable. Under the action of the cutting tool the machined surface is highly workhardened and the hardness increases to 450-550 kg/mm^2. Hence, intricate articles from Hadfield steel are made only by casting. Since the high workhardness makes the machining of products (casting) quite difficult, components are usually finished to the required dimensions grinding, preferably wet, to avoid formation of cracks.

The high wear resistance of Hadfield steel is due to the fact that it is highly strengthened by workhardening. The wear resistance of Hadfield steel in impact abrasion is by a factor of 10-12 greater than that of carbon and by a factor of 2-3 higher than that of graphitized steel (Fig. 2). Hadfield steel is welded with difficulty. Castings, as a rule, are arc welded using electrodes from the same steel additionally alloyed by 3-3.5% of nickel, or containing copper and molybdenum, and also from stainless chromium-nickel steel. Pressure workability in the hot and cold state is satisfactory. The G13L steel is sensitive to changes in the smelting process technology, for example, in the method and completeness of deoxidation, teeming temperature, etc. It is smelted primarily in an open-hearth and electric furnaces. Higher mechanical properties are characteristic of fine-grain steel.

When 0.1-0.2% of zirconium is introduced into G13L steel the transcrystallization and the metal structure becomes fine-grained; here the wear resistance of the steel is increased by 20%. The elimination of transcrystallization in castings is also observed when 0.003-0.006% of boron is added to the steel. t°_{pl} of the G13L steel is 1345°. The castability is high. The casting shrinkage (free) is 2.6%. The hardenability may be as high as 100 mm. Physical properties: $\gamma = 7.9$ g/cm^3, $\alpha = 18 \cdot 10^{-6}$ (0-100°) $°C^{-1}$, $c = 0.124$ (50-100°) cal/g·°C, $\gamma = 0.027$ cal/cm·sec·°C.

Intricately shaped Hadfield steel castings are used extensively in the mining, railroad, cement, construction and other branches of industry, for lips of dredges, scoops of drags, buckets and bucket teeth of powerful excavators, jaws of crushers, bowls of eddy and ball mills, trolleycar and railroad frogs and switching levers, caterpillar tracks and other components subjected to impact wear. Shaped Hadfield steel is used for fireproof safe casings, pipe rolling cores, for rails. The semifinished products made from Hadfield steel are: plates, sheets,

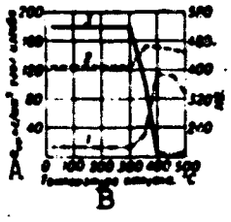


Fig. 1. Variation in the hardness (1), bending strength (2) and toughness (angle of twist) (3) of the G13L steel as a function of the tempering temperature. A) σ_{izg}, kg/mm^2; angle of twist; B) temperature of tempering, °C.

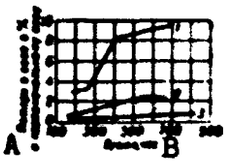


Fig. 2. Comparison of the wear resistance of various kinds of steel. 1) Carbon; 2) graphitized; 3) G13L manganese. a) Weight loss, % of the initial weight; B) time, hours.

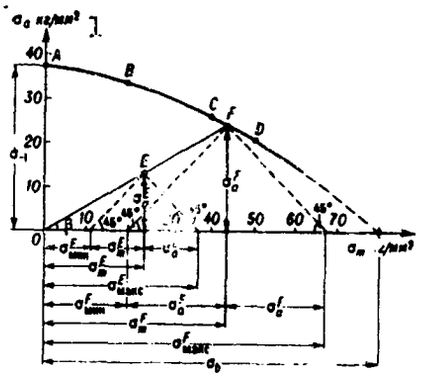
bars, sieve wire, etc.

References: Goncharov, P.A., Proizvodstvo lit'ya iz margantsovistoy stali [Producing Castings from Manganese Steel], Moscow-Leningrad, 1940; Termicheskaya obrabotka i svoystva litoy stali [Heat Treatment and Properties of Cast Steel], Moscow, 1955, (articles by Podvoyskiy L.N. and Kreshchanovskiy, N.S.); Stal'noye lit'ye. Spravochnik dlya masterov liteynogo proizvodstva [Casting of Steel. Handbook for Foundry Foreman], edited by N.P. Dubinin, Moscow, 1961; Metallovedeniye i termicheskaya obrabotka stali i chugnuna [Metal Science and Heat Treatment of Steel

and Pig Iron]. Handbook, Moscow, 1956; Gudremon, E., Spetsialnyye stali [Special Steels], translated from German, Vols. 1-2, Moscow, 1959-1960.

N.M. Tuchkevich

HAIGH'S DIAGRAM – is a graph which characterizes the relationship between the value of the mean stresses of a cycle and the value of the maximum amplitudes (Fig.) in the fatigue test. Haigh's diagram is graphed by means of the fatigue curves obtained from the test results of 3-4 series of similar specimens at different mean stresses of the cycle for each series. The mean stresses and amplitudes corresponding to the points A-D on the fatigue curves are the coordinates of the analogous points on the Haigh's diagram (see Fig.). Each service-life (basis) has its own corresponding Haigh's diagram. The sum of the abscissae and ordinates of the points on the AD curve represent the



1) kg/mm^2; 2) min; 3) maks.

fatigue limit: $\sigma^F_{maks} = \sigma^E_m + \sigma^F_a$; the sum of the coordinates of each point which lays below the AD curve represents the permissible maximum stresses of the cycle: $\sigma^E_{maks} = \sigma^E_m + \sigma^E_a$. Under the condition of similarity of the cycles, the ratio of the fatigue limit σ^F_{maks} to the maximum stress of the permissible cycle σ^E_{maks} is the safety factor: $n_\sigma = \sigma^F_{maks}/\sigma^E_{maks}$. All this is valid at mean negative stresses and for tangential stresses.

G.T. Ivanov

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[Transliterated Symbols]

1796 мин = min = minimum = minimum

1796 макс = maks = maksimal'nyy = maximum

HAIR CRACKS IN STEEL – thin (hair-like) clearly outlined small cracks which are situated in rolled (less frequently in forged) bars along the metal flow direction (along the fiber). To establish the degree to which the steel has been effected by hair cracks use is made of stepped machining of 250 mm long specimens which are taken from rolled bars (when specimens are made from forged bars a reduced number of hair cracks is obtained, which, in addition, are shorter). The round specimens are machined so as to produce three steps, each 50 mm long. The diameter of steps as a function of the bar diameters is shown in the Table. When producing the stepped specimens the last chip should be removed with a sharp cutter with a depth of cut of 0.5 mm and a feed of 0.25 mm. On inspection each step of a specimen is inspected (sometimes after light etching) by the naked eye or through a magnifying glass

Dimensions of Stepped Specimens

Диаметр штанги (мм) 1	Диаметр ступеней образца (мм) 2		
	3 1-я ступень	4 2-я ступень	3-я ступень 5
16–20	13	9	5
21–25	18	15	10
26–30	23	18	10
31–40	28	22	15
41–50	38	28	15
51–60	48	32	15
61–80	58	40	20
81–100	78	55	30
101–120	96	70	40
121–150	116	85	50

1) Bar diameter (mm); 2) diameter of specimen steps (mm); 3) 1st step; 4) 2nd step; 5) 3rd step.

with five-fold magnification and the length of the hair cracks is measured. The allowable norms of the quantity, maximum length and total length of the hair cracks are established by technical specifications

for steel deliveries.

Surface hair cracks are rolled surface flaws of the ingot, that is, gas bubbles, blow holes, double skins and fins. The interiors of hair cracks frequently are slag particles elongated along the shaping direction. Being points with a defective structure, hollows, slag inclusions, hair cracks reduce the mechanical properties of steel. The peculiarity of their effect on these properties is due to their shape which is elongated along the metal flow direction (on shaping). Hence the most extensive reduction in mechanical properties of steel which has an excessive number of hair cracks is observed attendant to the effect of tensile stresses (across the fibers) and compressive stresses (along the fibers). Since the majority of machine and equipment components is subjected to complex stresses it is necessary to achieve a reduction in the number of hair cracks in steel semifinished products. This is achieved primarily by improving the quality of the ingot structure (reduction of the number and size of bubbles, blow holes, slag inclusions, etc.), cleaning of the ingot surfaces and refining the shaping regime in which the flaws which are found could have been "brewed." Rejects due to hair cracks are sharply reduced in Vacuumed Steel.

References: Minkevich, N.A., Svoystva, teplovaya obrabotka i naznacheniye stali i chuguna [Properties, Heat Treatment and Uses of Steel and Pig Iron]. 2nd edition, Parts 1-2, Moscow, 1934; Metallovedeniye i termicheskaya obrabotka stali i chuguna [Metal Science and Heat Treatment of Steel and Pig Iron], Handbook, Moscow, 1956.

M.L. Bernshteyn, I.N. Kidin

HALF-HARD BRASS is brass which is pressure worked with an average degree of deformation (10-30%) and which as a result of this has higher strength and hardness than in the annealed condition. In the present standards the mechanical properties of the half-hard brasses, other than the LS63-3 brass, are specified by the minimal values of the tensile strength and the relative elongation. In the half-hard condition the LS63-3 brass must have a tensile strength from 35 to 44 kg/mm^2. According to the US standards the half-hard brasses must have definite minimal and maximal values of the tensile strength and hardness, while according to the German specs, in addition, they must have a minimal value of the relative elongation. The half-hard brasses are used for the production of ribbon, sheet and strip, wire, tubes, rods.

For the mechanical properties of these brasses see articles on Wrought Brass, Brass Ribbon, Brass Sheet and Strip, Brass Wire, Brass Tubes, Brass Rods.

Ye.S. Shpichinetskiy

HALITE – mineral (natural sodium chloride). Chemical composition (% by weight): Na 39.4, Cl 60.6. Engineering name of halite is common salt. Pure halite is colorless and transparent. An admixture of iron oxides imparts to halite yellow and red color, clay particle color it gray while organic substances color it brown and black. The characteristic spotty blue or violet color which arises upon radioactive or x-ray irradiation or after deformation is produced by inclusions of metallic sodium into the crystal lattice of halite. Halite forms regular cubic crystals. Specific weight 2.1680, Mohs hardness 2. Halite is brittle in air, in the absence of air or when wetted it becomes appreciably plastic. The strength of halite increases by deformation, particularly after homogeneous shear. t°_{pl} 800.4°, boiling temperature 1445°. Melting heat 517 joule/g. Specific heat (joule/g) at temperatures: – 200°-0.466, 0°-0.855, 200°-0.915, 400°-0.975, 800°-1.095. Thermal conductivity (watt/cm·degree·10^{-3}) at –190°-267, at 0°-69.7, at 100°--42.0, at 300°-24.9, at 400°-20.8. When mixed with ice in the amount of 22.4-24.8%, halite provides cooling to 21.2-22.4°. Crystalline halite is a dielectric, melts and solutions of halite have a high electrical conductivity. The dielectric constant of halite at room temperature and for a current frequency within the audible range is 6.2±0.1, that of halite aggregate (rock salt) is 5.6-6.3. The dielectric constant of halite decreases on plastic deformation. The electric strength (E_{pr}) is lower for colored halite crystals and is increased by heating. At 200° the electric breakdown of halite becomes a thermal breakdown. At 220--250° halite takes on electric rectification properties; the rectifica-

tion coefficient, depending on the voltage, varies from 10 to 30. Halite plates pass infrared and ultraviolet radiation. The crystal lattice of halite produces diffraction of x-rays.

Crystalline halite is used in optics as a spectral filter (lenses, prisms, plates, achromatic objectives for ultraviolet rays), as a diffraction lattice in rentgenoscopy; it can be used as a dielectric and electric current rectifier. The main use of halite is as a chemical raw material. More than 1500 regions of utilization of halite and its derivatives have been counted. Halite is used as a substance for prevention of wood and leather decay, and also in the tobacco, paper, cellulose, textile industries, for the production of glazes, in refrigerating engineering, soap production. The main users (in addition to food seasoning enterprises): production of soda, caustic soda, hydrochloric acid, metallic sodium, bleaching powder, etc.

References: Trebovaniya promyshlennosti k kachestve mineral'nogo syr'ya [Industrial Requirements Put to the Quality of Mineral Raw Materials]. Issue 22 – Chernyy, L.M. and Fiveg, M.P., Kaliynyye i magnezialnyye soli [Potassium and Magnesium Salts]. Moscow, 1947; Ivanov A.A., Prirodnyye mineral'nyye soli [Natural Mineral Salts]. Moscow, 1951; Minerals yearbook, Vol. 1, 1959 [Wash., 1960].

P.P. Smolin

HALYARD – see Cordage.

HAMMERED LACQUER AND PAINT COATINGS are decorative coatings which are characterized by the presence of a pattern which is reminiscent of the traces from hammer blows or chasing. To a considerable degree these finishes have replaced the "moiré" and "frosted" enamels, since along with good external appearance they have a smooth surface. The hammered lacquer/paint coatings are solutions of resins pigmented with aluminum powder (or paste) with the addition of a small quantity of the pattern-former (solutions high-molecular silicone compounds). A small quantity of pigment is introduced into the solutions to obtain colored hammered lacquer/paint coatings. The hot-drying hammered lacquer-paint coatings based on a mixture of solutions of the alkyd and melamine-formaldehyde resins have found the widest application. The hammered lacquer/paint coatings cover up slight defects of the painted surface, which reduces the cost of the painting process and in many cases eliminates straightening and grinding of the surface. The hammered lacquer/paint coating produced in accordance with VTU 414-59MEML25 is a synthetic enamel which is a suspension of aluminum paste in a mixture solutions of alkyd and melamine-formaldehyde resins with the addition of silicone oil, and for the colored enamels with the addition of a small amount of pigments. The hammered lacquer/paint coatings are used for decorative finishing of machine tools, instruments, sewing machines, etc. Prior to use, the hammered lacquer/paint coatings are mixed until the precipitate on the bottom of the container disappears, excessive mixing leads to deterioration and disappearance of the pattern. These coatings are thinned with xylene to the working viscosity of 45-75 seconds as meas-

ured on the VZ-4 viscosimeter at 18-20°. They are applied by paint sprayers in a single layer on the primed surface of the parts, which is prepared as follows: cleaning of the rust and grease contaminations, application of the primer (138, FL-013, FL-0Zk for the ferrous metals; ALG-1, ALG-5, FL-03Zh for the nonferrous metals) and hot drying in accordance with the specification, painting with onelayer of ML-12 synthetic auto enamel with a color close to that of the hammered lacquer/paint coating and drying for 1 hour at 130°. The hammered lacquer/paint coatings which give a nonuniform film with formation of the pattern do not provide adequate protective properties of the coating. For parts to be used indoors in a temperate climate it is permissible to apply the hammered lacquer/paint coating over just a primer or over a single coat of glyptal enamel. In case of severe demands on the stability of the coating, use is made of primer and one or two coats of ML-12 auto enamel as the sublayer. The viscosity of the hammered lacquer/paint coating, the thickness of the coating applied and the pressure of the air used for the spraying effect the formation of the pattern. To obtain a normal medium-size pattern it is recommended that the hammered lacquer/paint coating be applied with a viscosity of 45-50 seconds according to the VZ-4 with a rate of 180-200 g/m^2 with supply air pressure of 3-4 atmospheres. To obtain a large pattern the coating must be applied with higher viscosity and a thicker coat. The painted articles are exposed to air for 30 minutes to remove the majority of the solvent and then are baked at 120° for 1 hour. In case of disappearance of the pattern (after long storage) the addition of up to one percent of silicone oil solution is permitted for the ML-25 enamel.

B.I. Ivanov

HARD BRASS is brass which is pressure worked with high degrees of deformation. These materials have high strength (hardness and reduced plasticity. By the present standards the degree of hardness, i.e., the strengthening of the brass (other than the leaded LS63-3), is specified by the minimal values of the tensile strength and relative elongation. The mechanical properties of the LS63-3 brass are specified by the maximal and minimal values of the tensile strength (44-54 kg/mm^2) and the relative elongation (6%). The required mechanical properties of semi-manufactures made from the hard brasses are provided with a degree of work hardening of no less than 30%. The US standards for the hard brasses provide for limiting maximal and minimal values of the tensile strength and the hardness, while the German standards, in addition, specify the minimal values of the relative elongation.

Ye.S. Shpichinetskiy

HARD BRONZE - pressure-worked bronze deformed to a high degree (30-50%). It has high hardness, strength, and elasticity and is used for components of various types (springs, contacts, bushings). Hard bronze has a low plasticity.

O.Ye. Kestner

HARDENING – increase in the resistance to deformation with an increase in the degree of plastic deformation or as a result of alloying (for example, when adding Mn or Si to iron) and of structural changes in materials (for example, upon the precipitation of the $CuAl_2$ phase on aging of duralumin). Hardening is characterized by the secant modulus and the tangential modulus. An additional kind of hardening is that produced by the shape of the component or specimen (the so-called shape hardening); for example, in the presence of circular groove on a cylindrical rod the ultimate strength σ_b of plastic materials of construction is increased, which is due to the appearance of radial and circumferential tensile stresses, which reduce the acting tangential stresses (see Tangential Stress).

S.I. Kishkina-Ratner.

HARDENING OF STEEL – is a heat treatment consisting in heating the steel to a temperature in the critical range or higher, keeping at this temperature, and rapid cooling. Nonequilibrium structures are the result because the rapid cooling inhibits the phase transitions by diffusion. The phenomena of steel hardening are based on the transformation of austenite into martensite which shows a number of peculiarities differing it markedly from all other transformations in solid state. The mechanism of the austenite-martensite transformation consists in a cooperative regular translocation of the atoms against each other for distances which do not exceed the interatomar distances. Change in the shape and in the volume by a microscopic shift is the result of this arrangement of the atoms. The cooperativity, i.e., the interconnection and orderliness of the translocation of atoms during the transfer from the austenite lattice into the martensite lattice make possible the transformation at low temperatures at which a translocation of atoms by diffusion is very rare. The shift character of the lattice reconstruction causes considerable elastic deformations during the growth of the growth of the martensite crystals, and this fact explains the great influence of stresses on the kinetics of the martensite transformations.

Steel hardening used to obtaining the required mechanical and physical properties after a suitable tempering, to prepare the steel for a following heat treatment, for example, in order to annihilate the cementite network in the structure of hypereutectoid steel and in the surface layers of machine parts after case-hardening, in order to obtain a fine-grained structure and homogeneous properties before the

heat-treatment of structural steel (e.g., of chrome steel), in order to secure a homogeneous structure and to increase the corrosion resistance of stainless steel.

According to the heating temperature there are to be discerned: the complete hardening, if the heating temperature of the steel is higher than the critical point Ac_3, and the incomplete hardening, if the heating temperature lies within the critical range. The steel hardening may be carried out with a cooling rate which is higher than the critical one, causing a structure of martensite and residual austenite, or with a cooling rate lower than the critical one, forming a structure of a ferrite-carbide mixture with different degree of dispersity (hardening sorbite and troöstite).

According to the cooling method the following hardenings may be discerned: a) the usual, with continuous cooling in water, oil and other media, whose temperature is lower than the martensite point; b) the isothermal hardening, if the cooling is carried out in a salt or metal bath with a temperature high than the martensite point, with a holding sufficient for the total decomposition of the austenite; a particular case of isothermal hardening is the patenting of wire by cooling in a lead bath at 540-650°, resulting in a sorbite structure; c) the hardening by stages in a hot bath at a temperature higher than the martensite point with a holding time shorter than the incubation period at this temperature. The transformation of austenite into martensite occurs during the following cocling (usually in air); d) with precooling, the piece being kept some time in air before immersion into the cooling medium (the holding time is determined experimentally, the transformation of the austenite must not begin before the piece is immersed into the cooling medium); e) in two cooling media with a rapid cooling up to a temperature higher than the martensite point, and a delayed

cooling below this point, carried out usually by immersion of the piece into water and after this into oil (water-oil hardening); the cooling time is ascertained experimentally; f) with limited holding in the cooling medium and following cooling in air providing for a temperature of the piece not lower than the martensite point after it has been taken from the cooling bath; g) with self-tempering, the holding of the piece in the cooling medium being limited in such a manner that the internal zone of the cross section retains a heat quantity sufficient for a following tempering of the hardened surface layer in air; in practice, the piece is frequently immersed again into the cooling medium in order to avoid a too high temperature of the surface, being guided by the temper colors (hardening chisels, for example) or by the holding time which is known empirically. It is incorrect to attribute the "isothermal hardening" to the phenomena of the pure steel hardening because in the latter case martensite is the basic structure, in the case of isothermic hardening, however, in which heating above the transformation point occurs and then also rapid immersion in a medium with a temperature corresponding to the interstitial range in the diagram of the kinetics of austenite transformation, the steel structure is formed by bainite (acicular troostite) and sometimes (in low-carbon steels) by ferrite also.

Steel hardening may be carried out after heating the piece through or after a surfacial heating with high-frequency current, electric heating by contact, heating in an electrolyte or by a gas flame. The steel hardening may be complete, when the part is heated thoroughly and an almost homogeneous structure (martensite and residual austenite) with equal properties in the whole cross section are obtained, or incomplete, when the structure of the piece is inhomogeneous along the cross section (products of decomposition of austenite above the martensite point with

inequal properties). With regard to the state of the hardened surface, the hardening is subdivided into: usual hardening, when the surface of the piece is covered with oxides; pure hardening, when only oil cinder and temper colors are present on the surface, which is attainable by heating in furnaces with controllable atmosphere; and bright hardening, when heating is carried out in furnaces with controllable atmosphere and quenching is executed in bright-hardening oil or in molten alkali, and neither oxides nor oil cinder are present on the surface of the piece.

Mineral and vegetable oils, water, aqueous solutions of salts, acids or alkalis, molten lead and salts, emulsions, kerosene, solutions of silicates, etc., are used as hardening agents. The technological properties of the hardening agents (mainly the cooling rate of heated steel in them) depend on their physicochemical properties (viscosity, heat conductivity, heat capacity, heat of evaporation, etc.). The values of cooling rates (degrees/sec) in different agents are given below:

TABLE

1 Среда	2 Время охлаждения (сек) в интервале темп-р (°С)	
	550—650	200—300
3 Вода, 18°	600	270
Вода, 75°	30	200
4 10% NaOH в воде	1200	300
5 Дистиллиров. вода	250	200
6 Минеральное масло	150	30

1) Agent; 2) cooling time (sec) in a temperature °C interval of; 3) water; 4) 10% NaOH in water; 5) distilled water; 6) mineral oil.

During hardening, thermal and structural residual stresses spring up simultaneously which, adding together, may attain high values causing bluckling (deformation) or cracking. The main factors which affect the residual stresses in steel hardening are the heating temperature,

the cooling rate, the size of the piece of work, its shape, the composition of the steel, and its structure. Rise of the heating temperature as well as rise of the cooling rate increase the temperature gradient of the hardening and, therefore, the magnitude of the thermal and structural stresses. In order to prevent the formation of cracks, the cooling rate in hardening must be diminished. This is attained practice by different methods, for example, by hardening in water and oil, hardening in air after a short holding in the hardening agent, hardening in especially selected agents, etc. Alloying of steel is the most effective way to diminish the critical hardening rate because it increases the stability of austenite in the subcritical temperature range. This permits the hardening of alloyed steels with moderate quenching rates in oil and even in air, diminishing the residual stresses and avoiding deformation.

References: Kurdyumov G.V., Yavleniya zakalki i otpuska stali [The Phenomena of Steel Hardening and Tempering], Moscow, 1960; Goudremont E., Spetsial'nyye stali [Special Steels], translated from German, vol. 1, Moscow, 1959; Bochvar A.A., Metallovedeniye [Metal Working], 5th edition, Moscow, 1956; Cottrell A.H., Stroyeniye metallov i splavov [The Structure of Metals and Alloys], translated from English, Moscow, 1961.

M.L. Bernshteyn, I.N. Kidin

HARDENITE – a structural variety of quenched steel, that is, martensite, which has a so-called icicular structure. When observed under an optical microscope, the icicular structure of hardenite is not exposed due to the small dimensions of needles (plates) which are outside the limits of the resolving power of the microscope. By its physiochemical nature and kinetics of formation hardenite does not at all differ from martensite and it is even called needleless or structureless martensite. The term hardenite is infrequently used and has historical significance.

A. F. Golovin

HARD MAGNETIC MATERIALS - see Alloys with Special Physical Properties.

HARDNESS – usually the resistance of a material to local plastic deformation which arises when a body with a higher hardness penetrates it. Hardness can be determined under static and dynamic loads (see Hardness Testing) at room and elevated temperatures (see Hot Hardness). Independent of the testing method, hardness is denoted by the symbol H with the appropriate subscript which indicates the testing method. The extensive use of hardness testing is due to the simplicity of methods which do not require complex laboratory devices; possibility of checking the material without making special specimens, testing of components without destruction and determining of hardness in small volumes (see Microhardness Testing). Methods for determining hardness by static forcing of an indenter, i.e, the Brinell (see Brinell Hardness), Rockwell (see Rockwell Hardness) and Vickers (see Vickers hardness) methods, are the ones most extensively used. The Brinell hardness number HB and the Vickers hardness number HV correspond to the value of the average pressure at the surface of the impression and are close to one another up to values of HB ~400 kg/mm^2; the measuring of hardness of stronger materials by a steel ball may deform it, increase the impression's diameter and yield values of HB which are lower than the actual hardness (Fig. 1). Balls from hard alloys are used for testing the hardness of high-strength steels and alloys. The Rockwell RC and RB hardness values are determined by the depth to which the indenter can be forced and are thus more arbitrary than HB. No linear relationship exists between the HB and HR hardness numbers (Fig. 2). The relationship between the Brinell, Rockwell and Vickers hardness values, as

well as within the limits of one method, depending on the load, ball diameter and indenter shape, is described by the so-called conversion tables, which are supplied in various handbooks and instructions. Approximately (with an accuracy of up to 5%) it may be assumed that for the values

$$RC = 20-40 \quad HB = \frac{142 \cdot 10^3}{(100 - RC)^2};$$
$$RC > 40 \quad HB = \frac{25 \cdot 10^3}{100 - RC};$$
$$RB = 35-100 \quad HB = \frac{7300}{110 - RB}.$$

Quite stable relationships have been determined between the hardness and other physical, mechanical and production process properties

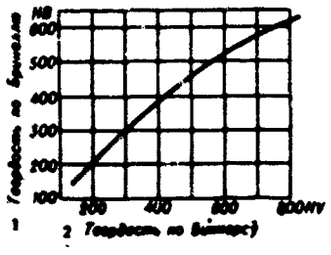

Fig. 1. 1) Brinell hardness; 2) Vickers hardness.

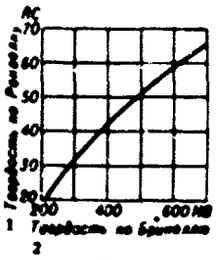

Fig. 2. 1) Rockwell hardness; 2) Brinell hardness.

of metals. Of the greatest practical interest is the relationship between the ultimate strength σ_b and the hardness, determined by the NB or HR impression method. For materials which are destroyed in tension with attendant necking, σ_b and HB have the same physical nature and characterize the resistance of the material to large plastic deformations. $\sigma_b = k \cdot HB$, where k is a coefficient, the average values of which for a number of materials are presented in Table 1. The coefficient k for the same material becomes higher with an increase in strength. Thus, for the 40 KhNMA steel with $\sigma_b < 130$ kg/mm^2 $k = 0.33$, for $\sigma_b <$ < 160 kg/mm^2 $k = 0.35$, for $\sigma_b < 185$ kg/mm^2 $k = 0.37$. For materials for which the ultimate load is identical with the load at failure, it is impossible to set up a quantitative relationship between σ_b and HB,

TABLE 1

1 Материал	$k=\frac{\sigma_b}{HB}$	Материал	$k=\frac{\sigma_b}{HB}$
2 Армко-железо	0,34	7 Алюминий . .	0.42
3 Малоуглеродистая сталь . .	0,34	Деформируемые алюминиевые сплавы . . .	0,38
4 Сталь типа хромансиль . . .	0,35	9 Магний	0,48
5 То же	0,36	Никель	0 50
6 Аустенитная сталь типа 18 Cr — 8Ni	0,45	10	

1) Material; 2) Armco iron; 3) low-carbon steel; 4) Cromansil-type steel; 5) same as above; 6) type 18 Cr-8 Ni austenitic steel; 7) aluminum; 8) aluminum shaping alloys; 9) magnesium; 10) nickel.

since in this case the strength (σ_b) is characterized by the resistance to failure, while the hardness is determined by the resistance to deformation. Hence the hardness of certain materials such as high-strength aluminum alloys, casting materials and pig irons can only approximately indicate the strength level.

The method of forcing a ball or conical penetrator through a certain specified value can be used to approximately evaluate the yield strength of the material. Sometimes, primarily for purposes of investigation, hardness is determined by scratching, which is by its substance related to the material's failure resistance. The Scratch Hardness can serve as an indirect method for determining the true rupture strength S_k. It was shown that $S_k = 4.02 \times (H_{ts} - 22.5)$ kg/mm^2, where $H_{ts} = 1/b_{50}$, where b_{50} is the width of the scratch made on the material by a diamond conical indenter with a vertex angle of 90° and a 50 kg load. For many materials, particularly steels, the characteristics σ_b and S_k determined in hardness and tensile tests give close values (see Table 2).

TABLE 2

Сталь 1	σ_b (кг/мм²) по 2		Sh (кг/мм²) по	
	растяжению 3	твердости 4	растяжению 3	твердости
У2 5	69	63	114	114
У4 6	93	91	164	161
30ХГСА (отпуск при 600°) 7	97	97	155	161
30ХГСА (отпуск при 200°) 8	177	177	257	255
18ХМВА 9	134	137	212	208

1) Steel; 2) kg/mm^2 according to; 3) tensile testing; 4) hardness; 5) U; 6) 30 KhGSA (tempering at 600°); 7) 30 KhGSA (tempering at 200°); 8) 18 KhNVA.

References: O'Neil, H. Tverdost' metallov i yeye izmereniye [Hardness of Metals and its Measurement], Translated from English, Moscow-Leningrad, 1940; Fridman, Ya.B., Mekhanicheskiye svoystva metallov [Mechanical Properties of Metals], 2nd Edition, Moscow, 1952; Davidenkov, N.N., "Zhurnal tekhn. fiz." [Journal of Technical Physics], Vol. 13, Issue 7-8, pages 389-393, 1943; Markovets, M.P., ibid, Vol. 19, Issue 3, pages 371-82, 1949; Davidenkov, N.N., Belyayev, S.E. and Markovets, M.P., "ZL," Vol. 11, No. 10, page 964, 1945; Vitman, F.F., ibid., Vol. 13, No. 2, pages 198-205, 1947.

N.V. Kadobnova

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[Transliterated Symbols]

1818 ц = ts = tsarapaniye = scratching

HARDNESS TEST – is the mechanical testing of materials consisting mainly in the determination of the resistance of the tested material to local plastic deformation carried out by means of an impressed indentor or by scratching with a special tip. The indentor is a body with a definite geometrical shape: spherical, pyramidal, conic, made from hard material (diamond, hardened steel, hard alloys). In contrast to other test methods, the hardness test does not require the destruction of the specimen or piece, and it is therefore used for the control of finished or semifinished pieces, although it must be taken into account that the indentor leaves a small hollow in the piece.

The indentation method is the most used one. The indentation hardness of structural steel proves a definite dependence on the limit strength σ_b, and this fact is widely utilized in the control of the properties of semifinished and finished pieces. The scratching method, in which the resistance to destruction is evaluated, is used very rarely. The indentor is pressed into the surface of the specimen usually by a static load, although dynamical methods of hardness tests are known also (see Shore Hardness, Poldi Device). The indentation hardness is evaluated quantitatively by the so-called hardness number which represents either the mean specific pressure on the surface of the impress (see Brinell Hardness, GOST 9012-59; Vickers Hardness, GOST 2999-59), or a conditional value depending on the indentation depth of the tip (see Rockwell Hardness, GOST 9013-59). The scratching hardness is determined either by the axial load which is necessary to obtain a scratch of a fixed width, or by the magnitude inverse to the width of the

scratch at a fixed constant load. Methods to determine the hardness by the rebound of a block freely falling on the surface of the specimen from a fixed height (according to Shore), and by the damping of the oscillations of a pendulum touching with a pin the specimen to be tested (according to Herbert) are also known. These methods are rarely used.

References: O"Neill G., Tverdost' metallov i yeye izmereniye [The Hardness of Metals and Its Measurement], Moscow-Leningrad, 1940; Shaposhnikov N.A., Mekhanicheskiye ispytaniya metallov [Mechanical Tests of Metals], 2nd edition, Moscow-Leningrad, 1954.

I.V. Kudryavtsev, D.M. Shur

HASTELLOY – see Acidproof nickel alloys.