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SCIENCE OF AVIATION MATERIAL

by

A. E. Leykin, E. S. Porotskiy and B. I. Rodin

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SCIENCE OF AVIATION MATERIAL

By: A. E. Leykin, E. S. Porotskiy and B. I. Rodin

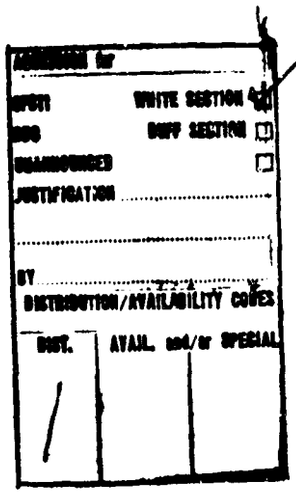
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A. E. Leykin, E. S. Porotskiy, B. I. Rodin

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ABSTRACT: This textbook is intended for students at tekhnikums. It may also be useful to technicians of the aircraft industry. The book reviews basic characteristics of the most important metallic and nonmetallic materials used in aircraft structures. Methods of investigating alloy properties, flaw detection, heat treatment, thermochemical treatment, and corrosion prevention are described. The authors express their thanks to Docent K. P. Romadin and Candidates of Technical Sciences A. I. Samokhotskiy and N. K. Zol'mikova.

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In book are considered basic characteristics of the most important metallic and nonmetallic materials applied in aviation constructions. Given are methods of investigation of properties of alloys and also their inspection (defectoscopy), heat and chemical-heat treatment, and protection from corrosion. Book is text for course of the same name for students of technicums. It will also be useful for average technical staff of industry.

Engineer critics A. I. Samokhotskiy and N. K. Zol'nikova

Editor K. P. Romadin, Cand. Tech. Sciences

PREFACE

Continuous progress of technology requires creation of new materials possessing assigned properties.

In his report to XXII Congress of CPSU N. S. Khrushchev underlined that "...of urgent value is sharp increase of strength and reliability of metals and other materials, in particular, those functioning under conditions of super-high pressures, temperatures, and speeds."

Production of contemporary machines would be inconceivable without use of specially pure metals, high-strength alloys metal ceramics, plastics, and other nonmetallic materials.

This text, written in accordance with program of course by same name, should prepare students of technical schools for correct selection and rational use of different materials for aviation constructions.

Future designer, when designing a new or modernizing existing aircraft, should know how on a technical and economic basis to select necessary materials. Future technologist should know how to select the most rational, in technical-economic respect, variant of technological process of treatment of materials utilized in given construction.

In text are expounded bases of aviation study of materials. In it are considered the most important characteristics of contemporary metallic and nonmetallic materials utilized during production of aviation materiel. Given are contemporary method of investigation of properties of materials and method of defectoscopy. Methods of heat and chemical-heat treatment of metals and alloys and their protection from corrosion are illuminated.

In first division (Chapters I-IX) are presented bases of metal science; second division (Chapters X-XIV) includes ferrous metals and special alloys; third division (Chapters XV-XX) includes nonferrous metals, alloys, and metal ceramic materials; in fourth division (Chapters XXI-XXII) are illuminated questions of corrosion; last, fifth division, (Chapters XXIII-XXVIII) is devoted to nonmetallic materials.

All mechanical characterists of materials are expressed in International System of Units [SI] (СИ). Besides, in text are given in parentheses dimensions in old units.

Book was written by collective of authors under leadership of A. Ye. Leykin.

Authors express deep gratefulness to K. P. Romadin, Cand. of Tech. Sciences, Docent, A. I. Samokhotski, and N. K. Zol'nikova for valuable remarks and councels made during creation of this text.

All remarks and proposals for improvement of text should be directed to publishing house "Mashinostroyeniye," (Moscow, B-66, 1 Basmannyy per., 3).

INTRODUCTION

In aviation industry are applied widely various metallic and nonmetallic materials.

Contemporary jet engineering demanded creation of latest heat-resisting metallic alloys and different new nonmetallic materials possessing properties in full measure responding to contemporary conditions of exploitation.

Development of aircraft construction is characterized by creation of constructions of high parameters (tremendous speeds, high gross weight, and others), working under conditions of high pressures, high and very low temperatures, deep vacuum, etc.

Structural materials working in conditions of high temperatures must have high strength and creep strength, must be resistant to thermal shock and oxidation.

During selection of materials for parts of aviation constructions, considered are their density and so-called specific strength, characterized by ratio of strength to specific gravity. As characteristic of strength can be taken one of following properties: ultimate strength, yield point, fatigue limit, modulus of normal elasticity, and other characteristics interesting designer. During the designing of aircraft preference should be given to material possessing greatest specific strength. This will allow one, other things being equal, to increase strength of construction to lower its weight, to increase flying range. Contemporary structural materials applied in aircraft construction have specific strength from 16 to 23 and in certain cases to 30.

Basic direction of creation of new aviation materials is obtaining of

compositions able to work reliably in conditions of high temperatures (for instance, 1200°C and more). Therefore criterion of appraisal and selection of materials of aviation constructions is frequently change of specific strength with increase of temperature.

In contemporary aircraft construction is applied large quantity of various materials, which it is expedient to divide into two basic groups – metallic and nonmetallic materials.

Metallic materials include metals and their alloys. In nature approximately two thirds of all elements are metals. They are divided into ferrous and nonferrous.

Practical value of metals is unequal. Of greatest application in industry are iron and its alloys, constituting group of ferrous metals. Remaining metals and their alloys belong to nonferrous group.

Application of nonferrous metals and alloys is limited by their smaller extent in nature and high cost. Volume of production of ferrous metals is approximately equal to 94% of world production of all metals, whereas production of nonferrous metals constitutes only 6%.

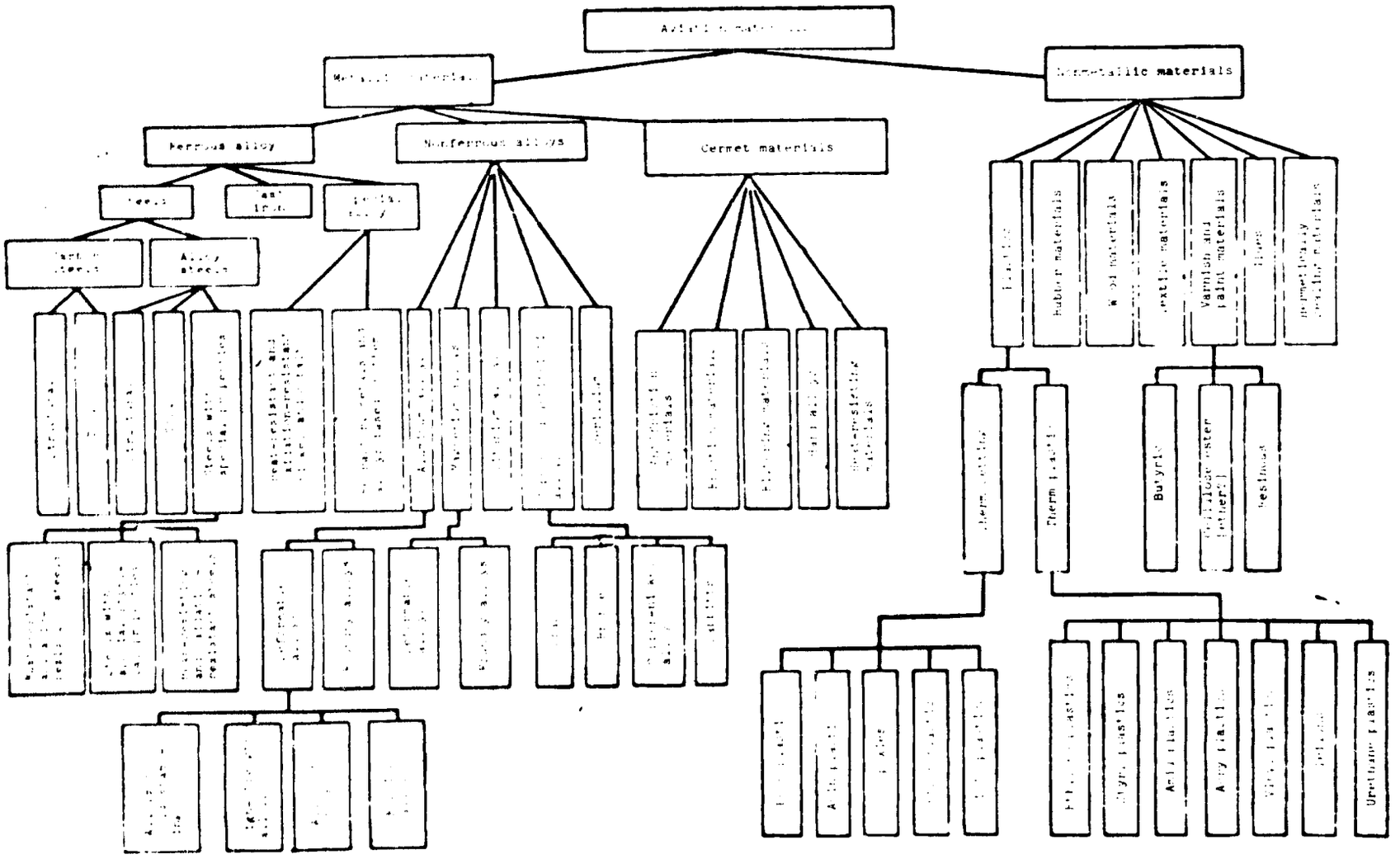
In aviation industry, besides ferrous metals, widely applied are light nonferrous alloys based on aluminum, magnesium, and titanium. Less widely applied are alloys of copper. Tin, lead, zinc, nickel, and chromium are applied in the form of alloying elements. Besides these are applied alloys based on nickel and refractory metals and also cermet materials.

Development of contemporary avaition technology in intimately connected use of nonmetallic materials: plastics, rubbers, textile, varnish and paint, hermetically sealing and wood materials, and also glues.

Value of some or other nonmetallic materials in aviation industry is changing considerably with development of aviation technology. Thus, if in past one of leading places belonged to woood, then at present first place belongs to plastics, rubber, and different hermetically sealing materials.

In accordance with decisions of December Plenum of Central Committee of the Communist Party of the Soviet Union (1963) on questions of development of production of synthetic materials, in book are specially considered questions of application of polymers in aircraft construction.

Creation of aircraft of successfully surmounting "sound barrier" led to development of latest aviation materials with special properties. Further improvement of


Nonmetallic materials
Ferrous alloy
Nonferrous alloys
Cermet materials
Rubber materials
Varnish and paint materials
Butyric
Therm
Therm
Urethane plastics

heat-resisting materials will allow us in the very near future to solve also the problem of "thermal barrier," appearing at supersonic speeds of flight.

Science involving general composition, structure, and properties of metals and alloys is called metal science.

Founders of scientific study of metals are Russian scientists P. P. Anosov and D. K. Chernov. Further development of metal science was promoted by work of N. S. Kurnakov, A. A. Baykov, A. A. Bochvar, N. T. Gudtsov, G. V. Kurdyumov, Sorbi, Austen, Osmond, Tamman, Martens, and others.

In study of materials properties of materials are considered in interaction with their structure: distribution and character of movement of electrons, atomic arrangement in space, dimensions and form of crystal formations.

Knowing structure of material, one can in known measure judge its properties and its fitness for work under some or other conditons.

Knowledge of properties and possibilities of application of different aviation materials has very important value in all stages of designing, creation, and exploitation of new aviation technology.

S E C T I O N O N E

PRINCIPLES OF METAL SCIENCE

CHAPTER I

STRUCTURE AND CRYSTALLIZATION OF METALS

§ 1. Structure of Metals

Metals are chemical elements possessing metallic luster, high electrical and thermal conduction, opacity in hard and liquid state, plasticity, and crystal structure.

As any substance, metals consist of atoms. Atoms of different metals differ from each other by number of electrons moving in electron shells and quanity of protons and neutrons forming atomic nuclei.

Atoms of the same element differing from each other only by number of neutrons in nucleus are called isotopes. Isotopes are varieties of the same atom.

Electrons move in circular or elliptic orbits. Electrons located in outer orbits are called valence electrons. Valence electrons are bound weakly with nucleus, and easily abandon the atom, crossing to outer orbits of other atoms.

A clear representation of metals and their structure is given by periodic system of elements of D. I. Mendeleyev.

Of the 103 elements of the Mendeleyev periodic system more than 70 are metals. Atomic number in periodic system is determined by quantity of protons (electrons) in atom.

For instance, for iron, occupying 26th place in table, in nucleus are concentrated 26 protons, and around it move 26 electrons in orbits. Elements in one group of Mendeleyev table possess related properties.

For elements in one period properties gradually are changed with their distance from each other, the character of this change being repeated in following row (line of table). Neighboring elements in one period possess relatively close properties.

Periodic System of Elements of D. I. Mendeleyev

Periods	Groups of elements																	
	Ia	IIa	IIIa	IVa	Va	VIa	VIIa	VIIIa			Ib	IIb	IIIb	IVb	Vb	VIb	VIIb	VIIIb
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I	1 H hydrogen Г																	2 He helium
II	3 Li lithium КЦ	4 Be beryllium ГП											5 B boron ГП	6 C carbon А,Г	7 N nitrogen КЦ	8 O oxygen Р, КЦ	9 F fluorine	10 Ne neon КГЦ
III	11 Na sodium КЦ	12 Mg magnesium ГП											13 Al aluminum КГЦ	14 Si silicon А	15 P phosphorus КЦ,РЭ	16 S sulfur Р	17 Cl chlorine Т	18 Ar argon КГЦ
IV	19 K potassium КЦ	20 Ca calcium КГЦ,ГЦ	21 Sc scandium КГЦ,ГП	22 Ti titanium ГП,КЦ	23 V vanadium КЦ	24 Cr chromium КЦ,КГЦ,Т	25 Mn manganese КС, ТГЦ	26 Fe iron КЦ,КГЦ	27 Co cobalt КГЦ, ГП	28 Ni nickel КГЦ, ГП	29 Cu copper КГЦ	30 Zn zinc ГП	31 Ga gallium Р, Т	32 Ge germanium А	33 As arsenic РЭ	34 Se selenium М,Г	35 Br bromine РЭ	36 Kr krypton КГЦ
V	37 Rb rubidium КЦ	38 Sr strontium КГЦ,ГЦ	39 Y yttrium ГП	40 Zr zirconium ГП,КЦ	41 Nb niobium КЦ	42 Mo molybdenum КЦ	43 [ну] Tc techne-tium ГП	44 Ru ruthenium ГП	45 Rh rhodium КГЦ	46 Pd palladium КГЦ	47 Ag silver КГЦ	48 Cd cadmium ГП	49 In indium ТГЦ	50 Sn tin А,Т	51 Sb antimony РЭ	52 Te tellurium Г	53 J iodine РЭ	54 Xe xenon КГЦ
VI	55 Cs cesium КЦ	56 Ba barium КЦ	57* La lanthanum ГП	72 Hf hafnium ГП,КЦ	73 Ta tantalum КЦ	74 W tungsten КЦ	75 Re rhenium ГП	76 Os osmium ГП	77 Ir iridium КГЦ	78 Pt platinum КГЦ	79 Au gold КГЦ	80 Hg mercury РЭ	81 Tl thallium ГП, КЦ	82 Pb lead КГЦ	83 Bi bismuth РЭ	84 Po polonium КП, РЭ	85 At astatine	86 Rn radon
VII	87 [223] Fr francium	88 Ra radium	89** [227] Ac actinium															

* 58-71 Lanthanides	58 Ce cerium	59 Pr praseodymium	60 Nd neodymium	61 [145] Pm promethium	62 Sm samarium	63 Eu europium	64 Gd gadolinium	65 Tb terbium	66 Dy dysprosium	67 Ho holmium	68 Er erbium	69 Tu thulium	70 Yb ytterbium	71 Lu lutetium
** 90-103 Actinides	90 Th thorium КГЦ	91 Pa protactinium Т	92 U uranium ОР, ТС, КЦ	93 [237] Np neptunium ОР, ТС, КЦ	94 [242] Pu plutonium С,КГЦ,Т, КЦ	95 [243] Am americium	96 [245] Cm curium	97 [249] Bk berkelium	98 [249] Cf californium	99 [253] Es einsteinium	100 [255] Fm fermium	101 [256] Md mendelevium	102 [253] No nobelium	103 [275] Lw lawrencium

Conditional designations:

К - simple cubic
КЦ - body-centered cubic
КГЦ - face-centered cubic
КС - complex cubic
Т - body-centered tetragonal
ТГЦ - face-centered tetragonal
ТС - complex tetragonal
Г - hexagonal
ГП - simple hexagonal
Р - rhombic
РЭ - rhombohedral
ОР - orthorhombic
М - monoclinic
А - diamond type
С - complex

Metal in solid state constitutes totality of positively charged ions with electrons distributed between them which move freely from ion to ion, forming "electron gas" (Fig. 1.1).

Such bond between atoms is called metallic. It explains such properties characteristic and inherent to only metals as high plasticity, electrical conductivity, and thermal conductivity.

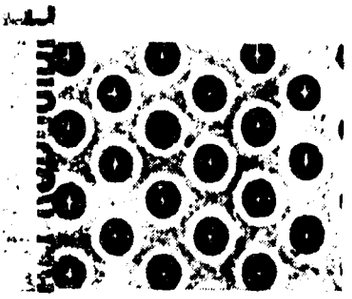


Fig. 1.1. Structure of metals. At lattice points are positively charged ions. In spaces are free electrons.

Crystalline and amorphous bodies are distinguished. In an amorphous body (glass, rosin) atoms are located chaotically, without any system. In crystalline substance atoms are disposed in defined geometrically regular order at defined distance from each other. Metals and their alloys are crystalline bodies.

In metals atoms (ions) are located in strictly defined order, forming so-called crystal space lattice (Fig. 1.2).

In Fig. 1.2a is shown location of atoms in one of crystallographic planes. Multiple repetition of crystallographic planes located in parallel gives representation of crystal space lattice, points of which are locations of atoms (Fig. 1.2b). In order to have an idea of atomic-crystal structure of given substance it is sufficient to depict one of its elementary crystal cells. The most simple is cell of cubic lattice.

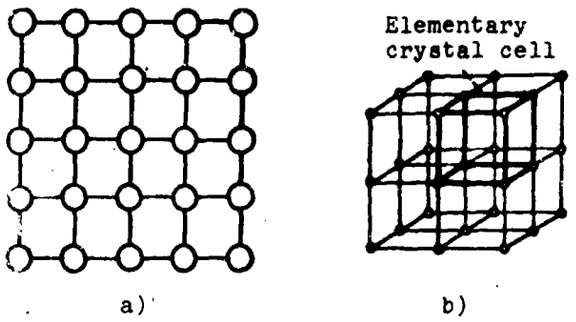


Fig. 1.2. Atomic arrangement (ions) of crystalline substance. a) crystallographic plane; b) crystal space lattice.

Types of crystal lattices. Atoms of various metals form unequal crystal lattices. Most frequently encountered are three types of lattices.

First type of lattice: b o d y - c e n t e r e d c u b i c. Atoms of metal in such lattice are at vertexes and center of cube. Every atom is surrounded by eight nearest "neighbors" (Fig. 1.3a). Having such lattice are α-iron, vanadium, tungsten, molybdenum, manganese, chromium, niobium, and others.

Second type of lattice: f a c e - c e n t e r e d c u b i c (Fig. 1.3b). Atoms of metal in it are located at vertexes and in center of cube faces. Such lattice

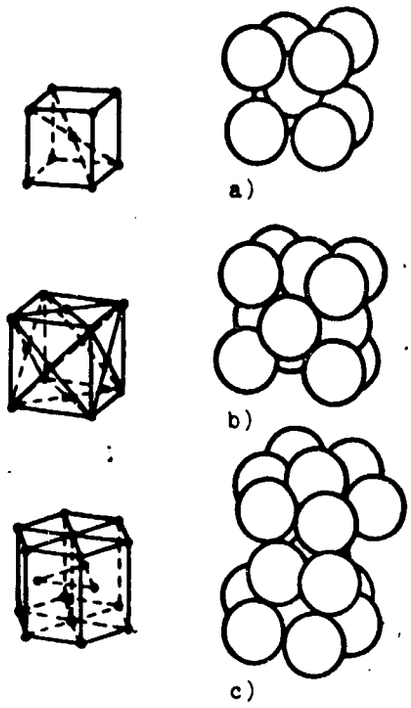


Fig. 1.3. Crystal lattices. a) body-centered cubic, b) face-centered cubic, c) close-packed hexagonal.

belongs to γ-iron, aluminum, lead, nickel, copper, and others.

Third type of lattice: c l o s e - p a c k e d h e x a g o n a l (Fig. 1.3c). It is encountered in zinc, magnesium, cadmium, beryllium, α-titanium, and α-cobalt.

Dimensions of crystal lattice are characterized by lattice parameters or so-called "constants." Parameters determine basic dimensions of elementary crystal cell. Thus, cubic lattice is characterized by one parameter – length of rib of cube a; hexagonal lattice is characterized by two parameters a and c or ratio c/a.

Parameter of crystal lattice is measured in nonometers (1 Nm = $1 \cdot 10^{-9}$ m).[1] Parameters of crystal lattices of metals usually are within limits 0.28 to 0.60 Nm.

Density of packing of atoms in crystal lattices is high. Thus, in body-centered cubic lattice atoms occupy 68% of space, and in face-centered cubic lattice 74% of space belongs to atoms.

Allotropy of metals. Allotropy or polymorphism of metals is their property to have different structure at various temperatures.

Process of transition from one type of crystal structure to another is called allotropic transformation or recrystallization.

Allotropic transformations of metal are accompanied by thermal effect, i.e., by emission (during cooling) or absorption (during heating) of heat and take place at constant temperature.

Different allotropic modifications of elements are customarily designated by Greek letters α, β, γ, δ, etc., where letter α designates that allotropic modification which exists at the lowest temperature. Allotropy is possesed by a series of technically important metals – iron, tin, cobalt, manganese, titanium, and others.

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[1]Parameters of crystal lattices were measured previously in kilo-x units (1 kXu = $1 \cdot 10^{-10}$ m = 0.1 Nm).

Table 1. Allotropic Forms of Metals

Metal	Allotropic form	Rangle of temperatures of stable state	Crystal lattice
Iron	Fe_α	to 910°C and 1400-1539°C	Body-centered cubic
	Fe_γ	910-1400°C	Face-centered cubic
Tin	Sn_α	To 18°C	Diamond type cubic
	Sn_β	From 18°C to melting point 232°C	Body-centered tetragonal
Colbalt	Co_α	To 477°C	Close-packed hexagonal
	Co_β	From 477°C to melting point 1490°C	Face-centered cubic
Manganese	Mn_α	To 742°C	Complex cubic
	Mn_β	742-1192°C	The same
	Mn_γ	From 1192° to melting point 1244°C	Face-centered tetragonal
Titanium	Ti_α	To 882°C	Close-packed hexagonal
	Ti_β	From 882°C to melting point 1660°C	Body-centered cubic

Anisotropy of crystals. In separate crystals mechanical and certain other properties are different in various directions. This property of crystals is called anisotropy. Anisotropy is explained by defined atomic arrangement in crystal: in one direction there always are more of them than in the other (Fig. 4a).

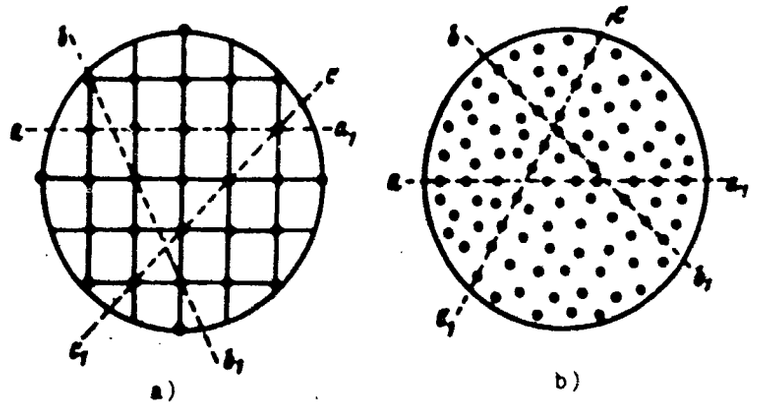


Fig. 1.4. Atomic arrangement. a) in crystalline body, b) in amorphous body.

Amorphous bodies are isotropic, i.e., all their properties are identical in all directions. This is explained by the fact that amorphous bodies in different directions have identical density of packing of atoms (Fig. 1.4b).

Metals are polycrystalline bodies, i.e., consisting of large quantity of variously oriented small crystals (Fig. 1.5). Therefore properties of metal will be approximately identical in all directions. This phenomenon is called quasi-isotropism (apparent isotropism). But this seeming isotropism of metal disappears if through some treatment crystals are given defined orientation.

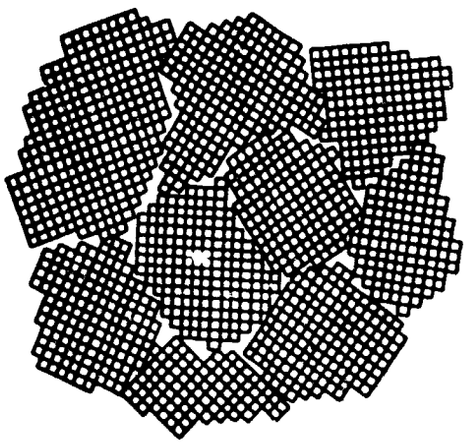


Fig. 1.5. Structure of polycrystalline body.

In crystals are so-called glide planes or cleavage planes, over which shift atoms (ions) of crystal lattice during mechanical influence on crystal.

Plastic deformation under action of forces most easily occurs on planes most closely packed with atoms.

Real structure of metallic crystals. Investigations of the recent years reveal crystals of metals are deflections from ideal location of atoms. It was revealed that mechanical and physical properties and also processes occurring in metals depend upon imperfection of structure of their crystals.

Atoms at points of crystal lattice are located in regular sequence. However, certain atoms are displaced in regular sequence. However certain atoms are displaced to interstices of lattice (so-called translations), and at certain lattice points atoms are absent (so-called vacancies) (Fig. 1.6).

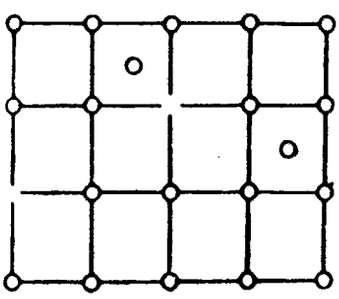


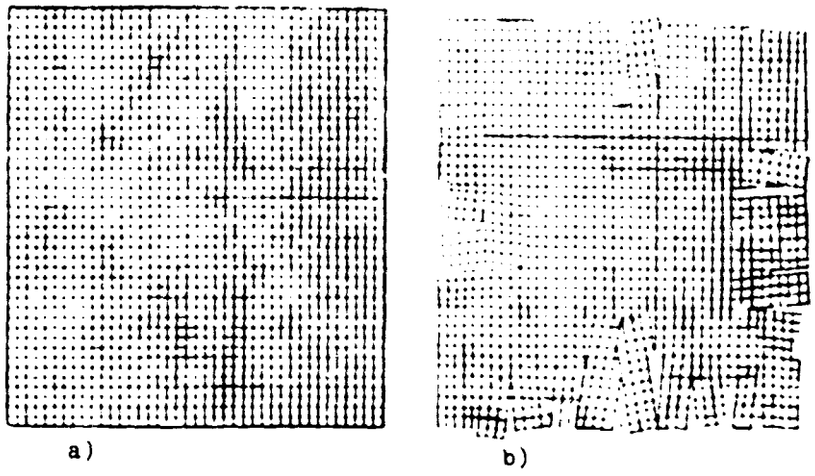
Fig. 1.6. Free points and atoms displaced into interstice.

With increase of temperature thermal agitation of atoms – average amplitudes of their oscillations – are increased and number of vacancies and displacements increases. However, number of them even at a temperature close to fusion point does not exceed 2%.

Transition of atoms to interstice, formation and shift of vacant sites, and distortion of lattice around them are causes of disturbance of regular geometric crystal structure. Disturbance of crystal lattice may

also be the result of influence of impurity atoms.

In structure of real crystals are more considerable defects of structure. Thus, crystals of metal in many cases consist of large number of regions having dimension of order of 1 micrometer (1 micron) and turned relative to each other by thousandths of a radian (tenths of a degree). These are separate regions having regular packing of atoms, called blocks (Fig. 1.7). On boundary between blocks, owing to their disorientation, packing of atoms is distorted.



GRAPHIC NOT REPRODUCIBLE

Fig. 1.7. Structure of crystals. a) structure of ideal crystals, b) structure of real crystals, c) photograph of block structure, ×20,000.

Thus, crystal constitutes unique mosaic of blocks. Such structure is called block or mosaic. Metals usually are polycrystalline bodies, i.e., consist not of separate crystal but a huge number of crystals (grains) with different mutual orientation of lattices. Owing to this, on boundary between separate grains or blocks atomic arrangement turns out to be less correct than that inside every grain.

Since surface layer of grain (grain boundary) abounds in defects, it differs essentially from core both in properties and also in chemical composition.

In real crystals are imperfection of crystal structure, called dislocation or translation. Dislocation is linear imperfection of crystal, forming boundary of nonuniform shift or rotation of crystal lattice. Dislocation forms as a result of deficiency (surplus) atom in given atomic row, which may cause elastic displacement of considerable quantity of atoms relative to their normal position of equilibrium and dispersion of vacancies by certain section of atomic row.

We distinguish edge and screw dislocations (imperfections). In Fig. 1.8 is shown diagram of formation of edge dislocation. Dislocations of crystal lattice can be formed in process of growth of crystals, during inosculation of grains and blocks with relatively small angle of orientation, during defined accumulation of vacancies, and during deformation of metal.

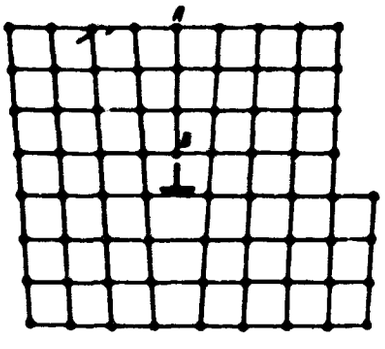


Fig. 1.8. Diagram of atomic arrangement during edge dislocation.

Theory of dislocation at present is applied widely for explanation of series of phenomena occurring in metals. Thus, in examining questions of strength of plastic deformation, diffusion and certain others theory of dislocations is used.

§ 2. Crystallization of Metals

Crystallization is process of formation of crystals. We distinguish primary and secondary crystallization. During primary crystallization crystals form from liquid in process of solidification of metal. Secondary crystallization is combined with change of crystal structure of metal or alloy in solid state.

Curves of cooling. For study of process of crystallization we plot curves of cooling, showing change of temperature with time as molten metal cools.

In Fig. 1.9 is depicted process of crystallization of pure metal. In order to cause crystallization liquid metal must be cooled to temperature $t_{кр}$, equilibrium temperature of crystallization of metal $t_{кр}$. Difference between equilibrium temperature of crystallization $t_{кр}$ and temperature $t_{кр}$, at which under given conditions occurs process of crystallization, bears the name of degree of cooling.

Amount of cooling depends on nature of metal and on rate its cooling. Other

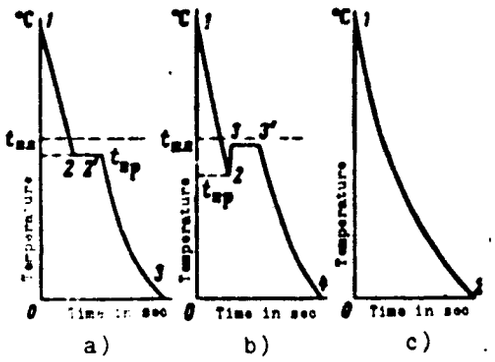


Fig. 1.9. Curves of hardening. a) crystalline body; b) crystalline body with loop of cooling; c) amorphous body.

things being equal, amount of cooling becomes greater the more complicated the lattice of metal and the higher the rate of cooling.

For majority of metals amount of cooling turns out to be very insignificant and is not detected under normal conditons of plotting of curve of cooling (Fig. 1.9a).

Section 1-2 of curve of cooling corresponds to cooling of metal in liquid state to beginning of crystallization. At temperature $t_{пр}$, at point 2, starts process of crystallization, which continues to point 2'. At moment corresponding to point 2' crystallization stops and entire metal crosses from liquid to solid state.

Transition of pure metals from liquid to solid state occurs as a result of loss of energy of motion by separate atoms. These atoms in relation to one another take position peculiar to their crystal lattice.

At the time of crystallization heat removal is compensated by emanated latent heat of crystallization, and therefore on curve appears horizontal section 2-2'. Section 2'-3 on curve corresponds to cooling of hardening metal.

Amount of cooling for certain metals can be very great, attaining several tens of degrees. For such metals on curve of cooling not infrequently is observed a , (Fig. 1.9b). Owing to intense generation of heat crystallization, temperature in the beginning intermittently is increased and then remains constant to full hardening of metal.

Amorphous substance hardens gradually owing to decrease of mobility of its particles, and curve of its cooling over its entire extent goes smoothly (Fig. 1.9c).

Process of hardening of amorphous substances takes place without temperature stops, i.e., without critical points.

Mechanism of crystallization. Crystallization, starting with cooling, does not occur instantaneously over entire volume but is developed gradually. It consists of two elementary processes:

a) onset of nuclei or centers of crystallization;

b) growth of crystals from these centers.

These processes occur simultaneously during crystallization.

Centers of crystallization are either hardened minute particles of metal or hard impurities in liquid metal. In the course of process of crystallization occurs both the onset of new centers of crystallization and growth of crystals (Fig. 1.10). In the process of crystallization, while growing crystal is surrounded by liquid, it has regular form. However, through collision and inosculation of crystals their regular form is disturbed.

After hardening of metal, there are obtained crystals of irregular shape, boundaries of which most frequently take round outlines. Such crystals are called grains or crystallites. Inside every grain is observed defined orientation of crystal lattice differing from orientation of crystal lattices of neighboring grains. Sometimes growth of crystals takes three directions, so that crystallite formed as a result of crystallization has arborescent form. These crystals are called dendritic (Fig. 1.11).

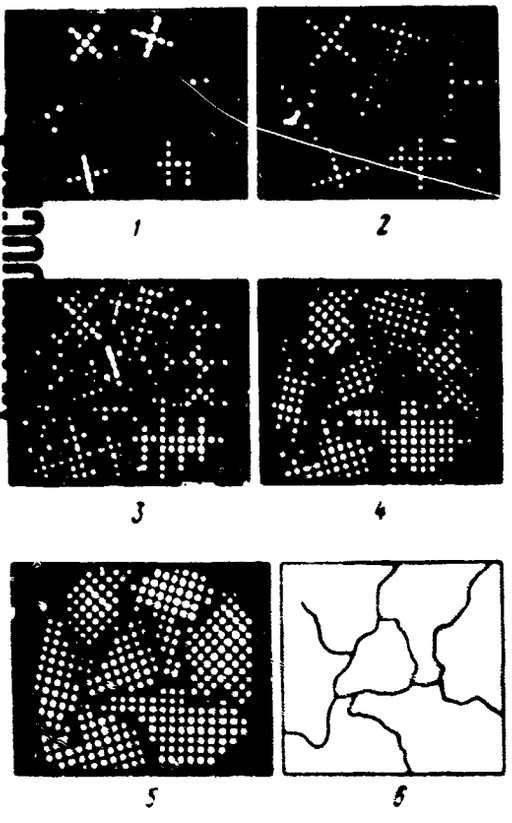


Fig. 1.10. Diagram of process of formation of crystals. 1 – first crystals formed; 2, 3, 4 – number of crystals increased; 5 – crystals came in contact in process of growth; 6 – form of hardened metal.

Properties of metals and alloys in considerable measure depend on dimensions of grains. Metals having fine-grained structure possess higher mechanical properties and better workability than metals with big grains.

Quantitatively the process of crystallization can be characterized if two quantities are known: rate of onset of centers of crystallization and rate of their growth.

Rate of onset of centers of crystallization is quantity of nuclei appearing in unit of volume in 1 sec, and is designated [n.c.] (n.u.) (number of centers).

Rate of growth of crystals constitutes linear increase of growing face of appearing crystal and is designated [r.g.] (c.p.) (rate

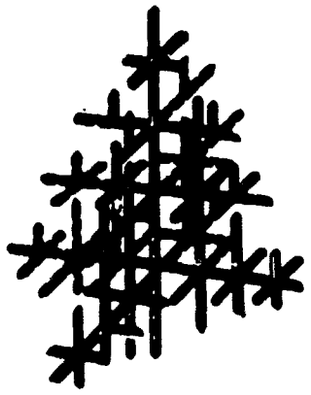


Fig. 1.11. Dendritic form of crystal per D. K. Chernov.

of growth of crystals).

Both these quantities depend on degree of cooling (Fig. 1.12). With increase of degree of cooling, number of centers of crystallization and linear crystallization rate first grow and then decrease. With slight cooling (line I), number of engendered centers and crystallization rate are small and big crystals are formed.

With strong cooling (line II), when crystallization rate attains maximum and number of centers of crystallization engendered in unit of time is comparatively small, crystals of medium size are formed. With very great degree of cooling (line III), minute crystals are formed.

Modification. At present in production of ferrous and nonferrous metals there is widely practiced the process of artificial control of dimensions and form of grains by introduction to molten metal of insoluble substances. This process is called modification. Through modification, thanks to equal distribution of mentioned substances (modifiers) over entire volume of liquid metal, grains are smaller and of somewhat different form. Such change of structure of metal improves its mechanical and technological properties.

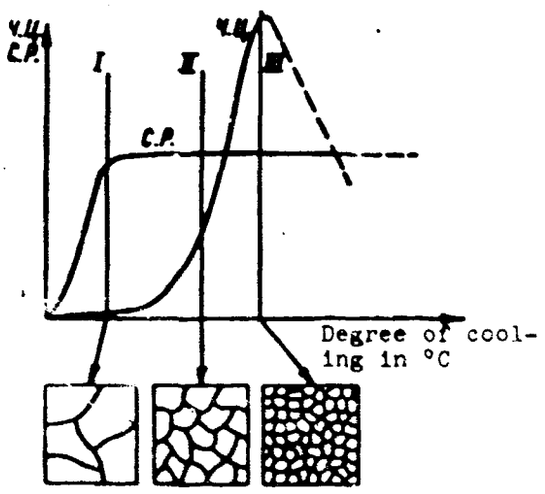


Fig. 1.12. Influence of degree of cooling on rate of onset of centers (n.c.) and rate of growth of crystals (r.g.).

As modifiers are applied: for steel – powder of aluminum oxide; for cast iron – alloys of iron and chromium or silicon and also magnesium; for silumin – sodium, etc.

Structure of steel ingot. In Fig. 1.13 is presented diagram of structure of steel ingot. It consists of three zones: fine-crystalline surface zone 1, zone of columnar crystals 2 and zone of equiaxial crystals 3 located in center of ingot. At top of ingot is shrinkage cavity 4.

Owing to intense cooling, directly at walls of casting mould is formed a shell of fine-crystalline structure. Between walls of casting mould and this shell is

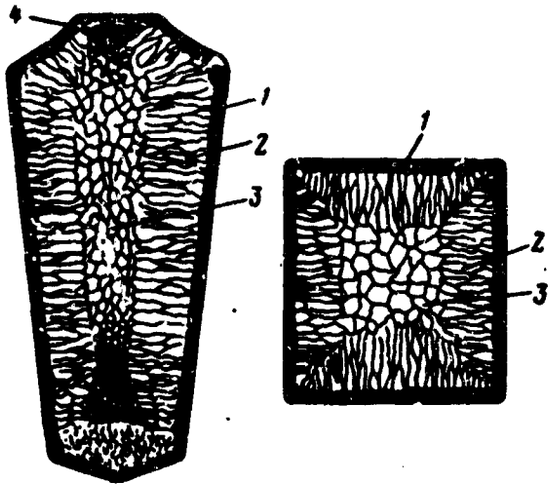


Fig. 1.13. Diagrams of longitudinal and cross sections of an ingot.

created air gap, heat radiation decreases, and this favors growth of crystals. From periphery toward center grow big columnar crystals. In central part of ingot, hardening last, conditions of heat radiation are changed and in it are formed equiaxial crystals of various dimensions. But this part of ingot is contaminated by harmful impurities - sulfu., phosphorus, which lowers its quality. Shrinkage cavity is formed due to decrease of volume of metal during its hardening.

C H A P T E R II

PROPERTIES OF METALS AND ALLOYS AND METHODS OF THEIR TESTING

§ 1. Properties of Metals

Application of metals in technology is conditioned by their properties. For correct selection of material and also for establishment of technological conditions of its treatment during manufacture of different parts, it is necessary to know physical chemical, mechanical and technological properties of materials and methods of their determination.

To physical properties pertain: color, specific gravity, melting point, thermal conductivity, thermal expansion, electrical conductivity, magnetic properties, and others.

By chemical properties of metals is understood their ability to interact with environment and with other elements in alloy.

For practical application of metals the following chemical properties are most important: oxidizability, solubility, and corrosion resistance. Questions of oxidizability and corrosion resistance are considered later.

Mechanical properties of metals characterize its ability to resist external stresses. This ability appears in various measure, depending upon form of stress and method of its application.

To mechanical properties pertain strength, rigidity, elasticity, plasticity, hardness, impact strength, and creep.

Strength – property of metals to resist beginning and development of plastic deformation and destruction under action of external forces.

Rigidity – ability of metals to resist elastic deformation.

Elasticity – property of metals to restore initial form after cessation of influence of external forces causing change of form.

Plasticity – irreversible property of metals to be deformed without destruction under action of loads.

Hardness – property of metals to resist penetration in them of other more solid bodies.

Impact strength – ability of metals to resist to impact loads without destruction.

Brittleness – ability of metals to be destroyed without noticeable plastic deformation.

Fatigue strength – property of metals to sustain large number of repeated variable loads without being destroyed. Fatigue is property opposite fatigue strength.

Creep – property of metals to be slowly and continuously plastically deformed during prolonged influence of loads.

Of greatest value are such mechanical properties of metals and alloys as strength, hardness, and plasticity. Impact strength has value for parts working under impact loads. Fatigue strength has value for parts subject to loads varying in magnitude and direction. Creep has important value for parts subject to prolonged load at high temperatures.

Technological properties of metal characterize its ability to be processed in hot and cold states.

To technological properties pertain: fluidity, casting shrinkage, hot- and cold-pressure workability, weldability, hardenability, and workability.

§ 2. Mechanical Tests of Metals

Under the action of loads appearing in process of exploitation of machines and mechanisms occur elastic or plastic deformations of parts. Essence of deformation of metal consists in change of dimensions and form.

Elastic deformation is that which disappears after removal of load. Plastic or residual deformation is that remaining after removal of load.

We distinguish three forms of application of load: static, dynamic, and oscillatory. Static load is that which grows smoothly or remains constant during prolonged time. Dynamic load is characterized by instantaneous (shock) application of force. Oscillatory loads are divided into variables (when applied force changes

in magnitude) and sign-alternating (which periodically change both in magnitude and direction).

Resistivity of material to these loads is unequal. When selecting material for manufacture of some or other structural part, one must consider resistivity of materials to different loads. For determination of properties of material characterizing its resistivity to various loads different methods of testing have been divised.

Basic forms of mechanical tests of metals and alloys applied in aviation industry are for tensile strength, hardness, impact, fatigue strength, and also tests at raised temperatures.

Tensile Test

Tensile test of metals is applied very widely in industry. This is explained by the fact that it enables one to determine strength and plastic properties of metals and alloys.

For carrying out of tensile test are necessary standard samples of tested material of cylindrical or flat form (Fig. 2.1a, b) and rupture-test machine.

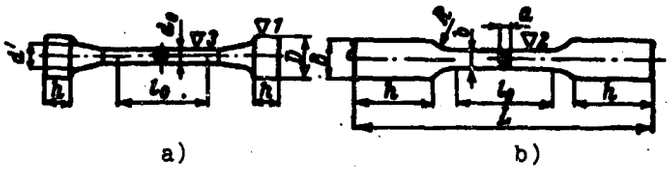


Fig. 2.1. Standard samples for tensile test. a) cylindrical, b) flat, h – length of head, a – thickness of flat sample, b – width of flat sample, l_0 – length of working or design part of sample, L – overall length of sample.

Samples with round cross section are prepared from forgings and rod material or are cast. Flat samples are prepared from sheet materials.

Samples consist of working part and heads, intended for fastening them in jaws of rupture-test machine.

Samples are subdivided into normal and proportional (short and long) types.

Diameter of working part of normal cylindrical sample is 20 mm. Design length for long samples is equal to ten diameters of sample, and for short ones it equals five diameters.

Nonstandard sample can have arbitrary cross section but defined effective length, which is calculated by formulas $l_0 = 11.3\sqrt{F_0}$ for long sample and $l_0 = 5.65\sqrt{F_0}$ for short sample, F_0 being area of cross section of sample in mm^2. Test is produced on special rupture-test machines (Fig. 2.2).

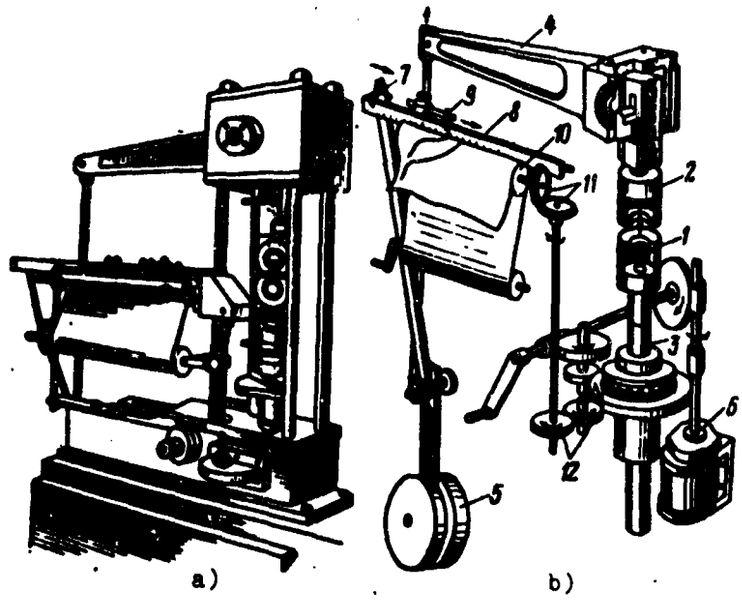


Fig. 2.2. Rupture-test machine IM-4R. a) general form, b) diagram. 1 and 2 – clamps, 3 – screw of loading mechanism, 4 – level, 5 – pendulum, 6 – electric motor, 7 – pointer, 8 – scale, 9 – pen for recording diagram of extension, 10 – diagram durm, 11 and 12 – gears.

All rupture-test machines have loading and self-measuring mechanisms and also device for automatically recording diagram of test.

Tested sample is secured in clamps of rupture-test machine and subjected to load.

Under action of gradually increasing load, sample is extended to destruction.

Stretching force creates stress in tested sample and causes its extension. Stress is load per unit of area of cross section of part (sample). When stress exceeds strength of sample, it fails. Through tensile test are determined characteristics of strength (proportional limit, plastic limit, yield point, ultimate strength) and characteristics of plasticity (elongation per unit length and reduction of area).

Proportional limit $\sigma_{пц}$ is stress to which lengthening of sample is increased proportionally to applied loads:

$$\sigma_{пц} = \frac{P_p}{F_0} \text{ [N/m}^2\text{(kgf/mm}^2\text{)]},$$

where P_p – load corresponding to proportional limit in newtons; F_0 – initial area of cross section in m^2.

Earlier load was measured in kgf and area of mm^2. Therefore mechanical stress were measured in kgf/mm^2 or in kgf/cm^2. In system of International units the universal unit of mechanical stress is newton per square meter (N/m^2).

In those cases when systematic unit of mechanical stress is small, one should apply multiple units of stress – kilonewton per square meter (1 $kN/m^2 = 10^3$ N/m^2), meganewton per square meter (1 $MN/m^2 = 10^6$ N/m^2): 1 $kgf/mm^2 = 10^7 N/m^2 = 10$ MN/m^2.

Plastic limit σ_{yn} is stress at which for the first time are obtained residual elongations of specified magnitude (usually 0.002% of calculated length of sample):

$$\sigma_{yn} = \frac{P_e}{F_0} [N/m^2 (kgf/mm^2)],$$

where P_e is load corresponding to elastic limit in newtons.

It is necessary to consider that for the majority of plastic metals and alloys magnitude of plastic limit is close to magnitude of proportional limit.

Yield point (physical) σ_T is stress at which, in spite of deformation, load either is not changed or is changed insignificantly:

$$\sigma_T = \frac{P_c}{F_0} [N/m^2 (kgf/mm^2)],$$

where P_c is load corresponding to yield point (N).

Yield point (conditional) $\sigma_{0.2}$ is stress at which residual elongation of sample is equal to 0.2% of its initial length:

$$\sigma_{0,2} = \frac{P_{0,2}}{F_0} [N/m^2 (kgf/mm^2)],$$

where $P_{0.2}$ is load corresponding to conditional yield point.

Yield point indicates loss by material of elastic properties.

Ultimate strength σ_B is conditional stress, corresponding to the biggest load preceding destruction of sample. Ultimate strength is defined as ratio of the biggest load P_B noted during test of sample to initial area of its cross section F_0:

$$\sigma_B = \frac{P_B}{F_0} [N/m^2 kgf/mm^2)],$$

Real stress at failure σ_z is defined as ratio of load at the time of failure P_z to area of cross section in neck of sample F_1:

$$\sigma_s = \frac{P_s}{F_1} \text{ [N/m}^2\text{(kgf/mm}^2\text{)]}.$$

Ultimate strength of different metals is different. Thus, for instance, cast iron has ultimate strength of 200-250 MN/m^2 (20-25 kgf/mm^2); low-carbon steel, 300-500 MN/m^2 (30-50 kgf/mm^2); and special steel, 600-2000 MN/m^2 (60-200 kgf/mm^2).

Knowledge of strength characteristics of different materials allows designers to select correctly material for manufacture of any parts of aviation materiel.

Elongation per unit length δ is increase of unit of length of sample expressed in a percentage.

Elongation per unit length is determined by the formula

$$\delta = \frac{l_1 - l_0}{l_0} \cdot 100\%,$$

where l_0 – initial length of sample in mm; l_1 – length of sample after extension in mm.

Difference $l_1 - l_0$ is absolute elongation and is designated Δl(mm).

Absolute elongation does not completely characterize plastic properties of metal, since it depends on length of sample. Elongation per unit length allows one to compare plasticity of different metals outside dependence on length of test samples.

Since ratio of calculated length to diameter for long sample is equal to 10 and for short one is 5, elongation per unit length is designated δ_{10} and δ_5.

Reduction of area ψ is reduction in area of cross section of sample at point of failure, expressed in percentage of initial cross section:

$$\psi = \frac{F_0 - F_1}{F_0} \cdot 100\%,$$

where F_0 – initial area of cross section of sample in mm^2; F_1 – area of cross section of sample after failure in mm^2.

Elongation per unit length and reduction in area characterize plastic properties of materials, which permit one to judge their ability to be processed by forging, stamping, rolling, etc.

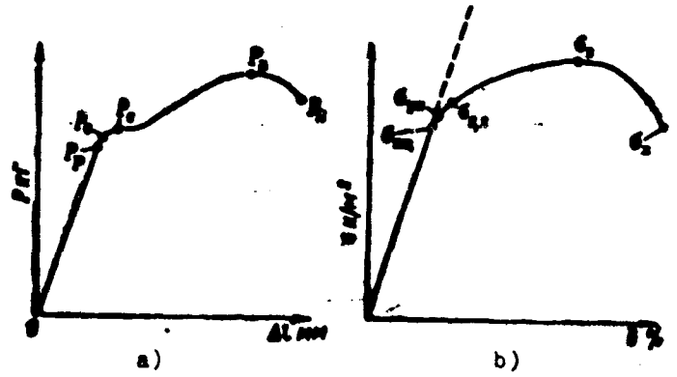
Various metals have different plasticity and consequently different elongation per unit length and reduction of area.

For brittle metals elongation per unit area δ and reduction of area ψ are close to zero; for plastic metals they attain several tens of percents.

Characteristics of properties of metals can be determined by means of diagram of extension, which is recorded automatically by special instrument. In the course of test on this diagram (Fig. 2.3) on vertical axis are plotted values of loads P and on horizontal axis are plotted absolute elongations Δl.

In the beginning, up to point P_p, corresponding to proportional limit, on diagram of extension is rectilinear section, indicating that elongation of sample increases proportionally to applied load. Up to proportional limit in metal appear only elastic deformations.

Then, with increase of load, on diagram appears curvilinear section, indicating disturbance of proportionality between elongation and stress. This load P_e corresponds to elastic limit. With this load, in metal there start to appear permanent deformation. With further increase of load to P_c, on diagram appears horizontal section. With this load sample is increased in length (flows) without increase of load. Load P_c corresponds to yield point.



a) b)

Fig. 2.3. Diagram of extension of low-carbon steel. a) on coordinates "load – deformation," b) on coordinates "stress – elongation per unit length."

If during extension of metal no horizontal site is formed, then as load of yield point is taken that load which causes residual elongation equal to 0.2% of initial length of sample.

Metal in process of deformation is strengthened, and for further extension it is necessary to increase load. The biggest value of load on sample during test P_B corresponds to ultimate strength. With this load in sample starts local narrowing, and so-called neck is formed. Load drops in connection with this, and finally, at

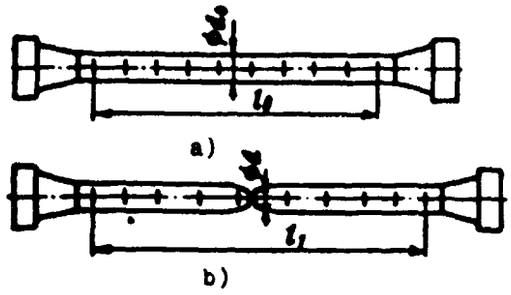


Fig. 2.4. Change of sample as a result of extension. a) sample before test, b) sample after test.

point P_z sample fails.

After formation of neck, further elongation of sample occurs mainly over length of neck, other part of sample being practically unextended (Fig. 2.4).

To exclude influence of dimensions of sample on coordinates "stress σ – elongation per unit length δ," as shown in Fig. 2.3b.

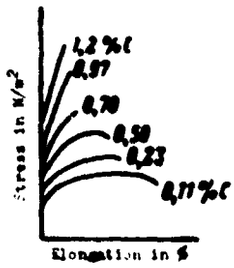


Fig. 2.5. Diagram of extension for steel with different carbon content.

Low plastic and brittle metals during extension behave differently than plastic metals, and for them diagram of extension bears another character (Fig. 2.5).

Hardness Test

Test of metals and alloys for hardness is very important and wide-spread form of mechanical test.

From hardness numbers it is possible with certain approximation to judge tensile strength of metal, its wear resistance, and machinability.

Test for hardness is not accompanied by destruction of part, is produced quickly, and does not require cumbersome and complicated machines.

Inasmuch as during determination of hardness surface layers of metal are tested, then for production of correct result surface of metal must not have such defects as scale, decarbonized layer, nicks, big scratches, etc.

Majority of methods of determination of hardness is based on principle of indentation. Here hardness can be determined:

– by magnitude of surface of imprint due to indentation of steel ball through test on Brinell press;

– by depth of imprint through indentation of diamond cone or steel ball during test on Rockwell instrument;

– by magnitude of surface of imprint due to indentation of diamond pyramid during test on Vickers instrument.

Less wide-spread are methods of determination of hardness founded not on indentation but on scratching, swinging of pendulum, elastic rebound, and other principles.

Measurement of hardness by Brinell method. Determination of hardness by this method is based on indentation of tested material by stell ball under action of load. As a result of indentation by ball, on surface of sample appears spherical imprint (Fig. 2.6a).

Diameter of imprint is measured by special magnifier (Fig. 2.6b) in two mutually perpendicular directions, and for determination of hardness average is taken from obtained magnitudes of diameters of imprint. Sample should be so located that distance from center of imprint to edge of sample is not less than two diameters of imprint to prevent "buckling" of edge of sample and distortion of results. It is necessary to make every subsequent measurement at distance of not less than two diameters from preceding imprint. Selection of diameter of ball is made in accordance with thickness of tested article. Thus, for thickness of article of more than 6 mm is applied ball of 10 mm, for thickness of article from 6 to 3 mm – a ball of 5 mm is used, for thickness of article of less than 3 mm – a ball of 2.5 mm is used. So that values of hardness be identical during use of balls of different diameter, it is necessary to observe requirements of so-called law of similarity, according to which ratio of diameters of imprint and ball should be constant:

$$\frac{d}{D} = \text{const},$$

where D – diameter of ball in mm; d – diameter of imprint in mm.

For observance of this relationship it is necessary that between load P and diameter of ball D there also exist defined relationship:

$$\frac{P}{D^2} = \text{const}.$$

Load is considered selected correctly if the relationship $0.2D < d < 0.6D$ is observed.

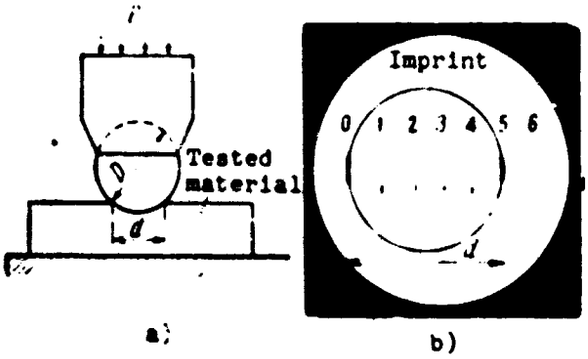


Fig. 2.6. Diagram of test of metals for hardness by Brinell method. a) formation of imprint, b) measuring imprint.

In Table 2 are given norms for tests by Brinell method, from which is selected magnitude of load and diameter of ball in dependence upon properties of tested metal.

Measure of hardness per Brinell is ratio of load P acting on ball to surface of imprint F

$$HB = \frac{P}{F} = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \left[\text{N/m}^2 (\text{kgf/mm}^2)\right].$$

Brinell hardness is designated HB, expressed in N/m^2 (kgf/mm^2), and determines average normal stress per unit of surface of imprint. Brinell hardness may be expressed by magnitude of diameter of imprint. Indentation of ball in tested metal is done on special instrument.

Table 2. Selection of Parameters During Determination of Hardness on Brinell Instrument

Metals	Hardness HB		Relationship between load P and diameter of ball D	Thickness of sample, mm	Diameter of ball, mm	Load P		Holding under load, sec
	N/m^2	kgf/mm^2				N	kgf	
Ferrous metals	1400—4500	140—450	$P=30D^2$	Above 6	10	30 000	3000	10
	1400—4500	140—450		6—3	5	7 500	750	10
	1400—4500	140—450		Below 3	2,5	1 875	187,5	10
Ferrous metals	to 1400	as 140	$P=30D^2$	Below 6	10	30 000	3000	30
	to 1400	as 140		6—3	5	7 500	750	30
	to 1400	as 140		Above 3	2,5	1 875	187,5	30
Nonferrous metals: brass	316—1300	31—130	$P=10D^2$	Below 6	10	10 000	1000	30
bronze	316—1300	31—130		6—3	5	2 500	250	30
Aluminum and magnesium alloys	316—1300	31—130	$P=10D^2$	Above 3	2,5	625	62,5	30
Aluminum	80—350	8—35	$P=2,5D^2$	Below 6	10	2 500	250	60
Nonferrous metals	80—350	8—35		6—3	5	625	62,5	60
Bearing alloys	80—350	8—35		Above 3	2,5	156	15,6	60

In Fig. 2.7 is given diagram of Brinell press with electric motor.

For determination of hardness tested sample is maounted on stand 1. Wheel 2 is rotated, raising table until preload is created. Achievement of preload is monitored in accordance with contact of moving graduation line with stationary line. Then be depressing push button motor 5 is started.

Motor frees lever supporting balance arm with weights 3. Weights are lowered, and through level system load is transmitted to ball 4, pressed into tested metal.

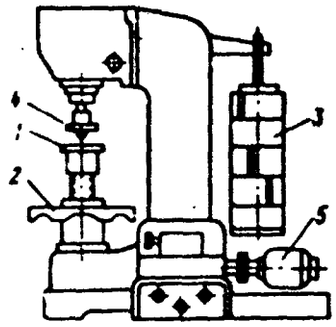


Fig. 2.7. Brinell press.

Holding under load usually is equal to 10-60 sec, depending on hardness of investigated metal. Load is removed automatically with help of motor. After automatic shutoff of motor, by turn of wheel 2 counterclockwise stand is lowered and sample is removed.

HB is determined from measured diameter of imprint by using special tables.

Mean values of hardness of certain metals and alloys are: for aluminun HB = 200 MN/m^2 (20 kgf/mm^2), for iron HB = 800 MN/m^2 (80 kgf/mm^2), for annealed medium-carbon steel HB = 1800 MN/m^2 (180 kgf/mm^2).

Between Brinell hardness and ultimate tensile strength for different materials are defined dependencies, established by experimental means:

for carbon steel σ_B = 0.36 HB;

for Cromansil steel σ_B = 0.35 HB;

for chromium and chromium-nickel steels σ_B = 0.34 HB;

for chromium-molybdenum steels σ_B = 0.33 HB;

for Duralumin σ_B = 0.37 HB;

for brass σ_B = 0.53 HB;

for pure copper σ_B = 0.48 HB;

for pure nickel σ_B = 0.57 HB.

Basic deficiencies of determination of hardness by this method are the following:

1. Impossibility of determination of hardness of materials with HB of more than 4500 MN/m^2 (450 kgf/mm^2), owing to deformation of ball and distortion of imprint.

2. Limited applicability of this method to parts of complicated configuration.

3. Impossibility of testing thin-sheet or surface-hardened material.

4. Damage of surface of tested material due to obtaining of large imprints.

5. Comparatively long time required for determination of hardness.

Measurement of hardness by Rockwell method. For test by Rockwell method into tested metal is pressed a diamond cone or steel ball and from depth of obtained imprint is determined hardness. For test of materials of low and medium hardness [HB < 2000 MN/m^2 (200 kgf/mm^2)] is applied steel ball with diameter of 1.59 mm (1/16") under load of 100 kgf (scale B, red): designation of hardness HRB. Scale B is used for tests of nonferrous metals and nonhardened steels. For test of hard materials [HB > 2000 MN/m^2 (200 kgf/mm^2)] is applied diamond cone with vertex angle of 120° under load of 150 kgf (scale C, black) or 60 kgf (scale A, black). Designations of hardness are respectively HRC and HRA. Scale C is used for hardened steels, scale A for hard alloys.

In both cases load is applied consecutively in two passes – first a preload of 10 kgf and then the main load, equal in combination with preload to 60, 100, and 150 kgf.

Measure of Rockwell hardness is a value that is the reciprocal of difference of depth of penetration of diamond cone or steel ball under action of main and preliminary loads. Hardness number is expressed in conditional dimensionless units.

Measurement of hardness is produced on press of Rockwell type (Fig. 2.8) on lower part of stationary bed of which is Table 1 for tested sample. On upper part of bed are mounted indicator 4, oil regulator to provide smoothness of load 5, and rod 6, in which is established tip with diamond cone or with steel ball of 1.59 mm diameter. Indicator 4 constitutes instrument on dial of which are two scales (black and red), and there are two pointers: large indicates hardness and small is for monitoring magnitude of preload.

Work on instrument is carried out as follows: wheel is turned to raise table until small pointer is aligned with red dot on dial. This signifies that tip has pressed into sample under action of preload. Such load is necessary for guarantee of tight contact between tip and sample and also for removal of gaps capable of influencing results of test.

After this, by turning scale of indicator figure 0 (zero) is aligned on black scale of dial (or figure 30 on red scale) with large pointer. Then with light pressure crank 7 is freed and it shifts smoothly to stop. Such shift of crank

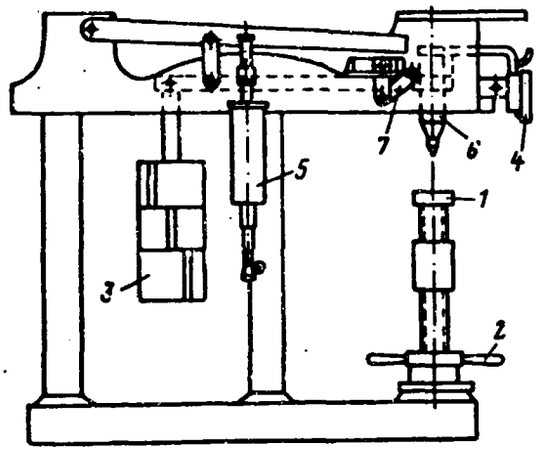


Fig. 2.8. Press of Rockwell type. 1 – table, 2 – wheel, 3 – weight, 4 – indicator, 5 – oil regulator, 6 – rod, 7 – crank.

transmits main load to tested sample through system of levers.

Loading is produced until lever system stops. Then crank 7 smoothly shifts upward, thereby removing main load but leaving preload. Figure indicated by large pointer on scale of dial represents Rockwell hardness number. After this by turning wheel counterclockwise table is lowered with sample, thereby removing preload.

Distance from center of imprint to edge of sample or to center of other imprint should be not less than 2.5 mm with cone and not less than 4 mm with ball.

Thickness of sample should be not less than 0.8 mm with diamond cone and not less than 1.5 mm with ball. Measurement of hardness, especially by diamond cone, should be made no less than three times on one sample with determination of average result.

Divergence between values of hardness of up to three units is allowed.

Measurement of Rockwell hardness has following advantage over measurement of hardness per Brinell:

1. For determination of hardness is required less time (30-60 sec).

2. Measurement of hardness leaves smaller imprint on surface of part.

3. There is posibility of determination of hardness of comparatively thin samples (to 0.8 mm).

4. Application of diamond cone permits one to determine hardness of hard materials [HB > 4500 MN/m^2 (450 kgf/mm^2)].

If it is required to measure hardness of layer of metal of thickness less than 0.3 mm by diamond cone under load of 60 kgf, analogous instruments are applied, but with smaller load (45, 30, and 15 kgf) and less depth of penetration (every scale division equal to depth of 0.001 mm).

There exists dependence between Brinell and Rockwell hardness. This dependence is given in Table 3.

Measurement of hardness by Vickers method. Determination of hardness by

Table 3. Relationship Between Brinell and Rockwell Hardness

Brinell hardness 10/3000		Rockwell hardness			
		diamond tip		steel ball 1/16"	
diameter of imprint, mm	hardness number HB MN/m^2	scale A, load 60 kgf	scale C, load 150 kgf	scale F, load 60 kgf	scale B, load 100 kgf
2,40	6580	83,0	6,3	—	—
2,45	6270	82,0	61,0	—	—
2,50	6010	81,0	59,0	—	—
2,55	5800	80,0	58,0	—	—
2,60	5550	79,0	56,0	—	—
2,65	5340	78,5	54,0	—	—
2,70	5140	78,0	52,5	—	—
2,75	4950	76,0	51,0	—	—
2,80	4770	76,0	49,0	—	—
2,85	4610	75,0	48,0	—	—
2,90	4440	74,0	47,0	—	—
2,95	4290	73,0	45,0	—	—
3,00	4150	73,0	44,0	—	—
3,10	3880	71,0	41,0	—	—
3,20	3630	70,0	39,0	—	—
3,30	3410	69,0	37,0	—	—
3,40	3210	68,0	35,0	—	—
3,50	3020	67,0	33,0	—	—
3,60	2850	66,0	30,0	—	—
3,70	2690	65,0	28,0	—	—
3,80	2550	64,0	26,0	—	—
3,90	2410	63,0	24,0	114,0	100,0
4,00	2290	62,0	22,0	112,5	98,0
4,10	2170	61,0	20,0	111,5	97,0
4,20	2070	60,0	18,0	110,5	95,0
4,30	1970	58,0	—	110,0	93,0
4,40	1870	57,0	—	—	91,0
4,50	1780	56,0	—	108,0	89,0
4,60	1700	55,0	—	107,0	86,0

Vickers method is based on pressing into tested material of tetrahedral diamond pyramid under action of defined load with subsequent measurement of diagonals of imprint with the help of microscope (Fig. 2.9).

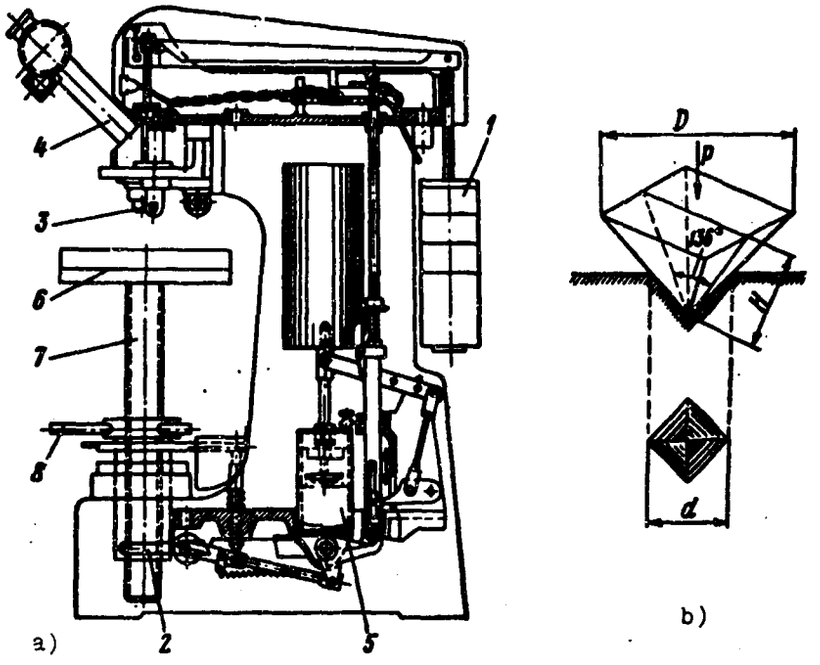


Fig. 2.9. Determination of Vickers hardness. a) general view of instrument. 1 – removable weights, 2 – crank, 3 – diamond pyramid, 4 – microscope, 5 – oil regulator, 6 – table, 7 – screw, 8 – wheel. b) measurement of imprint.

Vickers hardness HV is expressed by ratio of load P to surface of pyramidal imprint F, i.e.,

$$HV = \frac{P}{F} = \frac{2P \sin 68°}{d^2} \text{ [N/m}^2\text{(kgf/mm}^2\text{)]}.$$

Diamond pyramid has interface angle of 136°. Magnitude of load during Vickers test may be from 5 to 120 kgf and must be specified in records of test. Most frequently applied is load 5 or 10 kgf.

Samples for Vickers hardness test must have polished surface. Thickness of sample should be not less than 1.5 times diagonal of imprint.

Vickers method is especially convenient for measurement of hardness of surface-hardened parts having complicated configuration (for instance, nitrated and carbonitrated teeth of gears, etc.).

Hardness numbers HV to 400 units coincide with HB hardness numbers. For hardness of more than 400 Vickers numbers exceed Brinell numbers, and this by more the higher the hardness.

Measurement of microhardness. In a number of cases it is necessary to determine hardness of sections of material very small in area or thickness. For instance, hardness of light-gage sheet, thin surface layers, and separate structural components.

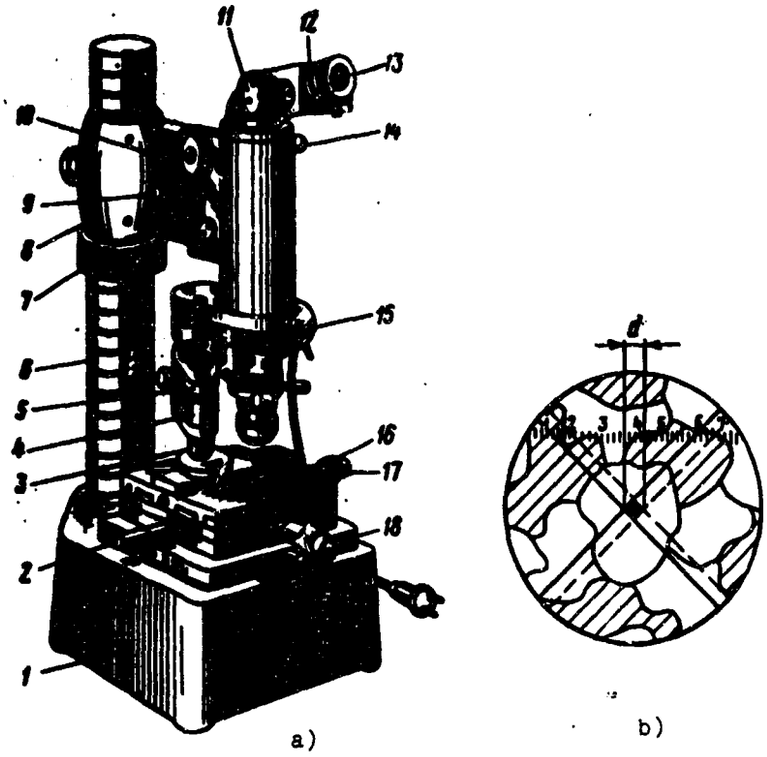


Fig. 2.10. Instrument for measurement of microhardness. a) general view of instrument. 1 – base, 2 – handle, 3 – mounting with diamond tip, 4 – weights, 5 – load mechanism, 6 – column, 7 – nut, 8 – bracket with sleeve, 9 – microfeed screw, 10 – coarse adjustment, 11 – micrometer drum, 12 – ocular micrometer, 13 – eyepiece, 14 – micrometer mounting screw, 15 – stop, 16 – stage, 17, 18 – micrometric screws; b) measuring imprint.

For solution of such problems, for determination of microhardness it is very convenient to apply Khrushchov-Berkovich method. In Fig. 2.10 is shown instrument [PMT-3] (ПМТ-3) for test of metals for microhardness. Principle of action of this instrument is based on indentation under loads of from 2 to 200 gf of diamond tetrahedral pyramid and subsequent measurement of imprint with help of microscope. Using table, from length of diagonal of imprint we find value of hardness.

Surface of tested sample should be buffed and work hardening on surface of sample removed by etching.

Impact Test

Ability of material to sustain dynamic loads is checked by impact test. Material is subjected here to deformation at high speed, by which its inclination to brittle fracture is revealed.

Impact test is applied basically to structural steel. Brittle materials (cast iron) or materials possessing great ductility (brass) are not suited to impact testing.

For impact test are applied special samples with notch, destruction of which is produced on special pendular drivers (Fig. 2.11a, b). Dimension of sample is 10 × 10 × 55 mm.

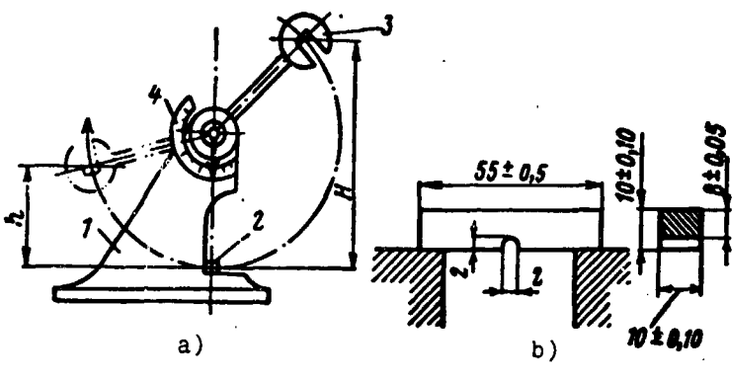


Fig. 2.11. Pendular driver. a) diagram of driver, b) sample for impact test. 1 – bed, 2 – sample, 3 – driver, 4 – scale.

Before test pendulum rises upwards by angle α and is secured by latch. Sample is placed on supports of driver with notch facing opposite blow of striker. Then pendulum is released and, dropping, destroys sample. After blow pendulum swings to other side of vertical axis by certain angle β, magnitude of which is fixed by scale pointer.

Impact toughness a_H, i.e., work of impact fracture, referred to cross section of sample at place of notch, is determined by the formula

$$a_н = \frac{A_н}{F_0} \text{ [J/m}^2\text{(kgf/cm}^2\text{)]},$$

where A_H – work of blow expended on destruction of sample, in Joules; F_0 – area

of cross section of sample in place of notch, in m^2;

$$1 \text{ kgf-m/cm}^2 = 10^5 \text{ J/m}^2 = 0.1 \text{ MJ/m}^2.$$

Different materials possess various impact toughness. Thus, for instance, low-carbon steel has a_H = 0.4-0.8 MJ/m^2 (4-8 $kgf\text{-}m/cm^2$), and alloy steel 1.0-1.8 MJ/m^2 (10-18 $kgf\text{-}m/cm^2$).

Besides appraisal of numerical values oftained during impact test, an important criterion of quality of metal is fracture of samples. Fibrous dull fracture without characteristic metallic luster testifies to ductile fracture. Brittle fracture gives lustrous crystalline fracture.

Endurance Test

Static and impact tests are insufficient for study of strength of metals subjected to action of repeatedly-varying and sign-alternating stresses.

Machine parts in which appears large number of repeated alternating stresses sometimes are subject to sudden and brittle fracture, occurring during stresses lying considerably below ultimate strength. Destruction of metals as a result of action of such stresses is called phenomenon of fatigue.

For fatigue breakdown is characteristic special form of break, consisting of two zones (Fig. 2.12): smooth lustrous zone of fatigue 1 and zone of brittle fracture with coarse crystalline structure 2.

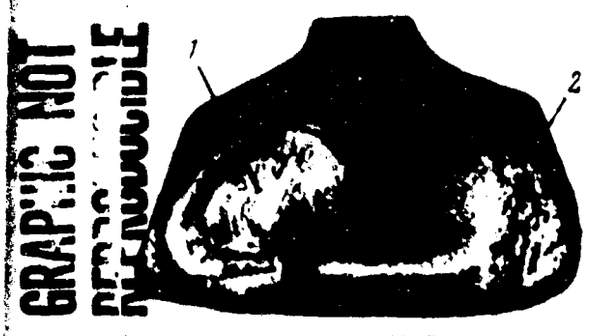


Fig. 2.12. Break of metal destroyed from fatigue.

In practice of exploitation of aviation materiel it is necessary to deal with many parts subject to fatigue breakdown. Such include: blades of gas turbine, crankshafts, aircraft longerons, chassis components, etc.

Test for determination of strength during alternating stresses is called endurance or fatigue test.

Such tests determine number of changes of loads (number of cycles which sample sustains before destruction under given stresses.

Endurance test is made on special machine in which rotatable sample is subjected to influence of buckling loads (Fig. 2.13).

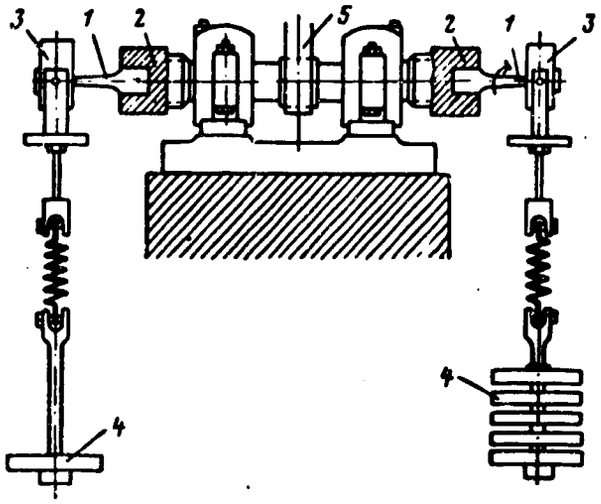


Fig. 2.13. Machine for endurance test. 1 – samples, 2 – chucks, 3 – bearings, 4 – weights, 5 – drive belt.

Results of test are recorded in the form of diagram called an endurance curve. On vertical axis are plotted stresses σ, under which samples are tested. On horizontal axis is plotted quantity of cycles N. On endurance curve is determined the biggest stress under which sample is able to sustain any number of changes of loads without destruction. This stress is called endurance or fatigue limit and is designated σ_{-1}. Endurance curve, plotted on coordinates σ-N (Fig. 2.14a), does not have sharp transition to horizontal section, which hampers possibility of exact determination of endurance limit. Therefore it is more convenient to use method of plotting endurance diagram on logarithmic coordinates (Fig. 2.14b), for which this transition is more clearly expressed.

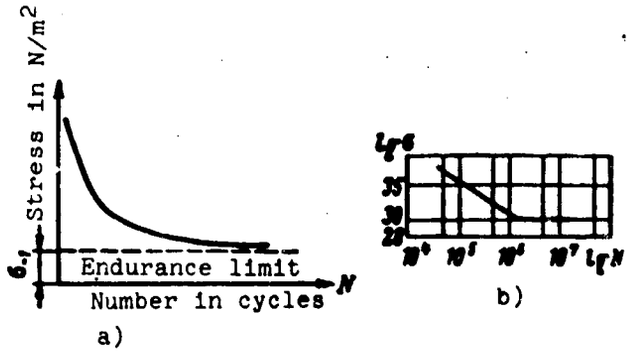


Fig. 2.14. Endurance curves. a) in usual coordinates, b) in logarithmic coordinates.

For determination of endurance limit it is sufficient to bring number of cycles to 5 million during test of steel and to 20 million during test of light and heat-resisting alloys. Samples of these materials sustaining shown quantity of cycles without break serve satisfactorily during large number of changes of load also; therefore they are considered suitable for manufacture of corresponding parts. In practice the endurance limit of steel is 35-50% of ultimate strength established

by usual tensile test.

Endurance limit depends on a series of factors: degree of contamination of metal by nonmetallic inclusions, state of surface, structure of metal, form of part, and others.

Endurance limit is increased by means of hardening surface and creation in external layers of metal of compressing stresses (by shot-blasting, nitration, carburizing, etc.).

Existing methods of testing metals for fatigue are distinguished by type of applied load and by conditions of carrying out experiment. Tests are conducted under bend, torsion, extension – compression, at high and low temperatures, in corrosive media, etc.

§ 3. Tests at High Temperatures

Work of majority of parts and assemblies of contemporary airplane constructions occurs under conditions of joint prolonged action of loads and heating.

Therefore in aviation technology of tremendous value are mechanical properties which materials have at high temperatures. High temperatures for given material is considered that composing not less than 0.5 $T_{пл}$ [meeting point] on absolute scale. Thus, high temperatures for steels are those over 600°C, and for aluminum and magnesium alloys those over 150°C.

Behavior of metals and alloys during prolonged high-temperature loading differs from their behavior at usual temperatures.

Characteristics of strength and ductility of majority of technical alloys at usual temperatures in practice do not change with time. And under action of high temperatures and loads in them occurs considerable change of mechanical properties with time. With increase of duration of loading, characteristics of strength and ductility worsen.

Since change of strength may differ with duration of test, for appraisal of exploitational properties of alloys under high-temperature loading it is necessary to consider character of change of their strength characteristics with time.

In Fig. 2.15 are given curves of change of ultimate strength of two alloys, depending upon duration of test. Ultimate strength of first alloy $\sigma_{в1}$ during small duration of test a less than ultimate strength of second alloy $\sigma_{в2}$. However, for parts working at high temperatures for prolonged time it is more profitable to use first alloy, since strength of second alloy strongly worsens with increase of duration

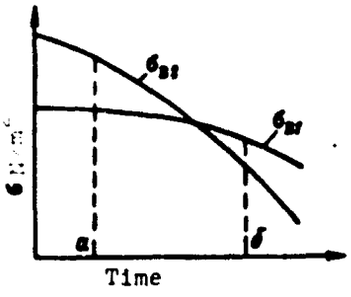


Fig. 2.15. Change of strength of two alloys in dependence upon duration of test.

of test. And after duration of test б ultimate strength of first alloy will be already greater than ultimate strength of second alloy.

At present in order to obtain reliable data about behavior of materials at high temperatures and under permanent loads, they are subjected to special mechanical tests.

Brief Tensile Tests

Tensile tests at high temperature are produced under ordinary static loading, when load increases during short interval of time calculated in minutes.

Brief tests do not characterize in full measure the properties of metals and alloys at high temperatures. On the basis of brief tests there can be obtained an idea about behavior of material of parts in initial period of their work.

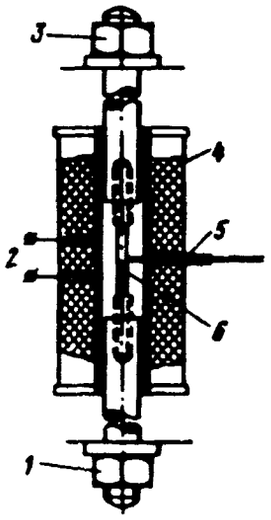


Fig. 2.16. Diagram of tensile test at high temperatures. 1, 3 – clamps of machine, 2 – feed of current, 4 – furnace, 5 – thermocouple, 6 – sample.

For brief tests are used ordinary machines applied for static tests, supplied with heating devices (Fig. 2.16).

Creep Tests

If at high temperature metal is loaded by constant stress lower than yield point at some temperature and left under load for sufficiently prolonged time, material during entire time of action of temperature and load will be deformed at certain speed. Such phenomenon is called creep. For steel creep is observed at temperatures over 350°C.

Basic form of creep test is that made under conditions of extension. In Fig. 2.17 is depicted diagram of machine for creep test. Sample for creep test is subjected to action of standed load at the same temperature, and after assigned intervals of time elongation of sample is determined. Results of test are compiled in the form of graph, called creep curve. Plotting creep curve is produced on coordinates "elongation per unit length – time" (Fig. 2.18).

Segment 0-1 characterizes elastic elongations, which form immediately after

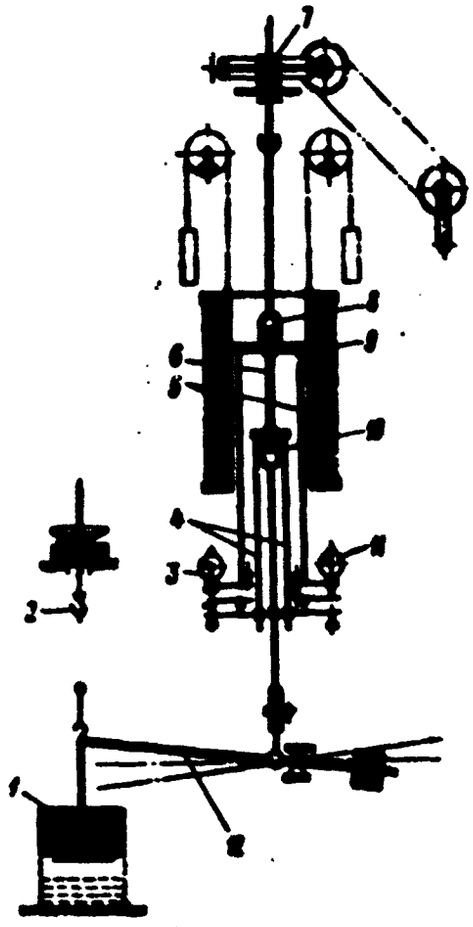


Fig. 2.17. Diagram of machine for creep test. 1 – weights, 2 – damper, 3, 11 – indicator, 4, 5 – rods, 6 – sample, 7 – loading mechanism, 8 – upper clamp, 9 – furnace, 10 – lower clamp, 12 – lever.

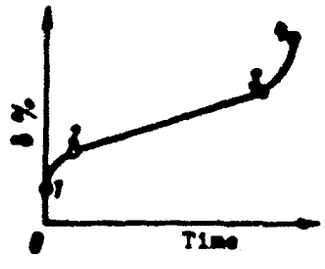


Fig. 2.18. Characteristic curve of creep.

loading of sample. Section of curve 1-2 is called period of transient creep, during which deformation takes place with nonuniform, decreasing speed. Section of curve 2-3 is called period of steady-state creep taking place with constant speed of deformation. Section 3-4 is chracterized by sharp growth of creep, terminating with destruction of sample.

In Fig. 2.19 are presented creep curves for the same material, tested at the same temperature under different stresses. The less the stress the less the speed of creep and the longer the sample will sustain load without destruction. With increase of stress, curve is steeper, speed of creep increases, and destruction of sample occurs.

In the same manner is changed character of creep curves of material under the same stress but at different (increasing) temperatures.

Creep limit is characteristic of resistance of metal to small plastic deformations.

Creep limit is stress which causes, after defined interval of time at given temperature, given total elongation or speed of deformation.

Creep limit designated by sign of stress with two indices. Thus, for example, $\sigma_{0.1/300}$ = 250 MN/m^2 (25 kgf/mm^2) signifies that at given temperature, for instance at 800°C, stress equal to 250 MN/m^2 (25 kgf/mm^2) for 300 hours of tests causes elongation of sample of 0.1%.

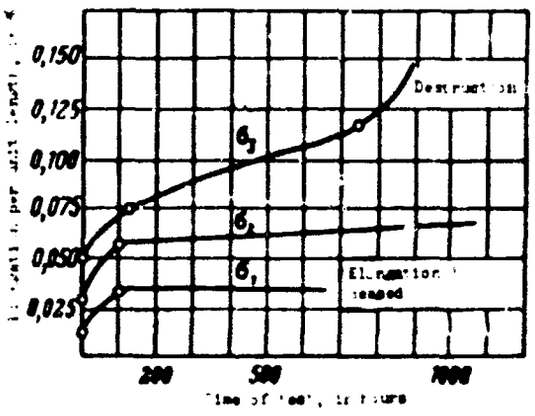


Fig. 2.19. Variation of creep with time of test for different stresses and constant temperature.

For different parts magnitude of allowance for deformation varies from 0.1 to 1% and duration of test varies from 100 to 500 hours.

Value of creep limit for the same material depends on duration and temperature of test and on allowance for deformation. With decrease of duration of test and constant allowance for deformation, value of creep limit is increased. With decrease of permissible deformation, other conditions being equal, magnitude of creep limit also decreases. An especially considerable decrease of creep limit under these conditions occurs with increase of temperature of test.

Tests for Stress-Rupture Strength.

Important property of alloy working at high temperatures is its ability to resist destruction under prolonged affect of loads. This property is called <u>stress-rupture strength</u>.

It is possible to produce tests for stress-rupture strength on the same machines used for creep tests, but they must have attachments for damping of blow of weights, dropping at the time of rupture, and for fixation of time of rupture of sample. Samples are tested under constant loads and temperature to destruction.

Tests for stress-rupture strength are more accelerated than tests for creep, since here are applied higher loads, provoking considerably greater deformations.

Most frequently tests for stress-rupture strength are continued for 100, 200, or 300 hours, and results of tests are depicted graphically on coordinates "stress - time to rupture" (Fig. 2.20).

Characteristic of resistance of metal to destruction at high temperatures is stress-rupture strength.

<u>Stress-rupture strength</u> is stress which causes destruction of sample at given temperature in defined interval of time.

For designation of stress-rupture strength is used the following notation: $\sigma_{300} = 150$ MN/m^2 (15 kgf/mm^2). This signifies that at given temperatures, for

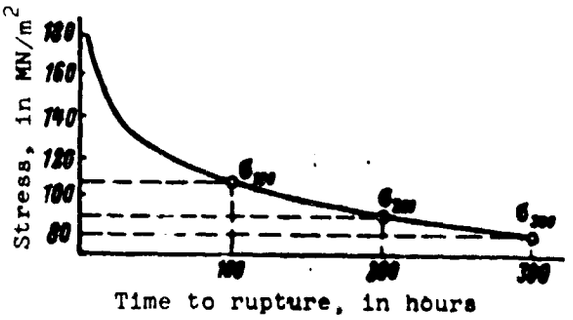


Fig. 2.20. Curve of stress-rupture strength.

instance at 800°C, stress equal to 150 MN/m^2 (15 kgf/mm^2) causes destruction of alloy after 300 hours.

Numerical values of stress-rupture strength and creep limit obtained under the same conditions of test for the same material do not coincide.

Value of stress-rupture strength for the same material depends on duration and temperature of test. The greater the duration and temperature of test, the less the value of stress-rupture strength for the same material. Obviously at given temperature metal can serve longer under smaller stress.

Endurance Tests

Of essential value for period of service of parts at high temperatures is ability of material to resist to destruction during action of repeatedly-varying loads, i.e., during work to fatigue.

Standard tests for endurance at high temperatures are produced by repeatedly-varying bending. For these tests are used ordinary machines supplied with heating devices.

In process of testing for endurance at high temperatures on endurance curve no horizontal section is obtained, which is characteristic for normal temperatures of test, i.e., during high-temperature tests for endurance stress bringing about failure continuously decreases with increase of number of cycles to very large values.

Endurance limit at assigned temperature is the biggest stress which sample sustains assigned number of cycles without destruction.

For determination of endurance limit at high temperatures as base are taken $5 \cdot 10^6$; $10 \cdot 10^6$; $50 \cdot 10^6$, and $100 \cdot 10^6$ cycles.

Hardness Tests

For determination of hardness at high temperatures or so-called "hot" hardness there chiefly are applied methods of indentation.

For this can be used any press supplied with heating attachment (Fig. 2.21).

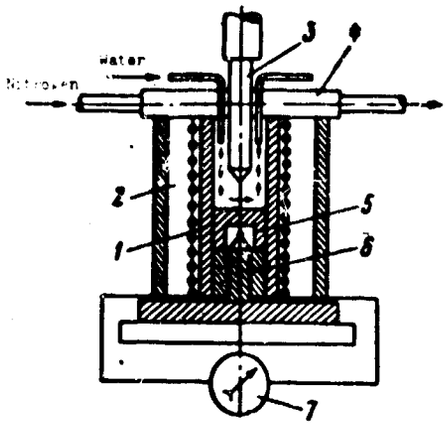


Fig. 2.21. Instrument for determination of hardness at high temperatures. 1 – porcelain cylinder, 2 – furnace, 3 – punch, 4 – cover, 5 – sample, 6 – thermocouple, 7 – galvanometer.

Sample having recess at bottom for introduction of thermocouple is established in electric oven heated to assigned test temperature.

During test a ball of 5 or 10 mm diameter is pressed under constant load into test sample, heated to assigned temperature. Measure of "hot" hardness is ratio of load to surface of obtained imprint. Ball is prepared from alloy steel or heat-resistant alloy.

The most important factor of "hot" hardness is time. With increase of duration of test, hardness drops.

§ 4. Technological Tests

Technological tests are for the purpose of determining fitness of material for particular technological processes. Results of technological tests are judged from state of surface after test. Sample is considered as having sustained test if on its surface after test are revealed no cracks, rents, stratification, or fracture. Methods of carrying out technological tests are specified by corresponding GOST's and OST's.

The most widely applied technological tests are flanging, fluxure, extrusion, and wire coiling.

Flanging is carried out for determination of ability of metal to take bend of given dimensions and form. It is conducted both in cold and heated states, depending upon form of material and its assignment. Flanging test is conducted differently; to defined angle, to parallelism of sides, to full contact (Fig. 2.22).

This test is applied to sheet and strip materials with high plasticity intended for cold or hot pressure working.

For production of flanging test are applied presses or vice.

Fluxure test serves for determination of ability of metal to sustain repeated bending and unbending (Fig. 2.23). For test sheet material sample of defined dimensions is selected, which is clamped in jaws of instrument in vertical position. During test sample is bent and unbent in plane perpendicular to tangent of jaws of

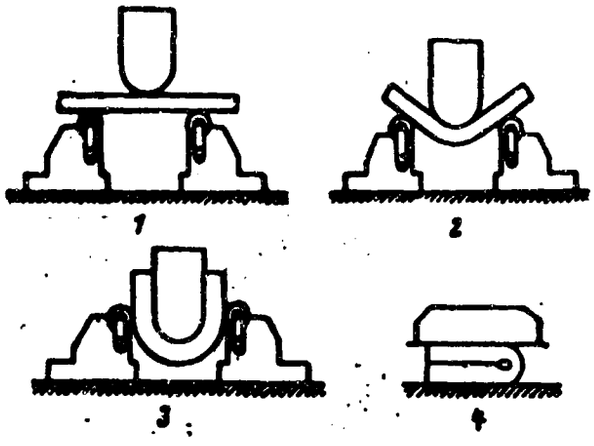


Fig. 2.22. Flanging test of metal. 1 – position before test, 2 – test to determined angle, 3 – test to parallelism of sides, 4 – test to full contact of sides.

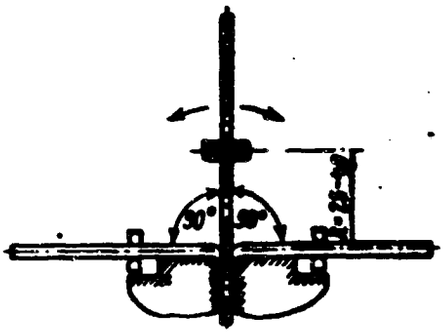


Fig. 2.23. Flexure test.

instrument. Bending is done alternately 90° to both sides at speed of up to 60 bends per minute. One cycle is composed of bending and unbending 90° to each side. Flexure test is conducted in cold state. To test are subjected sheet materials and wire.

Extrusion test is used for determination of ability of sheet metal to be subjected to stamping and drawing. For carrying out of test from sheet is cut sample, which is placed in special instrument (Fig. 2.24). This instrument consists of punch, of die, and clamp. During test sample is forced against die, and then by slow rotation of wheel there is forced into it the hardened, polished spherical element of working part of stamp (punch). Punch is pressed in until crack appears, which is detected by mirror. Plasticity of metal is judged from depth of drawing of sample to moment of appearance of crack.

Test for coiling of wire is applied only for test of wire of diameter up to 6 mm and serves for appraisal of ability to take assigned coiling (resile properties). Wire is coiled on cylindrical rod of defined diameter to defined quantity of turns (Fig. 2.25). After test, in material of sample and also in coverings must be revealed no stratifications, cracks, exfoliation, rents, breaks, etc.

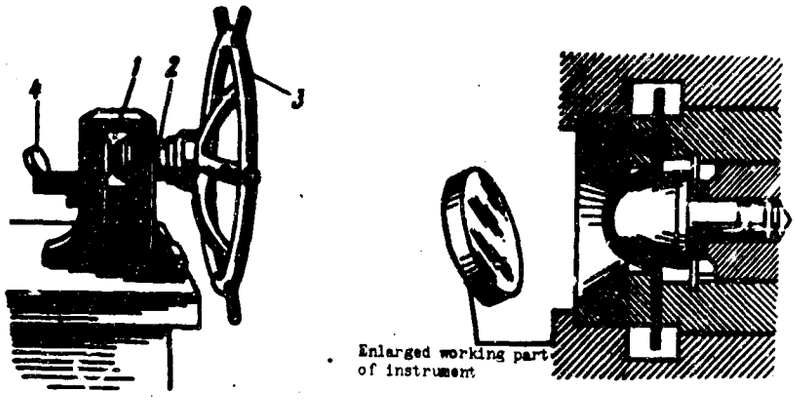


Fig. 2.24. Extrusion test of material. 1 – slot; 2 – screw; 3 – wheel, 4 – mirror.

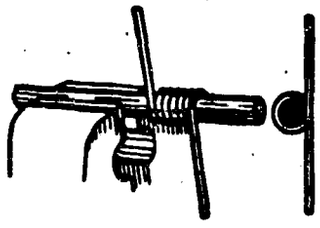


Fig. 2.25. Coiling test of wire.



Fig. 2.26. Test of tubes for bend.

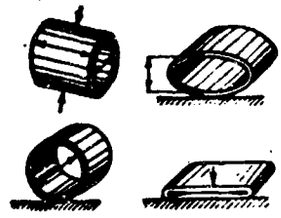


Fig. 2.27. Test of tubes for flattening.

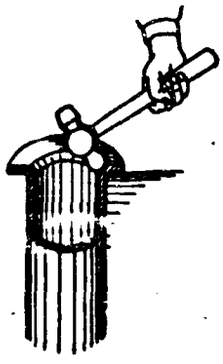


Fig. 2.28. Test of tubes for flattening.

Tests of tubes. Tubes are tested for bend (Fig. 2.26), for flattening (Fig. 2.27), and for beading (Fig. 2.28).

These tests serve for determination of ability of pipes to sustain different form of change of their form.

Foundry tests. During foundry tests, for determination of fluidity molten sample of metal is poured into channel molded in earth, having form of spiral. Measure of fluidity is length of flooded part of spiral.

C H A P T E R III

METHODS OF INVESTIGATION OF METALS AND ALLOYS

For study of structure of metals and alloys are applied various methods of investigation: chemical analysis, metallographic analysis, X-ray diffraction analysis, and thermal analysis. First method is used for determination of composition of alloy or establishment of purity of metal. The following two are used for study of structure and last for study of transformations which occur in metals and alloys with changes of temperature.

§ 1. Analysis of Chemical Composition

Chemical analysis permits one to determine content of elements entering in composition of some or another alloy and also to establish degree of contamination of pure metals by other elements. Chemical analysis is divided into qualitative and quantitative. Qualitative analysis permits one to determine what elements, and sometimes compounds, are in metal or alloy and their comparative quantities (much, little, or traces). Quantitative analysis permits one to determine exactly quantities by weight of elements in chemical compounds entering in composition of metal and alloy.

Spectral analysis of metals and alloys, in comparison with chemical analysis, has advantages, thanks to high sensitivity, accuracy, speed of carrying out, and cheapness. For carrying out of spectral analysis there are needed in all a few milligrams of investigated substance, which permits analyzing thin wires, metallic coverings, etc.

Spectral analysis is based on study of spectrum of metals and alloys. Heated

vapors of every metal have their own defined spectrum. This spectrum completely characterizes every element and helps one to detect it unerringly. Spectra of alloys constitute spectra of simple elements. This is why, depending upon defined lines of spectrum, it is possible to judge qualitative composition of alloy.

Brightness and intensity of spectral lines of separate elements entering in composition of alloy is changed in dependence upon their content in given alloy. Comparing intensity of spectral lines of separate elements, one can determine tentatively their percentage in given alloy.

§ 2. Structural Analysis

Structural analysis includes investigation of macrostructure, microstructure, and atomic structure (X-ray structure).

Macroanalysis is study of structure of metals and alloys with unaided eye or under slight magnification. Macrostructure can be studied directly on surface of metal (for example, a casting), in fracture of a part, or most frequently after preparation of investigated surface, consisting in grinding and etching.

On etched surface one can detect orientation of crystals in metal, presence of cracks, quality of weld seam, etc. In cast steel is revealed orientation of dendrites; in rolled or forged steel is seen fibrous structure of deformed crystals.

Macroanalysis allows one also to see distribution in steel such harmful impurities as sulfur and phosphorus.

In Fig. 3.1 is represented macrostructure of a cast blade of nozzle apparatus of gas turbine, and in Fig. 3.2 is shown macrostructure of a stamped valve.

Microanalysis is the study of structure of metals and alloys with the help of metallographic microscope.

Microanalysis as method of investigation of metals and alloys was first applied in 1831 by P. P. Anosov for study of patterns of appearing on surface of polished steel after etching it in acid.

At present microanalysis is one from basic methods of investigation of structure of metals and alloys, checking quality of metal, and studying causes of destruction of parts in exploitation.

For carrying out of microanalysis it is necessary to prepare microsection – sample with surface prepared for investigation. For manifestation of microstructure ground and then polished surface is etched in special chemical reagents, whose



Fig. 3.1. Macrostructure of cast blade of nozzle assembly of gas turbine.

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Fig. 3.2. Macrostructure of stamped valve.

composition includes acid, salt, or alkali. Reagent corrodes surface, giving it greater relief. Besides this, it colors different structural components of alloy differently. This purpose is served by electrolytic polishing of metals. In Fig. 3.3 is given diagram explaining visibility of grain boundaries under microscope a and microstructure of metal with clear outline of grain boundaries b.

Microanalysis allows one:

a) to determine structure of alloy and also dimensions and form of separate grains and on this basis to make conclusion concerning character of casting, degree of deformation during cold pressure treatment, and conditions of heat treatment;

b) to detect different flaws of metals and alloys, as, for example, nonmetallic inclusions, micropores, microcracks, traces of oxidation, overheating, overburning, etc.;

c) to detect composition of structural components;

d) to measure depth of penetration and to determine character of corrosion of parts.

For study of microstructure are applied metallographic microscopes (Fig. 3.4). Diagram of optical system of metallographic microscope is shown in Fig. 3.5. Beam from source of light 1 strikes prism 2 of microscope and, being refracted in prism, goes to objective 3. Above objective is located slide 4. Beam of light is reflected from slide and through objective heads through prism 5 to eyepiece 6.

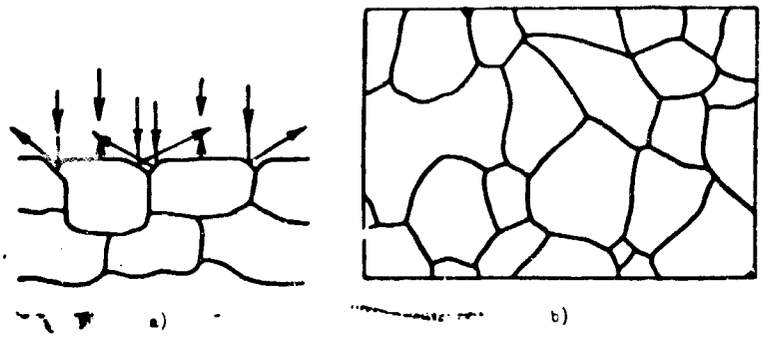


Fig. 3.3. Diagram of reflection of beams and manifestation of microstructure of metal.

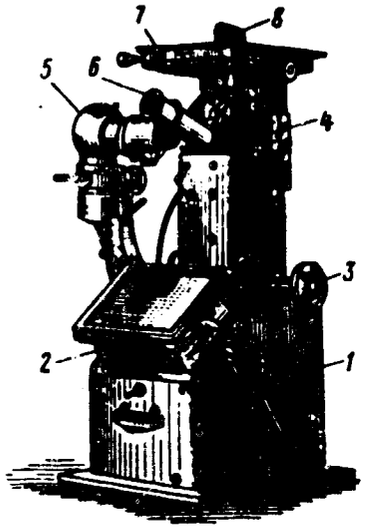


Fig. 3.4. Metallographic microscope. 1 – body, 2 – camera, 3 – screw for rough focusing, 4 – micrometric screw, 5 – illuminator, 6 – eyepiece, 7 – stage, 8 – microsection.

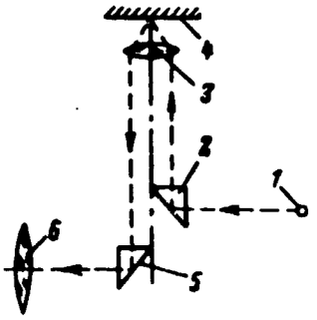


Fig. 3.5. Diagram of path of beams of metallographic microscope. 1 – source of light, 2 – prism, 3 – objective, 4 – microsection, 5 – prism, 6 – eyepiece.

Microstudy by optical microscope permits one to detect particles with minimum dimensions to 2 microns (μ): $1\ \mu = 1 \cdot 10^{6}$ m. Magnification applied is from several tens to 2000 times.

At present electron microscopes are finding ever wider application. Or electron microscope created in USSR study of microstructure is produced during magnification of up to 100,000 times, which permits observation of particles to 0.0003 μ. In Fig. 3.6 is presented diagram of electron microscope. In Fig. 3.7 is shown structure of steel as seen by optical and electron microscope.

X-ray diffraction analysis. X-ray diffraction analysis is important method of investigation of structure of metals. It is based on ability of X-rays to penetrate solids to one degree or another. X-rays are electromagnetic oscillations with small wavelengths, commensurable with parameters of crystal lattices of metals.

X-ray diffraction analysis allows one to establish types of crystal lattices of metals and alloys and their parameters. Definition of structure of metals and

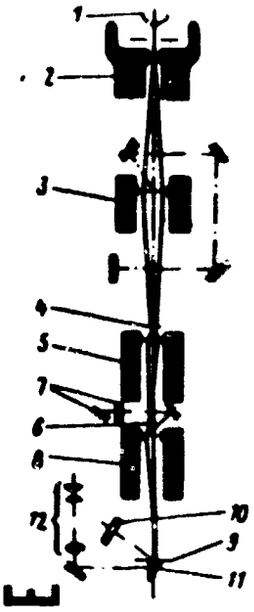


Fig. 3.6. Diagram of electron microscope. 1 – cathode, 2 – anode, 3 – condenser (electromagnetic lens), 4 – object, 5 – objective lens, 6 – fluorescent screen 7 – viewing hatch, 8 – projection lens, 9 – fluorescent screen, 10 – viewing hatch, 11 – prism, 12 – optical microscope.

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Fig. 3.7. Microstructure of steel. a) revealed by optical microscope (×1000); b) revealed by electron microscope (×15,000).

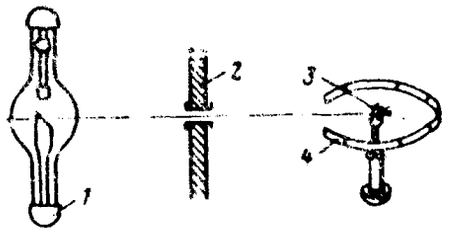
[illegible] of distance between them is based on reflection of X-rays by atomic planes of crystal lattice. Knowing wavelength of X-rays, one can determine distance between atomic planes (and separate atoms) and diagram (system) of location of atoms in space.

With X-ray diffraction analysis it is possible to investigate both separate crystals also metal or alloy in the form of fine powder.

In Fig. 3.8 is shown diagram of X-ray diffraction analysis. X-ray beam, striking investigated sample, is reflected from certain atomic planes and, combining, strikes film contained inside special chamber, as a result of which on film is obtained series of bands whose position and intensity depend on type of crystal lattice of material of sample. Deciphering thus obtained X-ray photograph, one can determine type and parameter of space lattice.

In recent years in metal science there has found wide application the method of radioactive isotopes (method of "tagged atoms").

This method is based on fact that tagged atoms introduced into alloy in the form of radioactive isotopes can be detected with the help of radiography or by other method. Tagged atoms introduced into alloy behave identically as ordinary atoms during different processes occurring in alloy. This enables one to study many physical and chemical processes occurring in alloys. Thus, with help of radioactive isotopes permits one to investigate self-diffusion in alloys [illegible]



[illegible] diagram of X-ray [illegible]. 1 - X-ray tube, [illegible], 3 - investigated [illegible], 4 - sensitive film.

[illegible] and phase [illegible] thermal-[illegible] treatment.

6.1. Thermal Analysis

Thermal analysis is important method of investigation of metals and alloys. Thermal analysis consists in determination of temperatures of transformations (critical points) during [illegible] cooling of metals and alloys by means of plotting "time – temperature" [illegible]. Any phase transition occurring in metal or alloy is accompanied by [illegible] during cooling, or absorption (during heating) of heat.

Therefore if in alloy no phase transitions occur, curve of cooling (heating) [illegible] smooth. In the presence of phase transformations on curve will be horizontal [illegible] or breaks.

These horizontal sections or breaks permit one to determine temperature of [illegible] transformations.

During production of thermal analysis are applied special instruments, allowing exact measurement of high temperatures.

For determination of temperatures the most widely used are thermoelectric pyrometers. Thermoelectric pyrometer (Fig. 3.9) consists of thermocouple and galvanometer. Thermocouple constitutes two wires 1 and 2 of different metals or alloys, welded at one end 3. Free ends of wires are connected to terminals 5 of galvanometer. When junction of wires is heated in closed circuit appears thermo-emf and pointer of galvanometer is deflected. The higher the temperature of junction of wires the bigger the deflection of pointer.

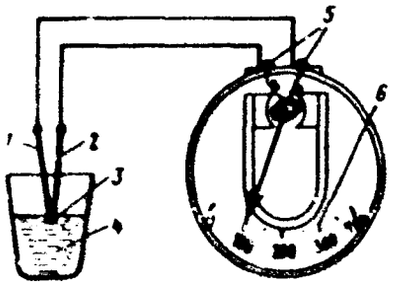


Fig. 3.9. Thermoelectric pyrometer. 1, 2 – wires of thermocouple, 3 – junction, 4 – melted metal, 5 – terminals of galvanometer, 6 – scale of galvanometer.

The most widely used are thermocouples: chromel-alumel (measuring temperature to 1300°C) and platinum-platinum-rhodium (measuring temperature [illegible]).

For determination of high temperatures also are used optical and radiation pyrometers. They [illegible] to determine temperature of [illegible] without introduction of [illegible] into [illegible] heated medium. [illegible] application of optical and

radiation pyrometers is based on measurement of value of radiant energy of heated bodies.

§ 4. Other Methods of Investigations

During investigation of metals and alloys are applied also methods of electrical resistance and magnetic analysis. These methods are based on the fact that during change of composition or structure of alloy its electrical resistance and magnetic properties are changed. These methods are based on the fact that with change of composition or structure of alloy its electrical resistance and magnetic properties are changed. Knowing law of change of these characteristics with composition and structure of alloy, from magnitude of electrical resistance and magnetic properties one can judge chemical composition and structure of some or another alloy.

C H A P T E R IV

PHYSICAL METHODS OF INSPECTION OF METALS AND ALLOYS (DEFECTOSCOPY)

Quality of parts of contemporary aviation te[illegible]ology which work under conditions f high speeds of high temperatures, and c[illegible]nsiderable loads should be exclusively igh. They are obliged to correspond to requirements [illegible] high strength, reliability, nd longevity in exploitation.

Increase of strength, reliability, and longevity of aviation parts is attained y means of application of new high-s[illegible]rength alloys, special surface hardening of arts, improvement of technology of mechanical and heat treatment.

However, in practice there occur cases when in finally prepared part are internal flaws of metallurgical origin or defects appearing sometimes in process of elding, forging, casting, heat treatment or machining. Use of such parts is extremely undesirable, since defects may cause their premature destruction and breakdown. Therefore during manufacture, exploitation, and repair of aviation materiel one of the most important problems is timely detection of flaws in parts and assemblies.

Totality of methods and inspection procedures for parts without their destruction is called defectoscopy.

At present the following physical methods of defectoscopy of parts are widely applied: magnetic, luminescent radioscopy, X-ray and gamma-ray, ultrasonic, and others.

§ 1. Magnetic Defectoscopy

Magnetic method of inspection is used for check of quality of steel ferromagnetic parts and assemblies without their destruction and damage.

making this, changes of magnetic properties of metal in process of its treatment is used also for quality inspection of heat-treated articles.

Magnetic method of defectoscopy is based on detection of magnetic fields of scattering appearing above defects in magnetized component.

During magnetization, in steel part appears flow of magnetic lines of force. If in path of force lines a defect is encountered, for instance, a crack or cavity, in this place strong lines will deviate from their normal direction and, striving to circumvent defect, will exceed the limits of part, forming on its surface local magnetic field of scattering (Fig. 4.1). This field, and consequently the defect also, can be easily detected. Article is magnetized with help of electromagnet and then covered with water containing fine magnetic powder or is covered with dry magnetic powder. Powder is drawn to region of greatest heterogeneity of magnetic field, located at cracks to a depth of up to 2 mm from surface. On surface of metal appear characteristic accumulations of powder, easily detected during inspection. In such a way it is possible to detect cracks of any origin (hardening, grinding, welding, hairline cracks, flocs, etc.).



Fig. 4.1. Field of scattering of magnetic flux at point of defect.

In Fig. 4.2 are represented flaws of parts revealed by magnetic defectoscopy

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Fig. 4.2. Flaws of parts revealed by magnetic defectoscopy. a) grinding cracks on bolt of aircraft chassis, b) fatigue crack on welded seam of aircraft chassis assembly.

§ 2. Luminescent Defectoscopy

Luminescent method of inspection is used for detection of surface cracks of parts made from nonmagnetic metals and other materials.

Luminescent method of inspection is based on use of phenomenon of fluorescence,

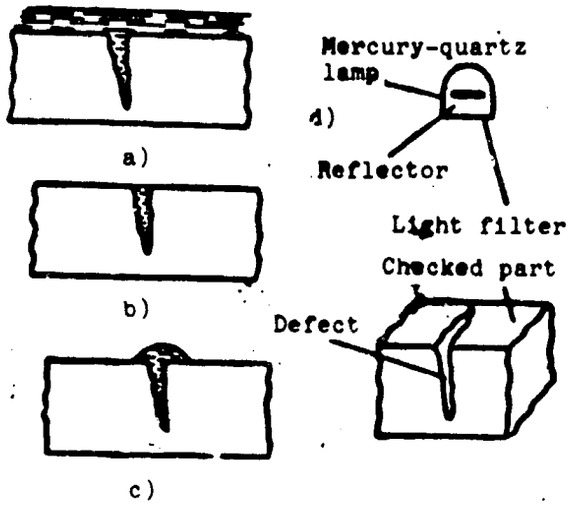


Fig. 4.3. Diagram of luminescent method of defectoscopy. a) penetration of liquid into crack, b) removal of liquid from surface of part and its drying, c) extraction of liquid from crack with help of magnesium oxide, d) illumination by ultraviolet rays and detection of defects.

i.e., glow of certain substances under influence on them of invisible ultraviolet beams. Such substances include mineral oils, certain salts, and their solutions: lumogen, anthracence, defektol', rhodamine, etc. These substances are able to absorb energy of ultraviolet rays and immediately radiate it in the form of glow. After cessation of influence of ultraviolet rays glow of substances vanishes. Each of fluorescent substances possesses its own characteristic glow color. Thus, for example, mineral oil MK under ultraviolet illumination gives bluish-white glow, lumogen gives yellow glow, defektol' gives yellowish-green, etc.

In Fig. 4.3 is shown diagram of luminiscent method of defectoscopy. Investigated part is covered with "active" liquid, which penetrates all pores, cracks, and other surface deepenings. Surplus of liquid is then removed from surface of part and on the latter is deposited any powder able to easily be absorbed in this liquid (for instance, burnt magnesia). Liquid getting in cracks is extruded by particles of powder, which permits on to location and form of cracks through subsequent irradiation of part by light of mercury-quartz lamp. Beams of visible spectrum radiated by lamp are trapped by filter of dark uviol glass. At place of crack appears bright luminescent line corresponding to it in configuration and extent.

By luminescent method are well revealed shrinkage cracks in castings, quenching and grinding cracks, cracks in welded seams, and so forth.

This method does not guarantee detection of cracks filled with products of corrosion, nonmetallic inclusions, or those bearing character of wide scratches. Therefore parts made from ferromagnetic metals subject to luminescent inspection only in those cases when magnetic inspection for some or other causes cannot be applied.

In Fig. 4.4 is presented flaw of part (crack of blade of turbine stator of gas

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Fig. 4.4. Flaw of part revealed by luminescent defectoscopy (crack of blade of turbine stator).

turbine) detected by luminiscent defectoscopy.

§ 3. Radioscopy by X- and Gamma-Rays

Radioscopy with help of X-rays (X-ray defectoscopy) or gamma-rays (gamma defectoscopy) is used for inspection of parts for the purpose of manifestation of internal flaws (cavities, porosity, etc.).

For this are used powerful X-ray installations with voltage of 200-300 kV or radioactive isotopes. Installations require attachments for protection of maintenance personnel from harmful influence of radiation.

X-ray flaw detector (radioscopy, photography) is based on property of X-rays to penetrate through bodies not transparent to visible rays, for instance, through metals and alloys. Here, with passage through article occurs dispersion and absorption of X-rays in material of article because there intensity decreases. Decrease of intensity depends on wavelength of X-ray, and also on material and thickness of article. The less the wavelength the greater the penetrating ability of rays. In connection with this, rays with great penetrating ability (shortwave) are called rigid and those with low penetrating ability (longwave) are soft.

X-rays directed towards part in which heterogeneities are structural (cavities, tighter inclusions, and so forth), after passage through part will possess unequal intensity. More intense will be beams encountering different voids on their way (cavities, blowholes, cracks, porous sections, etc.). In corresponding places on photographic film appear dark spots having contours of these defects (see diagram in Fig. 4.5).

Conversely, intensity of beams passed through inclusions denser than material of part (for instance, liquational inclusions of copper in aluminum alloys) will be considerably weakened, and such beams will cause brightening on negative film. On positive print relationship of light and dark areas will be correspondingly reversed.

This is basis for X-ray photography, allowing one to inspect quality of parts.

Conditions of photography depend on many factors: the most important is exposure time (holding), determined by quality of material, thickness of article,

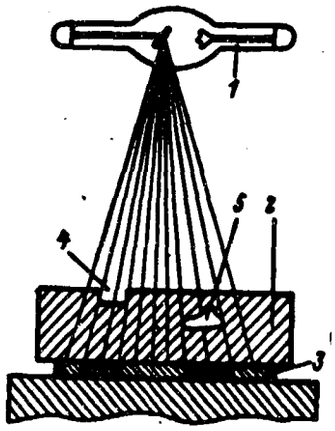


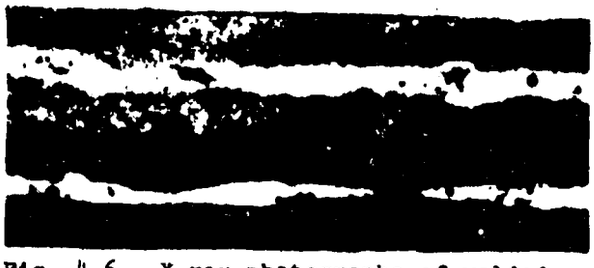
Fig. 4.5. Diagram of radioscopy by X-rays. 1 – X-ray tube, 2 – transilluminated metal, 3 – cassette with film, 4 – cut in metal, 5 – cavity.

voltage in tube, and force of working current.

Radioscopy of parts and subsequent photography is called by photographic method, and radioscopy with examination of defects on screen is called visual method.

Photographic method is considerably more sensitive than visual and permits transilluminating large thicknesses of steel (to 40-50 mm). Therefore it has found widest application. Visual radioscopy is less sensitive, but it is faster and cheaper; it is applied during defectoscopy of parts made from light alloys with thickness of not more than 40 mm and steel of not more than 8 mm in thickness.

X-ray photography is widely applied mainly for quality inspection of parts made from aluminum and magnesium alloys, for the purpose of detection in them casting defects (cavities, pores, friability and gas bubbles) and flaws of pressure treatment (internal rents, cracks, and so forth), and also for investigation of quality of welded seams in steel articles (nonfusion, overburning, cracks, etc.). As example, in Fig. 4.6 are given X-ray photographs of welded seams.



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Fig. 4.6. X-ray photographs of welded seams.

Gamma-defectoscopy. At present ever greater use is being found for methods of quality inspection of parts founded on use of gamma rays. Application of gamma rays has considerably expanded the assortment of transilluminatable parts with respect to their composition and thickness.

Gamma rays are shortwave electromagnetic oscillations, and in nature they do not differ from other forms of radiation – radio waves, visible light, ultraviolet radiation, and X-rays. The only distinction between them and X-rays is in

conditions of formation. Gamma rays appear as a result of radioactive disintegration of nuclei of natural and artificial radioactive substances.

The greater the energy of gamma rays the shorter the wavelength and the higher the penetrating ability. In penetrating ability the majority of radioactive substances gives very hard radiation.

As sources gamma rays earlier served as natural radioactive elements: radium, mesothorium, radiothorium, and also their mixtures. These elements are very deficient and cheap; therefore their application for defectoscopy was limited. Wide use in industry for radioscopy of parts has been made of gamma rays only in recent years, when it has become possible to obtain in sufficient quantity cheap artificial radioactive isotopes of different chemical elements giving gamma radiation of different rigidity: cobalt – 60, cesium – 137, iridium – 192, and others. Mentioned preparations are placed in metallic ampules, which absorb beta radiation (flux of negatively charged particles – electrons). Ampules are stored and transported in lead containers (protective housings), thickness of walls of which is determined by rules of protection of personnel and safety personnel during work with fissionable materials, depending upon activity and energy of radiation of radioactive preparation.

Photographic method of radioscopy of parts by gamma rays coincides with method of radioscopy by X-rays. To obtain photograph, radioactive preparation (Fig. 4.7) is on one side of transilluminated part and on the other is placed cassette with photographic film. After radioscopy and processing of film, gamma photograph is obtained.

Method of gamma defectoscopy possesses series of essential advantages over X-ray method, in view of portability of source of radiation and simplicity of applied equipment. Small dimensions of equipment facilitate its transportation and installation on inspected objects, make it possible to inspect directly on objects. High penetrating ability of gamma rays permits one to inspect more massive parts (for instance, steel parts with thickness of up to 250 mm). However, in sensitivity method of gamma inspection is somewhat inferior to X-ray method. Sensitivity of method of gamma defectoscopy depends on energy of gamma rays (i.e., on source of radiation used), density, and thickness of transilluminated material, and also on character of defect.

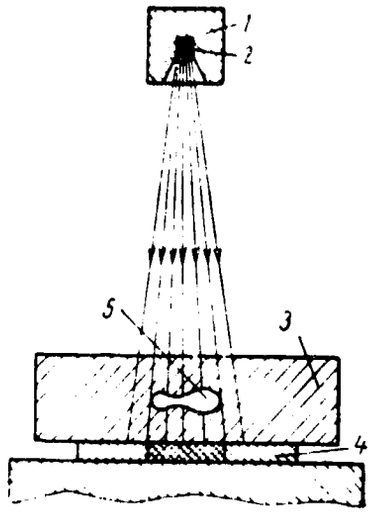


Fig. 4.7. Diagram of radioscopy by gamma rays. 1 – protective housing, 2 – radioactive preparation, 3 – transilluminated part, 4 – cassette with film, 5 – cavity.

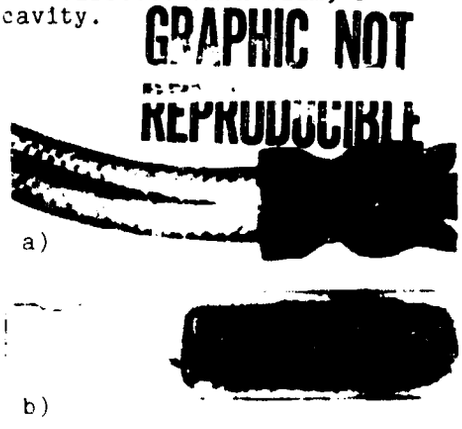


Fig. 4.8. Gamma photographs of parts with internal defects. a) fuel hose, b) rod of exhaust valve.

Gamma radioscopy, like X-radioscopy, makes it possible to inspect parts for the purpose of detection of internal flaws and malfunctionings. In Fig. 4.8 are given gamma photographs of aviation parts with internal defects.

§ 4. Ultrasonic Defectoscopy

By method of ultrasonic defectoscopy are inspected parts of any materials in which ultrasonics can spread.

Ultrasonics are oscillations having frequency of more than 20 thousand cps (20 kilocycles), i.e., lying beyond the borders of upper threshold of human audibility. In practice, for purposes of ultrasonic defectoscopy) are applied ultrasonics of frequency from 100 kilocycles to 10 Mc (10 million cps), obtained by artificial means.

With such frequencies wavelength of ultrasonics passing through metal is from 0.5 to 30 mm and is commeasurable with dimensions of defects.

As source of ultrasonic oscillations serve as piezoelectric radiators, basic part of which is piezoquartz plate, cut in a determined way from quartz crystal. This plate possesses property of piezoelectric effect, consisting in that during compression or extension of plate in defined direction on its surface appear charges whose sign is determined by direction of deforamtion and magnitude is determined by applied force (Fig. 4.9). Reverse piezoelectric effect appears if such plate is introduced into electrical field, which results in change of its dimensions in accordance with intensity and direction of field. If field is variable, the plate will accomplish forced oscillations with frequency of field. Thus, it is possible to use this plate as radiator

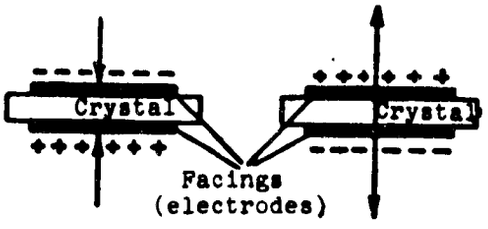


Fig. 4.9. Diagram of piezoelectric effect.

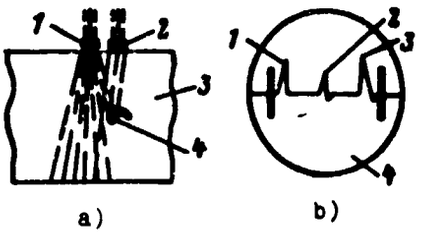


Fig. 4.10. Diagram of ultrasonic defectoscopy. a) part with defect. 1 – radiator, 2 – receiver, 3 – part, 4 – defect. b) screen with signals. 1 – initial signal, 2 – echo-signal from defect, 3 – bottom signal, 4 – electron-beam tube.

of ultrasonic oscillations [US] (УЗК), sending them to alternating voltage.

Recently, instead of quartz plate, there have been applied less scarce plates of barium titanate, which also possesses piezoelectric effect.

Contemporary ultrasonic defectoscopy is based on reflection of ultrasonic waves from defects in material and catching of reflected waves by special receiving-amplifying devices.

Principle of operation of ultrasonic flaw detector consists of the following (Fig. 4.10). With the aid of vacuum-tube oscillator are created electrical waves, which then go to piezoelements. The latter converts electrical oscillations to ultrasonic, signal which on screen of oscillograph is seen in the form of peak (initial signal). In the absence of defects this impulse passes inside part to its opposite face ("bottom"), and, being reflected, returns to receiver.

Reflected electrical oscillations go through amplifier to screen of oscillograph. On screen appears second peak (bottom signal). When defect is encountered along the path of beam, on screen there appears a third peak, corresponding to reverse signal from defect. It is located between peaks corresponding to initial and bottom signals. From distance to this peak one can determine depth of defect.

An important advantage of this method is possibility of detection of defects at large depths (to 3 m). Therefore it is especially valuable for inspection of big castings, forgings, stampings, and such articles.

C H A P T E R V

STRUCTURE AND CRYSTALLIZATION OF ALLOYS

§ 1. Bases of Structure of Alloys

Concept of alloys. Pure metals do not possess necessary complex of properties imposed on materials for parts of contemporary machines. Therefore of predominant application in technology are not pure metals but their alloys. Alloys are distinguished by higher strength properties than metals. However, they possess lower plasticity, electrical conductivity, and differ by a series of other physical properties.

Contemporary stage of development of technology is characteristic for the fact that along with increase of quantity of alloys and complication of their composition, metals of high purity are obtaining value. They are applied widely in atomic, electronic, and other branches of new technology.

An alloy is a complicated metallic body, consisting of two or more elements, obtained by their fusion, sintering, or other methods. Metallic alloys consist of metals but may also contain nonmetallic elements. However, in this case preservation by alloy of properties inherent to metals is obligatory. In every alloy we distinguish components and phases. Components are substances forming alloy. Phase is uniform part of alloy, separated from other parts of alloy by interface. In liquid state alloy most frequently contains one phase. During hardening there always are two phases - liquid and solid.

After hardening, one or serveral phases is formed. In liquid state majority of metallic alloys applied in technology constitute uniform liquids - solutions of components.

Structural components of alloys. Components of alloys possessing different properties enter into different interactions, forming metallic bodies of more complicated structure than pure metals. During hardening there occur processes leading to formation in alloy of following structural components: mechanical ixtures, solid solutions, chemical compounds. Properties of alloy depend on properties of structural components.

Mechanical mixture is formed if components of alloy do not interact with each other chemically but are in alloy in the form of independent interconnected grains. Alloys of such kind are nonuniform. Every component of alloy is crystallized in separate grains having crystal lattice inherent to given component (Fig. 5.1).

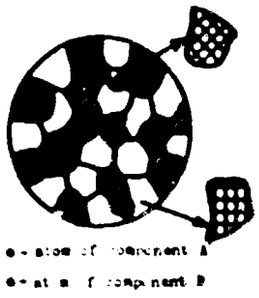


Fig. 5.1. Structure of mechanical mixture.

Mechanical mixture is formed by alloys of lead and antimony or tin and zinc. Besides this, mechanical mixture can be formed not only by grains of pure elements but also by grains of solid solutions and chemical compounds.

Solid solution is formed when components of alloy possess solubility in solid state. Solid solutions are compounds formed by means of penetration into crystal lattice of metal-solvent of atoms of dissolved metal. Solvent is an element whose crystal lattice is preserved during formation of solid solution.

Thus, for alloys possessing structure of solid solutions crystal structure of basic metal is kept and grains are uniform (Fig. 5.2).

In solid solutions can occur diffusion processes. Diffusion rate increases with increase of temperature and depends on difference of concentrations.

Properties of solid solutions are not similar with properties of component parts but do not differ sharply from them and depend on quantity of soluble metal. For instance, alloys of copper and zinc can have different properties, depending upon how much zinc is dissolved in copper.

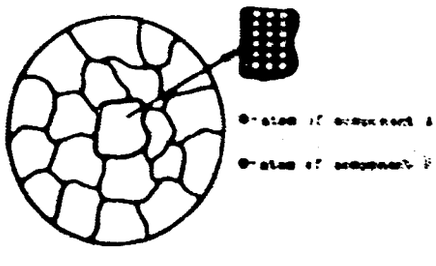


Fig. 5.2. Structure of solid solution.

Solid solutions can be of unlimited and limited solubility. In last case in crystal lattice of metal-solvent can enter only defined limited quantity of atoms of soluble metal. During formation of solid solutions of limited solubility, the

latter strongly depends on temperature. Usually with increase of temperature solubility is increased.

Depending upon distribution of atoms of dissolved metal in crystal lattice of metal-solvent we distinguish two forms of solid solutions: substitutional solid solutions and interstitial solid solutions.

In substitutional solid solutions atoms of dissolved component replace atoms of solvent (Fig. 5.3b). During formation of interstitial solid solutions, atoms of dissolved element are placed between atoms of solvent (Fig. 5.3c).

It has been established that substitutional solid solutions form metals whose atoms differ in dimensions by not more than 15% (for instance, copper and nickel, iron and chromium). Interstitial solid solutions are formed most frequently when metal dissolves in itself nonmetallic elements whose atoms are considerably smaller than atoms of metal (for instance, iron and carbon, iron and nitrogen).

Chemical compounds are obtained during interaction of components of alloy. They have constant composition, unique crystal lattice, and special physical, chemical, and mechanical properties. To chemical compounds in alloys are peculiar raised hardness and brittleness. Chemical compounds can be formed during interaction both of metals with metals and also of metals with metalloids. For instance, in iron-carbide alloys there forms a chemical compound of iron with carbon Fe_3C (so-called cementite); in alloys of aluminum with copper $CuAl_2$ forms, etc.

Chemical compounds in structure of alloy are in isolated state. When alloy is heated, crystals of chemical compounds can be dissolved in solid solution of alloy, and with lowering of temperature these form anew.

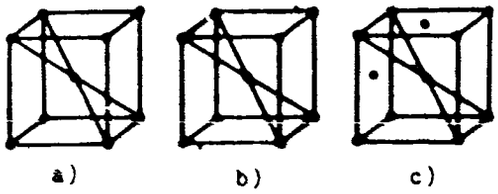


Fig. 5.3. Crystal lattices. a) pure metal, b) substitutional solid solution, c) interstitial solid solution.

With respect to quantity of components entering in alloy, we distinguish binary, ternary, and more complicated alloys.

Alloys applied in technology have complicated chemical composition. High-strength steels, for instance, have in their composition up to ten different chemical elements. The more complex the composition and structure of an alloy the more varied its properties usually are.

§ 2. Constitutional Diagrams of Alloys

Constitutional diagrams of metallic systems show change of state of alloys depending upon concentration of components and temperature. Constitutional diagrams characterize results of interaction of components in system during change of composition or temperature, which makes it possible to select correctly conditions of hot and heat treatment of alloys.

Constitutional diagrams are constructed in the following way.

At first, with help of thermal analysis, curves of cooling of alloys of different compositions are obtained. On these curves are found points of inflection and horizontal sites, characterizing critical temperatures of corresponding alloys. Then, on "temperature – concentration" coordinates is constructed constitutional diagram, onto which are transferred critical points of transformations of all alloys. Constitutional diagram is obtained by connection of these points (Fig. 5.4).

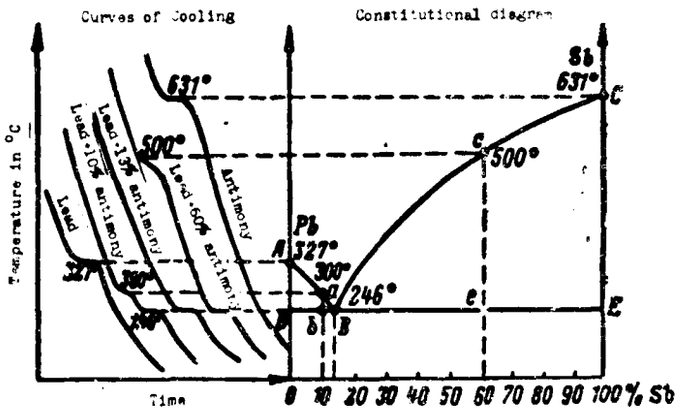


Fig. 5.4. Construction of constitutional diagram of alloys of lead-antimony from curves of cooling system.

Obligatory condition for construction of sililar diagrams is slow cooling of alloys, ensuring full course of all transformations and obtaining of stable state.

The more components in alloy the more complicated the form of constitutional diagram. Thus, for two-component system diagram is constructed in rectangular system of coordinates, where on axis of ordinates is plotted temperature and on axis of abscissas is plotted concentration of components. Diagram of three-component system is reproduced in space: Two axes, located on plane intended for appraisal of concentrations and one spatial, intended for appraisal of temperature.

Constitutional diagrams of alloys are similar if their components form

identical structures upon hardening.

There are several forms of constitutional diagrams of alloys of two components.

§ 3. Constitution Diagram of Type I

Constitution diagram of type I characterizes alloys whose components in liquid state are completely mutually dissolved and in solid state form mechanical mixture of crystals of both components.

In accordance with given constitutional diagram harden alloys: lead – antimony, tin – zinc, lead – silver, and others. In Fig. 5.5 is represented constitutional diagram of alloys of lead – antimony system. On this diagram points on curve ABC show for every alloy of lead and antimony temperature at which alloy begins to harden, and points on line DE show temperature at which hardening is finished.

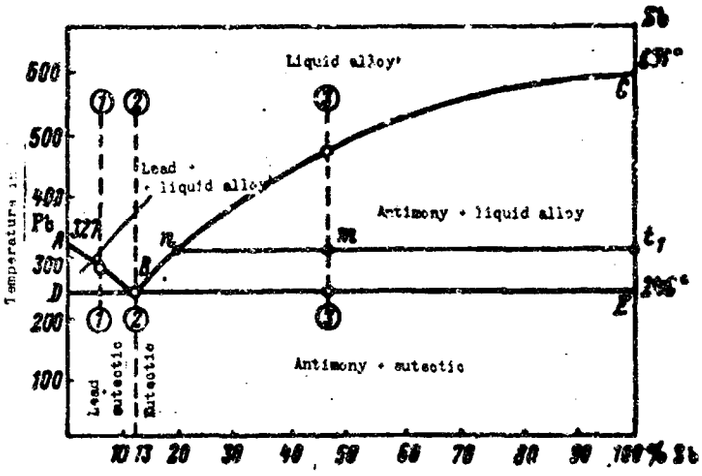


Fig. 5.5. Constitutional diagram of alloys of lead – antimony system.

Upper line ABC is called liquidus curve (from Latin "liquidus," meaning "liquid"). Lower line DE is called solidus ("solidus" means "hard"). Above liquidus alloys are in liquid state and below solidus they are in solid state.

At point B for content of 13% Sb and 87% Pb at a temperature of 246°C crystallization of lead and antimony occurs simultaneously; there forms a special mechanical mixture of crystals of lead and antimony. This mixture is called eutectic and alloy of corresponding composition is called eutectic alloy (alloy 2-2 in Fig. 5.5). Eutectic alloy has the lowest melting point of all alloys of given system.

Microstructure of lead – antimony eutectic alloy is shown in Fig. 5.6c.

Alloys containing less than 13% antimony (left of B) are called hypoeutectic (for instance, alloy 1-1 in Fig. 5.5). For them on line AB from liquid crystals of lead start to separate until liquid part of alloy is impoverished of lead to 87%. On line DE it is crystallized with formation of eutectic. After crystallization of

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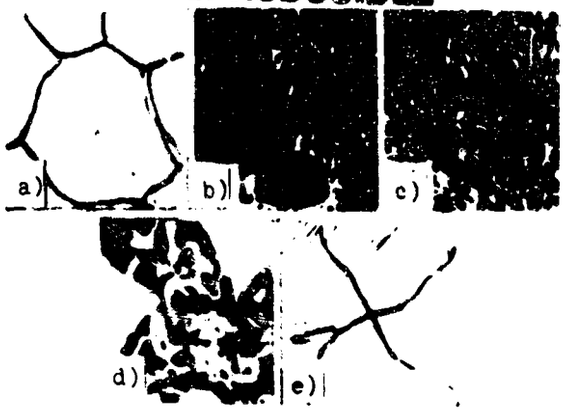


Fig. 5.6. Microstructures of lead – antimony alloys, ×200. a) pure lead, b) hypoeutectic alloy, c) eutectic alloy, d) hypereutectic alloy, e) pure antimony.

hypoeutectic alloys, they have structure consisting of eutectic and excess lead. In Fig. 5.6b is represented structure of hypoeutectic alloy (dark grains of lead and eutectic between them).

Alloys containing more than 13% antimony (right of point B) are called hypereutectic (for instance, alloy 3-3 in Fig. 5.5). Crystallization of hypereutectic alloys begins on line BC with separation of excess antimony, and on line DE occurs hardening of eutectic. After hardening of hypereutectic alloys, they have structure consisting of eutectic and excess antimony. In Fig. 5.6d is represented structure of hypereutectic alloy (light grains of antimony and eutectic between them).

Structure of pure lead is represented in Fig. 5.6a and that of pure antimony in Fig. 5.6e.

For determination of quantity of liquid and solid phase of alloy at given temperature we use "rule of lever." According to this rule, ratio of quantity of liquid phase to quantity of solid is proportional to the ratio of segments opposite them. If we consider this relationship on diagram (see Fig. 5.5, alloy 3-3 at point m) at temperature t_1, it will take form

$$\frac{\text{quantity of liquid solution}}{\text{quantity of antimony crystals}} = \frac{mt_1}{nm}.$$

If in alloys forming mechanical mixture during crystallization, components of which differ in specific gravity, we decrease cooling rate, crystals of separated excess component will not be evenly distributed in liquid alloy. Heavier crystals will be precipitated on bottom of casting mould or form. In this case up to moment of full crystallization, when liquid solution forms eutectic, the latter will be chiefly above and crystals of heavier excess component chiefly below. As a result, chemical composition of ingot or casting will be nonuniform.

Thus, in hypoeutectic alloys crystals of lead can settle on bottom of form, and

in hypereutectic alloys lighter antimony can surface. Such chemical heterogeneity is called liquation.

From constitutional diagram one can determine inclination of alloys of given system to liquation. The less the distance between liquidus and solidus on constitutional diagram the less the inclination of alloys of given system to liquation.

§ 4. Constitutional Diagram of Type II

Constitutional diagram of type II characterizes alloys whose component possess full mutual solubility both in liquid and in solid state, i.e., are able to form solid solutions of unlimited solubility.

In accordance with this constitutional diagram are crystallized the following alloys: bismuth – antimony, copper – nickel, iron – nickel, iron – chromium, iron – vanadium, and others.

In Fig. 5.7 is depicted constitutional diagram of bismuth – antimony alloys.

Through critical points of beginning and end of hardening of alloys of different concentration of bismuth and antimony are drawn curves ACB and ADB. The first of them is liquidus and second is solidus.

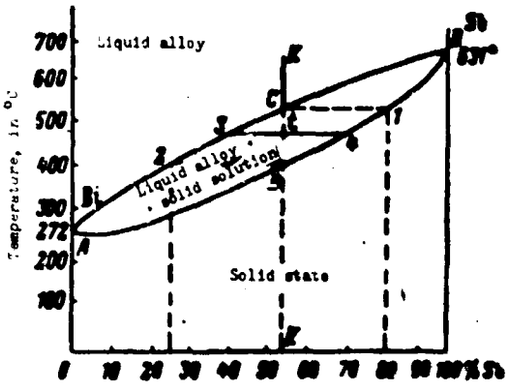


Fig. 5.7. Constitutional diagram of alloys of bismuth – antimony system.

On constitutional diagram are three regions: region of liquid alloy (above liquidus ACB), region of uniform solid solution (below solidus ADB), and region where alloy consists of liquid and crystals of solid bismuth – antimony solution (between liquidus ACB and solidus ADB).

During hardening of alloys in accordance with constitutional diagram of type II, composition of crystals of solid solution and composition of liquid phase continuously change. During hardening of any alloy, in process of crystallization grains of solid solution enriched by more refractory component are separated.

Let us consider process of hardening of alloy containing K% antimony. Point C on liquidus corresponds to temperature of beginning of crystallization of given

alloy. Above point C alloy is in liquid state. At point C crystallization of alloy starts. Grains are formed of solid bismuth – antimony solution. These crystals are of variable composition, changing along line 1-D. Concentration of liquid alloy changes along line C-2. At point D crystallization of alloy is completed.

Composition of phases in process of hardening is determined by intersection points of horizontal with liquidus and solidus lines. At temperature t composition of liquid phase is determined by projection of point 3, lying on liquidus, and composition of solid phase is determined by projection of point 4, lying on solidus.

Relationship between quantity of liquid alloy and quantity of crystals of solid solution, according to rule of the lever, is determined by ratio t4/t3.



Fig. 5.8. Microstructure of bismuth – antimony alloys. ·300. a) pure bismuth, b) uniform bismuth – antimony solid solution, c) nonuniform bismuth – antimony solid solution, d – pure antimony.

By determining composition of phases at different temperatures in process of hardening one can see that first crystals of solid solution are enriched by refractory component (antimony) and that with lowering of temperature both liquid and solid solutions are enriched by fusible component (bismuth).

Toward the end of hardening crystals of solid solution have to be uniform, i.e., have identical chemical composition, corresponding to initial composition (Fig. 5.8b). Levelling of composition occurs by means of diffusion. During slow cooling the process of diffusion succeeds in completion. Under conditions of fast cooling diffusion does not succeed in levelling composition of separate crystals and central part of dendrites will be richer in refractory component and periphery richer in fusible component (Fig. 5.8c). Such chemical heterogeneity, observed in different places of dendrites, is called dendritic liquation. Structure of pure bismuth is represented in Fig. 5.8d.

§ 5. Constitutional Diagram Type III

Constitutional diagram of type III characterizes alloys whose components possess unlimited solubility in liquid state and limited solubility in solid state, i.e.,

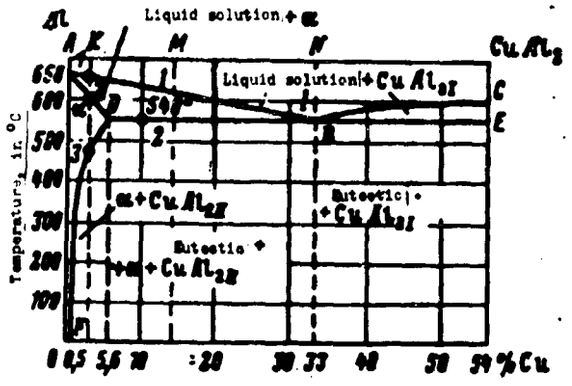


Fig. 5.9. Constitutional diagram of aluminum – copper alloys.

form solid solutions of limited solubility, decreasing with lowering of temperature.

Such diagram characterizes hardening of alloys of systems aluminum – copper, aluminum – silicon, copper – silver, and others.

In Fig. 5.9 is given constitutional diagram of Al – $CuAl_2$, of presenting part of Al – Cu diagram.

Line ABC is liquidus curve; above this line all alloys are in liquid state. Line ADBE is solidus.

In aluminum – copper solid state form solid solutions of limited solubility. Maximum concentration of solution of copper in aluminum is 5.6% at a temperature of 548° (point D). With higher concentration along line DBE is formed eutectic consisting of solid solution and chemical compound.

Curve DF is line of maximum solubility of copper in aluminum. It shows that with cooling of allcys below line of eutectic (DBE), solubility of copper in aluminum drops and at room temperature is 0.5% (point F).

All alloys of system Al – $CuAl_2$, according to copper content, may be subdivided into the following groups: from 0 to 5.6% alloys without eutectic, from 5.6 to 33% hypoeutectic alloys, 33% contains eutectic alloy, and from 33 to 54% hypereutectic alloys.

Let us trace crystallization of alloy without eutictic K, hypoeutectic alloy M, and eutectic alloy N.

Alloy K above point 1 is in liquid state. At temperature 1 crystallization starts and crystals of solid solution a are separated. At temperature 2 crystallization is finished and formed crystals of solid solution a undergo no changes to point 3. Owing to the fact that solubility of copper in aluminum changes along line DF, below point 3 solid solution a turns out to be oversaturated by copper, i.e., contains more copper than can be in solid solution at these temperatures. This excess part will be separated from solid solution in the form of secondary crystals of chemical compound $CuAl_2$.

By secondary crystals are understood those separated from solid solution (they are designated by index II) in distinction from primary crystals separated from liquid (they are designated by index I). Singling out of crystals of $CuAl_{2II}$ will continue to full cooling, when solid solution takes composition corresponding to point F. Final structure of alloy will consist of crystals of solid solution α and chemical compound $CuAl_{2II}$ (Fig. 5.10b).

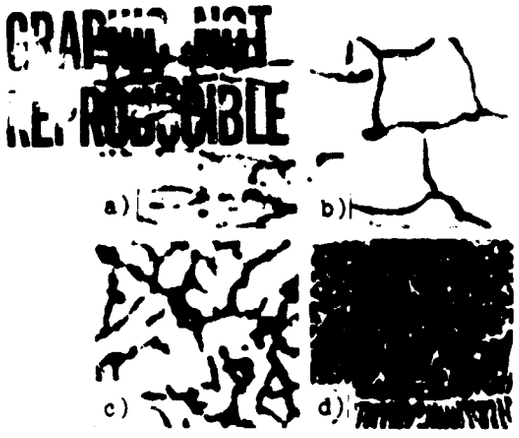


Fig. 5.10. Microstructures of aluminum – copper alloys. ×200. a) pure aluminum, b) alloy without eutectic, c) hypoeutectic alloy, d) eutectic alloy.

Alloy M at temperature 1 starts to crystallize, grains of solid solution α are separated. At eutectic temperature 2 liquid part of alloy takes composition corresponding to point B. Hardening will occur with formation of eutectic, consisting of mixture of crystals of solid solution α of composition of point D and chemical compound $CuAl_2$. During further cooling of alloy from solid solution α will be separated excess crystals of $CuAl_{2II}$, as during cooling of alloy K below temperature 3. Final structure of alloy will consist of eutectic, crystals of solid solution α, and excess crystals of $CuAl_{2II}$ (see Fig. 5.10c). Alloy N above point 1 has liquid state. At temperature 1 will occur crystallization of alloy with formation of eutectic (see Fig. 5.10d). Structure of pure aluminum is presented in Fig. 5.10a.

§ 6. Constitutional Diagram of Type IV

Constitutional diagram of alloys type IV chracterizes alloys whose components are soluble without limit in liquid state, insoluble in solid state, and form stable chemical compound.

Constitutional diagram of type IV is shown in Fig. 5.11.

Vertical line CD on diagram corresponds to chemical compound A_mB_n, formed by components A and B. Point C corresponds to melting point of chemical compound A_mB_n and is called singular point.

On diagram are two eutectic points E_1 and E_2. Eutectic alloy E_1 constitutes mechanical mixture of crystals of A and chemical compound A_mB_n, and eutectic alloy E_2 is mechanical mixture of crystals of B and chemical compound A_mB_n. Crystallization

of alloys per this diagram occurs just as crystallization of alloys of type I, only in this case there forms a mechanical mixture not of components A and B but mechanical mixture of chemical compound A_mB_n and crystals of component A or B. Regions formed by diagram are characterized by following state and structure: region I – liquid alloy; region II – liquid alloy + crystals of A; region III and IV – liquid alloy + crystals of chemical compound A_mB_n; region V – liquid alloy + crystals of B; region VI – crystals of A + eutectic of composition of point E_1 (crystals of A + crystals of chemical compound A_mB_n); region VII – crystals of A_mB_n + eutectic (crystals of A + crystals of A_mB_n); region VIII – crystals of A_mB_n + eutectic (crystals of B + crystals of A_mB_n): region IX – crystals of B + eutectic (crystals of B + crystals of A_mB_n).

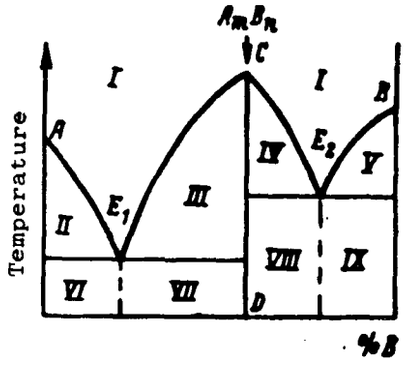


Fig. 5.11. Constitutional diagram in case of formation of chemical compound.

For chemical compound is characteristic strictly defined relationship between components and the circumstance that it is melted at constant temperature.

§ 7. Composition-Property Diagrams

During the analysis of constitutional diagrams it is important to study properties of alloys depending upon their composition. Method of construction of composition-property diagrams was developed by Academician N. S. Kurnakov, who discovered defined dependence between properties of alloys and constitutional diagram.

For construction of composition-property diagrams on axis of abscissas is plotted composition and on axis of ordinates are plotted values of properties measured at constant temperature (hardness, electrical conductivity, density, and others).

In Fig. 5.12 are given basic types of constitutional diagrams considered by us earlier and corresponding composition-property diagrams. Extreme ordinates on composition-property diagrams correspond to properties of pure components, and intermediate ordinates correspond to properties of alloys depending upon their composition.

During formation of mechanical mixtures properties of alloys are changed according to the law of straight line and values of properties of any of alloys are

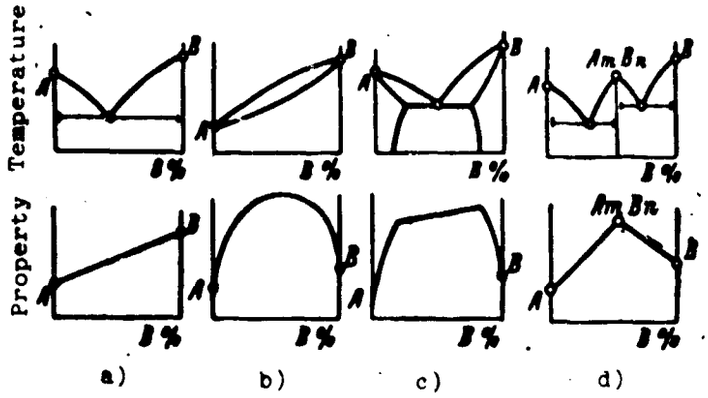


Fig. 5.12. Constitutional diagrams and corresponding composition-property diagrams.

within limits of properties of pure components (see Fig. 5.12a).

During formation of solid solutions properties of alloys are changed per curvilinear dependence, where certain properties can differ considerably from properties of components entering in alloy. Therefore during formation of solid solutions, or during their disintegration, sharp change of shown properties is observed (see Fig. 5.12b).

During formation of limited solid solutions properties are changed in accordance with belonging of some or other part of diagram to type I or II of diagrams.

Thus, properties in interval of concentrations, corresponding to solid solution, are changed per curvilinear dependence, and in region of mechanical mixtures are changed per rectilinear law (see Fig. 5.12c).

During formation of chemical compound properties of alloys are changed in the same way per rectilinear law, but with composition corresponding to chemical compound, on composition-property diagram is observed break of straight line with formation of maximum (see Fig. 5.12d).

Composition property diagrams have important value, since they permit one in practice to correctly approach selection of alloy for defined purposes. For example, alloys with high electrical resistance must be selected from solid solutions, those with high hardness must be found among alloys forming chemical compounds, etc.

C H A P T E R VI

PLASTIC DEFORMATION AND RECRYSTALLIZATION OF METALS

§ 1. Plastic Deformation

As was shown, metal in solid state is polycrystalline substance. It consists of large quantity of differently oriented grains of irregular shape (crystallites). Properties of polycrystals in many respects are determined by intrinsic properties of separate grains (single crystals).

Plastic deformation of single crystals. During loading of single crystal, in the beginning appear elastic deformations and elastic distortion of crystal lattice occurs. With increase of stress above defined value irreversible changes of crystal lattice of metal occur. For plastic (residual) deformation it is necessary to subject metal to stress which is greater than elastic limit. Plastic deformation of single crystal occurs by means of slip or twinning.

Slip (shift) consists in parallel displacement of separate parts of single crystal relatively to one another (Fig. 6.1). Slip or shift occurs on defined planes of crystal lattice, the most thickly studded with atoms (so-called glide planes).

Twinning consists in turn of part of crystal to another position symmetric with respect to first part with respect to plane called twinning plane (Fig. 6.2).

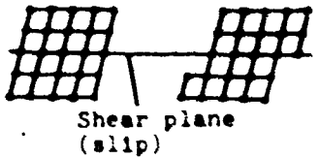


Fig. 6.1. Diagram of slip.

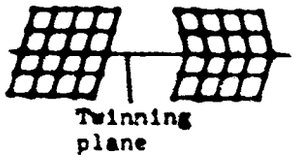


Fig. 6.2. Diagram of twinning.

In region of shift structure of metal sharply changes. In regions adjoining shear plane occurs distortion of crystal lattice. In the actual zone of shift occurs crushing or splitting

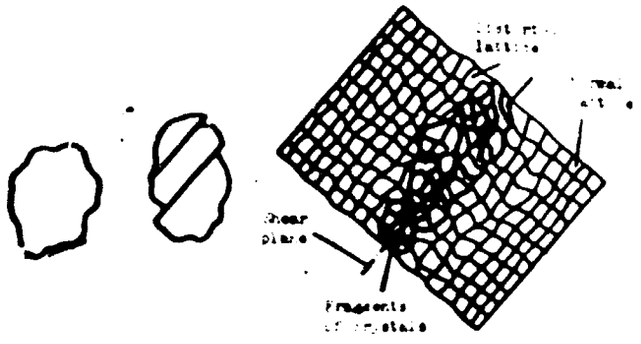


Fig. 6.3. Diagram of change of structure in zone of shear plane.

of grains. All this leads to hardening of metal. In Fig. 6.3 is given diagram of change of structure in zone of shear plane.

Plastic deformation of polycrystals. Plastic deformation of polycrystalline body is more complicated. In this case, besides slip and twinning of restricted variously oriented neighboring grains, there is observed intergranular shift.

In process of plastic deformation grains are crushed, extruded, and disposed in direction of deformation, forming fibrous structure (Fig. 6.4).

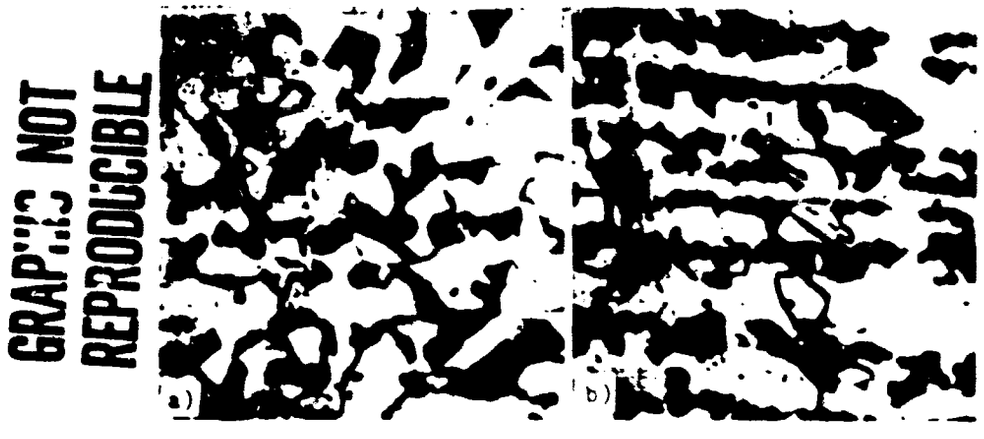


Fig. 6.4. Microstructure of steel. a) before cold deformation, b) after cold deformation.

Fibrous structure of metal is strengthened owing to the fact that impurities present in metal also are split, extruded, and disposed in boundaries of deformed grains.

Plastic deformation of metal in cold state strongly changes its mechanical properties: strength and hardness are increased, ductility and impact toughness drop.

Besides this, there is observed change of physical and chemical properties of metal: corrosion resistance decreases and electrical resistance and residual magnetism are increased.

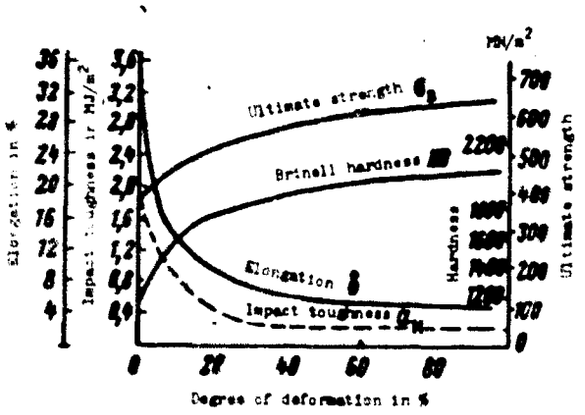


Fig. 6.5. Influence of cold deformation on mechanical properties of low-carbon steels.

Hardening of metal in process of plastic deformation is called cold working. Surface hardening of metal is called work hardening.

In Fig. 6.5 is shown change of mechanical properties of soft steel during cold rolling.

Preferable orientation of grains in work-hardened polycrystalline metal causes anisotropy of its properties. In most cases anisotropy of properties caused by cold treatment is undesirable, but in certain cases it is created intentionally (for instance, in transformer steel for improvement of magnetic properties).

§ 2. Recrystallization

Deformation, causing formation of internal stresses and distortion of crystal lattice, translates metal to unstable state.

Heating of cold-worked metal promotes its transition to stabler form. With heating of cold-deformed metal, in it consecutively occur processes leading to its softening.

During heating to low temperatures occurs recovery of metal. For instance, phenomenon of recovery for iron is observed during heating to temperature of 200-300°C. Recovery considerably lowers internal stresses and removes distortion in crystal lattice without change of microstructure. This leads to slight softening of metal (increase of plasticity and lowering of hardness and strength).

During heating to higher temperatures the process of recrystallization sets in, playing basic role in softening of metal. Recrystallization consists in appearance in deformed metal of centers of crystallization and growth around them of new equiaxial grains with undistorted crystal lattice. As a result of recrystallization there occurs restoration of microstructure, accompanied by full softening of metal (hardness and strength drop and plasticity is increased).

Recrystallization, or so-called recrystallization annealing, serves for removal

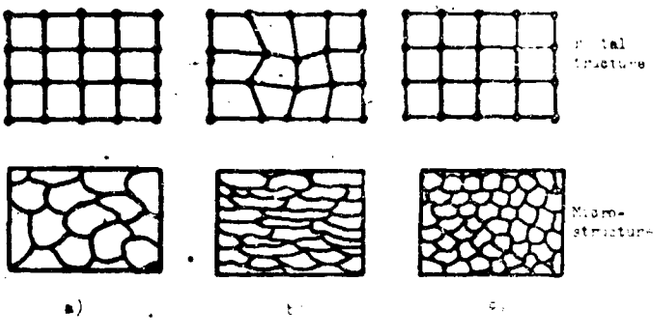


Fig. 6.6. Diagram of change of structure of metal during deformation and recrystallization. a) before deformation, b) plastically deformed metal, c) after recrystallization.

of cold working of metal after cold treatment by pressure.

In Fig. 6.6 are shown schematically changes of structure of metal as a result of plastic deformation and recrystallization.

Distortion of crystal lattice in process of plastic deformation can be detected with help of X-ray diffraction analysis. It is possible to observe deformation of grains and crushing of them after recrystallization under microscope.

Temperature at which new equiaxial grains start to appear is called recrystallization temperature. According to Academician A. A. Bochvar, for every metal there exists a unique recrystallization temperature, constituting 0.4 absolute melting point: $T_{рекр.} \approx 0.4\ T_{пл}$.

Using this formula, one can determine recrystallization temperature of different metals and alloys. For iron and steel this is approximately 450°C, for copper 280°C, brass 250°C, aluminum 100°C, lead 30°C. Temperature interval of recrystallization annealing for iron and steel is 600-700°C, for copper and brass 400-500°C.

Magnitude of grain obtained during recrystallization depends on temperature of heating of deformed metal and on degree of its deformation. With increase of temperature of recrystallization annealing, dimension of newly formed grains is increased. In still greater degree growth of grain depends on degree of deformation (Fig. 6.7).

Degree of deformation giving maximum dimension of grain during heating is called critical.

For more full characteristic there frequently are constructed three-dimensional diagrams of recrystallization, allowing one to judge growth of grains depending upon deformation and temperature (Fig. 6.8).

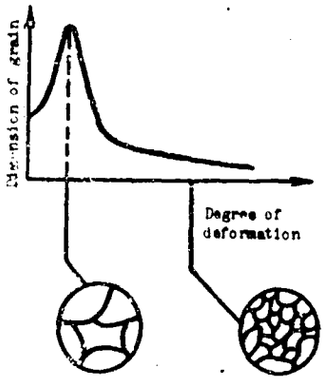


Fig. 6.7. Change of magnitude of grain depending upon degree of plastic deformation.

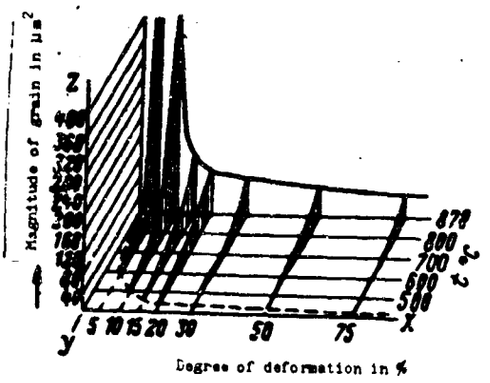


Fig. 6.8. Diagram of recrystallization of soft steel.

Recrystallization has great practical value in technology of treatment of metals and in all cases which are connected with mechanical softening of metal.

C H A P T E R VII

IRON – CARBIDE ALLOYS

Alloys of iron with carbon are the most important technical alloys applied in contemporary technology. To iron-carbide alloys pertain steel and cast iron. Iron-carbide alloys containing up to 2% carbon are called steels and those containing more than 2% carbon (practically from 2.5 to 4.5%) are cast irons.

Cast irons are obtained from iron ores in blast furnaces, and steel are obtained from steelmaking cast iron in open-hearth converters or electric furnaces.

Our country in reserves of iron ores occupies first place in world. Production of metals is growing from year to year at such a tempo as unknown in any capitalistic country. Control figures on development of People's economy of USSR for seven-year plan note high rate of growth of production of ferrous and nonferrous metals. In USSR in 1961 cast-iron production reached 51.5 million tons, that of steel 71.0 million tons. In 1965 was proposed the casting of 65-70 million tons of cast iron and 86-91 million tons of steel. According to directives of XXII congress of CPSU, in 1980 there should be smelted 250 million tons of steel.

§ 1. Components of Iron – Carbide Alloys

Components of iron – carbide alloys are iron and carbon. The purest iron obtained at present for technical purposes contains up to 0.15% impurities: sulfur, phosphorus, manganese, silicon, carbon, and others. This iron is called technical iron. For scientific purposes can be obtained iron of higher purity, containing total of 0.01% impurities.

Technical iron possesses specific gravity of 78.9 kN/m^3 (7.89 gf/cm^3) and

melting point of 1539°C. Iron pertains to number of metals resistant to atmospheric corrosion; in humid medium it corrodes.

Technical iron is characterized by good technological properties: it is easily forged, rolled in cold and hot states, has high ductility, and allows deep stamping. It welds well by gas and electric welding.

Technical iron possesses low ultimate strength [σ_B = 250-300 MN/m^2 (25-30 kgf/mm^2)], low hardness [HB = 500-700 MN/m^2 (50-70 kgf/mm^2)], and very high elongation per unit length (δ = 30-50%). Owing to low mechanical properties, technical iron in aircraft construction is not applied in practice.

Very important property of iron is polymorphism (allotropy). By thermal and X-ray diffraction analysis it has been established that iron has two modifications, differing from each other in crystal structure and properties. Let us trace allotropic transformations of iron on curve of cooling (Fig. 7.1).

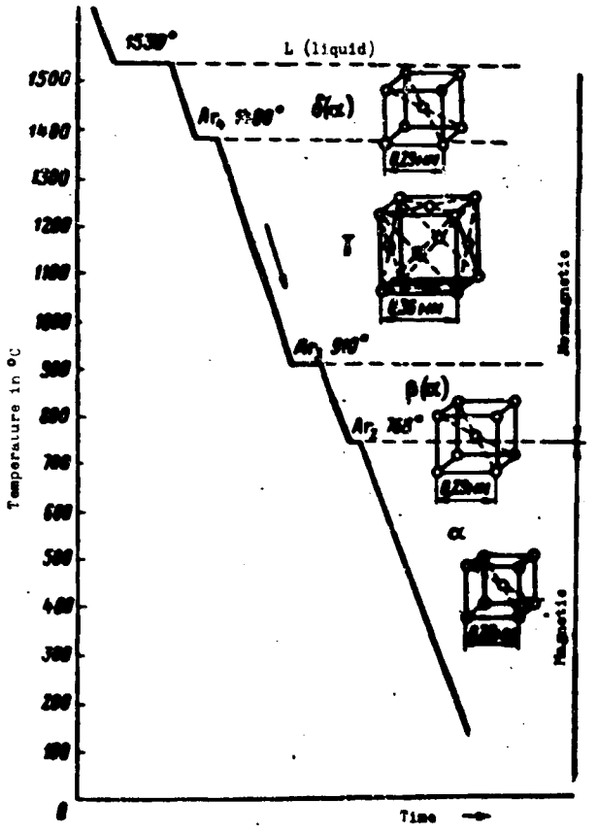


Fig. 7.1. Curve of cooling of iron.

Critical points of iron are designated by letter A, where during cooling to it is added letter r and during heating the letter c. For distinction of critical points from each other are introduced indices: "1," "2," "3," "4,", i.e., during heating these are points Ac_1, Ac_2, Ac_3, Ac_4, and during cooling respectively Ar_1, Ar_2, Ar_3, Ar_4.

Stop on curves of cooling and heating is observed at temperature of 1539°C and corresponds to temperature of hardening and fusion of pure iron. After hardening iron is in the form of modification δ, having crystal structure of body-centered cube with lattice parameter equal to 0.29 Nm. Further cooling of iron to temperature of 1400°C (point Ar_4) leads to formation of new modification, γ-iron, having crystal structure of cube with centered

edges and lattice parameter equal to 0.36 Nm. Modification γ-iron exists to temperature of 910°C, at which it passes to nonmagnetic modification, β-iron, with crystal lattice of body-centered cube and lattice parameter equal to 0.29 Nm. At temperature of 768°C (Curie point Ar_2) nonmagnetic β-iron passes to ferromagnetic α-iron, also having crystal structure of body-centered cube with lattice parameter equal to 0.28 Nm. Critical point Ar_1 or Ac_1 corresponds to temperature of 723°C; this transformation is accomplished only in alloys of iron with carbon; in pure iron it is absent.

Since α-, β-, and δ-iron have the same crystal lattice of body-centered cube, it is customarily considered that iron has only two modifications

to 910° and from 1400 to 1539°.....α-iron
from 910 to 1400°.....γ-iron

and not four as considered earlier.

When iron is heated from room temperature to melting point, transformations occur in reverse sequence. Here critical point of transformation α → β is designated Ac_2, β → γ, Ac_3, and γ → δ, Ac_4.

The most important is transformation α ⇄ γ and connected change of properties, since at room temperatures in structure of steel is solid solution based on α-iron, and for majority of forms of hot technological processes heating is produced to structure of solid solution on the basis of γ-iron. Iron of α and γ types have various specific gravity, densities, magnetic, and other physical properties. Solubility of carbon in these modifications of iron also is different. Solubility of carbon in γ-iron exceeds by 100 times maximum solubility of carbon in α-iron, which is used during heat and chemical-heat treatment of steel.

Second component of iron-carbide alloys is carbon. Two of its modifications are known: diamond and graphite. In iron-carbide alloys carbon is present either in the form of graphite or in the form of chemical compound with iron Fe_3C.

§ 2. Structural Components of Iron-Carbide Alloys

Depending upon temperature and content of carbon, iron-carbide alloys can have following structural components: ferrite, cementite, austenite, perlite, ledeburite, and graphite.

Ferrite constitutes solid solution of introduction of carbon in α-iron.

Solubility of carbon in α-iron at normal temperature is 0.006%, and at 723°C is 0.02%. Therefore ferrite may be considered in practice pure iron. Ferrite has body-centered cubic lattice and is characterized by insignificant values of hardness and strength but high ductility.

[σ_B = 250 MN/m^2 (25 kgf/mm^2), δ = 50%, HB = 800 MN/m^2 (80 kgf/mm^2)].

Microstructure of ferrite is presented in Fig. 7.2a. To 768°C it is ferromagnet and above that paramagnetic.

Cementite constitutes chemical compound of iron with carbon, i.e., iron carbide Fe_3C. Cementite contains 6.67% carbon, is very hard, and is brittle (HB ≈ 8000 MN/m^2 [800 kgf/mm^2], a_H is close to zero). Cementite has complicated crystal lattice. To 210°C it is ferromagnet and above is paramagnetic. Cementite is present in structure of iron-carbide alloys in different forms: in steel in the form of lattice on grain boundaries (see Fig. 7.2b); in cast iron in the form of needles, in form of separate light bodies and grains (see Fig. 7.2c).

Austenite is solid solution of introduction of carbon in γ-iron.

Maximum concentration of carbon in austenite is 2.0% at 1130°C. With lowering of temperature solubility of carbon in austenite decreases, and at 723°C it attains 0.80%.

Austenite has face-centered cubic lattice. It is characterized by low strength, hardness, and high ductility [δ = 40-50%, HB = 1600-2000 MN/m^2 (160-200 kgf/mm^2)]. Austenite is paramagnetic. Its microsturcture consists of light grains with characteristic double lines (see Fig. 7.2d).

Perlite is mechanical mixture of ferrite and cementite, the product of disintegration of slowly cooled austenite. Concentration of carbon in perlite is 0.8%. Temperature of formation of perlite is 723°C. Perlite can have laminar or granular structure if cementite has form of plates (see Fig. 7.2e) or grains (see Fig. 7.2f).

Mechanical properties of perlite depend on degree of fragmentation of particles of cementite – the bigger they are the lower the mechanical properties. For instance, laminar perlite has σ_B = 820 MN/m^2 (82 kgf/mm^2), δ = 15%, HB = 1900-2300 MN/m^2 (190-230 kgf/mm^2), and for granular perlite σ_B = 630 MN/m^2 (63 kgf/mm^2), δ = 20%, HB = 1600-1900 MN/m^2 (160-190 kgf/mm^2).

Ledeburite is mechanical mixture of austenite and cementite, formed during

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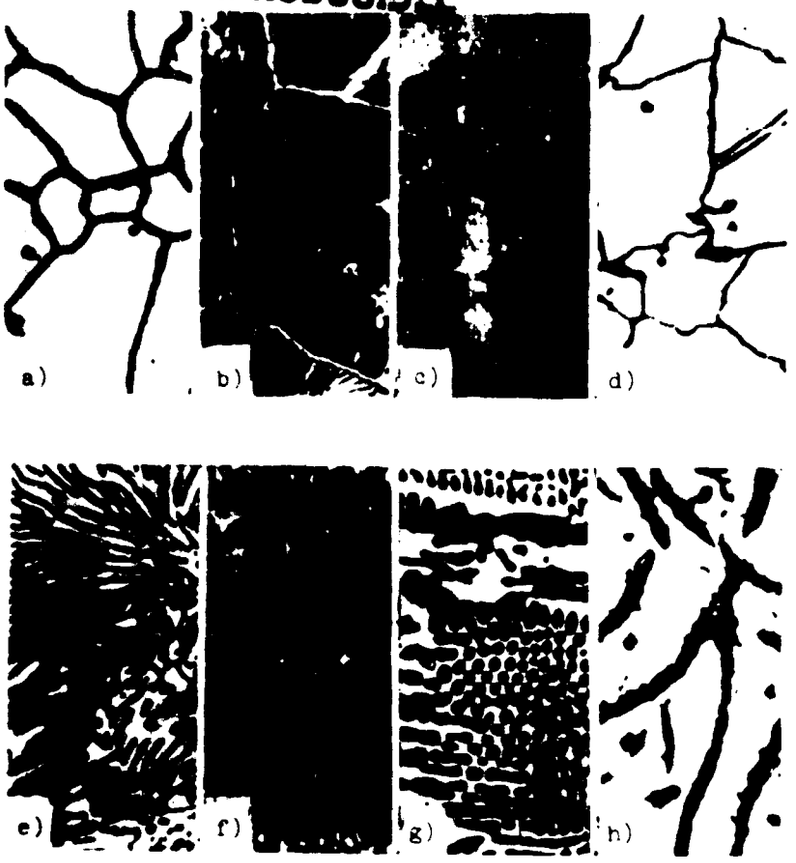


Fig. 7.2. Structural components of iron-carbide alloys. a) ferrite, ×300; b) thin light network of cementite against background of perlite, ×300; c) ledeburite and light particles of cementite, ×300; d) austenite ×250; e) laminar perlite, ×300; f) granular perlite, ×250; g) ledeburite, ×250; h) plate of graphite on light background of basic metal before etching, ×250.

crystallization of liquid alloy containing 4.3% C. At 723°C austenite is turned into perlite. This transformation occurs also with austenite entering into composition of ledeburite. Thus below 723°C ledeburite no longer constitutes mixture of austenite with cementite lent a mixture of perlite with cementite. In Fig. 7.2g is shown ledeburite, consisting of light cementite bases with dark round particles of perlite. Ledeburite is very hard [HB ≈ 700 (MPa)] and brittle. It is present in structure of white cast iron.

Graphite constitutes free carbon disposed in basic mass of metal. It is present in structure of cast iron (see Fig. 7.2h) and can have form of plates, flakes, or spherical particles of black color.

Mechanical properties of iron-carbide alloys are changed depending upon quantity of structural components, their form, quantity, and location.

§ 3. Constitutional Diagram of Iron – Carbon System

Constitutional diagram of alloys of iron – carbon system is plotted as a result of works of many scientists. Responsible for diagram is D. K. Chernov, who in 1868 first established critical points in steel.

Since carbon and iron form chemical compound Fe_3C (cememtite) or can be present in alloy in form of graphite, there exist two constitutional diagrams of alloys of iron and carbon: cementite and graphite. Cementite diagram, characterizing iron – cementite system, is metastable (since process of disintegration of Fe_3C is possible). Graphite diagram, chracterizing iron – graphite system, is stable.

Let us consider constitutional diagram of iron – cementite, which has large practical value.

First, diagram makes it possible to study structure of iron – carbide alloys and to grasp complicated processes occurring during their heating and cooling.

Secondly, it permits one to select optimum conditions of heat treatment steels and cast irons and to determine temperature limits of treatment by pressure.

Along the axis of abscissas of diagram is plotted content of carbon from 0 to 6.67% (corresponding to content of carbon in cementite); along the axis of ordinates is plotted temperature.

Alloys of iron with content of more than 6.67° carbon are not of interest, since alloys applied in technology contain no more than 5-6% carbon.

For simplicity of consideration of diagram we shall not consider its upper left corner, characterizing formation of solid solution δ. In Fig. 7.3 is represented constitutional diagram of iron – carbide alloys.

On diagram are the following characteristic points and lines. Point A (1539°C, 0% C) equals crystallization temperature of pure iron. Point D (~1550°C, 6.67% C) equals crystallization temperature of cementite. Line ACD (liquidus) characterizes beginning of crystallization of all alloys. Above this line all alloys are in liquid state.

During cooling alloys containing up to 4.3% carbon start to harden along line AC, separating crystals of austenite. Alloys containing more than 4.3% carbon start to harden along line CD, separating crystals of primary cementite Fe_3C_I. At point C (1130°C, 4.3% C) occurs simultaneous crystallization from liquid alloy of austenite and cementite, forming eutectic – ledeburite.

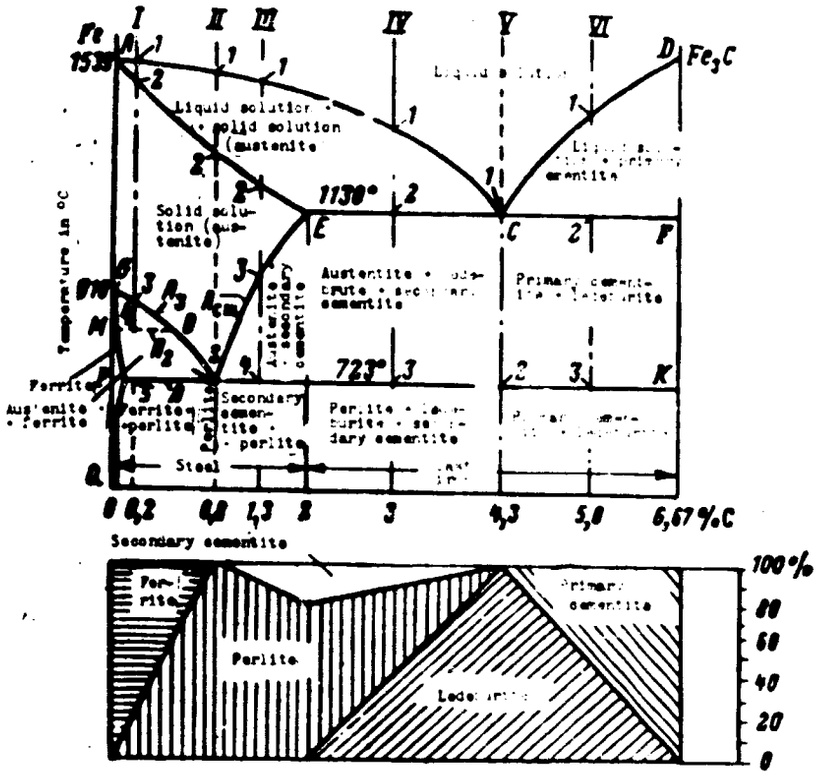


Fig. 7.3. Constitutional diagram of iron – carbon (cementite).

Point C is called eutectic point. Line AECF (solidus) characterizes end of crystallization of all alloys. Below this line all alloys are in solid state. Point G (910°C, 0% C) characterizes allotropic transformation of iron $\alpha \rightleftarrows \gamma$.

Line GOS characterizes beginning of transformation of austenite to ferrite.

Line GMP chracterizes end of transition of austenite to ferrite.

Line SE characterizes beginning of singling out of secondary cementite from austenite. Line MO characterizes appearance of magnetic properties for ferrite. Point E (1130°C, 2% C) characterizes the biggest quantity of carbon which can be dissolved in γ-iron. Line PSK characterizes disintegration of austenite with concentration of 0.8% carbon to eutectoid mixture of ferrite with cementite – perlite. Point S (723°C, 0.8% C) is called eutectoid or perlitic point. Line PQ characterizes beginning of singling out of tertiary cementite from ferrite.

In Fig. 7.4 is given diagram of division of alloys per iron – carbon constitutional diagram.

Transformations in iron – carbide alloys are explained by two processes:

1) primary crystallization (transformation from liquid state to solid);

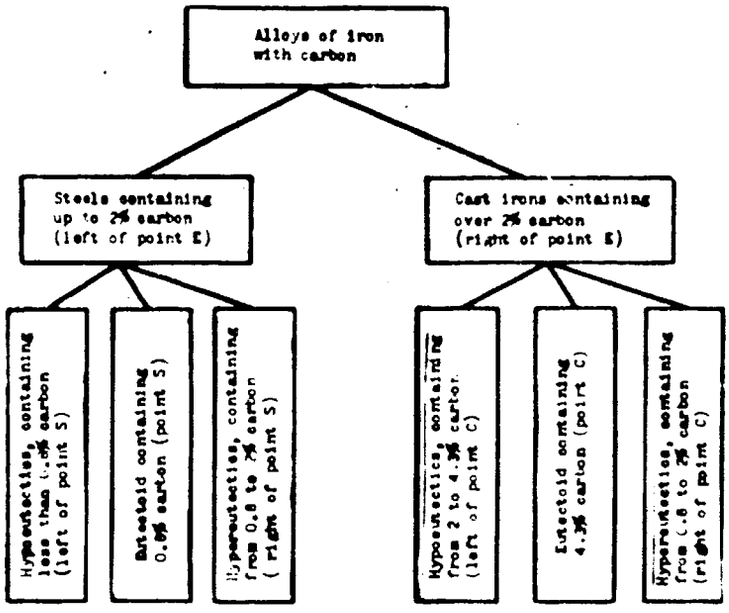


Fig. 7.4. Diagram of division of alloys per iron – carbon constitutional diagram.

2) secondary crystallization or recrystallization (transformation to solid state).

§ 4. Structures and Property Slowly Cooled Steels

For understanding mechanism of formation of structures of steel let us trace the process of slow cooling of hypoeutectoid, eutectoid, and hypereutectoid, steels.

Hypoeutectoid steel contains 0.2% carbon. Composition of this steel is marked on diagram by dotted line I (see Fig. 7.3). Above point 1, lying on liquidus, steel will be liquid. At point 1 starts crystallization of steel with formation of solid solution of austenite. At point 2, lying on solidus, crystallization of steel stops. During cooling, to point 3 no transformations in steel occur; it preserves structure of austenite.

Point 3 lies on line GOS, beginning of recrystallization $\alpha \rightarrow \gamma$. At this temperature austenite, containing 0.2% carbon, begins to turn to ferrite. Temperature of transformation of alloys on line GOS for brevity is designated A_3.

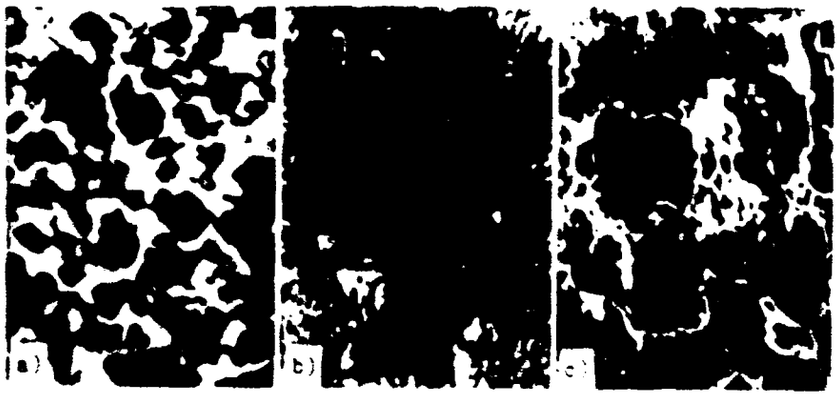
At point 4 at temperature of 768°C occurs magnetic transformation of ferrite: nonmagnetic ferrite becomes magnetic. Critical temperatures of transformation of alloys along line MO are designated A_2.

With lowering of temperature from point 1 to point 2 ferrite is separated ever faster, and at the same time austenite is enriched by carbon along line GS, striving to eutectoid composition (point S). Point S lies on line of eutectoid temperature of 723°C. Steel at this temperature consists of grains of ferrite and grains of austenite of eutectoid composition (0.8% carbon). At this temperature austenite disintegrates to ferrite-cementite mixture, i.e., to perlite. Below temperature of point 5 no transformations in steel occur and structure of this steel consists of grains of ferrite and perlite (Fig. 7.5 a).

Analogous transformations occur during slow cooling in all hypoeutectoid steels, but relationship between ferrite and perlite is changed. The more carbon in steel the more perlite and the less ferrite contained.

Eutectoid steel containing 0.8% carbon. Composition of this steels is marked on diagram by dotted line II (see Fig. 7.3).

At points 1 and 2 occur transformations of steel analogous to transformations of hypoeutectoid steel. As a result of hardening there forms austenite, stable to point 3. At point 3 (point S of diagram) occurs recrystallization of steel, as a result of which austenite is broken up completely into eutectoid mixture of ferrite and cementite, i.e., perlite. Below point 3 in steel no more transformations occur and it preserves structure of perlite to room temperature (see Fig. 7.5 b).



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Fig. 7.5. Microstructures of slowly cooled carbon steels. a) hypoeutectoid (0.2% C), ×250; b) eutectoid (0.8% C), ×300; c) hypereutectoid (1.2% C), ×[illegible]

Hypereutectoid steel containing 1.2% carbon. Composition of this steel is marked on diagram by dotted line III (see Fig. 7.3). At points 1 and 2 occur transformations analogous to transformations of eutectoid steels. At temperature

of point 3 starts crystallization of secondary cementite from austenite. Temperature of transformation along line SE is designated by A_{CT}. Separated cementite is disposed in boundaries of grains of austenite, forming network. Quantity of carbon in austenite between points 3 and 4 continuously decreases along line SE, striving to eutectoid composition (point S). At point 4 occurs disintegration of austenite to perlite. With further cooling of steel below 723°C no transformations occur. Final structure of hypereutectoid steels after slow cooling will consist of grains of perlite bordered by network of cementite (see Fig. 7.5c). Network of secondary cementite will be thicker the more carbon in steel (see Fig. 7.3).

§ 5. Structure and Properties of Slowly Cooled Cast Iron

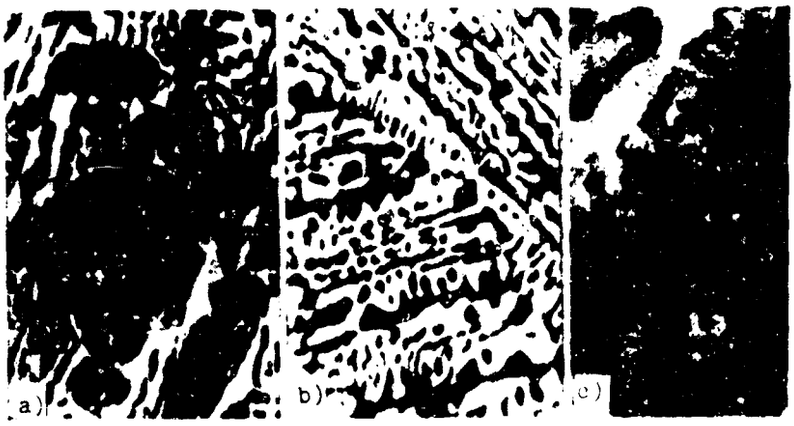
For understanding mechanism of formation of structures of cast iron let us trace process of slow cooling of hypoeutectic, eutectic, and hypereutectic cast iron.

Hypoeutectic cast iron containing 3% carbon. Composition of this cast iron is marked on diagram by dotted line IV (see Fig. 7.3). Crystallization of alloy starts at point 1 with formation of crystals of austenite, quantity of which is increased with cooling of alloy. During cooling between points 1 and 2, concentration of carbon in liquid alloy is increased to eutectic composition of 4.3% (point C). At point 2 at a temperature of 1130°C occurs final hardening of cast iron. Here, remaining quantity of liquid alloy is turned into eutectic mixture – ledeburite. Ledeburite consists of crystals of austenite containing 2% carbon and crystals of cementite. Below point 2 structure of alloy consists of austenite and ledeburite. With further lowering of temperature, owing to decreasing solubility of carbon in austenite, secondary cementite is separated, quantity of which is increased with lowering of temperature. At points 3 at temperature of 723°C remaining austenite with concentration of 0.8% C (corresponding to point S) is broken up into perlite.

Thus, structure of hypoeutectic cast iron after slow cooling consists of perlite, secondary cementite, and sections of ledeburite (Fig. 7.6a). Ledeburite at room temperature consists of cementite and disintegrating austenite (perlite).

Eutectic cast iron containing 4.3% carbon. Composition of this alloy is marked on diagram by dotted line V (see Fig. 7.3). At point 1 liquid alloy at a temperature of 1130°C (point C) hardens completely with formation of eutectic – ledeburite. Between points 1 and 2 from austenite entering in composition of ledeburite

is separated secondary cementite. Here, [illegible] of carbon in austenite decreases to 0.8% (in accordance with line [illegible]). At point [illegible] temperature of 723°C austenite entering in composition of ledeburite is turned into perlite. Below point 2 eutectic cast iron consists of ledeburite and [illegible] cementite (see Fig. 7.6b).



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Fig. 7.6. Microstructure of white cast iron, ×250. a) hypoeutectic (3.0% C), b) eutectic (4.3% C), c) hypereutectic (5.0% C).

Hypereutectic cast iron containing 5% carbon. Composition of this alloy is marked on diagram by dotted line VI (see Fig. 7.3). At point 1 starts crystallization of cementite (for distinction from cementite separated from austenite along the line SE it is called primary). Between points 1 and 2 crystals of cementite grow and liquid cast iron is impoverisned of carbon to eutectic composition (4.3% C).

At point 2 (1130°C) occurs full hardening of cast iron with formation of eutectic – ledeburite. After hardening, structure of hypereutectic cast iron consists of crystals of primary cementite and ledeburite. Further, between points 2 and 3 occurs singling out of secondary cementite from austenite entering in composition ledeburite. At point 3 (723°C) this austenite is turned into perlite. Thus structure of hypereutectic cast iron consists of primary cementite and ledeburite (see Fig. 7.6c).

C H A P T E R VIII

HEAT TREATMENT OF STEEL

Heat treatment is technological process of hot processing of metals and alloys as a result of which occurs change of internal structure of mechanical, physical and physicochemical properties.

Heat treatment depends on temperature of heating, duration of holding at given temperature, rate of heating, and rate of cooling. By changing these parameters it is possible with the same chemical composition of alloy to obtain different structure, and this means different properties. Therefore heat treatment is widespread and important technological process for improvement of exploitational characteristics of majority of parts and tools.

Basic forms of heat treatment steel are: annealing, normalization, hardening, tempering.

Annealing and normalization pertain to preliminary heat treatment and hardening and tempering – to final heat treatment. Purpose of preliminary heat treatment consists of crushing of grain of steel, destruction of internal stresses, increase of ductility, and lowering of hardness. To preliminary heat treatment are subjected half-finished products (stampings, forgings, and so forth) for improvement of workability ir process of manufacture of part. To final heat treatment are subjected finished parts and tools for imparting to them required properties, depending upon conditions of work.

§ 1. Bases of Heat Treatment of Steel

Heat treatment of steel is based on phenomena of recrystallization (secondary crystallization), occurring at temperatures corresponding to lines GOS (A_3), Se (A_{CT})

and PSK (A_1) of iron – carbon constitutional diagram. Obligatory for all forms of heat treatment are heating of alloy to defined temperature, holding at this temperature, and subsequent cooling at defined rate.

Transformations in steel during heating. Heating of steel and holding at given temperature, which are done during heat treatment, in most cases are for the purpose of obtaining structure of austenite. Before heating hypoeutectoid steels have structure of perlite and ferrite, eutectoid steels have that of perlite, and hypereutectoid steels have that of perlite and cementite. During heating of these steels to temperatures not exceeding 723°C (line PSK, point Ac_1, see Fig. 7.2), in their structure no changes occur. During heating above point Ac_I in steel occurs perlitic-austenitic transformation. This transformation consists of several simultaneously occurring processes: allotropic transformation of α-iron to γ-iron, dissolution of cementite to austenite, and diffusion of ions of carbon from cementite to austenite, and diffusion of ions of carbon from cementite grains in depth of austenite.

With further increase of temperature in eutectoid steel no changes occur and structure of steel constitutes solid solution – austenite.

With increase of temperature of heating to point Ac_3, in hypoeutectoid steels occurs process of transformation of ferrite to austenite, and in hypereutectoid steels to point A_{CT} takes place process of dissolution of secondary cementite to austenite. Upon achievement of shown temperatures process of transformation of ferrite to austenite and process of dissolution of cementite in austenite are completed.

After that, in steel takes place diffusion process of levelling of chemical composition of austenite, caused by different concentration of carbon both in separate grains and between grains.

For production of uniform austenite there is needed holding for defined time at these temperatures.

The process of transformation during heat treatment is influenced by temperature of heating and composition of steel. The more the temperature of steel is above critical level the less time necessary for completion of process. Increase of content of carbon in steel leads to acceleration of transformation.

After termination of transformations, steel obtains fine-grained structure.

Increase of temperature of heating above that shown or increase of time of holding can lead to unnecessary growth of grains of austenite. This phenomenon is undesirable, since grain size of austenite renders large influence on behavior of steel during heat treatment and mechanical properties obtained after it.

Increase of dimension of grain during heating occurs differently for different steels. We distinguish real and hereditary grains of austenite. Grain which is obtained as a result of given heating and which is observed directly under microscope is called real. Dimension of real grain depends on temperature of heating of steel. By hereditary grain in understood inclination of austenite to grain growth. Steel in which growth of grain starts with slight overheating above critical points are called hereditary coarse-grained. Steels in which grain growth starts only at considerable overheating above critical points are called hereditary fine-grained. Since size of real grain is determined mainly by temperature of heating and not size of natural grain, by changing conditions of heat treatment it is possible to correct initial coarse grain of steel. Grain size in steel is determined under microscope with magnification of 100 by means of comparison of grains visible on slide with standard dimensions. These dimensions are shown in Fig. 8.1, where figures 1, 2, 3, etc. signify number of grain. Steels with numbers 1-5 belong to coarse-grained group, those with numbers 6-8 are fine-grained. Size of real grain of austenite affects certain properties of steel. The finer the grain of austenite the greater the impact toughness of steel, the less the hardenability, the worse the machinability and others.

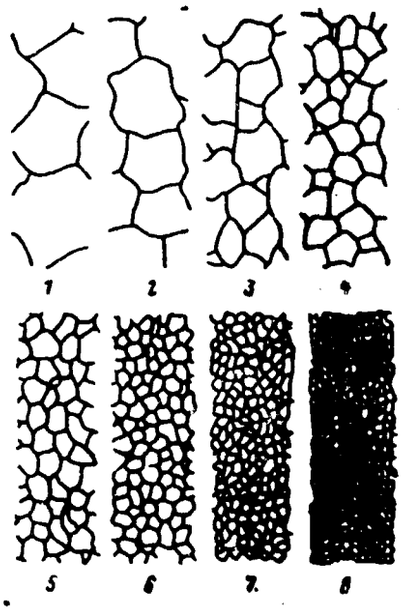


Fig. 8.1. Standard scale for appraisal of size grain of steel, ×100.

Hardness, ultimate strength, yield point, elongation per unit length, and certain other properties of steel almost do not depend on grain size of austenite.

Size of hereditary grain determines technological process of treatment of steel. Hereditary coarse-grained steel is more sensitive to overheating than steel hereditary fine-grained.

Structures and properties of fast-cooled steels. During cooling of steel from region of austenite there

occurs allotropic transformation of γ-iron to α-iron and disintegration of austenite.

Slow cooling of carbon steels causes disintegration of austenite with formation of ferrite-cementite mixture. This transformation consists of two stages: allotropic transformation of γ → α and diffusion of atoms of carbon with formation of cementite. Reconstruction of γ-lattice to α-lattice occurs instantaneously. Formation of plates of cementite occurs gradually: in the beginning are formed small particles of cementite, which then are increased and are turned into larger particles. Structures and corresponding properties of steel obtained here correspond to equilibrium state.

If, however, rate of cooling of steel is increased, temperature of austenitic-perlitic transformation drops more the higher the rate of cooling. Here are formed products of disintegration of austenite, differing in nature and properties from those which appear during slow cooling.

Depending upon rate of cooling of austenite, there forms one (or combination) of the following structures: martensite, troostite, sorbite (Fig. 8.2). Formation of these structures leads steel to unbalanced state and changes its properties.

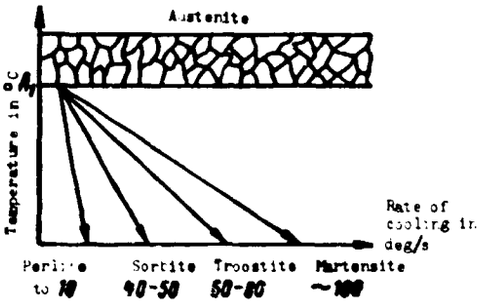


Fig. 8.2. Influence of rate of cooling on structure of steel.

Martensite – initial stage of disintegration of austenite – constitutes solid solution of carbon in α-iron. This structure can be obtained in steel during its cooling at rate of 180°C and more per second (see Fig. 8.2). Martensite contains as much carbon as was contained in initial austenite. Transformation of austenite to martensite leads only to change of form of lattice of solid solution, without its disintegration. At higher rates of cooling of austenite crystal lattice of γ-iron is reconstructed to crystal lattice of α-iron but carbon does not succeed in emerging from it. Carbon in lattice of α-iron in the same quantity as in initial austenite strongly distorts it, since α-iron in practice does not dissolve carbon. Therefore martensite possesses raised strength, hardness, and brittleness. Martensite is magnet and is distinguished by acicular structure (Fig. 8.3a). By nature it is unstable and capable of spontaneous disintegration, especially at raised temperatures.

Martensite has not cubic lattice, like α-iron, but tetragonal (Fig. 8.4a). This lattice can be obtained from that of α-iron if in one direction cubic cells are compressed and in the other are expanded. Degree of tetragonality of lattice, measured by ratio of height of cell to length of one of sides of base (c/a), is

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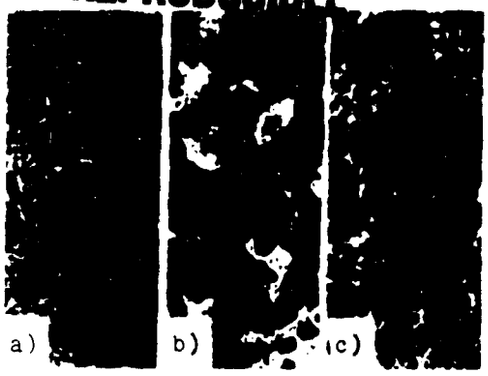


Fig. 8.3. Structures of fast-cooled steels, ×300. a) martensite; b) martensite + troostite (dark); c) sorbite.

greater than unity. Degree of tetragonality of martensite increases with increase of content of carbon in steel (see Fig. 8.4b).

Troostite – further stage of disintegration of austenite beyond martensite – constitutes mixture of ferrite and cementite of very high fineness (see Fig. 8.3b). This structure can be obtained during cooling steel at rate of 60-80°C per sec (see Fig. 8.2). Besides this, troostite structure can be obtained as a result of disintegration of martensite during its heating to temperature of 400-500°C. Troostite possesses lower hardness and higher toughness than martensite. Troostite also is unstable and capable under certain conditions of disintegration.

Sorbite – following stage, after troostite, of disintegration of austenite – constitutes fine-grained mixture of ferrite and cementite (see Fig. 8.3c). This structure can be obtained during cooling of steel at rate of 40-50°C per sec (see Fig. 8.2). Besides this, sorbite structure can be obtained as a result of disintegration of martensite or troostite during their heating to temperatures of 550-650°C. Sorbite in equilibrium state is close to perlite but has larger degree of crushing of particles. Sorbite has hardness close to that of perlite but is tougher and more elastic.

Consequently, perlite, sorbite, and troostite are mixtures of ferrite and cementite and differ from each other only in degree of crushing of cementite. Process of their formation is diffusion. Sorbite and troostite, in disinction from perlite, do not have constant chemical composition and are formed in steel with different content of carbon. Structure of martensite constitutes solid solution of carbon in α-iron, and process of its formation bears diffusionless character. Sorbite, troostite, and martensite structures obtained at rates of cooling, in distinction from perlite, are called unbalanced – unstable. With heating to certain temperatures below critical there occurs transition of martensite to troostite and further to sorbite.

Various structure brings about various properties of structures of steel. In Fig. 8.5 are given curves of change of ultimate strength, HB hardness, and elongation

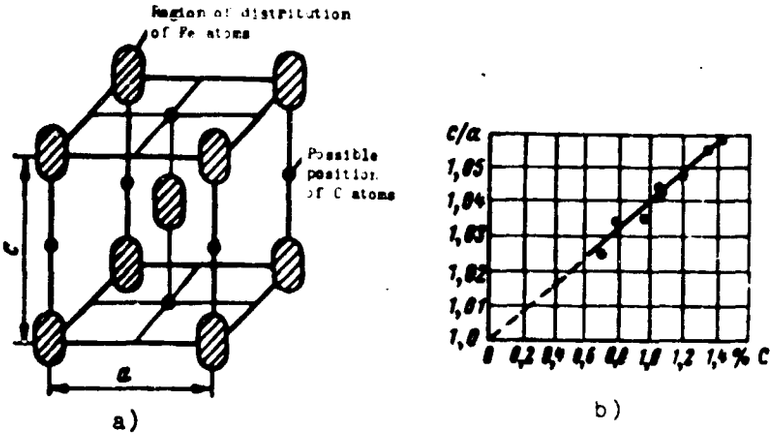


Fig. 8.4. Crystal structure of martensite (a) and dependence of tetragonality of martensite on carbon content (b).

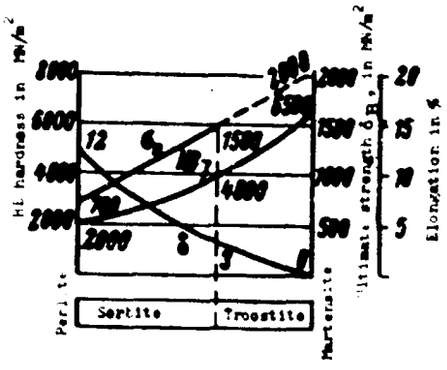


Fig. 8.5. Diagram of change of mechanical properties of eutectoid steels in different states from perlite to martensite.

per unit length δ of eutectoid steels in different states from perlite to martensite. From diagram one may see that properties of sorbite and troostite are midway between properties of perlite and martensite. Properties of structures of hypoeutectoid and hypereutectoid steels differ from properties of the same structures of eutectoid steels depending upon carbon content.

Transformation of austenite during continuous cooling. Cooling of steel is the most important stage of heat treatment. Rate of cooling of steel to state of austenite determines obtaining of one or another structure of disintegration of austenite, and this means imparting of defined properties to steel.

If steel heated to state of austenite is cooled with increasing rate, this will entail cooling of austenite. The higher the rate of cooling the greater the cooling of austenite. From iron – carbon constitutional diagram it follows that austenite is stable only at temperatures above point Ac_1 (for eutectoid steel). With cooling of austenite below point Ar_1 its disintegration occurs. With increase of rate of cooling point Ar_1 is lowered continuously (Fig. 8.6). Lowered critical point Ar_1 is designated Ar'. The lower the temperature of critical point Ar_1 the greater the

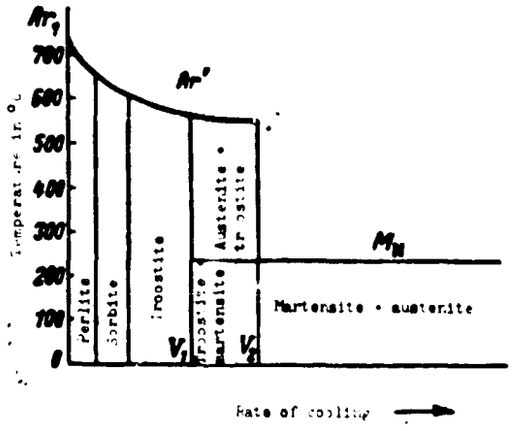


Fig. 8.6. Transformations of austenite during continuous cooling.

crushing of products of disintegration of austenite and the higher their hardness.

At low rate of cooling transformation of austenite will occur at temperature of the order of 700°C. Product of transformation will be perlite of coarse structure, possessing low hardness. At high rate of cooling transformation occurs at lower temperature, of the order of 650-600°C, structure of perlite becomes finer (sorbite forms), and hardness increases. With further acceleration of cooling temperatures of transformation are lowered ever more and in interval of temperatures from 600 to 500°C there forms structure of troostite, possessing high hardness. With rate of cooling V_1, on diagram along with point Ar' appears second point, which is point of beginning martensite transformation and is designated, in distinction from first point, Ar" (M_H). Here, martensite forms. Both these critical points exist up to rate of cooling V_2. For rate of cooling from V_1 to V_2 along with troostite is observed martensite (troostite-martensite structure). With further increase of rate of cooling point Ar' disappears. With rate higher than V_2 from austenite there forms only martensite. Minimum rate of cooling at which only martensite forms is called critical rate of hardening $V_{кр}$.

As follows from diagram (Fig. 8.6), formation from austenite of martensite is characterized by horizontal line, i.e., martensite, in contrast to perlite, sorbite, and troostite, forms not at various temperatures but always at the same temperature of rate of cooling from a temperature above critical.

At a temperature corresponding to critical point M_H occurs only the beginning of formation of martensite from austenite.

Further more full transformation of austenite to martensite occurs with decrease of temperature and is finished at defined temperature, which is designated M_K. Thus, process of formation of martensite from austenite takes place in interval of temperatures from M_H to M_K.

Position of points M_H and M_K is determined by chemical composition of steel and in the first place by carbon content. The more carbon in steel (Fig. 8.7) the

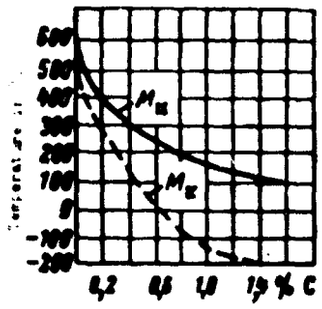


Fig. 8.7. Dependence of martensite points M_H and M_K on carbon content in steel.

lower the position of martensite points M_H and M_K. In high-carbon steels containing carbon more than 0.6% martensite transformation is finished at temperatures lower than zero. The lower the temperature of martensite points the more residual austenite is obtained. Residual austenite is austenite not transformed to martensite. Therefore in order to obtain in high-carbon steels more martensite it is necessary to cool them to temperatures lower than zero.

Transformation of austenite at constant temperature (isothermal transformation). It has been established that rate and character of disintegration of austenite depend on degree of its cooling. Austenite, depending upon to what temperature it is cooled, behaves differently: its stability is changed, i.e., time to beginning of its disintegration, speed of process of disintegration is changed, and character of transformation changes, i.e., products of disintegration. These peculiarities of transformation of austenite depending upon temperature of its cooling are characterized graphically by diagram of isothermal disintegration of austenite.

In Fig. 8.8 is given diagram of isothermal disintegration of austenite of eutectoid carbon steel. Diagram is plotted on semilogarithmic temperature – time coordinates.

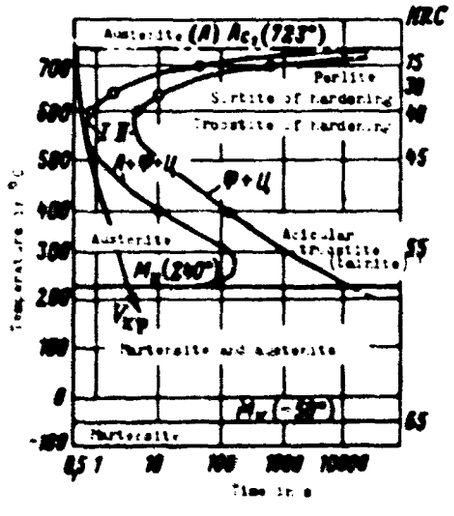


Fig. 8.8. Diagram of isothermal disintegration of austenite of eutectoid carbon steel (0.8% C).

On vertical axis is plotted temperature of cooling of austenite, i.e., that temperature to which austenite remains without disintegration. On horizontal axis is plotted time in logarithmic scale, which makes it possible to trace transformations occurring during interval of time from fractions of a second to days and more.

Curves on diagram were plotted as follows. Steel of defined composition is heated to region of uniform austenite and then fast-cooled, for instance, to 700°C. Then steel is held at this temperature for time sufficient for full

disintegration of austenite. Here, on diagram are plotted points corresponding to beginning and end of transformation of austenite at given temperature. Besides this, observations are made of changes in structure of steel. In precisely the same manner steel is cooled and held at other temperatures: 600, 500, 400, 300, 200, and 100°C.

Diagram of isothermal transformation consists of following lines (see Fig. 8.8). Upper dotted line is boundary of austenitic state. Above this line steel has structure of austenite. Austenite, as it is known, at a temperature higher than 723°C is stable, disintegration starts below this temperature, but during fast cooling, being undercooled, it can exist for certain interval of time without disintegrating. This time is called latent (incubative) period.

Two curves having form of Russian letter C characterize beginning (I curve) and end (II curve) of disintegration of austenite.

Segment from vertical axis to curve I characterizes stability of austenite in time (incubative period). As can be seen in Fig. 8.8, at temperatures of 500-600°C this segment has minimum dimensions, and consequently stability of austenite at these temperatures is least. Conversely, at 650-700°C and 250-300°C this segment has maximum dimensions, and consequently stability of austenite is the greatest.

Between curves I and II simultaneously exist austenite and products of its disintegration; to the right of curve II are only products of disintegration of austenite.

Depending upon temperature to which austenite is cooled, some or other structures of disintegration are obtained.

At high temperatures of isothermal transformation (650-700°C) final structure of disintegration is perlite, lower (600-650°C) sorbite, still lower (500-600°C) troostite, and at lower temperatures (250-450°C) acicular troostite or bainite. Acicular troostite is a mechanical mixture of ferrite and cementite of greater fineness than troostite, the ferrite in circular troostite being supersaturated by carbon. Besides this, during its formation are also present elements of martensite transformation.

In lower part of diagram are two horizontal lines - beginning ($M_н$) and end ($M_к$) of martensite transformation.

Formation of martensite begins only when austenite is cooled below line $M_н$ (240°C). Transformation of austenite to martensite below temperature of line $M_н$ is

diffusionless process. Full disintegration of austenite is possible only upon achievement of temperature of line M_H (-50°C) for given steel. Otherwise, in structure of steel remains part of undecomposed (residual) austenite, which lowers hardness.

Transformation of austenite is conveniently considered if one combines curves of cooling with diagram of isothermal disintegration of austenite.

As can be seen from diagram (Fig. 8.4), large influence on structure of products of disintegration of austenite is rendered by rate of cooling. For low rate curve of cooling V_1 intersects diagram of isothermal disintegration in region of high temperatures, and product of transformation is perlite. With higher rate curve of cooling V_2 intersects diagram of isothermal disintegration at lower temperatures and product of transformation is sorbite. With further increase of rate of cooling to V_3 temperature of transformation is lowered still more and structure of troostit is formed.

Curve V_4 shows partial transformation to troostite (section ab) and partial transformation to martensite (below M_H). Curve of cooling V_k, depicted tangent to decay curve, is critical rate of hardening. This is minimum rate of cooling for which disintegration of austenite up to martensite point M_H does not occur. As a result of transformation, martensite forms. Therefore for transformation of austenite to martensite it is necessary to cool steel at a rate not below critical (for instance, at rate V_k).

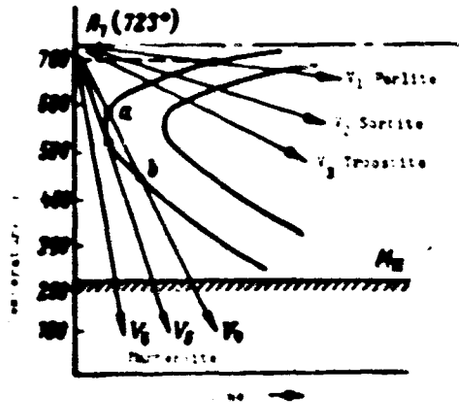


Fig. 8.4. Combination of curves of cooling with diagram of isothermal disintegration of austenite.

Ferrite-cementite mixtures (perlite, sorbite, troostite,) may be obtained both during continuous cooling and during isothermal disintegration, and martensite can be obtained only during continuous cooling. Fast cooling during hardening to martensite is necessary in order to pass through section of least stability of austenite without its disintegration to ferrite-cementite mixture.

Diagrams of isothermal transformation at present are plotted for many grades of steel and make it possible to designate exact conditions of such isothermal treatment

for which disintegration of austenite occurs in desirable direction.

Transformations during tempering. As it was shown, structure of steel after fast cooling at rate above critical (after hardening) consists of martensite and residual austenite and is unstable. Investigations have established that during heating of hardened steels to temperatures below critical (tempering) there occurs disintegration of unstable structure and formation of more equilibrium (stable) structures.

During tempering of hardened steels four transformations are observed.

First transformation occurs with heating to 80-170°C. It consists of decrease of degree of tetragonality of crystal lattice of martensite. Structure obtained here is called martensite of tempering. Decrease of tetragonality of tempered martensite is explained by singling out from oversaturated solid solution of this plates of cementite of several atomic layers in thickness. Martensite, owing to this, becomes low-carbon with smaller degree of distortion of crystal lattice. Plates of cementite are no longer isolated from lattice of solid solution and have common layer of atoms boundary with it. Microstructure of martensite of tempering has acicular structure but darker color than martensite of hardening.

Second transformation in steel takes place during heating to 200-300°C. It consists in that residual austerite is turned into tempered martensite. Besides this, there continues further disintegration of martensite accompanied by decrease in degree of tetragonality.

Third transformation at temperatures from 300 to 400°C is characterized by full disintegration of martensite to very fine ferrite-cementite mixture. Removal of considerable part of distortions of lattice and internal stresses is observed.

Fourth transformation at temperatures from 400 to 723°C consists in enlargement of particles of cementite (coagulation). Along with this is observed rounding of particles of cementite (spheroidization). Here distortions of crystal lattice of ferrite and internal stresses are removed completely.

In Fig. 8.10 presented diagram of transformations in steel during tempering. As a result of these transformations, hardened steel heated to 80-170°C obtains structure of martensite of tempering (Fig. 8.11a), that heated to 350-450°C takes on structure of troostite of tempering (see Fig. 8.11b), and that heated to 500-600°C takes on structure of sorbite of tempering (see Fig. 8.11c).

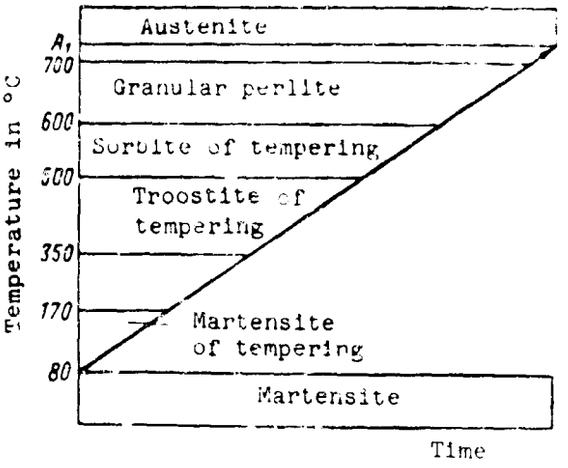
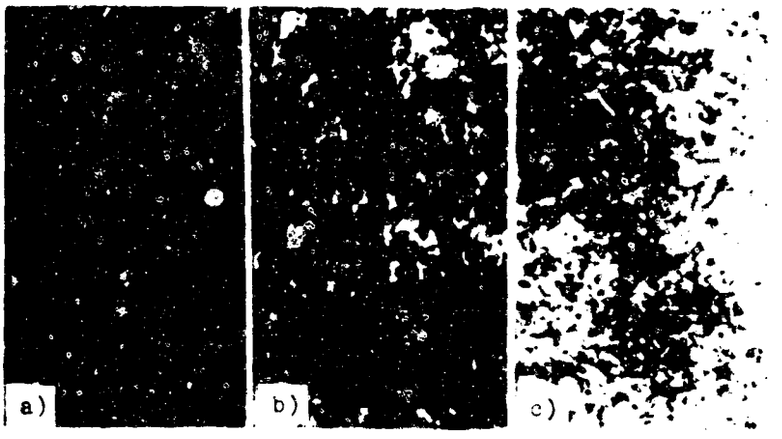


Fig. 8.10. Transformations in steel during tempering.



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Fig. 8.11. Microstructures of hardened carbon steel after tempering. a) Martensite; b) troostite; c) sorbite.

Increase of temperature of tempering above 650° leads to further enlargement of particles of cementite and formation of structure of granular perlite.

Structures of tempering differ somewhat from corresponding structures of hardening: with those same characteristics of hardness they possess best indices of toughness and ductility. Such change of properties of tempered structures is due to peculiarity of their structure: sorbite and troostite of tempering have granular structure of cementite, sorbite and troostite of hardening are laminar.

§ 2. Preliminary Heat Treatment of Steel

Steel billets, as a result of nonuniform cooling, after casting, rolling, forging, etc., take on heterogeneity of structure and properties, and internal

stresses in them appear.

For production fine-grained structure, elimination of chemical and structural heterogeneity, decrease of internal stresses, lowering of hardness of steel for the purpose of facilitating is machining, preliminary heat treatment is applied – annealing or normalizing. In certain cases normalization is operation of final heat treatment.

Annealing of Steel

Annealing is heat treatment consisting of heating steel to defined temperatures, holding, and subsequent slow cooling. Purposes of annealing are quite varied, as are conditions of its fulfillment. There exist different forms of annealing: full, incomplete, isothermal, spheroidizing, diffusion, and recrystallization.

Full annealing consists of heating steel to 30-50°C above line GS, holding at this temperature, and subsequent slow cooling (Fig. 8.12). Full annealing is connected with phase recrystallization and crushing of grains for hypoeutectoid steels at point Ac_3 and for eutectoid steels at point Ac_1. Full annealing of steel is applied for the purpose of obtaining uniform fine-grained structure and also for reduction of hardness and increase of ductility. Basically subjected to this form of annealing are steels slated for machining.

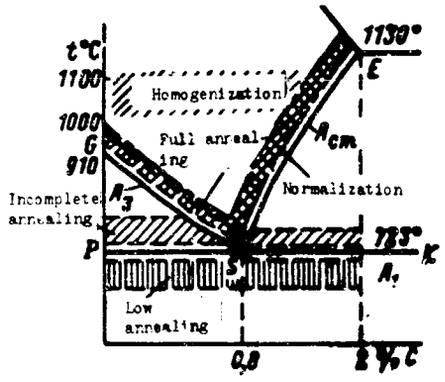


Fig. 8.12. Diagram of temperatures of heating of carbon steel for different forms of annealing.

Incomplete annealing consists of heating steel to 30-50°C above line PSK, holding at this temperature, and subsequent slow cooling (Fig. 8.12). Incomplete annealing is connected also with partial recrystallization of steel at point Ac_1. Excess structural components do not pass completely into solid solution (ferrite in hypoeutectoid, and cementite in hypereutectoid steels).

Incomplete (accelerated) annealing is used for removal of internal stresses and creation of fine-grained structure of hypoeutectoid steels with improved mechanical workability.

Isothermal annealing. For isothermal annealing (Fig. 8.13) part is heated to 30-50°C above line GSK, held at this temperature, and then rapidly transferred

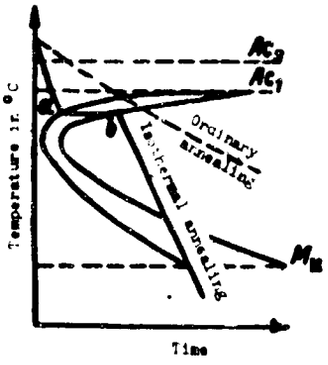


Fig. 8.13. Diagram of ordinary and isothermal annealing.

to medium having constant temperature somewhat below line PSK (point Ac_1), 680-700°C. At this constant temperature steel is held to full disintegration of austenite, after which it is air-cooled (hence the name isothermal annealing, i.e., annealing at constant temperature). During isothermal annealing transformation of austenite is accomplished not through cooling over defined temperature interval but at constant to temperature. Therefore this form of annealing gives more uniform structure.

Disintegration of austenite during isothermal annealing takes place just as disintegration during slow cooling.

After isothermal annealing steels have mechanical properties analogous to properties after full annealing. Basic advantage of isothermal annealing is that it completely removes residual stresses in steel. Besides this, isothermal annealing permits reducing time of annealing as compared to usual amount by almost twice. To isothermal annealing are subjected basically alloy steels.

Spheroidizing annealing (annealing to granular perlite). As a result of carrying out of full and incomplete annealing laminar perlite is obtained (inclusions of cementite in the form of plates). For production of granular perlite (inclusions of cementite in the form of grains) spheroidizing annealing is applied. Annealing to granular perlite consists of heating steel to temperature somewhat above line PSK (point Ac_1), prolonged holding (5-6 hours), and subsequent slow cooling. As a result of such operation laminar form of cementite is turned into granular.

Steel with structure of granular perlite has higher ductility, less hardness, and less strength than steel subjected to ordinary annealing. Spheroidizing annealing is used for hypereutectoid steels for the purpose of improvement of machinability.

Diffusion annealing (homogenization) consists of heating steel to 1000-1150°C (see Fig. 8.12), prolonged holding (10-15 hours) at this temperature, and subsequent slow cooling. As a result of diffusion annealing, there occurs levelling of heterogeneity of steel in chemical composition and decrease of liquation. To homogenization are subjected ingots of alloy steel, heavy steel castings, and others. High temperature of heating and prolonged holding lead to coarse-grained structure. This defect is removed in process of subsequent hot pressure working or

through application of full annealing to small grains.

Recrystallization (low) annealing consists of heating steel to temperature 50-100°C below line PSK (but above temperature of recrystallization), holding at this temperature, and subsequent cooling in air (Fig. 8.12). Recrystallizational annealing is applied for the purpose of removal of work hardening and internal stresses in steel after cold pressure treatment (rolling, drawing, or stamping). Besides this, it is possible to apply both intermediate annealing for increase of ductility and prevention of appearance of cracks in steel during its cold pressure treatment.

As a result of recrystallizational annealing, there forms uniform fine-grained structure with low hardness and maximum toughness.

After being annealed, steel displays structure corresponding to iron-carbon constitutional, i.e., for hypoeutectoid steels perlite and ferrite, for eutectoid steels perlite, for hypereutectoid steels perlite and cementite.

Normalization of Steel

Normalization is heat treatment consisting of heating steel to 30-50°C above line GSE, holding at this temperature and subsequent cooling in air (Fig. 8.12).

Normalization is used for correction of structure of overheated steels and hot-deformed billets, for removal of cementite lattice of hypereutectoid steels, and for levelling of structure of welded seam. After normalization, steel takes on more fine-grained structure than after annealing.

Depending upon carbon content in steel, structure and mechanical properties vary after normalization, For low-carbon steels (to 0.3%C) structure is perlite-ferrite and for medium-carbon and low-alloy steels structure is sorbite perlite or sorbite and structurally free ferrite.

For medium-carbon steels (0.3-0.5% C) distinction in properties of annealed and normalized steels is more considerable, since during normalization there is obtained sorbite-like perlite or sorbite with free ferrite with higher hardness and strength than obtained through annealing. Thus, normalized steel possesses higher hardness and lower toughness than annealed.

Normalization, being more a economical thermal process than annealing, has almost completely replaced annealing of low-carbon steels.

Conditions of Preliminary Heat Treatment

Selection of variant of preliminary heat treatment is determined by composition of steel and technological process to which parts or half-finished products are subjected.

For levelling of chemical composition of ingots or heavy castings is applied diffusion annealing. For lowering of hardness of steel after hot working, for the purpose of facilitating machining, full or incomplete annealing is chosen (depending upon composition of steel). After cold pressure treatment, for removal of work hardening and internal stresses, parts are subject to recrystallizational annealing.

Result of annealing and normalization is influenced by temperature and rate of heating, duration of holding, and rate of cooling.

Temperature of heating is selected from iron – carbon constitutional diagram depending upon carbon content in steel.

Rate of heating obtains especially large value when massive articles are heated, since in this case difference in temperature of internal and external parts of article increases. Articles of complicated form should also be subjected to slower heating.

During selection of rate of heating one should consider chemical composition of steel. The more carbon in steel the lower its thermal conductivity. Thermal conductivity decreases especially sharply with alloy steel. And the less the thermal conductivity of steel the slower must be its heating to avoid appearance of internal stresses and formation of cracks. Therefore it is impossible to indicate general rule for selection of rate of heating useful for all grades of steel. Duration of heating of steels during annealing and normalization is approximately 30-90 minutes per 25 mm of thickness of article.

Holding after heating to assigned temperature should ensure heating of all article and full completion of all processes accomplished in steel during its heating. Time of holding depends on thickness of article, initial structure, and chemical composition of steel. The more massive the article, the larger the grain of initial structure, the more prolonged must be holding. In practice holding is allotted 20-25% of duration of heating. To more prolonged holding is subjected steel during annealing to granular perlite (6-10 hours) and during diffusion annealing (10-15 hours).

Cooling after heating and holding should be of such duration that disintegration of solid solution can occur completely. Rate of cooling depends on cooling medium and dimensions of annealed article. Cooling should be uniform and slow to 500-400°C. Cooling of article is carried out together with furnace in ashes or sand. Here, carbon steels cool at rate of 100-200°C per hour, alloy steels at 20-60°C per hour, and further cooling can be performed in air.

In Fig. 8.14, as example, is given graph of annealing to granular perlite of У8 carbon tool steel. From graph one may see that steel is heated to 750°C for 3 hours, sustained at this temperature for 9-10 hours, and cooled first with furnace to 650°C for 5 hours and then in air. Total duration of annealing is about 20 hours.

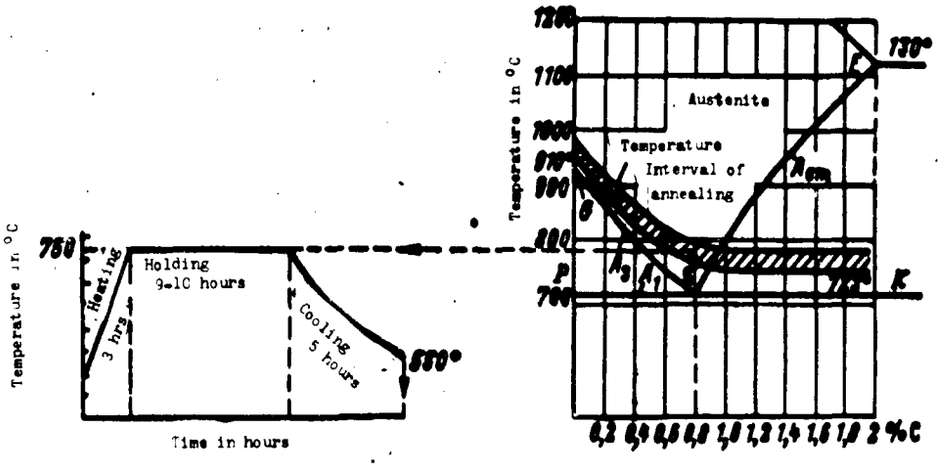


Fig. 8.14. Graph of annealing of carbon tool steels of grade У8.

§ 3. Final Heat Treatment of Steel

Finished articles, depending upon conditions of work, must possess defined properties. Thus, parts working under conditions of prolongedly applied static loads must have high strength and sufficient toughness; tool should possess high cutting properties, ability to preserve these properties when heated during cutting, etc.

For guarantee of required properties finished articles are subjected to final heat treatment – hardening and tempering.

Hardening of Steel

Hardening is called heat treatment consisting of heating of steel to 30-50°C above line GSK, holding at this temperature, and subsequent fast cooling. During

hardening are posed different problems, depending upon assignment of steel: structural steels are imparted high strength, tool steels are given greatest hardness, ensuring high cutting properties and wear resistance.

Such changes of properties of steel during hardening are result of formation in it of unbalanced structures – martensite, troostite, sorbite. Practice of carrying out hardening of steel is based on phase transitions during heating and cooling. Through fast cooling of steel during hardening is prevented transformation of austenite to perlite and obtaining of one of intermediate structures of disintegration of austenite – martensite, troostite, or sorbite. By changing coolants during hardening there is selected rate of cooling necessary for production of required structure and properties.

In order not to cause stresses, hardening medium should cool fast in interval of temperatures of low stability of austenite (600-550°C) and slowly in interval of martensite transformation (300-200°C).

As cooling media for hardening the most widely applied are water and different mineral oils. For increase of cooling ability of water to it are added table salt, caustic soda, soda, sulfuric acid, etc. For lowering hardening ability of water to it is added soap, emulsion of oil, or it is heated.

For moderate cooling the best coolers are considered mineral oils, although they are inclined to self-ignition.

During isothermal hardening as hardening media are applied mixtures of nitrates (KNO_3 – $NaNO_3$ in 1:1 relationship) or oil with high flash point.

Basic technological property during hardening is hardenability. Hardenability of steel (depth of hardening) is depth of penetration of martensite or semi-martensite zone from surface inside article.

Surface layers of steel, touching hardening medium, are cooled faster than internal layers; therefore in article it not always is possible to obtain through hardenability. With incomplete hardenability structure, and this means properties of surface layers, will be different from structure and properties of internal layers. Hardness of surface layers, having structure of martensite, will be higher than hardness of internal layers, taking on structure of troostite or even sorbite. Depth of hardening depends mainly on composition of steel, temperature of heating before hardening, kind of coolant, and grain size. The stabler the austenite, i.e., the further to the right lies C-curve of isothermal disintegration of austenite, the

less the critical rate of hardening and the greater the hardenability of steel.

Least hardenability belongs to carbon steels, which are heated through only with thickness of sections up to 8-10 mm. Consequently, for big steel articles after hardening is observed heterogeneity of structure, and this means of properties throughout cross section. Alloy steels have greater hardenability than carbon steels. Certain grades of alloy steels are completely hardenable in sections of more than 100 mm. Therefore if it is necessary to obtain high strength and hardness over entire cross section, part is prepared from alloy steels. In practice hardenability is evaluated from hardness.

Methods of hardening. In practice is applied a series of methods of hardening, depending upon composition of steel, form of article, and hardness which it is necessary to obtain.

Depending upon temperature of heating, we distinguish full and incomplete hardening.

Full hardening is obtained during heating of steel above line GSE. It ensures, after cooling at critical rate of hardening, martensite structure for all carbon steels.

Incomplete hardening is obtained during heating of steel below line GSE but higher than PSK. As a result of cooling at crictical rate of hardening, in hypoeutectoid steels is obtained ferrite and martensite structure and in hypereutectoid martensite and secondary cementite are obtained.

It is necessary to apply full hardening for articles of hypoeutectoid steels. Here, obtaining of soft ferrite inclusions will be eliminated. Incomplete hardening is profitably applied for tools of hypereutectoid steel, since presence of inclusions of secondary cementite increases hardness of hardened tool (cementite exceeds martensite in hardness Fig. 8.15).

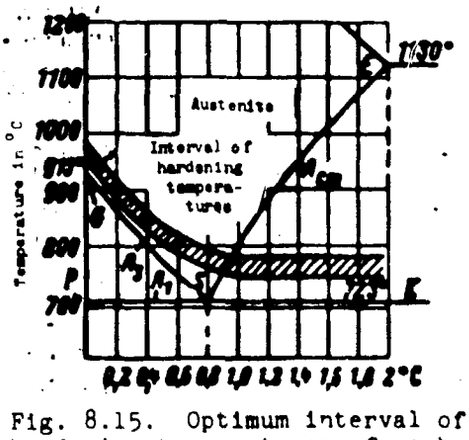


Fig. 8.15. Optimum interval of hardening temperatures of carbon steel.

Depending upon conditions of cooling, we distinguish hardening in one coolant, intermittent hardening, step hardening, and isothermal hardening.

Hardening in one coolant (Fig. 8.16, curve 1) is accomplished by means of submersion of part in coolant, where it remains to full cooling. As coolant there most frequently is

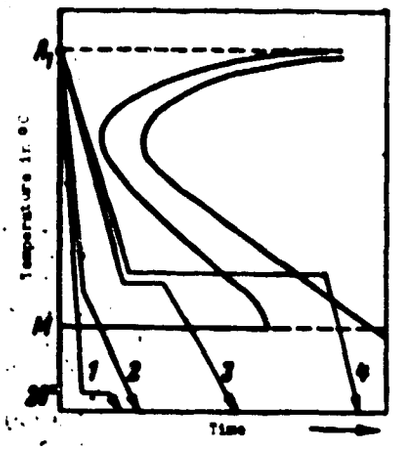


Fig. 8.16. Curves of cooling for different methods of hardening, plotted on diagram of isothermal disintegration of austenite. 1 – hardening in one coolant; 2 – intermittent hardening (hardening in two media); 3 – step hardening; 4 – isothermal hardening.

applied water (for carbon steel) and mineral oils (for alloy steel). So that no vapor layer is formed (steam jacket), which decreases rate of cooling, it is necessary to create energetic movement of parts in hardening medium. Hardening in one coolant is the simplest and most wide-spread method but can lead to considerable internal stresses.

For decrease of internal stresses there is applied hardening with partial cooling, for which part is held in air for a certain time before submersion in coolant. Here temperature of part must not drop below temperature of line GSK.

Intermittent hardening or hardening in two media (see Fig. 8.16, curve 2) is executed by consecutive cooling of part, first in water to 300-350°C and then in oil or in air for more delayed cooling in interval of martensite transformation. This decreases internal stresses connected with transformation of austenite to martensite. Deficiency of given method of hardening is difficulty of control of time of holding in first coolant.

Step hardening (Fig. 8.16, curve 3) is produced by fast submersion of heated part in salt bath having temperature somewhat higher than martensite point; after small holding for temperature balance over entire section, article is cooled to room temperature in air. Advantanges of step hardening are smaller internal stresses and decrease of warping. We apply this method only for hardening of small articles of carbon steels, since for big articles rate of cooling can be lower than critical in zone of low stability of austenite (600-500°C).

Isothermal hardening (Fig. 8.16, curve 4) differs from step hardening by more prolonged holding at temperature of quenching bath (above martensite transformation) for guarantee of full disintegration of austenite. Essence of isothermal hardening consists in that steel is heated to state of austenite and then sharply overheated to temperatures of isothermal disintegration of 250-300°C, corresponding to obtaining of acicular troostite. This structure is close in hardness to martensite but is tougher. Duration of holding in tempering medium is determined from diagram

of isothermal disintegration of austenite for given steel. Subsequent cooling is produced in air.

Isothermal hardening in this interval of temperatures gives steels high hardness (HRC = 45-55) and raised ductility as compared to usual hardening.

Basic advantage of isothermal hardening consists in that it does not cause in articles large internal stresses that frequently are the cause of warping and cracks of parts. But in order to avoid disintegration of austenite during isothermal hardening in the beginning is required high rate of cooling, not less than critical.

Therefore parts with diameter to 8-10 mm of carbon steels are subjected to isothermal hardening, since reserve of heat in more massive parts does not permit obtaining necessary rate of cooling. Majority of grades of alloy steel has lower critical rate of hardening and is well suited to isothermal hardening.

Decisive influence on quality of hardening is rendered by cooling. Cooling should be fast and full. This is attained by submersion of entire article in coolant, with obligatory mixing for constant contact of part with cold medium.

Quality of hardening is influenced also by method of submersion of parts in coolant. Small articles may be submersed in any position. Parts with large ratio of length to diameter or width should be submersed in coolant vertically.

Tempering of Steel

Tempering is heat treatment consisting of heating hardened steels to temperature below line PSK (point Ac_1), holding at this temperature, and subsequent arbitrary cooling.

Assignment of tempering consists in lowering internal stresses, decreasing hardness and brittleness, and increasing toughness and ductility of hardened steels to needed values, depending upon conditions of work of article.

As it was shown, after hardening are obtained different structures giving to article some or other properties. However, selection and supporting of necessary rate of cooling for articles of different dimensions and forms are conjugate with considerable difficulties. Therefore in practice for production of necessary structure of steel (and this means properties also) hardening and tempering are applied. At first article is hardened to martensite. Then hardened steel is tempered at 180-650°C. Here, martensite of hardening passes to stabler structures - troostite or sorbite (see Fig. 8.10).

During tempering of hardened steel there occurs also change of its properties. In Fig. 5.17 is shown influence of temperature of tempering on mechanical properties of hardened steel. From curves one may see that with increase of temperature of tempering, hardness (HB) and ultimate strength of steel (σ_B) drop and toughness (a_H) and indices of ductility (δ and ψ) are increased. Especially strong change of mechanical properties of steel takes place at temperatures of tempering higher than 400°C.

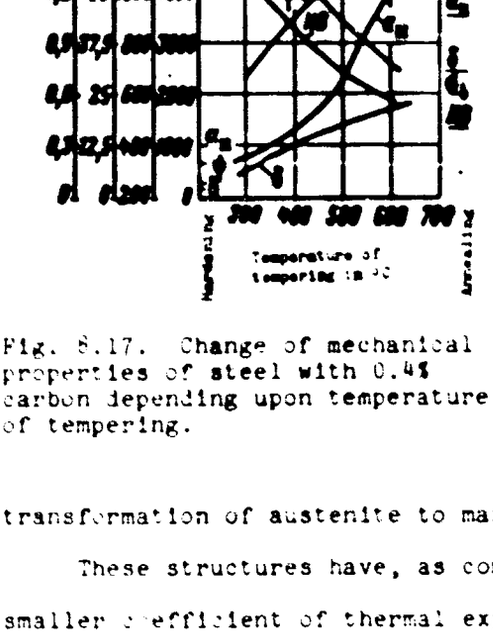


Fig. 5.17. Change of mechanical properties of steel with 0.4% carbon depending upon temperature of tempering.

Besides, during tempering occurs decrease or removal of internal stresses obtained as a result of hardening. Residual internal stresses, which appeared as a result of hardening, form from thermal and structural stresses. Thermal stresses appear as result of difference of temperatures between separate sections of cooled part. Structural stresses are due to volume changes connected with transformation of austenite to martensite, troostite, or sorbite.

These structures have, as compared to austenite, greater specific volume and smaller coefficient of thermal expansion. Therefore transformation of austenite to martensite (or other structures of hardening) leads to increase of volume of steel, and this means to appearance of internal stresses.

Internal stresses distort crystal lattice and lead to warping and deformation of articles, and in separate cases to appearance of cracks.

Fig. 5.18. Influence of temperature and duration of tempering magnitude of residual stresses.

Influence of temperature of tempering on internal stresses in steel are shown in Fig. 5.18. From curves one may see that maximum removal of residual stresses is attained through holding from 1 to 4 hours at a temperature of 550 - 650°C. Rate of cooling after tempering does not have value, however, to prevent appearance of secondary stresses due to fast cooling, it is recommended that parts prepared from carbon

and majority of alloy steels after being tempered at 500-600°C be cooled in air.

For separate alloy steels for which there is observed lowering of impact toughness after tempering at temperatures of 450-600°C (temper brittleness) cooling in water or in oil is applied.

Depending upon temperature of heating of hardened steels, we distinguish following forms of temper: low, medium, and high.

Low temper is characterized by low temperatures of heating, to 250°C, at which martensite of tempering is formed. Low temper leads to insignificant decrease of hardness, increase of toughness, and also to decrease of internal stresses in parts. Such tempering is applied for tools and articles which have to possess high hardness and wear-resistance.

Medium temper is characterized by heating of hardened steels to temperatures of 350-500°C, at which structure of troostite of tempering is formed. Such tempering ensures obtaining in steel of sufficiently high hardness along with high elasticity. Medium temper is applied mainly for springs, dies, percussion tools, etc.

High temper is characterized by heating of hardened steel to temperatures of 500-650°C, at which internal stresses are removed completely and structure of sorbite of tempering is formed. As a result of high temper, steel obtains best complex of mechanical properties – raised values of strength, toughness, and ductility. Therefore double heat treatment, consisting in hardening to martensite and subsequent high tempering, is called by improvement of steel. High temper is applied for majority of parts of structural steels subject to action of high stresses.

Thus, tempering is necessary technological operation after hardening, ensuring the obtaining of required mechanical properties of steel.

To prevent cracking of articles after hardening due to large internal stresses, it is recommended that tempering be done as soon as possible after hardening.

Monitoring of temperatures during low tempering in the absence of pyrometer may be done in accordance with colors of iridescence appearing on surface of article polished with emery. Appearance of these colors is connected with appearance of fine films of oxides of iron on surface of part during its heating. Depending upon thickness of film, there appears defined color of iridescence – from light-yellow to gray. Table 4.

Table 4. Temperature of Colors of Iridescence

Color	Temperature °C	Color	Temperature °C
Light-yellow	220	Violet	285
Straw-yellow	240	Cornflower-blue	295
Brownish-yellow	258	Light-blue	315
Brownish-red	265	Gray	330 and above
Purplish-red	275		

During determination of temperature from colors of iridescence one should consider that color of iridescence gives correct idea only of temperature of surface of article.

Aging of Steel

If low-carbon steel is cooled rapidly from temperatures of 600-700°C, then during subsequent holding occurs its aging, leading to increase of hardness and considerable lowering of ductility and toughness. Cause of aging is variable solubility of carbon in α-iron. During fast cooling from 700°C occurs fixation of supersaturated solid solution. During subsequent holding occurs disintegration of solid solution with precipitation of ultimate particles of tertiary cementite along line PQ of iron-carbon diagram which also involves change of properties of steel.

Process of aging is influenced more by temperature. Aging occurs naturally and artificially.

Natural aging occurs at room temperature. Maximum hardness during natural aging appears only after very prolonged holding.

Artificial aging occurs during heating of steel to temperatures of 100-170°C. Heating strongly accelerates process of aging. Artificial aging is used for stabilization of structures of properties and dimensions of measuring tool.

Besides this, for low-carbon steels aging is encountered after cold pressure treatment, called deformation aging. As a result of such aging, stampability of steel is worsened. Inclination of steel to aging is lowered through deoxidation of steel.

Conditions of Final Heat Treatment

Selection of conditions of final heat treatment depends on assignment of article (conditions of its work) and on chemical composition of steel. Thus for

tool which should possess high hardness and wear-resistance hardening is done in sharp coolants and low temper is applied (in case of its manufacture from carbon steel) or hardening in moderate coolants and low temper (in case of its manufacture from alloy steel). For different parts of structural steels, which have to possess good combination of strength and toughness sharp hardening and high temper are applied (in case of manufacture of them from carbon steel) or moderate hardening and high temper (for parts of alloy steels).

Results of final heat treatment are influenced by: temperature of heating, rate of heating, duration of holding at assigned temperature, and rate of cooling.

Temperature of heating. For hardening temperature of heating is selected from iron-carbon constitutional diagram. For tempering temperature of heating is determined by conditions of carrying out of some or other form of tempering.

Rate of heating during hardening has the same value and influence on metal as during annealing. Heating of articles of structural carbon steel (carbon 0.3-0.5%) should be done at such rate that necessary temperature is attained in one hour per every 25 mm of thickness. During tempering rate of heating does not play role.

Holding at the highest temperature of heating during hardening and tempering is determined by time necessary for full completion of structural transformations through entire thickness of article. Holding during hardening composes approximately 20-25% of time expended on heating and during tempering approximately one hour for every 25 mm of thickness of article. During tempering of articles of alloy steels time of holding is increased by one and a half or even twice as compared to shown norms for carbon steel.

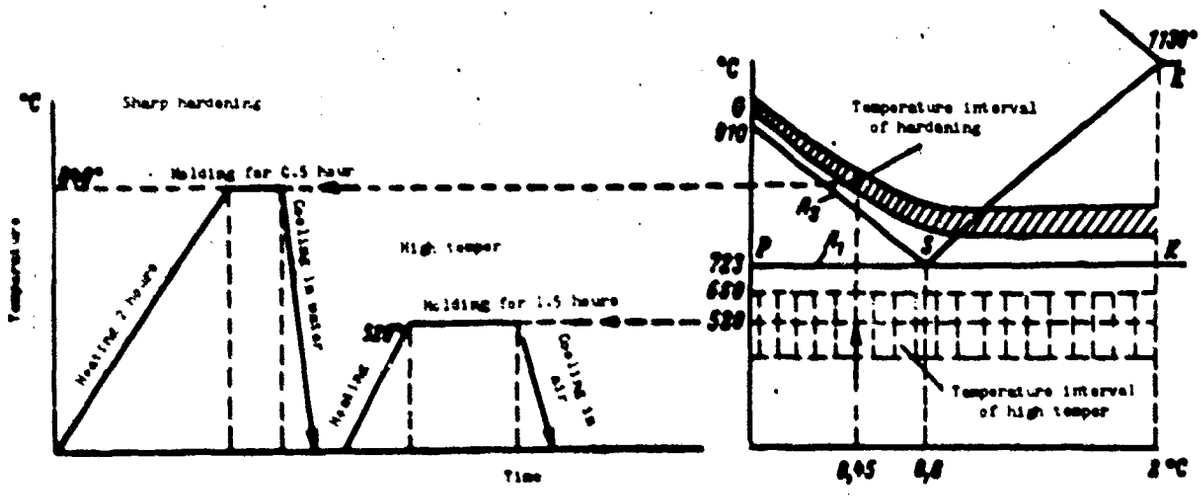


Fig. 8.19. Graph of hardening and tempering of structural carbon steel (steel 45) containing 0.45% C.

Rate of cooling during hardening should ensure formation of needed structure from austenite: martensite, troostite, or sorbite. During tempering rate of cooling in most cases does not have value. But still it is preferred that articles cool slowly, since during fast cooling internal stresses appear. Alloy steels inclined to temper brittleness are an exception; they are cooled after heating not in air but in water or oil.

As example, in Fig. 8.19 is presented graph of hardening and tempering of a shaft of steel 45 (containing 0.45% carbon).

§ 4. Defects of Heat Treatment of Steel

All defects which can appear during heat treatment are consequence of disturbance of conditions of technological process.

Defects of Annealing and Normalization

During annealing and normalization there frequently are encountered the following defects: overheating, burning, and decarburization.

Overheating of steel. Very high temperature of heating during annealing leads to large growth of grains of austenite and formation of coarse-grained structure (Fig. 8.20). Such steel is brittle and of lowered strength. Phenomenon of formation of coarse-grained structure as result of high-temperature heating of steel is called overheating, which can be removed by means of secondary full annealing.

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Fig. 8.20. Structure of overheated steels, ×400.



Fig. 8.21. Structure of burnt steel, ×300.

Burning of steel is characterized by strong growth of grains and appearance of oxides on grain boundaries (Fig. 8.21). Burning is result of prolonged holding at considerably raised temperature as compared to that permissible for given grade of steel. This defect imparts raised brittleness to steel. Burning is incorrigible defect, and burnt part goes to scrap.

Decarburization. As a result of chemical interaction at high temperature between steel and atmospheric oxygen in furnace, its decarburization and oxidation occurs.



Fig. 8.22. Structure of decarburized surface of steel. a) decarburized layer, ×100.

Decarburization of steel is connected with burning out of carbon in surface layers (Fig. 8.22). Such steel possesses lowered hardness. Besides, as a result of oxidation of steel, on surface of part there forms cinder consisting of oxides of iron. To prevent decarburization and oxidation of steel during its heating, at present furnaces with protective (controlled) atmosphere are applied, i.e., filling with inert gases.

Considered defects can take place not only during annealing or normalization but also during other operations of heat treatment.

Defects of Hardening and Tempering

As result of change of volume during heating and nonuniform cooling of internal and external layers during hardening, the following defects are possible: hardening cracks, warping, insufficient hardness, raised brittleness, formation of soft spots, and others.

Hardening cracks are the most dangerous and incorrigible defect. Formation of cracks is result of appearance in part of stresses whose magnitude exceeds ultimate strength of steel. Internal stresses appear in connection with change of volume of steel during heating and cooling and also during transformation of austenite to martensite. Sharp corners, cuts, and scratches left by tool on article lead to appearance of cracks in these places during hardening.

In order to prevent appearance of cracks one should evenly heat such parts without overheating them and cool them in soft hardening media (oil).

Warping is consequence of internal stresses appearing in steel as a result of nonuniform heating or nonuniform cooling.

Warping depends on form of part, difference in wall thickness, presence of sharp transitions, and can appear on parts of complicated configuration. Warping can also appear in the form of shrinkage or swelling.

To prevent warping, one should make heating and cooling as uniform as possible. It is recommended that complicated parts be hardened in dies, special clamps, or hardening attachments.

Warping can lead to full spoilage, but in certain cases it can be removed by mechanical correction of parts.

Insufficient hardness of hardened part can be obtained for the following causes: temperature of heating before hardening less than required for given grade of steel; too little holding at working temperature of heating; insufficient rate of cooling; strong decarburization from surface. It is possible to correct this defect by repeated hardening with exact observance of conditions of heat treatment. Low hardness after tempering occurs as a result of excessive temperature of tempering or of prolonged holding at normal temperature of tempering. It is possible to correct this defect only by correctly conducted hardening and tempering.

Here, before repeated hardening there first have to be removed internal tempering stresses by annealing, normalization, or high tempering.

Raised brittleness is consequence of excessive temperature of heating before hardening and also of incorrectly conducted tempering. It is possible to correct this defect also by correctly conducted hardening and tempering.

Formation of soft spots. During hardening of steel articles, in different places on surface of hardened article sometimes is observed unequal hardness. Soft spots can be due mainly to insufficient heating of articles or their insufficiently fast cooling. Sometimes soft spots are due to nonuniform initial structure of steel and formation of so-called steam jacket during submersion of part in tempering medium.

§ 5. Special Methods of Heat Treatment of Steel

Sub-Zero Treatment of Steel (Hypothermia)

Sub-zero treatment, i.e., at negative temperatures, is applied to steels for which after hardening considerable quantity of residual austenite is kept. As it was shown earlier, martensite transformation ($M_н$) for steels containing more than

0.6% carbon is finished below room temperature (see Fig. 8.17). During usual hardening austenite-martensite transformation consequently is not complete and in steel certain quantity of austenite is maintained. With increase in steel of carbon content or alloy elements, quantity of residual austenite strongly increases. Sub-zero treatment of these steels causes transformation of residual austenite of hardened steels to martensite. Here, hardness and strength are increased and magnetic properties are improved.

Sub-zero treatment consists in cooling hardened part below zero (from -40 to -190°C). Temperature of sub-zero treatment is selected depending upon composition of steel from which part is prepared. To prevent stabilization of austenite, lowering effect of sub-zero treatment, cooling must be produced directly after hardening or after small interval of time.

Sub-zero treatment is used for:

increase of wear-resistance and cutting ability of tools made from high-speed cutting and other tool steels;

stabilization of dimensions of measuring tools and parts working at low temperatures;

increase of hardness and wear-resistance of many parts prepared from high-carbon and stainless steels.

For parts of complicated form before sub-zero treatment usual tempering is applied. Its purpose is to remove tempering stresses and thereby prevent appearance of cracks and warping.

Low temperatures for sub-zero treatment are obtained by applying liquid oxygen, nitrogen, or air, a mixture of dry ice with acetone, and others.

Surface Hardening of Steel

Essence of surface hardening consists in that heat treatment is applied only to surface layer, to a small depth. Here, the core remains ductile and surface layer obtains high hardness. Surface hardening is done for the same purpose as carburizing, nitriding, and cyanidation, but it has a series of advantages as compared to other methods of surface hardening.

Heating of surface layer of part can be carried out with help of currents of high frequency, by gas flame, and in electrolyte.

Surface hardening by currents of high frequency was proposed and developed by

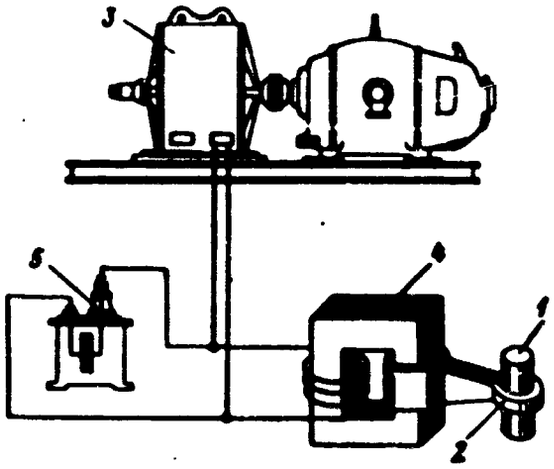


Fig. 8.23. Diagram of installation for high-frequency hardening. 1 – hardened part; 2 – inductor; 3 – high-frequency oscillator; 4 – hardening transformer; 5 – battery of capacitors.

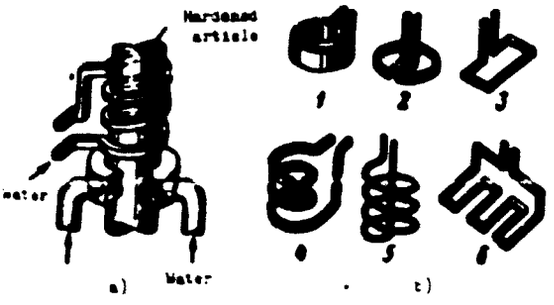


Fig. 8.24. Inductors for high-frequency hardening. a) inductor with cooler; b) types of applied inductors. 1, 4 – for external cylindrical surfaces; 2, 5 – for internal cylindrical surfaces; 3 – for brackets of complicated form and plates by method of shift; 6 – for plates and planes by method of shift.

Prof. V. P. Volgin. Essence of method of surface hardening by currents of high frequency [hf] (T.B.Ч.) consists in that part is placed, with considerable air gap, inside special inductor. Inductor is copper tube (oval or square), bent in form of heated part, in which water circulates for the purpose of cooling. Then through inductor is passed an electrical current of high frequency (from 500 Hz to 10 MHz) and great force. Resultant electromagnetic high-frequency field excites eddy currents, which heat surface of part. Depth of heated layer depends on frequency of current and duration of heating. The higher the frequency of current the less its penetration into part. The greater the duration of heating the bigger the depth of layer.

By regulating frequency of current and time of heating it is possible to attain required depth of heating and, consequently, depth of hardened layer. During treatment of different articles it varies from 1 to 10 mm.

In Fig. 8.23 is presented diagram of installation for hardening through heating by hf.

Cooling of surface layer is done either through inductor, which in this case is made hollow and has holes directed towards part, or a dryer is placed in series with inductor (Fig. 8.24a).

In Fig. 8.24b are shown types of inductors for surfaces of hardening of series of parts.

As compared to usual hardening, high-frequency hardening has following

advantage. Process of treatment of articles is accelerated tens of times and is more productive; heating is not accompanied by oxidation and decarburization, warping is eliminated, and cracks are absent. Therefore hardening by high-frequency currents is the most progressive method of heat treatment and is being ever more adopted in practice of machine building.

Surface hardening with heating by gas flame consists in the following: oxyacetylene flame of gas burner, having temperature near 3100°C, is directed on surface of processed part and heats it to hardening temperature. Cooling is produced by water from tube following burner (Fig. 8.25). By this method can be obtained hardened layer of depth to 6 mm.

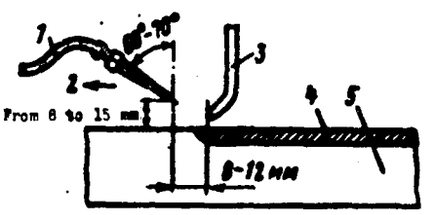


Fig. 8.25. Diagram of oxyacetylene surface hardening. 1 – burner; 2 – direction of movement of burner; 3 – tube for cooling water; 4 – hardened surface of article; 5 – nonhardened part of article.

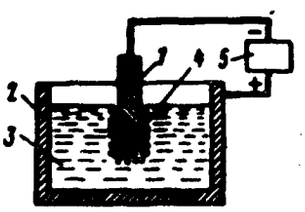


Fig. 8.26. Diagram of electrical heating of part in electrolyte. 1 – heated part (cathode); 2 – bath (anode); 3 – electrolyte; 4 – hydrogen shell; 5 – source of current.

By applying oxyacetylene flame it is impossible to obtain uniform heating of steel from surface. Besides, with this method of heating is obtained structural heterogeneity of hardened layer. Therefore oxyacetylene heating is applied comparatively rarely.

Surface hardening with heating in electrolyte is produced with help of electrical current of high voltage (330-380 V), passed through electrolyte in which heated articles are placed (Fig. 8.26). On surface of article forms shell of hydrogen. This shell creates high resistance to passage of current, in consequence of which surface heating of article occurs. After achievement of assigned temperature, current is turned off and article is cooled in the same electrolyte.

After being hardened, parts are subjected to low temper at a temperature of 160-220°C for 1.5-2 hours for removal of internal stresses.

Advantage of this method is that parts hardened in electrolyte show practically no oxidation and are not deformed.

C H A P T E R IX

CHEMICAL-HEAT TREATMENT OF STEEL

Chemical-heat treatment is process of saturation of surface of steel article by chemical elements - carbon, nitrogen, aluminum, silicon, chromium, and others.

Assignment of chemical - heat treatment is to increase surface hardness with preservation of ductile core, to increase wear resistance at normal and raised temperatures, to increase fatigue strength and corrosion resistance. Chemical-heat treatment is based on use of process of diffusion, which can be carried out only in that case when diffusing element is dissolved in the basic metal of article. Here, the following processes take place:

1) dissociation, i.e., decomposition of molecules of diffusing element with formation of atoms;

2) adsorption, i.e., absorption of atoms by surface of steel;

3) diffusion, i.e., penetration of atoms into surface layers of steel articles.

For carrying out chemical-heat treatment articles are placed in medium rich in saturating element (C, N, Al, Cr, Si, and others), and they are heated to defined temperature.

With increase of temperature of process, concentration of saturating element in hardening layer is increased. Duration of process depends on required depth of layer.

Chemical-heat treatment is applied widely in those cases when parts work under wear and are subject to impact loads and when with high surface hardness ductile core is needed. Such parts include various kinds of gears, pins, bushings, sleeves, shafts, and others.

In airplane industry are applied [illegible] steel, carburizing, nitriding, cyanidation, and [illegible]

§ 1. Carburizing of Steel

Carburizing is process of saturation of surface layer of steel by carbon. Process of carburizing is based on ability of carbon to dissolve in γ-iron.

Assignment of carburizing is to change properties of article by changing its chemical composition and structure of surface layer. By applying heat treatment after carburizing we obtain high surface hardness with preservation of soft and ductile core, which increases wear resistance and fatigue limit of steel parts.

Carburizing is the most wide-spread operation of chemical-heat treatment. Examples of parts subjected to carburizing are gears, pins, camshafts, shafts, levers, worms, and others, and also bearings parts. Carburizing is applied to carbon and alloy steel with low carbon content (0.1-0.2%), which is due to necessity of obtaining ductile core in article. Recently for many parts carbon content in steel has been increased to 0.3% for the purpose of increasing strength properties of core. Parts are carburized after final machining, with small allowance for final grinding. Portions of part not subjected to carburizing are protected by special masking, copper film applied by electrolytic method, or by leaving an allowance to be removed by machining. For carburizing articles are placed in medium rich in carbon, called carburizer.

Results of carburizing depend on following factors:

1) conditions of carburizing (temperature and time of holding);

2) composition of carburizer;

3) composition of steel;

4) conditions of heat treatment after carburizing.

According to kind of applied medium, we distinguish carburizing in solid, gas, and liquid carburizer (the last one is applied rarely).

Carburizing in solid carburizer. Cleaned parts are loaded into metallic box filled with carburizer and are heated in carburizing furnace (Fig. 9.1). Carburizer is pulverized charcoal with addition of different carbonate salts, accelerating process of carburizing (soda, potash, and others). Most widely used are carburizers of the following composition: barium carbonate 20-25%, soda 3-5%, coke 5%, the remainder charcoal. Temperatures of heating of steel are selected from iron-carbon

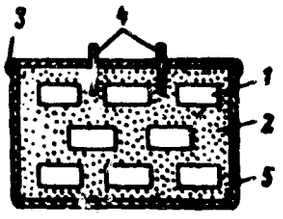


Fig. 9.1. Packing of parts in box for carburizing by solid carburizer. 1 – parts, 2 – carburizer, 3 – putty, 4 – samples, 5 – carburizing box.

constitutional diagram above point Ac_3 by 30-50°. Usually it is equal to 900-950°. At this temperature carbon of carburizer, combining with oxygen of atmosphere, forms carbon monoxide CO per reaction

$$2C+O_2=2CO.$$

Carbon monoxide upon contacting parts is decomposed to carbon dioxide CO_2 and atomic carbon:

$$2CO \rightleftarrows CO_2+C \text{ (atomic)}.$$

Formed active carbon diffuses in metal, forming solid solution with γ-iron. Carbonate salts in carburizer accelerate process, promoting additional formation of active atomic carbon. Process of diffusion occurs during prolonged holding, established in dependence upon necessary concentration of carbon and thickness of carburized layer (Fig. 9.2).

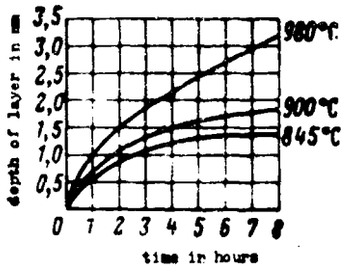


Fig. 9.2. Influence of temperature and time of holding on depth of carburizing by solid carburizer (charcoal + 40% $BaCO_3$).

Usually for production of carburized layer with depth of from 0.5 to 2 mm holding is from 5 to 12 hours. Termination of process of carburizing is judged from depth of carburized layer. Carburized layer is determined with help test samples, which are inserted in carburizing box in such a manner that their ends extend above cover. In process of carburizing these samples are removed, and depth of carburizing is judged from their fracture.

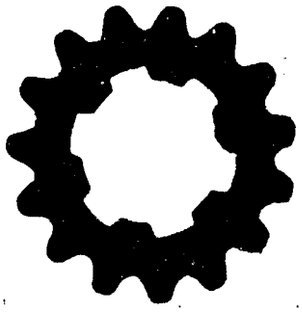


Fig. 9.3. Macrostructure of gear with carburized teeth.

More exact determination of depth of carburized layer is made through metallographic analysis. The latter is widely applied also for judgement of uniformity of distribution of carburized layer over contour of part (Fig. 9.3).

After carburization box together with parts is removed from furnace and cooled in air.

Essential deficiencies of process of carburizing in solid carburizer are abundance of dust and dirt, difficulty of control, labor involved, and low productivity.

Gas carburizing consists in saturation of surface layer of steel articles by carbon during heating of them in atmosphere of carbon-containing gases. In composition of carburizing gas enter carbon monoxide and gaseous hydrocarbons: methane, ethane, propane, and others. For gas carburizing are applied natural and artificial gases, obtained during decomposition of oil products. Besides these, there are used liquid carburizers (kerosene, synthine).

At present gas carburizing finds wide application in mass and heavy-serial production.

For gas carburizing parts are placed in special chambers, muffles, through which pass carburizing gas. In chambers is maintained temperature of 900-930°C. At this temperature gases flowing around part are decomposed, with formation of atomic carbon.

Duration of carburizing process depends on required depth of carburized layer. Thus, for production of depth of carburizing of 0.5-1.5 mm time required is 2-3 hours.

As compared to carburizing in solid carburizer, gas carburizing has following advantages:

1) higher productivity of process;

2) assigned depth of carburized layer and desirable distribution of carbon in it are attained considerably more simply, thanks to possibility of control through progress of process of temperature and composition of gas;

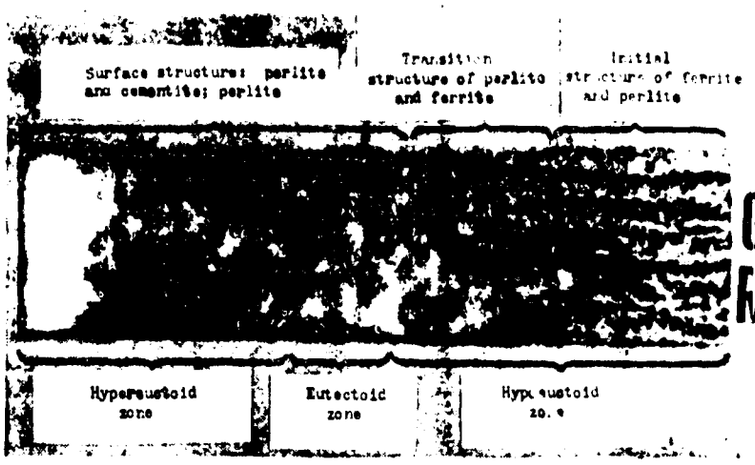
3) there is the possibility of full mechanization and automation of process;

4) necessary workshop area is halved;

5) briefer holding of parts in process of carburizing decreases possibility of overheating of parts, which permits producing hardening (with partial cooling) directly from carburizing furnaces.

During gas carburizing intensification of process is possible through increase of working temperature (heating by high-frequency currents).

Microstructure of carburized layer. Structure of carburized steels is nonuniform in cross section, since different sections contain different quantity of carbon. For normally conducted process of carburizing in surface layers of steel is contained 1.0-1.2% carbon (with greater content brittleness of layer is observed). With distance from surface of part toward core carbon content decreases to initial (0.1-0.2%).



GRAPHIC NOT REPRODUCIBLE

Fig. 9.4. Microstructure of carburized steel.

Structure of carburized layer after slow cooling from temperature of carburizing is shown in Fig. 9.4. It consists of three zones: first zone contains 1.2-0.9% carbon, consists of perlite and cementite, and is called hypereutectoid zone; second zone contains 0.8% carbon, consists of perlite above, and is called eutectoid; third zone, with content of 0.7-0.1% carbon, consists of ferrite and perlite and is called hypoeutectoid (transition) zone. This zone connects carburized layer with basic metal. The nearer to the core the less perlite and the more ferrite in transition zone.

As technical depth of carburized layer usually is taken distance (in mm) from surface to half of transition zone. Depth of carburizing of aviation parts varies from 0.5 to 3-4 mm.

Heat treatment of carburized parts. Through carburizing is achieved only suitable distribution of carbon over cross sections of part. After carburizing part must be subjected to heat treatment, which has the following purpose: to remove coarse-grainedness of steel, formed as a result of prolonged holding at high temperature; to give part high hardness and wear-resistance of surface, with ductile core.

Most frequently after carburizing is applied following heat treatment:

1. Normalization or hardening in oil from temperature of 860-880°C. Purpose of this operation is to destroy cementite network and to remove overheating (to crush structure) of core of part.

2. Hardening in water or oil from temperature of 760-800°C for removal of overheating of carburized layer caused by first hardening from high temperature (860°C) and imparting high hardness to layer. Parts of simple configuration made

from steels with carbon content of 0.1-0.2% usually are cooled in water; those of complicated configuration are cooled in oil; parts of special steels are cooled in oil.

3. Tempering at a temperature of 150-170°C for 2-4 hours for removal of internal stresses.

The simplest form of heat treatment after carburizing is direct hardening from carburizing furnace with preliminary partial cooling to 820-840°C and tempering at 180-200°C.

Such hardening is applicable only after gas carburizing for parts prepared from natural fine-grained steels. Only in this case will fine-grained structure be preserved, warping be lowered, and content of residual austenite on surface be reduced.

For destruction of residual austenite in carburized and then hardened parts, sub-zero treatment is applied.

After heat in surface layer is formed martensite structure and carbides with hardness HRC = 60-64.

After carburizing the following flaws are encountered: coarse-grained structure, soft places on surface, and formation of soot on parts with gas carburizing. Increase of grain size of steel is result of high temperatures of heating and prolonged holdings. It is necessary to apply steels with small natural grains or to apply heat treatment for removal of coarse-grained structure.

Soft places on surface of parts after hardening can be the result of insufficient carburization, heterogeneity of concentration of carbon in initial austenite, or insufficiently fast cooling during hardening.

To prevent formation of soot on parts, preventing penetration of atomic carbon to surface of part, it is necessary to select composition of carburizing gas correctly and to designate conditions of gas carburizing.

§ 2. Nitriding of Steel

Nitriding is process of saturation of steel articles by nitrogen. Through nitriding are increased hardness, wear-resistance, and strength of surface layer of article, and corrosion resistance of steel is increased in such media as atmosphere, superheated steam, fresh water, etc.

To nitriding, as a rule, are subjected machine parts subject to wear at high

temperatures and parts working in atmosphere of exhaust gases. Such parts include cylinder sleeves, valves, gears, shafts, and so forth.

Process of nitriding was first proposed by Academician N. P. Chizhevskiy. Wide introduction of process of nitriding was due to works of N. A. Minkevich, Yu. M. Lakhtin, V. I. Prosvirin, and others.

Change of properties of steel through nitriding is result of formation in surface layer of nitrided articles of nitrides – stable chemical compounds of nitrogen with other elements (iron, aluminum, chromium, molybdenum, vanadium, and others).

Nitriding of carbon steels does not ensure sufficient surface hardness; therefore nitriding is applied to alloy steels containing elements forming stable nitrides.

Technique of nitriding consists in the following: since nitriding is one of finishing operations of technological process, parts subjected to nitriding after final machining are heat-treated to give them necessary properties and then are nitrided.

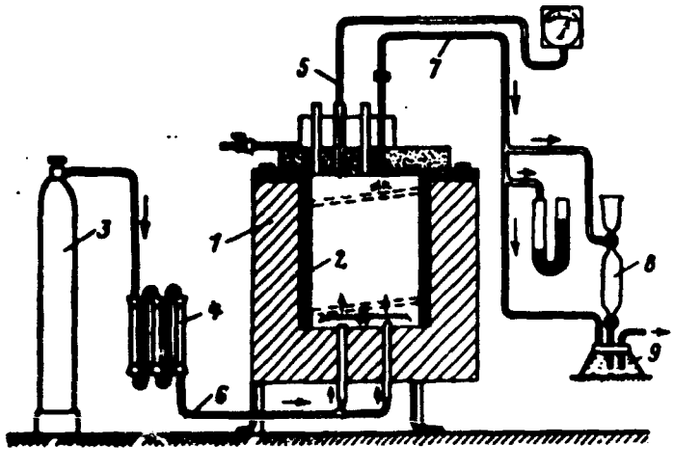


Fig. 9.5. Diagram of installation for nitriding 1 – furnace for nitriding, 2 – door, 3 – ammonia bottle, 4 – drier, 5 – pyrometer, 6 and 7 – tubes for feed and removal of ammonia, 8 – dissociation meter, 9 – tank for cooling gases.

When nitriding is not applied to entire surface of part, those portions not to be nitrated are covered with special masking or a thin layer of tin is deposited by electrolytic means. After this, parts are loaded in tightly closed muffle of furnace (Fig. 9.5), through which at defined speed is passed ammonia (NH_3).

Depending upon accepted conditions of nitriding, furnace is heated to assigned temperature, which is sustained for defined time. Ammonia entering hot furnace is decomposed, with precipitation of atomic nitrogen, which diffuses into surface layers of steel part and forms nitrides. Ammonia is decomposed in hot furnace per reaction:

$$2NH_3 \rightarrow 3H_2 + 2N_{atomic}$$

Upon termination of process furnace with parts is cooled slowly. After nitriding part is subjected only to final grinding.

Basic factors affecting process of nitriding are: temperature and duration of nitriding and degree of dissociation of ammonia.

The higher the temperature of nitriding the lower the hardness of nitrided layer but the faster the diffusion of nitrogen into steel.

Degree of dissociation of ammonia is from 15 to 45%, depending upon temperature of nitriding.

To obtain hardness and wear-resistance, there are nitrided mainly steels containing aluminum, chromium, molybdenum, and vanadium. In aircraft construction most frequently nitrided are parts made from alloy chromium-molybdenum-aluminum steel [38KhMYuA] (38ХМЮА) of composition 0.3-0.4% C; 1.35-1.65% Cr; 0.2-0.3% Mo; 0.7-1.2% Al. In this case the process of nitriding is conducted at a temperature of 500-520°C for 20-60 hours, depending upon required depth of layer. There usually is obtained layer with depth of 0.25-0.65 mm and nitrogen concentration of 3-4%. Higher nitrogen content causes raised brittleness in steel. Hardness after nitriding attains 1200 MN/m^2 Vickers.

For acceleration of process of nitriding a two-stage process is applied. In the beginning nitriding is conducted at a temperature of 500-520°C, which provides nitrided layer of required hardness. Then process is continued at 600-620°C, which decreases time required to obtain assigned depth of nitrided layer. This accelerates process by 1.5-2 times and has almost no effect on quality of nitrided layer.

For increase of fatigue strength alloy structural steels are nitrided. As a result of nitriding of these steels, in surface layer of article are formed compressive stresses, which increases their endurance. Hardness of surface after nitriding in this case attains 600-800 MN/m^2 Vickers.

For increase of corrosion resistance both alloy and carbon steels are nitrided. Process is conducted at high temperature (600-700°C) and is completed in less time (0.5-6 hours). Here, on surface is formed mainly iron nitride Fe_2N, being the most corrosion-resistant.

As compared to carburizing, nitriding has the following advantages:

- hardness of nitrided layer is 1.5-2 times higher than hardness of carburized layer, which considerably increases wear-resistance of part;

- nitrided layer does not lose its hardness when heated to 500-600°C, whereas hardness of carburized layer is lowered at temperatures of 250°C;

- hardening of parts to be nitrided is done before nitriding and carburized parts are hardened later, which leads sometimes to spoilage of parts (warping);

- carburized surface is less resistant to corrosion than nitrided surface.

Deficiencies of nitriding are high costs and duration of process and also ineffectiveness of nitriding of carbon steels.

§ 3. Cyaniding of Steel

Cyaniding is process of simultaneous saturation of surface of steel by carbon and nitrogen. Purpose of cyaniding is to increase hardness and wear-resistance of surface layer of articles and also to increase their corrosion resistance. Cyaniding is less widely applied in aviation industry than carburizing and nitriding.

Liquid, gas, and solid cyaniding are applied. Most widely applied is cyaniding in liquid and gaseous media.

Liquid cyaniding is done in molten cyanide salts (sodium cyanide NaCN, potassium cyanide KCN, calcium cyanide $Ca(CN)_2$, and others). For increase of fusion temperature and less evaporation of cyanide neutral salts are added to them (sodium chloride NaCl, barium chloride $BaCl_2$, and others).

When cyanide salts are melted, they decompose, forming nitrogen and carbon, which diffuses into surface of article, nitriding and carburizing it.

Basic factors determining depth and concentration of cyanided layer are temperature of heating and time of holding. The higher the temperature the less nitrogen and the more carbon in layer. The longer the holding time the deeper the cyanided layer.

Before being cyanided, articles are completely processed mechanically and those portions not to be cyanided are covered by protective layer. Then articles are

loaded in bath with molten cyanide salts for defined time. After cyanidation parts are hardened and given low temper. Microstructure of cyanided layer after hardening consists of the following zones: nitrous martensite on surface and troostite in core.

We distinguish low-temperature cyaniding, applied for tools, and high-temperature cyaniding, applied for structural carbon and alloy steels.

Low-temperature cyanidation (550-600°C) is applied mainly for increase of cutting properties of tools made from high-speed cutting steels. Duration of process is 60-80 minutes, depth of layer is 0.03-0.05 mm. With this process nitriding is superior to carburizing.

High-temperature cyanidation (800-840°C) is used for obtaining of deeper diffusion layer, resistant to wear under small specific loads. Duration of process is from 5 to 90 minutes, depth of layer is 0.2-0.5 mm. With this process carburizing is superior to nitriding.

For production of deeper layers deep cyaniding is applied. Process is conducted at 900-950°C for 1-6 hours. With this process there forms a layer with depth of 0.5-2 mm, containing 1-1.2% carbon and 0.2-0.3% nitrogen.

Deep cyaniding fully replaces carburizing in results but takes place considerably faster.

After cyaniding there is obtained a quite hard layer (HRC = 63-65).

Deficiency of process is poisonous nature of cyanide salts, which necessitates that thorough precautions be taken.

Gas cyaniding (nitrogen case hardening) is produced in mixture consisting of 75% carburizing gas and 25% ammonia. Carburizing gas (pyrolysis and generator gases, Saratov gas, and others) is decomposed in furnace, with precipitation of atomic carbon, and ammonia, with precipitation of active nitrogen. Process is conducted at 800-840°C and holding of from 1 to 6 hours. After cyaniding is produced hardening of articles. Depth of cyaniding here is 0.4-0.6 mm, and hardness of hardened cyanided layer is not below 56 HRC.

Gas cyaniding, as compared to gas carburizing, has the following advantages: lower temperature of process; smaller duration of process; twice greater wear resistance of cyanided layer; smaller growth of grains in core, which makes it possible to harden parts directly from furnace.

§ 4. Diffusion Metallizing

Diffusion metallizing is process of saturation of surface of steel by metal. For this purpose is applied mainly aluminum (calorizing), and less often chromium (chromizing) and silicon (siliconizing).

Diffusion metallizing is produced by means of heating and holding of steel parts in contact with substances containing saturating element. Diffusion metallizing increases resistance to scaling, corrosion resistance, and also hardness and wear-resistance. High temperatures and duration of processes of diffusion metallizing limit their application. Practical value so far has been found for process of calorizing. Less widely applied are diffusion chromizing and siliconizing.

Calorizing is process of surface saturation of layer of steel with aluminum. Calorizing is applied during treatment of different parts of carbon steel for the purpose of increasing their resistance to scaling. Calorized parts do not oxidize and work stably at temperatures up to 800-900°C. Process of calorizing permits replacement of expensive high-alloy steels by cheaper carbon steels for parts subjected to multiple heating. Resistance to scaling of calorized steels is explained by the fact that during work under conditions of high temperature on surface of part there forms durable film of Al_2O_3 oxides. This film protects part from further oxidation.

Applied are solid, liquid, and gas calorizing.

Solid calorizing finds greatest application. Essence of process consists in heating of parts in boxes with calorizing mixture, whose composition includes powdered aluminum or ferroaluminum, ammonium chloride, and inert additions – aluminum oxide, kaolin, and chamotte. Temperature of calorizing is 950-1050°C, time of holding is 4-12 hours, depth of layer is from 0.1 to 2 mm.

Liquid calorizing is applied basically for small parts. Essence of it consists in that parts are submerged for 40-90 minutes at temperature of 750-800°C in molten aluminum saturated by iron (7-8%). Iron is included in order to prevent intense dissolution of steel part in liquid aluminum. Depth of layer is 0.2-0.3 mm. Deficiency of method is raised brittleness due to its supersaturation by aluminum.

Gas calorizing is produced at 1000°C in vapors of aluminum chloride $AlCl_3$. After 2 hours calorized layer [illegible] mm depth is obtained.

Calorizing, increasing resistance of steel to scaling simultaneously imparts

to it poor wear resistance. To lower brittleness of calorized layer, diffusion annealing is applied to calorized parts at 900-1150°C for 5-6 hours.

Depth of calorized layer depends on temperature of heating, duration of process, composition of mixture, of state of surface of article, and carbon content in steel.

The higher the temperature and the greater the duration of calorizing the depth of layer. Presence of scale on surface of article delays process of diffusion of aluminum. To calorizing are best suited steels containing small quantity of carbon, since carbon retards diffusion rate of aluminum. Majority of alloy elements also delays process of calorizing, thereby lowering depth of layer.

Diffusion chromizing is process of saturation of surface layer of steel by chromium. Purpose of diffusion chromizing is to obtain high surface hardness and wear resistance and also to increase corrosion resistance at high temperatures (to 800°C).

Applied are solid, liquid, and gas chromizing. Most widely applied is solid diffusion chromizing. It is produced in mixture consisting of 60-65% ferrochrome, 30-35% alumina, and 5% hydrogen chloride (ammonium chloride). Process is conducted in furnaces at a temperature of 1050-1150°C for 12-15 hours. Before being loaded in furnace, parts are placed in iron boxes filled with the indicated mixture. Surface hardness of chromized low-carbon steel is low and approximately equal to 200-250 Vickers units. For high-carbon steel it attains 1380 units and exceeds hardness of not only carburized and hardened but also nitrided steels.

Siliconizing is process of saturation of surface layer of steel by silicon. Siliconized layer possesses high acid-resistance, is heat-resistant to 850°C, and wear resistance. Therefore it is expedient to apply siliconizing for parts working under abrasion in aggressive media. Siliconizing is conducted in gas, and less often in solid, media.

Gas siliconizing is produced at 950-1050°C in vapors of silicon chloride. After termination of process, parts are cooled in furnace to 500-400°C and then in air.

Process of gas siliconizing is very intense. Thus for production of layer of 1-mm depth duration of holding at 1050°C does not exceed 2 hours.

For diffusion metallizing saturation of steel by other metals is possible. Thus, there sometimes is applied saturation of surface of steel by beryllium (beryllizing). Beryllized layer is characterized by great hardness and high heat resistance.

S E C T I O N T W O

FERROUS METALS AND SPECIAL ALLOYS

CHAPTER X

CARBON STEELS

Carbon steels in aviation industry have limited application. This is explained by the fact that they possess a series of deficiencies. With increase of carbon content strength and hardness are increased, but simultaneously ductility are toughness are sharply reduced and brittleness is increased.

In connection with high critical rate of hardening, carbon steels possess low hardenability. As a result of hardening, only surface of part takes on structure of martensite; internal layers are hardened to troostite or sorbite and for massive parts are not hardened at all.

In addition to that, carbon steels do not satisfy certain special requirements imposed on a series of parts of motors, aircraft, and their equipment, such as heat resistance, resistance to scaling, acid resistance, special magnetic and thermal properties, and others.

§ 1. Influence of Carbon and Constant Impurities on Properties of Steel

In carbon steels, besides basic elements of iron and carbon, there constantly are present the following impurities: manganese and silicon (introduced as deoxidizing agents), sulfur and phosphorus (inevitably coming from ore and fuel).

Let us consider influence of carbon and constant impurities on properties of steel.

Influence of carbon. Carbon is basic element of carbon steels and strongly affects their mechanical and technological properties.

In Fig. 10.1 are given curves of change of mechanical properties of steel depending upon carbon content. Hardness (HB) and ultimate strength (σ_B) are increased continuously with increase of carbon content to 1.2%; indices of ductility (δ,ψ) and impact toughness (a_H) simultaneously decrease. This change of properties is explained by change of quantity of cementite and ferrite in structure of steel with increase in it of carbon content.

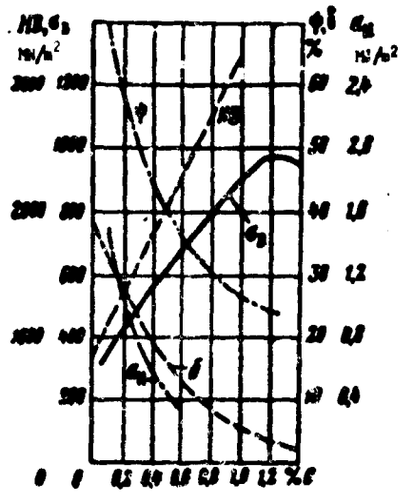


Fig. 10.1. Influence of carbon content on mechanical properties of steel.

With increase of quantity of carbon technological properties of steel are changed also. Forging of it in cold state is impossible and is hampered in hot state. Machinability is hampered, weldability worsens, but casting qualities are improved.

Influence of manganese and silicon. Presence in steel of manganese and silicon is caused by process of smelting steel. In order to be free of ferrous oxide, formed during melting and worsening properties of steel, manganese and silicon are introduced. This process is called deoxidation of steel. Here, manganese content must not exceed 0.75% and that of silicon 0.35%.

Content of silicon and manganese in such quantity has practically no influence on mechanical properties of carbon steels.

Higher content of these elements essentially changes properties of steel and affects its behavior during mechanical and heat treatment. Steels which contain more than 1% manganese and more than 0.8% silicon are called special steels.

Influence of sulfur and phosphorus. Sulfur and phosphorus are harmful impurities. Presence of more than 0.05% of each of these impurities sharply worsens quality of steel. Harmful action of sulfur consists in that it causes red-shortness in steel, i.e., raised brittleness (formation of cracks) in hot state during forging and rolling. Red shortness of steel is explained by the following: sulfur, combining with iron, forms eutectic whose melting point is equal to 985°C, much lower than melting point of steel. During crystallization of steel this eutectic is disposed on grain boundaries. And when steel is heated for forging or rolling eutectic melts,

connection between grains is broken, and steel becomes brittle.

Red-shortness is removed by addition of manganese to steel, which, combining with sulfur, forms manganese sulfide (its melting point is 1620°C).

Harmful action of phosphorus consists in sharp increase of brittleness of steel at normal temperature. This phenomenon is called cold-shortness. Cold-shortness of steel is due to fact that phosphorus, dissolved in ferrite, imparts high brittleness to steel at normal temperatures.

Harmful influence of phosphorus shows up more strongly with raised carbon content. However, in so-called automatic steels (with carbon content of up to 0.3%) raised content of phosphorus is allowed (to 0.15%) and of sulfur (to 0.2%) to facilitate removal of shavings and for obtaining smooth surface during machining, in particular during cutting of threads.

§ 2. Classification and Grading of Carbon Steels

Classification of Carbon Steels

According to method of production, we distinguish the following steels:

1) carbon steel of ordinary and raised quality, which is smelted in converters and large open-hearth furnaces; in these steels content of harmful impurities should be within the following limits; sulfur 0.05-0.09% and phosphorus 0.06-0.075%. In turn, carbon steel of ordinary and raised quality is divided into three groups:

I group – steel supplied with guaranteed mechanical properties;

II group – steel supplied with guaranteed chemical composition;

III group – steel of raised quality supplied with guaranteed chemical composition and mechanical properties;

2) quality steel smelted in basic open-hearth furnaces with observance of stricter requirements with respect to charge and the actual process; in these steels content of sulfur and phosphorus must not exceed 0.04% (each);

3) high-quality steel smelted in acid and basic open-hearth furnaces or in electric furnaces; this steel is distinguished by lowered content of harmful impurities (sulfur and phosphorus) up to 0.03% each.

Depending upon assignment of steel and its carbon content, we distinguish:

1) structural steels, intended for constructions and machine parts; these steels must possess sufficiently high complex of mechanical properties;

2) tool steels, intended for manufacture of tools of different assignment; these steels must possess high hardness and good cutting properties.

With respect to heat treatment, we distinguish steels:

1) not subjected to heat treatment; these include carbon steels of ordinary quality, applied in state of delivery;

2) carburized steels; these include low-carbon structural steels with carbon content to 0.3%;

3) improved steels; these include medium-carbon structural steels which contain from 0.35 to 0.55% carbon and are subjected to hardening and tempering.

According to degree of deoxidation, steels are divided into:

1) mild steel, which is deoxidized completely during smelting;

2) rimmed steel, which is deoxidized during smelting by manganese only.

Grading of Carbon Steels

Grade of steel is conventional designation which characterizes chemical composition, quality, content of separate elements, and in certain cases method production.

Structural carbon steels of ordinary and raised quality.

Steels of group I have following grades: St. 0, St. 1, St. 2, St. 3, [St. 3kp] (St. 3кп), St. 4, St. 5, St. 6, St. 7. Letters "St." denote steel and numbers 0, 1, 2, 3, etc. denote number of steel. With increase of number, ultimate strength (carbon content) increases. Letter ["B"] ("В") before grade indicates that steel is Bessemer, absence of letter means that steel is open-hearth. Grades of rimmed steel have at the end the index "kp"; absence of these letters signifies mild steel.

Steels of group II have following grades: B09kp, B09, B16, B23, B33, and M09kp, M12kp, M18kp, M18, M21, M26, M31, M44, M56. First letter shows method of smelting of steel (B – Bessemer steel, M – open-hearth steel), and figure shows average carbon content in hundredth shares of a percent.

Steels of group III have following grades: M09, M12, M16, M18a, [I21a] (И21а), M26a, M31a, M44a, M56a. These steels are graded like steels of group II, but to grade of steels this group is added letter "a," which indicates raised quality.

Quality and high-quality structural carbon steels. Structural carbon steels have following grades: 0.5, 0.5kp, 08, 08kp, 10, 10kp, 15, 20, 20kp, 25, 25kp, 30, 35, 40, 45, 50, 55, 60, 65, 70. Letters are not placed ahead of grade of these

steels: for instance, "steel 30" or "steel of grade 30." Two-digit figures in grade of steel denote average carbon content in hundredth shares of a percent. For example, steel of grade 15 contains on the average 0.15% carbon, steel 50-0.50% carbon, etc. Letters "kp" signify that steel is rimmed, i.e., is deoxidized during smelting by manganese only.

If to designation of grade of carbon steel is added letter "A," for instance, 15A, 20A, it signifies that given steel is high-quality, i.e., has minimum content of harmful impurities.

Besides pure-carbon steel, there is applied steel with raised manganese content – grades [15G] (15Г), 20G, 40G, 30G2, 40G2, 50G2, and others. In these grades letter "G" indicates raised manganese content (near 1%) and figure 2 after letter "G" signifies that in steel is about 2% manganese. Letter ["L"] ("Л") after grade indicates that steel is for casting.

Carbon tool steels. Quality tool steels have grades [U7] (У7), U8, U8G, U9, U10, U11, U12, and U13; and high-quality grades are U7A, U8A, U8GA, U9A, U10A, U11A, U12A, and U13A. Letter "U" in designation of grade of steel denotes that this is carbon steel. Figure standing after letter "U" shows content of carbon in tenth shares of a percent. For instance, U7A designates carbon tool steel with 0.7% carbon. Letter "A" indicates that steel is high-quality, i.e., contains minimum quantity of sulfur and phosphorus.

§ 3. General Characteristics and Assignment of Carbon Steels

Structural Steels

Structural carbon steels contain from 0.05 to 0.75 and in special cases up to 0.85% carbon. Structural carbon steels of ordinary quality are supplied without heat treatment in the form of sheet and assorted rolled stock. They are applied for building structures and machines.

Structural carbon steels (quality and high-quality) possess sufficiently high complex of mechanical properties, but they do not always satisfy technical requirements. They are used for manufacture of less vital, comparatively lightly-loaded and nonloaded aviation parts.

In Table 5 are given chemical composition and mechanical properties of these steels.

Table 5. Chemical Composition and Mechanical Properties of Carbon Structural Steels

Grade of steel	Carbon content in %	Mechanical properties of normalized steels (not less			HB hardness after annealing MN/m²
		ultimate strength σ_B MN/m²	elongation δ, %	reduction of area ψ, %	
08	0,05—0,10	300—450	33	60	—
10; 10A; 10кп	0,07—0,13	300—490	29	55	—
15; 15A	0,12—0,20	440—540	25	55	—
20; 20A	0,17—0,24	520—620	22	55	—
25	0,22—0,30	460—580	21	50	—
35	0,32—0,40	580—680	17	45	1430—1870
45; 45A	0,42—0,50	710—820	13	40	1970
50	0,47—0,55	680—850	12	40	2070
70(BC,OBC)	0,67—0,75	1100	8	30	2280

Depending upon carbon content, quality structural steels are divided into low-carbon, medium-carbon, and high-carbon types.

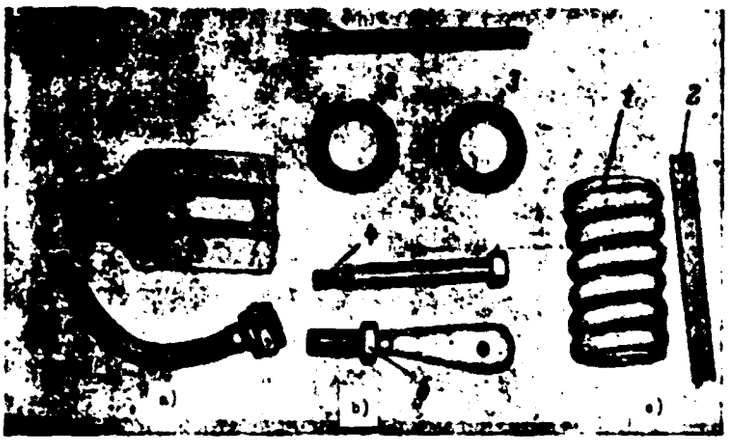


Fig. 10.2. Part made from carbon structural steels. a) parts of low-carbon steels. 1 — welded bracket of steel 20, 2 — section of line of hydraulic system of steel 20A, b) parts of medium-carbon steels. 1 — pin of engine crankcase, 2 — slotted nut, and 3 — casing of sealing rings of hydraulic system of steel 35, 4 — bolt for control rod of bracket for control of engines, prepared of steel 45, 5 — rod clevis for hydraulic cylinder, prepared of steel 45A, c) parts of high-carbon steels. 1 — coil spring of cylinder for emergency release of front gear of aircraft, prepared of steel 70, 2 — flat spring for holding clutch block of brake wheel, prepared of steel U8A.

In Fig. 10.2 are presented parts prepared from low-carbon (a), medium-carbon (b), and high-carbon (c) steels.

Low-carbon steels contain from 0.05 to 0.30% carbon. They possess low strength, high ductility, and good weldability. Low-carbon steels are applied in airplane industry mainly for lightly-loaded parts or parts during whose manufacture considerable plastic deformation is required. As a rule, these steels are applied without hardening.

Steel 08 has high ductility, allows deep stamping, complicated bending, knockout, welds excellently, and is supplied in the form of sheets and wire. It is applied in state of delivery for welded and stamped nonvital parts subjected to considerable plastic deformation.

Steels 10, 10kp, and 10A possess high ductility, weld well by all forms of welding, are carburized and cyanided, and allow deep stamping, complicated bending, knockout, etc. They are supplied in the form of rods, sheets, tubing, and wire. They are applied in annealed and normalized state for low-strength parts of aircraft and motors, prepared by welding, bending, or stamping: tanks, joints, bolts, nuts, washers, angles, frames, mesh, and rings.

For manufacture of carburized parts not experiencing considerable stresses but subject to wear steel 10 is applied. Steel 10kp is used for manufacture of parts by means of deep stamping, for instance, housings for combustion chambers of jet engines. Wire of steel 10A is applied as filler material during welding of joints and parts.

Steels 15 and 15A have high ductility and weld well by all forms of welding. They are supplied in the form of wire and are applied mainly for manufacture of rivets with low shear resistance.

Steels 20 and 20A are well suited to cold plastic deformation, weld well by arc and resistance welding, and can be subjected to calorizing, carburizing, and cyaniding. They are supplied in the form of sheets and tubing. These steels are applied basically in annealed or normalized state for welded and stamped parts with low strength: shoes, joints, corner plates, brackets, levers, rockers, collars, main oil lines, sealing rings, of flanges of fittings, hose tips, housings of solenoids, packing washers, transition flanges of gas collectors, and others. Tubing is applied for manufacture of tubular rivets and also lines for hydraulic air brake and other systems.

Steel 25 welds well by arc and resistance welding. It is supplied in the form of rods, wire, and forgings. This steel is applied mainly in annealed or normalized state for lightly-loaded parts: bolts, nuts, screws, nipples, tubes, plugs, bushings, suspension joints, and others.

Medium-carbon steels contain from 0.32 to 0.55% carbon. They possess medium strength, satisfactory ductility, and good machinability. In aviation industry medium-carbon steels are used for mechanically processed parts. As a rule, these steels are applied in normalized or annealed state. When these steels are used for manufacture of medium-loaded parts, they are improved (hardening with high temper).

Steel 35 machines well. It is welded satisfactorily by all forms of welding. It is supplied in the form of rods, tubing, sheets, and forgings. This steel is applied in normalized state and also, after hardening with tempering, for welded and mechanically processed parts such as shafts, suspension joints, bolts, nuts, washers, and others.

Conditions of heat treatment: annealing and normalization from temperature of 850-900°C, hardening from 850-870°C, cooling in water or oil, high tempering.

Steels 45, 45A, and 45L machine well. They are welded satisfactorily by arc and unsatisfactorily by gas.

Steel 45 in annealed, normalized, and work-hardened states is used for manufacture of lightly-loaded machined parts: bolts, pins, plugs, nuts, unions, tees, housings of stuffing boxes, and others. Parts of steel 45 can be subjected to heat treatment. Conditions of heat treatment: annealing and normalization at 850°, hardening from 820°C in oil.

Steel 45A is used for ribbon braces, shafts and their couplings. Heat treatment: temperature of heating before hardening (in oil), annealing, and normalization is 840-860°C.

Steels 45 and 45A are supplied in the form of rods, tubing, sheets, wire, and forgings.

Steel 45L is used for shaped castings. In annealed state machinability is good. Conditions of heat treatment: hardening from 840-850°C, tempering to required strength. It is used for manufacture of castings of lightly-loaded parts, brackets, turret rings, and others.

Steel 50 machines well and possesses satisfactory ductility. It is supplied in the form of rods and tapes and is applied in normalized state and also, after hardening with temper, for flat springs and mechanically processed parts. Conditions of heat treatment: annealing, normalization, and hardening at a temperature of 790-810°.

High-carbon steels contain from 0.60 to 0.75% carbon. They possess great strength, high elastic and fatigue limits. High carbon steel has found wide application in the form of tapes and wire for manufacture of flat and coil springs.

We distinguish wire of high resistance [VS] (BC) and specially hig sistance [OVS] (OBC); they belong to the same grade – high-carbon steel 70.

Heat treatment of wound springs made from cold-drawn wire consists in tempering at 260-300°, after which steel, depending upon diameter of wire, is characterized by ultimate strength of 1400-2650 MN/m^2 (140-265 kgf/mm^2).

Besides this, for manufacture of different flat springs are applied tapes of high-carbon steels of grades U8, U8A, U9, and U9A.

Conditions of heat treatment of these springs: hardening from temperature of 770-790°C in oil and tempering at 350-420°C; after which they have HRC hardness of 44-48.

For manufacture of semivital parts (bolts, nuts, screws) prepared on automatic machines are applied so-called automatic steels. They machine well and can be processed at high speeds. High workability of automatic steels and good quality of surface are due to raised content of sulfur and phosphorus. Chemical composition and mechanical properties of automatic steels are given in Table 6.

Table 6. Chemical Compcsition and Mechanical Properties of Automatic Structural Steels

Grade of steel	Chemical composition in %					Mechanical properties (not less)	
	C	Si	Mn	P not more	S	σ_b MN/m^2	δ %
A12	0,08—0,16	0,15—0,35	0,60—0,90	0,08—0,20	0,08—0,15	420—800	7—22
A20	0,15—0,25	0,15—0,35	0,60—0,90	0,06	0,08—0,15	460—820	7—20
A30	0,25—0,35	0,15—0,35	0,70—1,00	0,06	0,08—0,15	520—840	6—15

In grades of steel letter A denotes automatic, figure indicates average carbon content in hundredth shares of a percent. Automatic steels are supplied in hot-rolled and in cold-drawn states in the form of rods.

Tool steels. Carbon tool steels contain from 0.6 to 1.4% carbon; as compared to structural steels, they have higher strength and hardness and lower ductility. They are designed for manufacture of cutting, measuring, and stamping tools. For manufacture of tools steels are supplied in the form of rods, tapes, wire, forgings, and so forth. For good workability carbon tool steels have to be well annealed. Finished tool is subjected to hardening and tempering. Temperature of hardening is selected from iron-carbon constitutional diagram and that of temper is selected in dependence upon assignment of tool and required hardness.

Carbon tool steels have high critical rate of hardening and low hardenability (10-12 mm); therefore it is recommended that they be applied for tools of small cross section.

Merits of carbon tool steels include: low hardness, good machinability and pressure workability in annealed state, and also high impact and vibration strength due to preservation of ductile core as result of low hardenability.

Carbon tool steels have the following deficiencies: narrow interval of tempering temperatures; necessity for carrying out sharp hardening, what involves considerable deformations and warping of tool. Tool of carbon steel is unfit for treatment of strong and hard alloys, cannot be used for treatment at high speeds or rapid feed. Therefore on contemporary highly productive machines of basic application are tools of special and high-speed cutting steels.

Properties and application of carbon tool steels, and also conditions of heat treatment, depend mainly on their carbon content.

In Fig. 10.3 are given samples of cutting (a) and measuring (b) tools made from carbon tool steels.

Approximate assignment of various grades of carbon tool steels are:

Steels U7 and U7A (0.65-0.74% C) - for tools subjected to blows and shocks and requiring considerable ductility, with moderate hardness: centers of machine lathes, chisels, set dies, sledge hammers, forging and metal-working hammers, stamps, and others.

Steels U8 and U8A (0.75-0.84% C) - for tools subjected to blows and requiring good ductility with high hardness: dies, punches, shears and knives for metal,

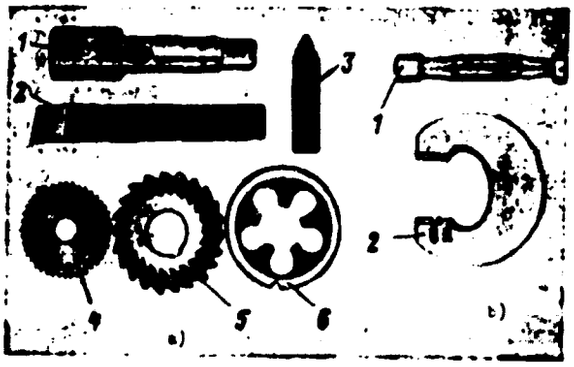


Fig. 10.3. Tools made from carbon steel. a) cutting tools: 1 – end-milling cutter, 2 – through cutter, 3 – thread cutter, and 6 – machine screw die from steel U10; 4 – groom-milling cutter and 5 – conical milling cutter of steel U12. b) measuring tools: 1 – bore gauge and 2 – outside caliper of steel U13.

carpenter's and pneumatic tools, and others.

Steels U9 and U9A (0.85-0.94% C) – for tools requiring hardness in the presence of certain ductility punches, hole punching dies, and others.

Steels U10 and U10A, U11 and U11A (0.95-1.09% C and 1.05-1.14% C) – for tools not subjected to strong blows, with high hardness on cutting edge: cutters, drills, taps, screw dies, reamers, milling cutters, blades, shaping dies, and others.

Steels U12 and U12A, U13 and U13A (1.15-1.24% C and 1.25-1.35% C) – for tools not subjected to blows and requiring hardness: lathe and planing cutters, files, scrapers, gauges, razors, drawing tools, and others.

C H A P T E R XI

ALLOY STEELS AND SPECIAL ALLOYS

§ 1. Concept of Alloy Steels

Alloy steel is that in which for production of required properties alloy elements are specially introduced: chromium, nickel, manganese, silicon, tungsten, molybdenum, vanadium, cobalt, titanium, niobium, aluminum, and others. Manganese and silicon, present in steel as constant impurities, are considered alloy components only when content of manganese is more than 1% and that of silicon is more than 0.8%.

Alloy elements introduced in steel change its mechanical or physicochemical properties. Basic advantages of alloy steel are revealed only after its heat treatment. Series of alloy steels does not change microstructure during heat treatment. Such steels are hardened by means of plastic deformation.

By alloying it is possible to increase considerably strength and hardness, preserving under known conditions satisfactory and good ductility.

Alloying of steel increases its hardenability and also makes it possible to produce hardening to martensite in moderate coolants, which decreases danger of appearance of cracks and warping of parts.

By alloying it is possible to give steels a series of special properties, such as heat resistance, resistance to scaling, acid resistance, and others.

Alloy steels are widely applied in aviation industry.

§ 2. Influence of Alloy Elements on Properties of Steel

Properties of steel during alloying are changed in dependence upon quantity of introduced alloy elements and character of their interaction with iron and carbon.

Alloy elements can be dissolved in ferrite to form carbides and chemical compound with iron.

Alloy elements affect phase transitions occurring in steel on character of its structure and on its properties.

Influence of alloy elements on allotropy of iron. Alloy elements, being dissolved in iron, influence position of critical points A_3 and A_4, and consequently region of existence of α- and γ- iron. One group of alloy elements expands region of γ-solid solutions of constitutional diagram of iron-alloy element system, other group narrows this region.

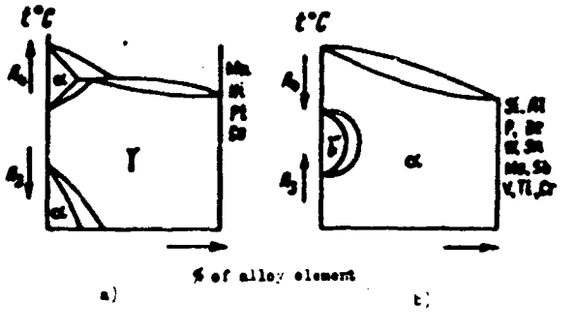


Fig. 11.1. Influence of alloy elements on allotropic transformations in iron. a) open domain of γ-iron, b) closed domain of γ-iron.

To first group belong nickel, manganese, carbon, copper, and nitrogen. They lower critical point A_3 and raise point A_4, i.e., form with iron expanded γ-region (Fig. 11.1a). With large quantity of these elements alloys will not have allotropic transformations and austenite will be stable even at room temperature. Such alloys are called austenitic.

To second group pertain silicon, chromium, aluminum, molybdenum, tungsten, vanadium, titanium, boron, zirconium, and phosphorus. They increase critical point A_3 and lower point A_4, i.e., form with iron closed γ-region (Fig. 11.1b). With large quantity of these elements alloys also will not have allotropic transformations, region of γ-iron will be suppressed and at any temperature structure of steel will consist of α-solid solution. Such steels are called ferrites.

Solubility of alloy elements in iron. As alloy additions there most frequently are applied elements capable of dissolving in iron. Solubility of majority of alloy elements in iron promotes small difference in atomic radii and similarity of crystal lattices.

Only elements with very small atomic radius (B, C, N, O, H) form with iron solid solutions of introduction of small concentration. All remaining elements dissolved in iron (Si, Ni, Co, Mn, Cr, Mo, W) form substitutional solid solutions.

Alloy elements, being dissolved in iron, change its properties: increase ultimate strength, yield point, hardness and lower ductility. Atoms of alloy elements, differing from iron atoms in dimensions and structure, create stresses in crystal lattice, causing changes in its parameters. Parameter of lattice is changed more the greater the difference between atomic dimensions of iron and alloy element.

Change of dimensions of crystal lattice of iron and causes considerable change of its properties. Alloy elements, having the same crystal lattice as ferrite and differing little in dimension from atoms from iron, strengthen ferrite insignificantly. Such elements include chromium, molybdenum, and tungsten. Conversely, elements having crystal lattice differing from ferrite sharply differ from iron in physicochemical properties and strengthen ferrite more than any others. These elements include manganese.

Ductility of ferrites below that of molybdenum, tungsten, manganese, and silicon. This is explained by large distinction in dimensions of atomic radii of iron and these alloy elements.

The most valuable element is nickel. It increases strength of ferrite and consequently strengtn of steel without lowering of its ductility and toughness. In ferrite is dissolved up to 25-30% nickel, where content of carbon in steel does not practically affect magnitude of maximum solubility of nickel in ferrite.

Nickel also increases toughness of structural steels, where the greater it is the less carbon is contained in steel.

Other elements even if not lowering toughness of ferrite, do increase its strength (chromium) or strongly increase strength, sharply lowering toughness (manganese and silicon).

Essential influence on mechanical properties of steel is rendered by its microstructure, which can be changed qualitatively through increased content of alloy elements. For instance, chromium little affects properties of steel in perlitic state but sharply increases strength of steel in martensite state.

Ratio of alloy elements to carbon. Depending on ratio of carbon, behavior of alloy elements can be different. According to ratio of carbon, alloy elements are

divided into two groups: carbide-forming and graphite-forming.

Carbide-forming elements are those which with carbon of steel form carbides - chemical compounds stabler than carbide of iron. They include the following elements: niobium, titanium, vanadium, tantalum, molybdenum, tungsten, chromium, manganese, and iron. These carbide-forming elements fall, according to degree of their affinity for carbon, in diminishing series. This means that niobium is the strongest carbide-forming element and iron is the weakest.

Carbide-forming elements can be dissolved in small quantity in cementite, forming alloyed cementite. Alloy elements can form simple carbides, for instance, Cr_4C, WC, TiC, and others, and complex (double) carbides, for instance, $(Fe, Cr)_4 C$, $(Fe, W)_6 C$, and others. Carbides formed by alloy elements are harder and more wear-resistant than carbide of iron (cementite). Role of carbides in forming of properties of steel is very great, since very many changes of properties of steel are connected with processes of dissolution, precipitation, or coagulation (enlargement) of carbide phase.

Elements which do not form carbides with carbon and lower stability of carbides of other elements form group of graphite-forming alloy elements. These elements include silicon, aluminum, nickel, and cobalt. They are arranged according to diminishing degree of graphitizing. Interacting with iron, these elements form solid solutions, and consequently are in ferrite or austenite.

Influence of alloy elements on heat treatment of steel. Alloy elements change position of critical points with respect to their position for carbon steel. This has large value during determination of temperature of heating of alloy steels for their heat treatment. Elements narrowing γ-region increase temperature of eutectoid transformation, and elements expanding γ-region lower it. Obviously, for steels alloyed with elements narrowing γ-region temperature during heat treatment is higher than for carbon steels. For steels alloyed with elements expanding γ-region temperatures reached before heat treatment will be lowered. Besides this, all alloy elements decrease concentration of carbon in perlite.

Essential influence on growth of grains of austenite during heating of steels is rendered by alloy elements. All alloy elements, with the exception of manganese, decrease inclination of austenite to grain growth when heated. Elements not forming carbides, and consequently being in solid solution during formation of austenite,

weakly influence this inclination. Carbide-forming elements strongly prevent growth of grains of austenite. We consider that carbides not dissolved in austenite mechanically prevent growth of grains of austenite. Analogously to carbide-forming elements, growth of grains of austenite is influenced by elements forming stable oxides (aluminum, silicon, titanium, and vanadium).

Very large influence is rendered by alloy elements on isothermal disintegration of austenite. All alloy elements, with the exception of cobalt, in this or that degree increase stability of austenite, shifting curves of isothermal transformation to the right.

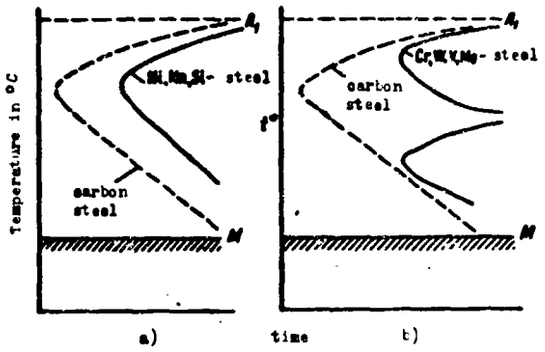


Fig. 11.2. Diagrams of isothermal disintegration of austenite. a) carbon steel and steel alloyed with noncarbide-forming elements, b) carbon steel and steel alloyed with carbide-forming elements.

Character of isothermal disintegration of austenite during cooling of alloy steels differs from character of disintegration of austenite of carbon steels. Noncarbide-forming elements and also manganese, shifting diagram of isothermal disintegration of austenite, does not change its character. With alloying by carbide-forming elements, on diagram of isothermal disintegration of austenite appears second maximum (Fig. 11.2). Thus for these steels in interval of temperatures between two maxima austenite possesses very great stability. The greatest stability of austenite is noted at 500-600°C, i.e., in this interval of temperatures, where steels alloyed with noncarbide-forming elements have stability of austenite. Therefore simultaneous alloying of steel with elements of both groups permits obtaining high stability of austenite.

However, carbide-forming elements increase stability of austenite only in that case when they are dissolved in it. Carbides outside solution of austenite lower

its stability. Increasing stability of cooled austenite, alloy elements strongly lower critical rate of hardening and increase hardenability (exception is cobalt). Therefore alloy steels are hardened at slower rate of cooling. This permits application as liquid coolant of oil (instead of water) and the obtaining of raised mechanical qualities for parts of considerable dimensions. Hardenability is especially strongly increased by molybdenum, manganese, chromium, and nickel. Hardenability of steel is influenced in strong degree by small additions of boron (about 0.004%).

Majority of alloy elements (besides Al and Co) lowers temperatures of martensite transformation and increases quantity of residual austenite. The biggest influence on martensite point is rendered by manganese, chromium, and nickel. With sufficiently large content of these elements, temperature of beginning of martensite transformation can fall below zero. In such steels at room temperature austenitic structure can be obtained. Temperature of end of martensite transformation also is lowered by majority of alloy elements, but less energetically than temperature of beginning of transformation.

Alloy elements not forming carbides affect character of change of hardness during tempering. Carbide-forming elements change condition of transformations during tempering. Alloying of steel with carbide-forming elements delays process of disintegration of martensite. Therefore in order during tempering to lower hardness to assigned limit it is necessary to heat alloy steel to higher temperature or to give more time to tempering than for carbon steel.

Owing to the fact that alloy elements decrease thermal conductivity of steel, alloy steels during heat treatment must be heated and cooled more evenly and slowly. Otherwise considerable internal stresses are formed, which can lead to cracks and warping of article.

Characteristics of influence of alloy elements. So as to make correct selection of steel for different articles it is necessary to know the influence on its properties rendered by most important alloy elements.

Chromium – cheap element, widely applied in alloy steels. In structural steels it is contained in quantity up to 3%. It increases hardness and strength of steel and simultaneously insignificantly lowers ductility and toughness. Presence of chromium increases hardenability of steel. Thanks to high wear-resistance of chromium steels, from it are prepared antifriction bearings. Chromium is introduced

into composition of high-speed cutting steels. With chromium content of over 13% steel becomes rust-resistant. Further increase of chromium content imparts oxidation resistance to steels at high temperatures. Chromium also imparts stability of magnetic properties to steel.

Nickel - costly alloy element. Due to its high cost it is applied only in those cases when it is impossible to replace it by a cheaper element. In structural steels is contained from 1 to 5% nickel. It gives steels strength, high ductility, and toughness. Large nickel content is used in those cases when it is necessary to obtain nonmagnetic steel and raised corrosion resistance. For alloying of tool steels nickel is not applied.

Tungsten - costly alloy element. Present in small quantities in structural steels (not over 1.5%). It increases hardness and strength of steel and promotes formation of fine-grained structure. Tungsten in raised quantities (not more than 22%) is introduced into tool steel for improvement of cutting properties and is indispensible addition in high-speed cutting steels. Presence of tungsten is desirable in heat-resisting steels.

Molybdenum - scarce element. Present in small quantities in structural steels (0.2-0.6%). Increases strength and hardness of steel, insignificantly lowers ductility and toughness, and decreases temper brittleness. In tool (high-speed cutting) steels molybdenum increases red hardness. The most valuable property of molybdenum is that it imparts heat resistance to steels.

Vanadium is introduced in small quantities into structural steels (0.1-0.3%), tool steels (0.15-0.65%), and high-speed cutting steels (up to 2.5%). It increases hardness of steel and gives it fine-grained structure with raised elasticity and fatigue strength.

Manganese - cheap alloy element. An inevitable impurity introduced into steel for deoxidation. It is considered an alloy element if its content is higher than 1%. In structural steels it is present in not more than 2%. Manganese promotes deep hardenability of steel and improves its mechanical properties. Raised content of manganese gives steels wear-resistance and makes it nonmagnetic.

Silicon - accessible and cheap element. It is like manganese, an inevitable impurity of steel, introduced for deoxidation.

In structural steels it is contained in up to 2%, it increases strength and

elasticity of steel while preserving toughness (in spring steels). Raised content of silicon in steel, up to 2-4%, increases its electrical resistance and magnetic permeability.

Niobium and titanium are added to steel in small quantities (0.1-0.2%). In rust-resistant chromium-nickel steels they prevent appearance intercrystalline corrosion. They promote fine-grained structure, favorably reflected in mechanical properties of steel.

Aluminum is introduced into steel subjected to nitriding to increase hardness. Besides this, with content of 5-6% it imparts resistance to scaling to steels. Aluminum in 12-15% is introduced into alloys going to manufacture of permanent magnets with high magnetic properties.

Boron in very small quantities (to 0.002%) considerably increases hardenability of steel. Presence of boron increases resilience of steel after low tempering. Even 0.01% boron in heat-resisting alloys increases their heat resistance.

§ 3. Flaws in Alloy Steels

In alloy steels can appear the following flaws: dendritic liquation, flakes, temper brittleness, and slaty fracture.

Dendritic liquation of alloy steels consists in that during slow cooling of ingot there first hardens solid solution impoverished of carbon and alloy elements, and then in interdendritic spaces occurs formation of crystals richer in carbon and alloy elements. Dendritic liquation is due to the fact that in alloy steels temperature interval of crystallization is great. And since diffusion rate of alloy elements in steel is low, dendritic liquation is preserved. After being rolled, such steel frequently takes on characteristic banded structure (Fig. 11.3), which imparts to it different properties with and across direction of rolling, lowers strength, and worsens workability. It is possible to decrease dendritic liquation by prolonged diffusion annealing of ingot before they are rolled.



Fig. 11.3. Banded structure of steel.

Flakes are very dangerous flaw in alloy steel. Flakes are very small internal cracks revealed in break of alloy steels in the form of white spots (Fig. 11.4).

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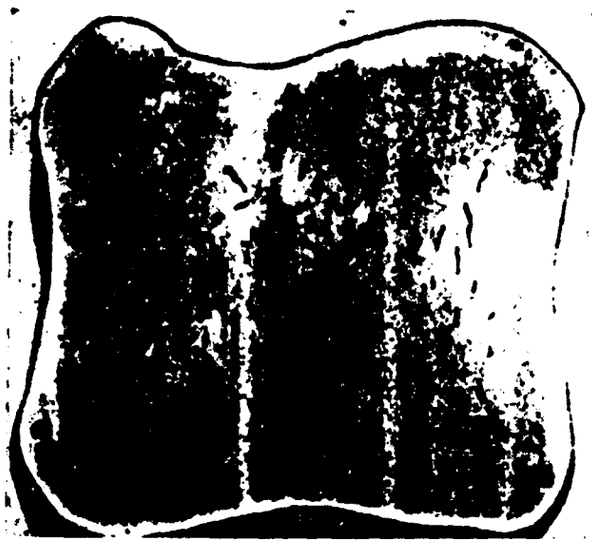


Fig. 11.4. Flakes in chrome-nickel steels.

Most subject to formation of flakes are steels containing chromium. Flakes strongly lower impact strength of steel and its resistance to variable loads.

Flakes can be formed in steel owing to appearance of high internal stresses, provoking cracks. Cause of appearance of such high internal stresses can be accumulation of liberated hydrogen, dissolving in liquid steel. During fast cooling after rolling or forging hydrogen liberated as result of lowering of solubility is not able to diffuse from internal layers, are created bubbles with high internal pressure, which leads to breaks. In addition to this, cracks in ingot can be formed as a result of appearance of internal stresses during nonsimultaneousness phase transitions in connection with heterogeneity of steel.

To prevent appearance of flakes is possible by melting steel under conditions preventing entry of hydrogen. For decrease of formation of flakes it is expedient to apply slow cooling of ingots, during which hydrogen absorbed by steel departs from it without causing breaks. Steel in which flakes already have formed is corrected by rolling to small profiles or by applying large forging reduction ratio, resulting in welding of cracks.

Temper brittleness. Many alloy steels (chrome-nickel, chrome-manganese) display sensitivity to method of cooling after high tempering. Through slow cooling after high tempering they obtain very considerable brittleness, which is not observed under conditions of rapid cooling.

Supposed cause of temper brittleness is precipitation of small carbides on

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Fig. 11.5. Slaty fracture steel.

grain boundaries during slow cooling of steel after tempering in interval of 500-600°.

Steels sensitive to temper brittleness must be cooled rapidly after high tempering. Additional alloying of these steels with molybdenum also removes temper brittleness.

Slaty fracture - laminar structure of steel (Fig. 11.5). Such steel possesses raised brittleness. Slaty fracture appears after hot pressure working in accordance with place of structural location of defects. The less harmful impurities and blowholes in ingot the less the probability of formation of slaty fracture.

§ 4. Classification and Grading of Alloy Steels

Classification of Alloy Steels

Alloy steels are classified according to four criteria: chemical composition, assignment, structure in annealed state, and structure after cooling in air.

Classification by chemical composition considers those elements besides iron and carbon and in what quantities they exist in steel.

Depending upon quantity of alloy elements, we distinguish ternary, quaternary, and complex-alloy steels.

Ternary steels contain iron, carbon, and one alloy element; quaternary alloys contain iron, carbon, and two alloy elements; and complex-alloy steels contain three and more alloying elements.

Depending upon what elements are present in steel, it is called, for instance, chromium, manganese, chromium-manganese, chrome-nickel, chromium-manganese-silicon, and so forth.

Depending upon total content of alloy elements, we distinguish: low-alloy steels, with total content of alloy elements not higher than 3%; medium-alloy steel, with total content of alloy elements of from 3 to 10%; and high-alloy steel, with total content of alloy elements higher than 10%.

Classification by assignment considers criterion of application of steels. According to assignment alloy steels are divided into three basic classes: structural, tool, and steel of special assignment.

Structural steel is intended for manufacture of machine parts. Of structural steels is required good complex of mechanical properties.

Tool steels are applied for manufacture of tools of different assignment: cutting, measuring, stamping, and others. Of tool steels is required mainly hardness and wear-resistance.

Steels of special assignment are designed for special purposes. They include steels with any sharply expressed property. For instance, stainless steel is evaluated according to chemical stability; heat-resisting steel is evaluated according to mechanical strength at high temperatures; transformer steel is evaluated according to energy losses to polarity reversal, etc.

Classification according to structure in annealed state considers those structures of steel in equilibrium state. In accordance with this criterion alloy steels are divided into the following classes: hypoeutectoid, hypereutectoid, and ledeburite.

Hypoeutectoid steels contain free ferrite in their structure. Hypereutectoid steels have excess carbides in their structure. Ledeburite steels contain primary carbides in their structure, separated from liquid steel.

It is necessary to consider that for alloy steels boundary between hypoeutectoid and hypereutectoid steels on the one hand and hypereutectoid and ledeburite steels on the other hand corresponds to smaller content of carbon than in carbon steels. This is explained by the fact that the majority of alloy elements displaces points S and E of iron-carbon constitutional diagram toward smaller concentrations of carbon. Thus, carbon steels containing less than 0.8% carbon belong to hypoeutectoid class and those containing more than 2% carbon belong to ledeburites. With 5% chromium steel with 0.6% carbon content will be hypereutectoid and steel with 1.5% carbon content will be ledeburite.

Besides this, steels of ferrite and austenitic classes are also possible.

With small content of carbon and high content of alloy element, narrowing γ-region (chromium, tungsten, molybdenum, vanadium, silicon, and others), ferrite steels are obtained, having only structure of α-solid solution.

With high content of alloy elements, expending γ-region (nickel, manganese, and others), austenitic steels are obtained, having only structure of γ-solid solution.

Classification by structure after cooling in air considers what structures are taken by steel samples of small cross section after normalization. According to this criterion alloy steels are divided into three basic classes: perlite, martensite, and austenite. This classification is very important, since structure of steel uniquely determines its properties. Thus, steel having perlitic structure possesses low hardness and high ductility, and steel having martensite structure is very hard and brittle. The first well and easily machines, the second is difficult to machine and responds poorly.

Formation of these classes of steel is determined by stability of cooled austenite. The greater the content of alloy element in steel the greater the stability of cooled austenite and the lower the temperature of martensite transformation. Therefore for the same rate of cooling (in air) in steels of equal composition are formed different structures: mixtures of ferrite with cementite, martensite, or austenite.

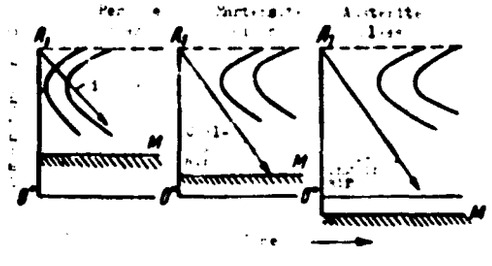


Fig. 11.6. Diagrams of isothermal disintegration of austenite for three classes of steels.

In Fig. 11.6 are depicted diagrams of isothermal disintegration of austenite for steels of various classes. From diagram one may see how curves of cooling rate having the same slope, depending upon how far to the right C-shaped diagrams are shifted, intersect them at various temperatures, which also determines structure of disintegration of austenite.

Steels of perlite class contain comparatively small quantity of alloy elements (not more than 3-4%). After cooling in air, austenite in these steels disintegrates in region of high temperatures, with formation of ferrite-cementite mixture (perlite, sorbite, or troostite). To this class belongs the overwhelming majority of structural and tool steels.

Steels of martensite class contain raised quantity of alloy elements, expanding γ-region (Mn, Ni). These elements shift diagram of isothermal transformation to the right, so that austenite is cooled to martensitic point.

After cooling in air structure, steels are alloyed martensite, in which can be included excess carbides. Application of these steels is small.

Steels of austenitic class contain up to 20-25% alloy elements (basically Ni, Cr, Mn). Owing to high stability of austenite [illegible] martensite point in

region of negative temperatures, cooling in air leads to preservation of austenite at room temperature (see Fig. 11.1a). These steels include chrome-nickel stainless steels, certain heat-resisting steels, high-manganese wear-resisting steels, and other steels with special properties.

Steels containing large quantity of ferrite-forming elements with small carbon content can be placed in ferrite class (see Fig. 11.1b).

Besides this, steels having primary carbides in their structure, independently of structure of metallic base, frequently are called carbide or ledeburite steels. They have in their composition considerable quantity of carbon and carbide-forming elements (Cr, W, V, Mo).

Alloy steels, depending upon form of heat treatment, are additionally divided into carburized and improved steels.

Carburized steels contain up to 0.25% carbon and one or several alloy elements, promoting hardening during carburizing (Ni, Cr, Mn, W).

Improved steels are hardened and given high temper (thermal improvement), they contain average quantity of carbon (0.25-0.45%) and such alloy elements as nickel, chromium, tungsten, and molybdenum.

Also encountered is classification of steel in accordance with technological criterion. Basis for this is workability of steel by some method. According to this classification, steels are divided into deformable, casting, machinable, heat-treatable, and others.

Considered types of classification of steel are tightly interconnected. Thus, the same steel can be: low-alloy, chromium, structural, perlite, hypoeutectoid, forge, or improved.

Grading of Alloy Steels

Designation of grades of alloy steels follows literal-digital system. Alloy elements are designated by following letters: nickel [N] (Н), chromium [Kh] (Х), tungsten [V] (В), vanadium [F] (Ф), molybdenum [M] (М), titanium [T] (Т), cobalt [K] (К), silicon [S] (С), manganese [G] (Г), aluminum [Yu] (Ю), copper [D] (Д), niobium [B] (Б), boron [R] (Р), phosphorus [P] (П).

Every grade consists of combination of figures and letters. First figures of grade of steel denote average content of carbon in hundredth shares of a percent. Figures following letters indicate average content of given element in steel in

whole percents if its content exceeds 1.5%.

Letter A at the end of grade indicates high quality steel (purity with respect to harmful impurities) and high requirements of metallurgical control.

For instance, steel [30KhGSA] (30ХГСА), on the average, contains 0.30% carbon, 1% chromium, 1% manganese, 1% silicon, 0.03% sulfur, and 0.03% phosphorus.

If ahead of grade is one figure, it indicates carbon content in tenth shares of a percent. For instance, steel 2Kh18N9 contains 0.2% carbon, 18% chromium, and 9% nickel.

If there are no figures ahead of grade, carbon in steel, on the average, is 1% or more. For instance, to steel KhV5 contains 1.25-1.5% carbon, about 1% chromium, and about 5% tungsten.

In separate cases simplifications in designation steel are allowed, certain figures being omitted. For instance, instead of 18Kh2N4VA, we write simply 1-KhNVA.

Certain high alloy steels are divided into special groups and are designated by letters placed ahead of designaton: [Zh] (Ж) chromium stainless steels, [Ya] (Я) chrome-nickel stainless steels, [Ye] (Е) electrical steels with special magnetic properties, P high-speed cutting steels, [Sh] (Ш) ballbearing steels. For instance, steels Zh1, Ya1, Ye12, R18, and ShKh15.

Steels smelted at "Elektrostal'" factory are designated by letter [E] (Э), those smelted in the same place as experimental grades are designated by letters [EI] (ЭИ) and a reference number. For instance, EI402, EI618, etc.

§ 5. Structural Alloy Steels

Structural steels are applied for manufacture of machine parts and mechanisms. On basis of conditions of their work, they have to possess complex of high mechanical properties. high strength, for resistance to large static loads; high ductility and toughness, for resistance to dynamic impacts; high endurance limit, for resistance to sign-alternating loads.

For parts of vital assignment are applied structural alloy steels possessing high mechanical properties and hardenability than carbon steels.

The biggest increase of mechanical properties is attained as a result of addition of several elements simultaneously. Best effect is given by alloying steels with elements in following combinations: Ni + Cr; Ni + Cr; Ni + W; Ni + Cr + W; Ni + Cr + W; Mn + Cr + Mo; Mn + Cr + Ti.

Here, it is necessary to consider that manganese, silicon, and chromium are cheap elements and nickel and molybdenum are scarce.

Best combination of properties of alloy steel is revealed after heat treatment; therefore machine parts prepared from alloy steel must be strengthened by heat treatment.

Most frequently structural steels are hardened in oil with subsequent high or low tempering. For certain steels good combination of strength and toughness is obtained as a result of isothermal hardening at a temperature of 300-400°C.

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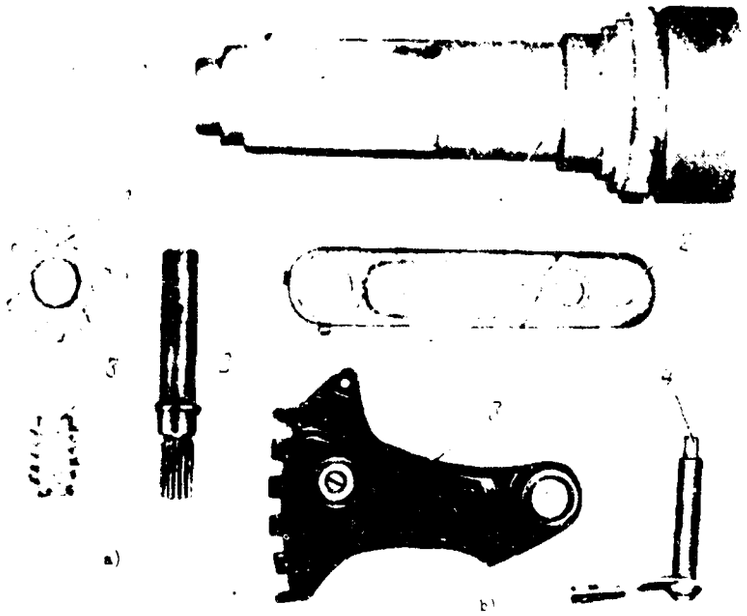


Fig. 11.7. Parts made from structural steels. a) carburized parts. 1 – oil pump gear, 2 – splined drive shaft of aircraft generator, and 3 – worm reduction gear for flap-limit switch of steel 12KhN3A; b) improved parts. 1 – shaft of gas turbine of jet engine of steel 40KhNMA, 2 – rocker of aileron control, 3 – toothed sector of elevator control, 4 – handle of landing-flap hoist of steel 30KhGSA.

In Fig. 11.7 are presented samples of parts made from structural alloy steels.

Let us consider the most important structural alloy steels.

Ternary Alloy Steels

Ternary alloy steels include steels containing, besides iron and carbon, one more alloy element. For instance, addition of nickel gives nickel steels, addition of chromium gives chromium steels, etc.

Nickel steels have high strength, considerable ductility and toughness, and good productibility (are processed well by pressure and cutting).

Chemical composition of nickel steels is characterized by content of nickel from 1.2 to 5.5% and carbon from 0.1 to 0.4%.

Low-carbon nickel steels, containing up to 0.15% carbon, are carburized. They include steels 13N2A (0.10-0.16% C; 0.3-0.6% Mn; 1.7-2.2% Ni), 13N5A (0.10-0.17% C; 0.3-0.6% Mn; 4.5-5.5% Ni), and others.

These grades are used for manufacture of camshafts, cam discs, and lightly-loaded parts.

Owing to scarcity of nickel, nickel steels find limited application.

Chromium steels have high strength and hardness after heat treatment, are cheap, and find wide application. Chromium is strong carbide-forming element. Property of chromium to increase hardness of steel is utilized in high-carbon bearing steels. In Table 7 are given approximate chemical composition and mechanical properties of the most common chromium steels.

Table 7. Chemical Composition and Mechanical Properties of Chromium Steels

Grade	Chemical composition in %				Mechanical properties (not less)		
	C	Si	Mn	Cr	σ_B MN/m²	δ %	σ_{in} MJ/m²
15XA	0,12—0,17	0,17—0,37	0,30—0,60	0,70—1,00	600—700	11—15	0,9
38XA	0,34—0,42	0,17—0,37	0,50—0,80	0,80—1,10	900—950	12	0,9
ШХ15	0,95—1,10	0,15—0,35	0,20—0,40	1,30—1,65	600—730	15—25	0,45

Carburized steel 15KhA after being carburized at 900-920°C is subjected to final heat treatment, which consists in hardening from 860°C in oil and tempering at 150-170°C. Steel is supplied in the form of rods. It is used for manufacture of small carburized parts and is substitute for steel 13N2A.

Improved steel 38KhA machines well in annealed state but welds poorly. For imparting final properties parts are hardened from 860°C in oil and tempered at 590°C. Steel is supplied in the form of rods and forgings. It is used for manufacture of pins, shafts, bolts, studs of gears, and other parts.

Ball bearing steel ShKh15 for improvement of workability and preparation of structure for hardening is annealed to granular perlite for 4-6 hours at 780-790°C. It is hardened from 820-840°C in oil or water and is tempered at 180-200°C. It is used for manufacture of parts requiring high resistance to wear, for ball bearings,

and others. It is supplied in the form of rods, bands, and tubing.

Silicon steels, having 1.5-2.0% Si and raised carbon content, possess good resile properties and are used widely for manufacture of springs subjected to heat treatment.

Of greatest application are silicon steels of grades 55SA and 60S2A.

They are supplied in the form of bands, rods, and tapes and are used for manufacture of flat and coil springs. After hardening and medium tempering, they are distinguished by high hardness and elasticity. For instance, steel 60S2A (0.56-0.64% C; 1.6-2.0% Si) after being hardened from 870°C in oil and tempered at 460°C, has following mechanical properties: σ_B = 1300 MN/m^2 (130 kgf/mm^2); $\sigma_{0.2}$ = 1200 MN/m^2 (120 kgf/mm^2); δ = 5%.

In addition to that, silicon steels find wide application for manufacture of parts of electrical and radio equipment.

Manganese steels, containing to 2% manganese, are applied widely as structural material. Manganese increases their strength and hardenability. With small content of carbon (0.1-0.25%) these steels possess high ductility and good weldability, and with raised carbon content (0.60-0.70%) they are hard and elastic.

Chemical composition and mechanical properties of those grades of steel most widely applied in aircraft building are given in Table 8.

Table 8. Chemical Composition and Mechanical Properties of Manganese Steels

Grade	Chemical composition in %		Mechanical properties (not less)	
	C	Mn	σ_B MN/m^2	δ %
10Г2А	0,08—0,17	1,20—1,60	400—580	22
12Г2А	0,12—0,20	2,0—2,4	500—650	18
20ГА	0,18—0,26	1,30—1,60	500—700	10
65Г	0,60—0,70	0,90—1,20	1500—1650	4

Steels 10G2A and 12G2A possess excellent weldability and do not form welding cracks even under very severe conditions of welding.

Steel 10G2A, thanks to high plasticity, is well suited to stamping, bending, and other technological operations. It is applied in annealed or normalized state for welded and stamped parts with ultimate strength up to 400-500 MN/m^2 (40-50 kgf/mm^2). This steel is supplied in the form of thin sheets, tubing, and rods.

Steel 12G2A, in view of raised content of carbon and manganese as compared to steel 10G2A, has higher mechanical properties. Of steel 12G2A are prepared welded and stamped aircraft parts with ultimate strength of 600-900 MN/m^2 (60-90 kgf/mm^2).

Steel 20GA is applied in aircraft building as material for rivets in vital parts and constructions. The most important merits of rivets of steel 20GA are their good upsetability and high shear strength.

Steel 65G possesses bad workability. It is subjected to heat treatment (hardening and temper), which gives it raised strength and elasticity. It is supplied in the form of rods, wire, and sheets. It is used for manufacture of springs and washers.

Quaternary and More Complex Alloy Steels

Chrome-nickel steels are the most widespread steels in aviation industry. Chromium and nickel as alloy elements complement one another very successfully. Simultaneous introduction to steel of chromium and nickel leads to increase of complex of mechanical properties (strength, hardness, toughness, and ductility) and to increase of hardenability.

The most favorable combination of mechanical properties is observed with content in steel of carbon of from 0.15% to 0.45%, chromium of from 0.5% to 2%, and nickel of from 2 to 5%. By changing the relationship between these elements in steel the most varied properties can be obtained.

Chrome-nickel steels with small content of carbon are carburized and those with raised content of carbon are improved.

Further strengthening of chrome-nickel is attained by additional alloying with small quantities of tungsten or molybdenum.

Deficiencies of chrome-nickel are inclination to temper brittleness and formation of flakes.

Chrome-manganese steels are a substitute for chrome-nickel steels. Raised hardenability in them is attained by introduction of cheap manganese instead of scarce nickel. Additional alloying of them with titanium led to creation of widely-spread carburized chromium-manganese-titanium steels.

Chromium-silicon-manganese steels (Cromansil) have successfully replaced chromium-molybdenum steel, which until relatively recently was one of basic steels in aircraft building. Cromansil possesses high hardness plus good stampability

and weldability. At present it is basic aircraft steel.

Chromium-vanadium and chromium-aluminum steels also find wide application. The first possess fine-grained structure with raised ductility, toughness, and elasticity. They are best material for manufacture of vital springs. The second constitute high-hardness materials. Chromium and aluminum are nitride-forming elements; therefore these elements are introduced into steel for manufacture of nitrided articles.

Carburized alloy steels are applied for heavily loaded parts which must have, besides high hardness and wear-resistance of surface, sufficiently strong and ductile core.

Chemical composition of certain carburized and nitrided structural steels is given in Table 9 and mechanical properties are given in Table 10.

Table 9. Chemical Composition of Carburized and Nitrided Steels in %

Grade	C	Si	Mn	Cr	Ni	Other elements
12KhN3A	0,09–0,16	0,17–0,37	0,30–0,60	0,60–0,90	2,75–3,25	—
12Kh2N4A	0,09–0,15	0,17–0,37	0,30–0,60	1,25–1,75	3,25–3,75	—
15Kh2GN2TRA	0,12–0,18	0,17–0,37	0,70–1,00	1,40–1,80	1,40–1,80	Ti 0,06–0,12; B 0,002–0,006
18Kh2N4VA (18KhNMA)	0,14–0,21	0,17–0,37	0,25–0,55	1,35–1,65	4,00–4,5	W 0,80–1,20 or Mo 0,25–0,30
38KhMYuA (nitrided)	0,35–0,42	0,17–0,37	0,30–0,60	1,35–1,65	< 0,60	Al 0,70–1,10; Mo 0,15–0,25

Table 10. Mechanical Properties of Carburized and Nitrided Steels

Grade	Heat treatment	Mechanical Properties (not less)		
		σ_B MN/m^2	δ %	a_H MJ/m^2
12KhN3A	First hardening from 860°C in oil, second hardening from 780-810°C in oil, and tempering at 150-170°C	950	12	1.2
12Kh2N4A	Hardening from 760-780°C in oil and tempering at 150-170°C	1000	12	1.0
15Kh2GN2TRA	Hardening from 810-850°C in oil and tempering at 160-180°C	1050	13	1.0
18Kh2N4VA (18KhNMA)	First hardening from 950°C in air, second hardening from 850°C in air, and tempering at 160°C	1150	11	1.0
38KhMYuA	Hardening from 930-950°C in water and tempering at 600-670°C	1100	15	0.9

Steel 12KhN3A possesses raised strength and ductility. It is used for manufacture of gears, camshafts, shafts, rollers, regulating screws, and other carburized parts.

Steel 12Kh2N4A possesses raised content of chromium and nickel as compared to steel 12KhN3A, which provides it higher strength and ductility. It is supplied in the form of rods and forgings. It is used for manufacture of vital gears, different shafts, studs, pistons, shafts, rollers, etc.

Steels 12KhN3A and 12KhN4A are subject to temper brittleness.

Steel 12Kh2GN2TRA contains less nickel than other chrome-nickel carburized steels. Therefore raised content of residual austenite in surface layer after carburization and heat treatment is not observed. Steel 15Kh2GN2TRA, possessing high strength, can serve as equal substitute for chrome-nickel and steels still more complicated in composition, with raised nickel content (12KhN3A), 12Kh2N4A, and 18Kh2N4VA, and others). From this steel are prepared gears, shafts, and other carburized parts.

Steel 18Kh2N4VA is medium-alloy steel. Presence in it of 1% tungsten or 0.4% molybdenum (steel 18KhNMA) increases hardenability of steel, making it unreceptive to overheating, increases strength and impart toughness. This steel possesses high endurance limit.

Steel 18Kh2N4VA belongs to martensite class; therefore hardening in oil for it can be replaced by normalization.

This steel is applied both in carburized and uncarburized form for manufacture of heavily loaded engine parts: shafts of turbines, connecting sleeves, crankshafts and connecting rods of piston engines, gears, and other vital parts.

Uncarburized parts can be subjected to low or high temper. Here, their mechanical properties are characterized by following indices:

	σ_B MN/m^2	δ %	a_H MJ/m^2
After double hardening and tempering at 170°C	1200	10	1.0
After hardening and tempering at 550°C with cooling in oil	1100	12	1.0

Since steel 18Kh2N4VA is subject to temper brittleness, after high tempering cooling in oil is required.

Steel 18Kh2N4VA preserves its strength indices to temperature of 350°C. Therefore it may also be applied for manufacture of carburized engine parts working

at raised temperature.

Steel 38KhMYuA is the steel most widely used for nitriding. It is alloyed with chromium. molybdenum, and aluminum. Aluminum during nitriding of this steel forms stable nitrides and considerably increases hardness of surface layer. Chromium is introduced for increase of strength of core of part and molybdenum for increase of hardenability of steel. Before being nitrided, part undergoes final heat treatment (hardening in oil and high temper), which decreases deformation of part occurring during nitriding and improves complex of mechanical properties of steel. Nitrided layer possesses high wear-resistance and raised fatigue strength. Of steel 38KhMYuA are prepared cylinder sleeves of aircraft engines, highly-loaded gears, and other parts. Nitriding may also be applied to steels 38KhA, 18Kh2N4VA, and other grades, but effect of nitriding for these steels is less.

Improved alloy steels usually are hardened and given high temper, to sorbite. Such steels are used for manufacture of loaded parts experiencing variable loads during work.

Chemical composition of certain improved structural steels is given in Table 11, and mechanical properties are given in Table 12.

Table 11. Chemical Composition of Improved Alloy Steels in %

Grade	C	Si	Mn	Cr	Ni	Other elements
[illegible]	0,47–0,55	0,15–0,35	0,30–0,60	0,75–1,10	< 0,3	V 0,15–0,25
[illegible]	0,33–0,44	0,17–0,37	0,80–0,80	0,60–0,90	1,25–1,75	Mo 0,15–0,25
[illegible]	0,35–0,45	0,35–1,35	0,40–1,10	0,80–1,10	< 0,4	–
[illegible]	0,37–0,34	0,35–1,35	1,00–1,30	0,90–1,30	1,40–1,80	–
[illegible] (ЭИ712)	0,00–0,15	0,17–0,37	0,30–0,70	1,50–2,40	0,80–1,30	V 0,15–0,30 W 1,00–1,40
[illegible] (ЭИ689)	0,10 0,35	0,17–0,37	0,30–0,60	1,50 2,40	0,80–1,30	V 0,15–0,30 W 1,00–1,40

Steel 50KhFA. Vanadium introduced into steel increases its hardness and crushes structure, which improves mechanical properties. Steel possesses high elastic and fatigue limits.

It is applied in heat-treated state for valve and other springs and springs of vital assignment working at raised temperatures. Steel hardens well and is resistant to overheating.

Steel 50KhNMA is used widely for manufacture of parts of aircraft engines

Table 12. Mechanical Properties of Improved Steels

Grade	Heat Treatment	Mechanical Properties		
		σ_B MN/m^2	δ %	a_u MJ/m^2
50KhFA	Hardening from 860°C in oil, tempering at 475°C	1500	10	–
40KhNMA	Hardening from 850°C in oil, tempering at 600°C	1100	10	0.7
30KhGSA	Hardening from 870-890°C in oil, tempering at 510-570°C	1100	10	0.5
30KhGSNA	Hardening from 900°C in oil, tempering at 200-300°C	1600	8	0.6
12Kh2NVFA (EI712)	Hardening from 910°C in oil, tempering at 550°C	1090	15.6	0.85
23Kh2NVFA (EI659)	Hardening from 890°C in oil, tempering at 500°C	1350	12.5	0.65

subjected to large variable and impact loads. Molybdenum introduced into steel (to 0.3%) increases hardenability, decreases inclination of steel to brittle fracture, and provides high mechanical properties. Molybdenum is carbide-forming element and therefore lowers inclination of steel to grain growth and expands interval of heating during heat treatment. Steel 40KhNMA is cheaper than steel 18Kh2N4VA, although their mechanical properties are almost identical. It possesses high strength, toughness, and endurance. It is supplied in the form of rods and forgings. Parts made from this steel are subjected to improvement. When necessary it may be nitrided. Steel 40KhNMA is used for manufacture of shafts, turbines, connecting rods, vital bolts, and other parts.

It is applied also for shaped casting. It possesses good fluidity. Casting machines well. This steel is used for manufacture of castings of engine parts.

"Cromansil" is basic steel applied in aircraft building. It does not contain expensive alloy elements, but as a result of successful combination of chromium, manganese, and silicon, has good mechanical and technological properties. When this steel is heated, silicon jointly with chromium brakes grain growth of austenite, promoting stability of martensite and preservation of hardness during tempering. Presence of chromium, manganese, and silicon leads to improvement of hardenability but at the same time increases inclination to temper brittleness. The following grades of Cromansil exist: 25KhGSA, 30KhGSA, and 35KhGSL.

Steel 30KhGSA is the most widely applied in aircraft building. In annealed state it has satisfactory ductility, is suitable for stamping, is processed

satisfactorily by cutting tools, welds well by arc welding and satisfactorily by other forms of welding.

Steel possesses good hardenability (to 25 mm). Heat treatment of it consists of hardening from temperature of 890 ± 10°C in oil and tempering at 200-600°C for production of assigned properties. With low temper steel has very high strength but low impact toughness. With increase of temperature of temper impact toughness is increased. Best combination of strength and toughness is obtained after tempering at 480-580°C (see Table 12). For hardening steel is cooled in oil or in hot water. Cromansil is inclined to temper brittleness; therefore parts made from it after being tempered at 400-500°C must be cooled fast (in water or oil). For small or thin-walled parts for decrease of warping and prevention of hardening cracks is applied isothermal hardening at a temperature of 320-400°C.

Steel 30KhGSA possesses inclination to formation of cracks in zone of welded seam, which makes it necessary to carry out heat treatment of welded joints after welding.

Cromansil is supplied in the form of sheets, tubing, rods, profiles, wire, and forgings. It is used for manufacture of longerons, girders, chassis components, and other vital parts of aircraft.

Steel 25KhGSA differs from steel 30KhGSA only by lowered carbon content, which decreases strength somewhat. It is more weldable and stampable steel better than 30KhGSA. Steel 25KhGSA is used for manufacture of vital welded and stamped parts with ultimate strength not higher than 1100-1150 MN/m^2 (110-115 kgf/mm^2).

Steel 35KhGSL is used for manufacture of high-strength shaped castings. It differs from steel 30KhGSA by raised content of carbon and manganese. Castings machine well.

High-strength steel 30KhGSNA differs from steel 30KhGSA by presence of 1.5% nickel. Introduction of nickel considerably increases mechanical properties of steel (especially impact toughness) and increases hardenability to 75 mm. This steel possesses low sensitivity to concentration of stresses.

Subjected to hardening and low temper, steel possesses raised strength. The highest complex of mechanical properties of steel 30KhGSNA is obtained after isothermal hardening. It welds well by arc, satisfactorily by atomic-hydrogen arc, and unsatisfactorily by gas.

Steel 30KhGSNA is used for manufacture of the most vital parts of aircraft: chassis, bands of wing and center section, butt joints, big bolts, and so forth.

Steel 12Kh2NVFA (EI712) and 23Kh2NVFA (EI656). For manufacture of separate load-carrying parts of aircraft structures subjected to heating due to great speed of flight or thermal radiation from motor, necessity for new materials arose.

First of all they have to possess ability to preserve properties and not to be oxidized at raised operating temperatures.

These requirements are not satisfied by considered structural alloy steels.

In some cases heat treatment of large steel assemblies after welding is hampered or impossible. Here, necessity arises for application of material not requiring heat treatment after welding. Such material was not available for aircraft building until recently.

Steels 12Kh2NVFA (EI712) and 23Kh2NVFA (EI659), developed recently, satisfy enumerated requirements: they possess satisfactory mechanical properties at raised temperatures and do not require heat treatment after welding. Steel 23Kh2NVFA (EI659) differs from steel 12Kh2NVFA (EI712) by higher carbon content and raised strength (see Table 12).

It is possible to apply steels for manufacture of welded and nonwelded parts working at raised temperatures (up to 500°C). Before being welded these steels are subjected for hardening to heat treatment consisting of hardening in oil or normalization and subsequent high tempering.

After welding of parts of steel 12Kh2NVFA (EI712) heat treatment is not obligatory, and for parts of steel 23Kh2NVFA (EI659) tempering at 500°C is necessary.

§ 5. Alloy Tool Steels

In production of aviation materiel large role is played by tools, attachments, equipment, etc.

For manufacture of basic cutting, measuring, and stamping tools are applied alloy tool steels. Peculiarity of tool steel is presence in its structure of very hard carbides of chromium, tungsten, vanadium, and molybdenum. Chromium ensures good hardenability, high wear resistance, and high hardness. Tungsten promotes the obtaining of good wear resistance. Vanadium creates especially stable carbides and promotes obtaining of natural small-grained structure.

As compared to carbon tool steel, alloy tool steel possesses high stability

when tool is heated during work and allows high cutting speeds.

Alloy tool steel possesses greater hardenability than carbon steel. Therefore big tools are prepared only from alloy steel. Besides this, alloy tool steel, having lower critical hardening rate than carbon steel, permits applying oil instead of water as tempering medium. Thanks to this, after hardening in tools fewer cracks and other defects are obtained.

Steels for cutting tools. Cutting tools include cutters, drills, taps, milling cutters, broaches, etc. Material of these tools should possess high hardness, wear resistance, and ability to preserve its hardness when heated.

Besides this, cutting steels have to possess sufficient strength with certain toughness for prevention of warpage of tool in process of work. Hardness for metal-cutting tools should be 60-65 HRC.

Chemical composition of certain steels most widely applied for manufacture of cutting tools is given in Table 13, and mechanical properties are given in Table 14.

Table 13. Chemical Composition of Certain Steels Applied for Cutting Tools in %

Grade	C	Mn	Si	Cr	Other elements
X	0,95–1,10	< 0,40	< 0,35	1,3–1,6	–
9XC	0,85–0,95	0,30–0,60	1,20–1,60	0,95–1,25	–
XBГ	0,90–1,05	0,80–1,10	0,15–0,35	0,90–1,20	W 1,2–1,6
XB6	1,25–1,50	< 0,30	< 0,30	0,40–0,70	W 4,5–5,5 V 0,15–0,30

Table 14. Mechanical Properties of Certain Steels Applied for Cutting Tools

Grade	Temperature in °C				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
X	780–800	835–850	[illegible]	–	62–64
9XC	820–840	850–870	[illegible]	1970–2410	61–63
XBГ	780–800	820–850	[illegible]	2070–2550	61–62
XB6	770–800	820–840	[illegible]	2850–2290	65–67

These steels, as a result of heat treatment (hardening and low temper), obtain high hardness and wear resistance. However, they do not possess raised stability against temper, considerably lower hardness when heated above 250°C, and therefore can be applied only for tools intended for low cutting speed of materials of low strength and hardness.

Steel Kh possesses high hardness and small degree of hardening strain. It is used for drills, reamers, and taps.

Steel 9KhS has wide application for cutting tools. From it are prepared milling cutters, reamers, and drills. Presence of silicon promotes stability of carbides, ensures good hardenability and small degree of hardening strain.

Steel KhVG is used for manufacture of drills, milling cutters, screw dies, gauges, cold dies, and also parts with minimum allowance for grinding in hardened state and long rod tools.

Steel KhV5, called by extra hard steel, is used for finishing tools, cutters, and milling cutters utilized for treatment of hard materials.

Steels for dies. On die steels is imposed a series of raised requirements. They have to possess high strength, toughness, and hardness under conditions of work at high temperatures and impact loads. Hardness of die steels varies within limits of 56-63 HRC.

Chemical composition of the most widely applied dies steels is given in Table 15.

Table 15. Chemical Composition of Die Steels in %

Steel	C	Mn	Si	Cr	Other elements
		For cold dies			
X12F1	1,30—1,70	< 0,40	< 0,40	11,00—12,50	V 0,7—0,9
4X5V2C	0,35—0,44	0,20—0,40	0,60—0,90	1,00—1,30	W 2,0—2,5
		For hot dies			
5KhT	0,50—0,60	0,50—0,80	< 0,35	0,90—1,25	Ni 1,4—1,8; Ti 0,08—0,15
5KhK	0,50—0,60	0,30—0,60	0,60—0,90	1,30—1,60	Ni 0,8—1,2
3Kh2V8	0,30—0,40	0,20—0,40	< 0,35	2,20—2,70	W 7,5—9,0; V 0,2—0,5
4Kh5V2 (3M100)	0,35—0,45	0,20—0,40	< 0,35	7,0 —9,0	W 2,0—3,0

Steels for dies for cold deformation are subjected in process of work to strong wear and therefore must have high surface hardness. These requirements are satisfied by steels Kh12F1, 4KhV2S, KhVG, 9KhS, and others.

Steel Kh12F1 belongs to carbide class and possesses very high wear resistance, good hardenability, and low deformability when hardened. This steel is hardened in oil from 1100°C and is tempered at 200-220°C. It is used for manufacture of dies with the highest wear resistance. Besides, from this steel are prepared cutting (milling cutter, broaches, screw dies) and measuring (gauges, patterns, rings) tools.

Steel 4KhV2S, owing to raised silicon content, possesses great stability when heated. Annealing of steel 4KhV2S is produced at 800-820°C. This steel is hardened in oil from 850-900°C. Temper is applied at 300-550°C, depending upon assignment of tool. From this steel are prepared metal shears, pressure molds, and so forth.

Steels used for manufacture of dies for hot deformation have to possess high strength, toughness, and wear resistance at raised temperatures, and also good machinability and deep hardenability.

For manufacture drop-forge dies are applied alloy steels with medium carbon content and good hardenability, for instance, 5KhNT and 5KhNS. After heat treatment, consisting of hardening and high temper, they obtain high hardness and sufficient toughness. For manufacture of pressure molds are applied steels 3Kh2V8 and 4Kh8V2.

Steel 3Kh2V8, after being hardened in oil and high tempered, obtains high hardness, stable to 550°C. It is used for manufacture of hot dies for work under the most severe conditions.

Steel 4Kh8V2 (EI160) is substitute of more expensive steel 3Kh2V8. Thanks to high chromium content, it approaches martensite class and is easily hardened in oil. Articles of steel 4Kh8V2 are hardened from 1050-1100°C in oil and tempered at 500-575°C. After such treatment this steel has HRC hardness of 40-48 and is stable to temperature of 500-550°C.

Steels for measuring tools have to possess high hardness, wear resistance, and constancy of dimensions during entire period of service of tools. Their hardness should be 62-64 HRC. Steels most frequently applied for measuring instruments are grades Kh, KhG, and ShKh15.

§ 7. High-Speed Cutting Steels

Tool prepared from carbon tool steel preserves its hardness and cutting properties only to 200°C.

Cutting edge of tool made from high-alloy high-speed cutting steel can be heated during work and preserve its structure and cutting properties to 600°C, i.e., to red hardness.

Red hardness is the ability of steel to preserve its hardness, wear resistance, and cutting properties at high temperatures arising on cutting edge of tool in process of cutting at high speed.

Of all tool steels high-speed cutting steels are the most complicated in composition. They contain large quantity of alloy elements.

Chemical composition of the most important grades of high-speed cutting steels is given in Table 16.

Table 16. Chemical Composition of High-Speed Cutting Steels in %

Grade	C	W	Cr	V	Mo
P18	0,7—0,8	17,5—19	3,8—4,4	1,0—1,4	< 0,3
P9	0,85—0,95	8,5—10	3,8—4,4	2,0—2,6	< 0,3

High cutting properties of high-speed cutting steels are imparted by large quantity of carbide-forming elements introduced into its composition – tungsten, chromium, and vanadium.

Tungsten provides red hardness of high-speed cutting steel. Chromium promotes increase of hardenability. Vanadium promotes stability of carbides, which increases productivity of cutting tool. However, surplus of vanadium worsens grindability of high-speed cutting steel.

High-speed cutting steels belong to carbide (ledeburite) class. In cast state structure of high-speed cutting steel consists of ledeburite eutectic with inclusions of austenite or products of its disintegration (Fig. 11.8a).

In structure of high-speed cutting steel are three types of carbides: primary, formed during crystallization of steel; secondary, separated from austenite during cooling; and eutectoid, formed as a result of perlite transformation.

GRAPHICS NOT REPRODUCIBLE

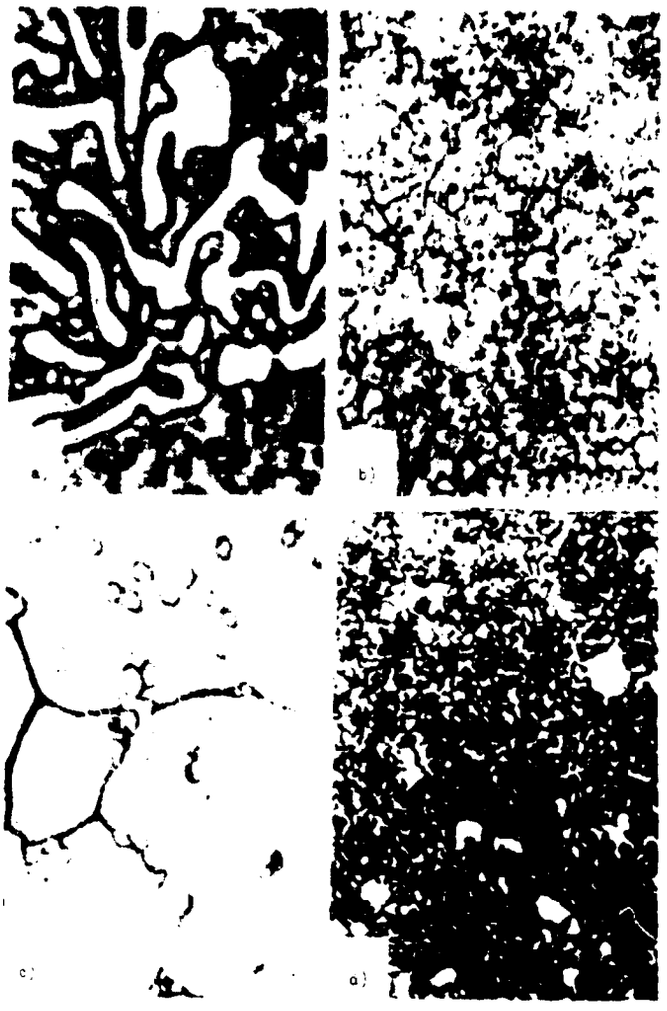


Fig. 11.8. Microstructure of high-speed cutting steels. a) cast, ×1000; b) after annealing, ×1000; c) after hardening, ×1000; d) after triple temper, ×500.

Heterogeneity of structure of cast high-speed cutting steel is removed in considerable degree by pressure treatment. In deformed and annealed high-speed cutting steel primary and secondary carbides are distributed evenly in basic metallic mass, constituting sorbite-like perlite (Fig. 11.8b).

To facilitate machining of high-speed cutting steels, they are subjected to isothermal annealing: heated to 850-900°C and rapidly transferred to furnace with temperature of 720-750°C, where they are sustained for 4-6 hours for completion of disintegration of austenite. Then steel is cooled in furnace to 600°C at rate of 40-50° per hour and then in air. Hardness of steel after annealing is 207-241 HRC.

To impart high red hardness to steel, tool is subjected to heat treatment, consisting of hardening, tempering, and sometimes sub-zero treatment. In Fig. 11.9

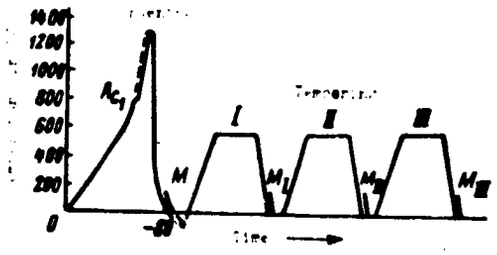


Fig. 11.9. Diagram of heat treatment of steel R18.

is presented diagram of heat treatment of steel R18.

Purpose of hardening of high-speed cutting steel is to obtain fullest possible dissolution of carbides in austenite, which ensures, after hardening, the obtaining of high-alloy martensite possessing high stability against temper and high red hardness.

Process of hardening of high-speed cutting steels consists of slow heating (preheating) to 800-850°C, holding at this temperature, fast (final) heating to hardening temperature of 1260-1280°C, brief holding at this temperature, and cooling in oil.

Structure at 1280°C consists of austenite and carbides. For decrease of hardening strain in a number of cases is applied step cooling, which consists in transferring tool heated to hardening temperature to salt bath, having temperature of 450-550°C. After brief holding, further cooling is produced in air.

After hardened high-speed cutting steel has hardness of 60-64 HRC and structure consisting of martensite, carbides, and residual austenite in quantity of up to 30% (see Fig. 11.8c).

During tempering there occurs precipitation of secondary carbides and transformation of residual austenite to martensite. Optimum temperature of temper of high-speed cutting steels is 550-570°C. For more complete transformation of residual austenite to martensite multiple temper is applied (to 3 times).

As a result of such tempering, almost full transformation of residual austenite to martensite is attained (see Fig. 11.8d), which increases hardness of high-speed cutting steels to 62-65 HRC.

For decrease of quantity of residual austenite not infrequently after hardening (after no more than 0.5-1 hour) tool is subjected to sub-zero treatment at a temperature of minus 70-80°C. After sub-zero treatment should follow immediately tempering, for lowering of internal stresses and transformation of residual austenite to martensite. Sub-zero treatment permits applying single temper. For still greater increase of wear resistance of tool made from high-speed cutting steel it is subjected to cyanidins.

From steel R18 are prepared tools applied for treatment of hard steels (30-40 HRC). Besides high cutting properties, steel R18 possesses good grindability considerable toughness, and wide interval of hardening temperatures.

Steel R9 is not inferior in cutting properties to steel R18 and is its substitute. Deficiency of steel R9 is poor grindability and lowered stability during action of impact loads.

C H A P T E R XII

STEELS AND ALLOYS WITH SPECIAL PHYSICAL AND CHEMICAL PROPERTIES

In connection with creation of new aviation materiel, wide application has recently been found for steels and alloys with special physical and chemical properties.

Depending upon assignment, steels and alloys with special physical and chemical properties are divided into the following groups: 1) stainless steels; 2) steels and alloys with high electrical resistance; 3) steels and alloys with special thermal expansion; 4) magnet steels and alloys; 5) steels and alloys for work at high temperatures.

§ 1. Stainless Steels

Stainless steels are those possessing high corrosion resistance under influence of atmosphere, air, water, and solutions of acids, salts, and many other reagents.

Carbon and low- and medium-alloy steels are distinguished by low corrosion resistance.

Alloying of steel with large quantity of chromium or chromium and nickel gives it high corrosion resistance.

We distinguish stainless chromium and chrome-nickel steels.

High corrosion resistance of stainless chromium steel is explained by the fact that on its surface forms very thin but durable and impenetrable oxidized film, Cr_2O_3, which possesses high protective properties. High corrosion resistance of stainless chrome-nickel steel is explained also by uniform austenitic structure,

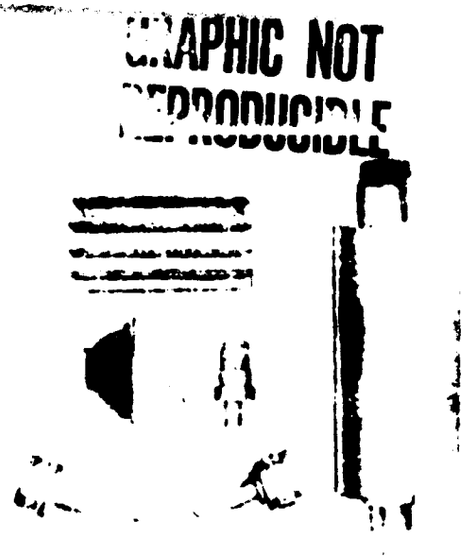


Fig. 12.1. Parts from stainless steels. 1 – corrugated element of aircraft frame, 2 – bracket prepared of steel 1Kh13, 3 – bushing of fuel spray nozzle, 4 – reducer of steel 2Kh13, 5 – section of hydraulic line of steel Kh18N9, 6 – blade of guide-vane assembly of axial flow compressor made from aluminum alloy with welded protective cowl of steel Kh18N9.

which is obtained thanks to high content of chromium and nickel in steel.

In Fig. 12.1 are shown samples of certain parts made from chromium and chrome-nickel stainless steels.

Chromium stainless steels have to contain not less than 12% chromium. Only in this case they will possess high corrosion resistance. Properties of chromium stainless steel depend on its carbon content. With increase of its carbon content hardenability and hardness of steel increases in great degree. Hardening and tempering give chromium stainless steels best mechanical properties. However, in connection with the fact that carbides of chromium are precipitated during tempering, uniformity of structure and its corrosion resistance are lowered. Therefore highest corrosion resistance of chromium stainless steels is obtained after hardening and subsequent polishing.

These steels possess high corrosion resistance under atmospheric conditions and in river water and satisfactory stability in nitric acid at room temperature. Salt and sulfuric acid destroy chromium stainless steels. Besides this, these steels do not oxidize in air to 700°C.

In aviation industry chromium stainless steels have limited application. They are used for manufacture of parts of aviation instruments and units.

Chemical composition of chromium stainless steels applied in aircraft construction is given in Table 17 and mechanical properties are given in Table 18.

Steels [1Kh13] (1X13) [EZh1] (3Ж1) and 2Kh13 (EZh2) belong to ferrite-martensite class, and steel 3Kh13 (EZh3) belongs to martensite class. For production of best mechanical and anticorrosive properties they are subjected to heat treatment (hardening with high temper). These steels possess high ductility, satisfactory weldability, and in annealed state machine well. They are supplied in the form of rods, sheets, and wire.

Table 17. Chemical Composition of Chromium Stainless Steels in %

Grade	C	Si	Mn	Cr	Other elements
1X13 (ЭЖ1)	< 0,15	< 0,6	< 0,6	12,0—14,0	—
2X13 (ЭЖ2)	0,16—0,24	< 0,6	< 0,6	12,0—14,0	—
3X13 (ЭЖ3)	0,25—0,34	< 0,6	< 0,6	12,0—14,0	—
1X18 (ЭИ229)	0,9—1,0	< 0,8	< 0,7	17,0—19,0	Ni < 0,6
X28	< 0,15	0,5—1,3	< 0,8	27—30	Mo < 0,6
0X17T (ЭИ645)	< 0,08	< 0,8	< 0,7	16,0—18,0	Ti 0,7—0,8
1X17H2 (ЭИ268)	< 0,17	< 0,8	0,3—0,8	16,0—18,0	Ni 1,5—2,5

Table 18. Mechanical Properties of Chromium Stainless Steels

Grade	State of material	Mechanical properties (not less)			
		σ_B MN/m^2	δ %	a_H MJ/m^2	HB MN/m^2
1Kh13 (EZh1)	Hardening from 1050°C in air or in oil, tempering at 680-780°C in oil	600	20	0.9	1700-1950
2Kh13 (EZh2)	Hardening from 1050°C in air or in oil, tempering at 600-700°C in oil	850	10	0.6	2410-3410
3Kh13 (EZh3)	Hardening from 1050°C in air, tempering at 150-170°C	1250	8	0.5	4290-5340
0Kh17T (EI645)	Hardening from 950°C in oil, low temper	750-800	18	—	—
1Kh17N2 (EI268)	Hardening from 1050°C in oil, tempering at 275-350°C	1100-1300	10	—	—

Steel 1Kh13 (EZh1) is used for manufacture of parts of aviation instruments and parts of jet engines of low hardness and raised ductility.

Steel 2Kh13 (EZh2) is used for manufacture of bushings, gears of aviation instruments, parts of system of direct fuel injection, and of compressor blades.

Steel 3Kh13 (EZh3) belongs to martensite class. After hardening and low tempering it obtains high hardness and strength but lowered ductility. This steel welds badly. It is supplied in the form of rods and sheets. Steel 3Kh13 (EZh3) is designed for parts of raised strength in the presence of corrosional influence, for instance, springs, parts of fuel and other equipment, and so forth.

Steels 1Kh18 [EI229] (ЭИ229) and Kh28 belong to ferrite class. This gives them best resistance to acids and hot gases. Steel 1Kh18 (EI229) can be applied as scale-resistant material at temperatures to 900°C, and steel Kh28 can be applied at temperatures to 1100°C. These steels possess good weldability and satisfactory machinability.

Basic deficiency of these steels is coarse-grained structure, appearing during heating and welding, which makes them brittle. Crushing of structure in these steels is possible only as a result of hot pressure working.

For improvement of properties of steel containing over 17% chromium it can be additionally alloyed with small quantity of titanium or niobium. They decrease danger of appearance of coarse-grained structure and improve corrosion resistance of welded joints in near-seam zone.

Steel 0Kh17T (EI645) contains additionally a small quantity of titanium. After heat treatment it possesses good strength and sufficient toughness, which profitably distinguishes it from steel 1Kh18 (EI229). This steel is suitable for pressure treatment in hot and cold states, possesses good weldability, and heat treatment after welding is not obligatory. It is supplied in the form of rods and sheets and is applied as scale-resistant material.

Steel 1Kh17N2 (EI268) contains additionally about 2% nickel. Presence of nickel increases mechanical properties and improves hardenability. Steel has high scale resistance and welds well; part after welding are subjected to obligatory heat treatment. Resistance to permanent loads for this steel to temperatures of 450°C exceeds corresponding indices of such steels as [30KhGSA] (30ХГСА) and [18Kh2N4VA] (18Х2Н4ВА), that permits using it as substitute of these steels.

Steel 1Kh17N2 (EI268) finds considerable application in aircraft construction. From it are prepared housings and combustion chambers, bodies of compressors, turbine stators, blades and disks of compressors, and other parts.

Chrome-nickel stainless steels. Thanks to high chromium and nickel content, properties of these steels as compared to properties of chromium stainless steels are improved considerably: mechanical properties are increased, corrosion and acid resistance are increased. These are steels of austenite class. They have found wide application in aviation industry. For production of austenite steel is hardened from 1100°C in water. High temperature of heating during hardening is necessary for dissolution of carbides and obtaining of single-phase structure (Fig. [illegible]).

Austenite chrome-nickel steels in hardened state, besides high corrosion resistance, have good technological properties. They possess high ductility in cold state, are well suited to rolling, stamping, and drawing. These steels well weld

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Fig. 12.2. Microstructure of stainless chrome-nickel steels in hardened state, ×450.

by all forms of welding.

After being hardened chrome-nickel stainless steels have low strength. For increase of strength these steels are subjected to cold deformation. However, ductility of steel is lowered noticeably here. Thus, with 50% compression ultimate strength of these steels is increased from 600 to 1300 MN/m^2 (from 60 to 130 kgf/mm^2) and elongation per unit length decreases from 45 to 25%. So considerable strenghtening is consequence of cold hardening, which lowers corrosion resistance of steel somewhat.

When austenite chrome-nickel steels are heated above 500°C, then is observed precipitation of carbides of chromium along grain boundaries (Fig. 12.3). Presence of carbides of chromium in basic mass of austenite in the presence of active corrosive medium causes intercrystallite corrosion of these steels.



Fig. 12.3 Microstructure of stainless chrome-nickel steels with separated carbides on grain boundaries of austenite, ×450.

Inclination of chrome-nickel stainless steels to intercrystallite corrosion is removed either by lowering carbon content to 0.007% or introduction into steel of stabilizers – titanium or niobium.

Chemical composition of chrome-nickel stainless steels is given in Table 19, and mechanical properties are given in Table 20.

Of chrome-nickel stainless steels the most widely applied is low-carbon austenite steel of type 18-8 (18% Cr and 8% Ni), which per GOST is marked Kh18N9 [EYal] (ЭЯ1).

Steel Kh18N9 (EYal) is resistant to oxidation in air medium at a temperature of up to 850°C and in atmosphere of products of combustion of aviation fuels up to 750°C; it is also resistant in concentrated nitric acid. For the purpose of

Table 19. Chemical Composition of Chrome-Nickel Stainless Steels in %

[illegible]	C	Mn	Si	Cr	Ni	Other elements
X18N9 (EYa1)	< 0,14	<2,0	<0,8	17,0—20,0	8,0—11,0	—
2X13N4G9 (EI100)	0,15—0,30	8,0—10,0	<0,8	12,0—14,0	3,7—5,0	—
X18N9T (EYa1T)	< 0,12	<2,0	<0,8	17,0—19,0	8,0—9,5	Ti < 0,7
0X18N12B (EI402)	< 0,10	<2,0	<1,0	17,0—20,0	9,0—13,0	Nb < 1,5
X15N9Yu (EI904)	0,06—0,09	<0,7	<0,7	14,8—16,5	7,0—9,4	Al 0,9—1,4

Table 20. Mechanical Properties of Chrome-Nickel Stainless Steels

Grade	State of material	Mechanical properties (not less)		
		σ_B MN/m²	δ %	a_H MJ/m²
Kh18N9 (EYa1)	Hardening from 1100-1150°C in water	5[illegible]	4[illegible]	1.[illegible]
	Cold hardening without heat treatment	12[illegible]-12[illegible]	1[illegible]	-
[illegible]Kh13N4G9 (EI100)	Hardening from 1120-11[illegible]°C in water	6[illegible]	4[illegible]	-
	Cold hardening without heat treatment	1[illegible]	1[illegible]	-
Kh18N9T (EYa1T)	Hardening from 1100-1150°C in water	[illegible]	4[illegible]	1.[illegible]
	Cold hardening without heat treatment	1[illegible]	1[illegible]	-
[illegible]Kh18N12B (EI402)	Hardening from 110[illegible]-11[illegible]°C in water	[illegible]	[illegible]	-
	Cold hardening without heat treatment	[illegible]	[illegible]	
Kh15N9Yu (EI904)	Normalization from [illegible]	[illegible]	[illegible]	
	Aging at [illegible]	[illegible]	[illegible]	
	Cold hardening	[illegible]	[illegible]	

[illegible] structure of uniform austenite, steel is subjected to hardening from [illegible]. After such heat treatment it is the most resistant to corrosion and the most ductile; however, it has low strength. Through cold deformation it is possible to increase its ultimate strength. It is supplied in the form of sheets, tubing, and tapes.

Steel Kh18N9 (EYa1) is used for manufacture of parts and elements of aircraft which are welded cold-rolled sheets or tapes. Operating temperature of parts produced from this steel must not exceed [illegible]°C.

Steel 0Kh18N9 (EYa0) is distinguished by smaller carbon content than steel Kh18N9 (EYa1), which increases its acid resistance. Steel is resistant to oxidation in the atmosphere of heated air at temperatures to 900°C. Hardening of steel is from temperature of 1000-1120°C. It welds well by all forms of welding. Parts prepared from this steel during prolonged work in aggressive media, in water, or in steam can be destroyed by intercrystallite corrosion.

It is supplied in the form of sheets, tapes, tubing, and is used for manufacture of welded oxygen bottles.

Steel 2Kh18N9 (EYa2) contains raised quantity of carbon with respect to steel Kh18N9, that gives it somewhat greater strength but less ductility in hardened state. Steel 2Kh18N9 (EYa2) has the same application as steel Kh18N9 (EYa1).

Steel 2Kh13N4G9 (EI100) contains quantity of chromium and nickel, which are replaced partially by less scarce manganese. This steel is substitute for steel Kh18N9 (EYa1). Technology of manufacture, heat treatment, structure and properties are the same as for steels Kh18N9 (EYa1) and 2Kh18N9 (EYa2). It is supplied in the form of rods, sheets, tape, and wire.

Steel 2Kh13N4G9 (EI100) is used for manufacture of structural parts of aircraft heat during work not higher than temperature 500°C, for instance, parts of wing, fuselage, fire bulkheads, and others.

As it was shown, for prevention of appearance of intercrystallite corrosion of austenitic steels of type 18-8 additional alloying with titanium or niobium is used. These elements, as compared to chromium, are stronger carbide-forming elements; they connect part of stainless steel without making it dissolve in austenite during hardening. Thus, precipitation of chromium carbides on grain boundaries does not occur, and intercrystallite corrosion is not observed. Steel with titanium of grade Kh18N9T (EYa1T) or that with niobium of grade Kh18N9B (EYa1B) may be applied for welded parts and those working at raised temperatures with a fear of intercrystallite corrosion.

Steel Kh18N9T (EYa1T) is resistant to oxidation in air and in atmosphere of products of combustion of aviation fuel in gas turbines at temperatures of [illegible]. It possesses high ductility and corrosion resistance after hardening. It is suitable for deep drawing and other forms of cold stamping.

The [illegible] deformable steel can be strengthened [illegible] with preservation of good ductility. [illegible]

form of welding. It is supplied in the form of rods, sheets, profiles, tubing, rings, and tubes.

Steel Kh18N9T (EYalT) has found wide application in manufacture of jet engines. From it are prepared parts of exhaust systems of gas-turbine engines: cone, exhaust pipe, jet nozzles, and others (Fig. 12.4). Besides this, it is used for manufacture of parts and welded articles working under conditions of humid medium.

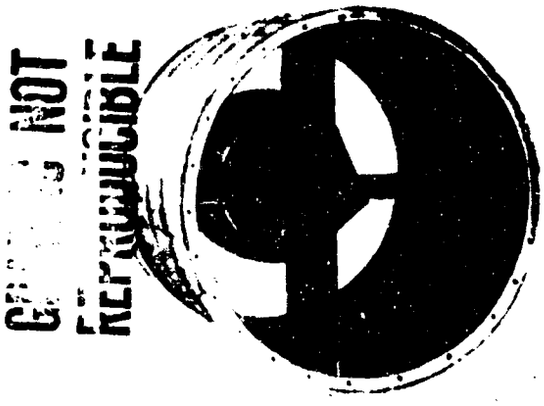


Fig. 12.4. Exhaust pipe of gas-turbine engine of steel Kh18N9T (EYalT).

Steel 0Kh18N12B (EI402) in properties, heat treatment, and application is close to steel Kh18N9T (EYalT). But it is necessary to consider that, in spite of good weldability, this steel is inclined to formation of hot cracks in fused metal. This steel is supplied in the form of rods and sheets.

Steel 0Kh18N12B (EI402) is used for manufacture of exhaust nozzles, collectors of aircraft engines, systems of communication of hot gases of turbocompressors, parts of nozzle apparatus, parts working under small stresses and low temperatures not higher than 850°C, and also for welded equipment and parts resistant to nitric acid.

Austenite chrome-nickel steels possess insufficient strength under prolonged high-temperature load. Thus, stress-rupture strength of steel Kh18N9T (EYalT) in hardened state at 600°C σ_{100} = 250 MN/m^2 (25 kgf/mm^2); at 700°C σ_{100} = 130 MN/m^2 (13 kgf/mm^2); and at 800°C σ_{100} = 50 MN/m^2 (5 kgf/mm^2).

Additional alloying of these steels with small quantity of boron (0.01%) increases their stress-rupture strength.

There recently was developed a new group of stainless steels possessing during work at temperatures of 400-450°C strength exceeding strength of stainless steels of austenite and martensite classes. These steels of transition austenite-martensite or semiaustenite class have found application in construction of high-speed aircraft subjected to aerodynamic heating.

After hardening or normalization of these steels there is obtained structure like that of steels of austenite class. But in distinction from the latter, obtained structure of austenite is unstable and can be transformed to martensite with help of sub-zero treatment. Thus, steels of transition semiaustenite class

can be strengthened by heat treatment, whereas steels of austenite class are strengthened only through plastic deformation. Steels of semiaustenite class can be strengthened also by cold hardening. However, it is expedient to apply it only after heat treatment for additional hardening. It is necessary to note that in corrosion resistance semiaustenite steels are inferior to those of austenite type.

Steel Kh15N9Yu (CH2, EI904) is steel of semiaustenite class. Its chemical composition is so selected that martensite point is near zero degrees. After normalization from temperature of 1000°C it obtains structure of unstable austenite. In this state it possesses the greatest ductility and is easily processed by pressure. During deformation steel is rapidly work hardened; for softening of steel between operations of cold hardening intermediate annealing is recommended.

Steel welds well by argon arc, point, and seam welding, and can be processed by cutting.

In soft austenite state steel Kh15N9Yu (EI904) is not strengthened by aging. For this it should be given sub-zero treatment. Steel is normalized from 950°C and sustain at a temperature of minus 70°C for 2 hours for production of martensite structure. Then it is hardened by aging at 500°C for 1 hour. Further strengthening of steel can be produced by cold hardening. Strength of steel Kh15N9Yu (EI904) is preserved well to 400-450°C.

Steel Kh15N9Yu (EI904) is released in the form of sheets, tapes, rods, and pressed profiles. It is applied in contemporary aircraft for manufacture of sheathing and internal parts working in contact with atmosphere and fuel.

§ 2. Steels and Alloys with High Electrical Resistance

In electrical and radio equipment of aircraft are applied materials with high electrical resistance. As such materials usually are used different alloys of type of uniform solid solutions of high concentration or alloys whose basic mass is composed of such solutions, since specific electrical resistance of these alloys is always higher and temperature coefficient of resistance is considerably lower than for intial metals.

Specific electrical resistance depends on plastic deformation, heat treatment of metal or alloy, and presence of impurities in them. During cold pressure treatment alloy is work hardened, which is accompanied by increase of specific electrical resistance. This is explained by the fact that during work hardening

considerable distortions of crystal lattice, specific [illegible] of [illegible]. Analogously electrical resistance is affected by impurities in metal or alloy, which cause distortion of crystal lattice. Annealing, restoring work hardening and making alloy more uniform, lowers specific electrical resistance of alloy.

Depending upon field of application, alloys of high resistance may be divided into two groups:

1) alloys for electrical measuring instruments, precision equipment, resistance standards, rheostats, and so forth;

2) heat-resistant alloys for heating devices and electrical resistance furnaces.

On materials of first group are imposed the following basic requirements:

1) high resistivity with low temperature coefficient;

2) high stability of properties with time;

3) raised heat stability to 400-500°C. Such materials include alloys of copper with nickel, zinc, and manganese – manganin, constantan, and nickelin.

Characteristics of these materials are given in Table 21.

Table 21. Chemical Composition and Properties of Nonheat-Resistant Alloys with High Electrical Resistance

Alloy	Chemical composition %			Maximum working temperature °C	Specific electrical resistance $\Omega \cdot mm^2/m$	Temperature coefficient of electrical resistance
	Cu	Ni	Mn			
Manganin	84	4	12	200	0.42	0.00002
Constantan	59	40	1.0	500	0.50	–
Nickelin	55	45	–	500	0.52	0.0001

Manganin is distinguished by characteristic yellow color. For stabilization of properties it is subjected to aging. Alloy has following mechanical properties: σ_B = 450-600 MN/m^2 (45-60 kgf/mm^2); δ = 15-30%. It is supplied in the form of wire and tapes. Manganin is used widely for manufacture of precision resistors.

Constantan of all copper-nickel alloys possesses the highest specific electrical resistance and least coefficient of specific electrical resistance. Temperature coefficient of electrical resistance is equal to zero and is not changed to 500°C. Constantan has ultimate strength σ_B = 500 MN/m^2 (50 kgf/mm^2). Alloy is very ductile, which permits preparing from it cold-drawn wire with diameter to 0.02 mm.

Constantan is used for manufacture of slider-type rheostats. Main deficiency, limiting its application as material for standard resistors, is high thermo emf when paired with copper. This property of contantan is used widely for manufacture of copper-constantan thermocouples for measuring temperature to 700°C.

Nickelin, as compared to constantan, has lower electrical resistance and larger temperature coefficient of resistance. It is used for starting and regulating rheostats.

From materials of second group is required high resistance to oxidation at high operating temperatures, high specific resistance, and small temperature coefficient of resistance. Besides this, they must have sufficiently high mechanical properties at high temperatures.

For articles working under conditions of high temperatures are applied steels and alloys prepared:

1) on nickel base (Nichrome);

2) on iron base (fecraloy and chromal).

These materials are used for manufacture of electrical resistance furnaces and heating devices with operating temperature of 1000-1200°C.

Chemical composition and properties of heat-resistant alloys with high electrical resistance are given in Table 22.

Table 22. Chemical Composition and Properties of Heat-Resistant Alloys with High Electrical Resistance

Alloy	Grade of alloy	Chemical composition in %					Maximum working temperature °C	Specific electrical resistance $\Omega \cdot mm^2/m$
		C	Ni	Cr	Fe	Al		
Nichrome 60	Kh15N60	0.15	55.0-61.0	15.0-18.0	Remainder	–	1000	1.1
Nichrome 80	Kh20N80	0.15	75.0-78.0	20.0-23.0	Remainder	–	1100	1.15
Fecraloy	1Kh17Yu5	0.12	0.6	16.0-19.0	Base	4.0-6.0	1000	1.24
Chromal	1Kh25Yu5	0.12	0.6	23.0-27.0	Base	4.5-6.5	1150	1.35

Nichrome possess high ductility and strength both at room and raised temperatures. From them can be prepared very thin wires and tape. Resistivity of nichrome changes little with temperature. The more chromium contained in these alloys the greater

their heat resistance.

Additional alloying of Ni-Cr-Fe with small quantities of aluminum and manganese increases its heat resistance and electrical resistance. Large content in Nichrome of scarce nickel appreciates these alloys.

When possible, Nichrome is replaced by cheaper alloys based on iron - fecraloy and chromal. These alloys are distinguished by high heat resistance (especially for chromal) and high electrical resistance. However, they are less ductile and are more brittle than Nichrome. Chromal can be applied only in the form of cast heating elements, and fecraloy can be used in the form of wire, but not such thin wire as from Nichrome.

§ 3. Alloys with Special Thermal Properties

In instrument making have found application alloys with special thermal properties. These are alloys with large quantity of nickel.

Large quantity of nickel in steels gives them austenite structure and ensures obtaining in them of very low coefficient of thermal expansion.

In Table 23 are given characteristics of alloys possessing special thermal properties.

Table 23. Chemical Composition and Properties of Alloys with Special Thermal Properties

Alloy	Grade of alloy	Chemical Composition in %				Characteristic property
		C	Ni	Cr	Fe	
Invar	N36	0.30	35-37	0.5	Remainder	$\alpha = 1.5 \cdot 10^{-6}$ deg^{-1}
Platinite	N42	0.30	47-49	0.5	Remainder	$\alpha = (4-11) \cdot 10^{-6}$ deg^{-1}
Elinvar	Kh8N3Yu	0.3-0.4	35-37	7.5	Remainder	E = 140,000-160,000 kg/mm^2

Invar has minimum coefficient of linear expansion, varying little in practice in interval of temperatures from -80° to +100°C. Invar is supplied in the form of sheets and tapes and is used for precision instruments whose parts must not change dimensions with change of temperature.

Platinite has the same coefficient of linear expansion as glass and platinum. Platinite is supplied in the form of wire and is used for replacement of expensive platinum when it is necessary to fuse wires in glass. It is used for manufacture of electrodes in incandescent lamps, many small parts in devices for lenses, etc.

Elinvar possesses high elastic modulus which in practice is not changed to temperature of 100°C. Elinvar is supplied in the form of tapes and wire. It is used for manufacture of elastic elements of measuring instruments.

Besides this, for manufacture of instruments and apparatuses are applied thermobimetals.

Thermobimetals constitute soldered plates of two different metals or alloys with sharply heterogeneous (small and large) coefficients of linear expansion. Thermobimetals are designed for manufacture of special thermobimetalic elements of different electrical apparatuses of remote control (various relays and regulators).

As one of components of thermobimetalic plates, having small coefficient of linear expansion, there usually is applied nickel alloy, invar [N36] (H36). Its coefficient of linear expansion is $\alpha = 1.5 \cdot 10^{-6}$ deg^{-1}. For other component of thermobimetalic elements, having great coefficient of linear expansion, are applied: iron, nickel, constantan (copper-nickel alloy), hard copper (grade MT), monel (copper-nickel alloy), and also nonmagnetic steel. Coefficient of linear expansion of these materials lies within limits of $(10\text{-}16) \cdot 10^{-6}$ deg^{-1}.

Thermobimetalic materials are supplied in the form of tape and sheets.

§ 4. Magnetic Steels and Alloys

Magnetic materials play a very important role in contemporary electrical- and radio-engineering. Especially great is role of magnetic materials in aviation electrical engineering. From them are prepared parts of electrical machines, apparatuses, and instruments. On magnetic materials, depending upon their assignment in various radiotechnical devices, are imposed various requirements.

Basic characteristics of magnetic materials are their magnetic properties: remanence B_r, in gauss; coercive force H_c, in oersteds; and permeability μ.

Remanence B_r and coercive force H_c characterize residual magnetism in steel after its magnetization. They show on hysteresis curve dependences of magnetic induction B on magnetic field strength H (Fig. 12.5).

Permeability μ is equal to

$$\mu = \frac{B}{H},$$

where B – magnetic induction;

H – magnetic field strength (magnetizing force).

According to magnetic properties, all materials are divided into diamagnetics, paramagnetics, and ferromagnetics. To diamagnetic substances, permeability of which is less than unity, belong: copper, silver, zinc, mercury, and others. For paramagnetic materials – aluminum, platinum, cobalt, nickel, and others – permeability is somewhat greater than unity. Ferromagnetic substance (iron, nickel, cobalt, their alloys, alloys of chromium and manganese, and others) are distinguished by high permeability. They are used mainly as magnetic materials. For ferromagnetic materials is characteristic sharply expressed dependence of permeability on field strength H.

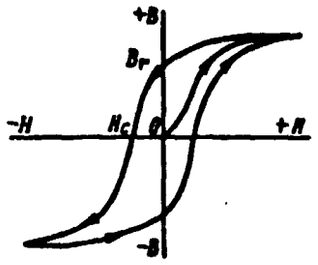


Fig. 12.5. Dependence of magnetic induction B on magnetic field strength H (hysteresis curve).

Magnet steels and alloys, depending upon magnitude of coercive force and permeability, are subdivided into hard magnetic, applied for permanent magnets, and soft magnetic, which are designed for cores of transformers, electric motors, generators, and also in low-current industry.

Hard-magnetic steels and alloys have wide hysteresis loop, high remanence and coercive force, and low permeability.

The most suitable structure for hard-magnetic steels is martensite with small particles of cementite or carbides, obtained after hardening or aging.

Hard-magnetic materials are used for manufacture of permanent magnets in electrical and radio equipment (in magnetos, different measuring instruments, relays, magnetic memory devices, and in [illegible]).

Permanent magnets are prepared from high-carbon and alloy steels and special alloys. Chemical composition, heat treatment, and magnetic properties of certain hard-magnetic materials are given in Table 24.

Carbon steel obtains sufficient magnetic properties after hardening. Thanks to low hardenability, it can be applied only for manufacture of small magnets (4-7 mm). However, owing to inclinaiton of carbon steels to aging, their magnetic properties are changed with time.

Steels alloyed with chromium, tungsten, and cobalt possess high hardenability as compared to carbon steels, and therefore it is possible to prepare bigger magnets from them. Chromium steels have the same magnetic properties as carbon

Table 24. Chemical Composition, Heat Treatment, and Properties of Hard-Magnetic Materials

Designation	Grade of steel or alloy	Chemical composition in %						Heat Treatment	Magnetic properties	
		C	Cr	Ni	Al	Co	Cu		H_c Oe	B_r G
Carbon steels										
–	Y7	0.60-0.74	–	–	–	–	–	Hardening from 800°C in water	50	10,000
–	Y10	0.95-1.04	–	–	–	–	–	Hardening from 780°C in water	65	8,000
Chromium steels										
–	EX2	0.95-1.1	1.3-1.6	–	–	–	–	Hardening from 780-800°C in water or hardening from 820-840°C in oil	58 60	9,000 95,000
–	EX3	0.9-1-1	2.8-3.8	–	–	–	–	Hardening from 800-820°C in water Hardening from 840-860°C in oil	65 70	10,000 9,000
Special alloys on iron base										
Alni 1	AH1	≤0.03	–	22.0	11.0	–	–	Hardening from 1200°C in boiling water	250	7,000
Alni 2	AH2	≤0.03	–	24.5	13.0	–	3.5	Hardening from 1200°C in boiling water, tempering at 550°C	430	6,000
Alnisi	AHK	≤0.03	–	33.0	13.5	–	–	Normalization at 1200°C	750	4,000
Alnico 12	AHK 01	≤0.03	–	18	10	12	6	Normalization at 1250°C	500	6,800
Alnico 15	AHK 02	≤0.03	–	20	9	15	4	Normalization at 1300°C, tempering at 600°C	600	7,500
Alnico 24	AHK 04	–	–	13.5	9	24	3	Normalization at 1300°C, tempering at 600°C	500	12,300

steels. Tungsten and cobalt steels have considerably better magnetic properties, distinguished by great stability. But in connection with high costs, they are replaced by chromium steels.

Special magnetic alloys possess very high magnetic properties, which permits preparing from them magnets of small dimensions but great power. They constitute low-carbon iron-nickel-aluminum alloys, to which is added copper or copper and cobalt. Magnetic properties of these alloys are attained as a result of aging after

[illegible] Magnets made from these alloys are prepared by [illegible]

Soft-magnetic steels and alloys possess small [illegible] and very great permeability μ. When magnetized by alternating current, they are distinguished by small losses to hysteresis and eddy currents.

Phosphorus, sulfur, oxygen, nitrogen, and especially carbon harmfully affect soft magnetic materials. Even in small quantities they sharply lower permeability and increase hysteresis losses.

Soft-magnetic materials are applied as magnetic circuits for transformers, armatures, and stators of electrical machines; cores of electromagnets, induction coils, relays, etc. Soft-magnetic materials include: technical iron, electrical steel, and special alloys.

Chemical composition of soft-magnetic steels is given in Table 25.

Table 25. Chemical Composition of Soft-magnetic Steels in %

Designation	Grade	C	Si
Low-carbon electrical steel	Э, ЭА, ЭАА	< 0,04	< 0,20
Electrical thin-sheet silicon steel	311, 312	—	0,8—1,8
	321	—	1,8—2,8
	331, 334, 3310, 3320, 3330, 3340, 3370	0,01—0,1	2,5—4,0
	341, 342, 343, 344, 345, 346, 347, 348	—	4,0—4,8

Technical iron (low-carbon electrical steel) is characterized by small quantity of carbon and impurities worsening magnetic softness.

High permeability, small coercive force, and also good mechanical and technological properties are responsible for its wide application for cores and yoke of electromagnets. Low electrical resistance and large losses to eddy currents make it unfit technical iron for transformers and electrical machines.

Electrical thin-sheet silicon steel is the most widely applied magnetic material in electrical engineering. In this steel the most important alloy element is silicon. Being dissolved in iron, silicon sharply increases electrical resistance of steel, thereby lowering loss to eddy currents. Raised electrical resistance of silicon steels permits their highly effective use for magnetic circuit

magnetized by alternating current. Besides this, in electrical steels for production of high degree of magnetic softness there must be maintained minimum quantity of carbon and harmful impurities – oxygen, sulfur, and phosphorus.

As in iron, in silicon steels big grains promote increase of permeability and decrease of losses to eddy currents. Therefore high-silicon steel always is processed to big grain.

Silicon electrical steels containing up to 2.5% silicon are frequently called dynamo steels and those containing 3.5–4.5% silicon are called transformer steels.

Transformer steels, possessing higher soft-magnetic properties as compared to dynamo type, possess also higher brittleness than dynamo steels.

From transformer steels are prepared cores and armatures of transformers, cores of electromagnets, and other parts. Dynamo steel, possessing higher ductility than transformer steel, is applied in dynamos and electric motors, where figure stampings are required for manufacture of parts of rotor and stator.

Development of low-current industry requires high-quality materials with high permeability in small magnetic fields. This requirement is satisfied by iron-nickel alloys called permalloys.

Alloys of this group possess high initial permeability and low magnitudes of saturation induction. They are applied in apparatuses and instruments working during low intensity of magnetic fields (relays, electrical measuring instruments, magnetic shields, cores of coils, transformers, and others).

Chemical compositon and properties of soft-magnetic alloys of permalloy type are given in Table 26.

Table 26. Composition and Properties of Iron-Nickel Alloys of Permalloy Type

Designation of alloy	Chemical composition, %			μ_0	μ_m	H_c, Oe
	Ni	Other elements	Fe			
Permalloy	78,5	—	Remainder	$1 \cdot 10^4 - 1,2 \cdot 10^4$	$9 \cdot 10^4 - 12 \cdot 10^4$	0,025
Supermalloy	78,5	Mo 3,8	-	$2 \cdot 10^4$	$7,5 \cdot 10^4$	0,03
Permalloy	78,5	Cr 3,8	-	$1,2 \cdot 10^4$	$6 \cdot 10^4$	0,03
Permalloy	72,0	Cu 15,0 Mo 3,0	-	$5 \cdot 10^4$	$1 \cdot 10^5$	0,08
Supermalloy	79,0	Mo 5,0 Mn 0,5	-	$5 \cdot 10^4 - 15 \cdot 10^4$	$6 \cdot 10^5 - 12 \cdot 10^5$	0,004
Permalloy	50	—	-	$4,5 \cdot 10^3$	$1 \cdot 10^5$	0,075

The highest values of initial permeability μ_i and maximum permeability μ_m belong to permalloy containing 78.5% nickel. Small deviations in composition of alloy and also in conditions of heat treatment considerably lower properties of this alloy. Plastic deformation sharply worsens soft magnetic properties of permalloy. Besides this, it possesses low electrical resistance. High cost of permalloy, due to high content of nickel, sensitivity to work hardening, low electrical resistance, and complexity of heat treatment limit its wide application. Permalloy is applied now and then in sensitive dc relays and in shields.

More widely used are alloy permalloys and low-nickel permalloys, called hypernik. High indices distinguish molybdenum permalloy (Mo-permalloy), which is used widely for cores of inductance coils, magnetic shields, transformers of low and raised frequencies, and for measuring instruments. Certain grades of permalloy (supermalloy) are subjected to special treatment, consisting in cooling in magnetic fields, possess especially high magnetic properties.

Besides permalloys this group of magnetic materials includes alloy of iron with silicon and aluminum, called alsifer. Its composition is the following: silicon – 9.6%, aluminum – 5.4%, iron – 85%. Alsifer possesses following properties: μ_a = 35,000; μ_m = 117,000, H_c = 0.029. Alloy is very brittle and hard and is not subjected to treatment by pressure and cutting. Therefore parts made from it are prepared by method of shaped casting with subsequent grinding. Alsifer is used for manufacture of magnetic shields, bodies of instruments, etc. This alloy finds basic application in the form of powder during manufacture of magnetodielectrics.

Magnetodielectrics are high-frequency magnetic materials. They constitute mixture of powder of ferromagnetic material and dielectric. As ferromagnetic material (base) are applied iron carbonyl, alsifer, and permalloy. As dielectric (binder) are applied polystyrene, bakelite resin, and nitrolak.

Magnetodielectrics are applied as pressed cores of high-frequency magnetic systems: inductance coils, filters, generators, circuits of radio receivers.

Sheet and ribbon soft magnetic materials under conditions of high frequencies (over 100 kilocycles) are not applicable, owing to sharp impairment of magnetic properties.

Nonmagnetic steels and cast irons. In certain cases in electrical machine building for manufacture of nonmagnetic parts of magnetic instruments and electrical machines are applied nonmagnetic materials. As substitutes for nonferrous alloys

in these cases are applied nonmagnetic steel and cast iron with austenite structure. Such structure is obtained owing to high content of manganese and nickel, which lower interval of transformation of γ-iron to α-iron up to room temperatures.

Nonmagnetic steels are applied in devices in which material absorbs high mechanical loads. As nonmagnetic steels are applied nickel steel N25, containing 22-25% Ni, and nickel-manganous steel N9G9, containing 8-9.5% Ni and 8-10% Mn. Nickel steel N25 possesses better technological properties and corrosion resistance than steel N9G9; however, the latter is cheaper. These steels are used for manufacture of parts of electrical machines and apparatuses and for compass boxes.

Nonmagnetic cast irons are applied in those devices subject to small mechanical loads. Of nonmagnetic cast irons the most widely applied are nickel-manganese cast iron and manganese cast iron. They are used for casting parts of electromagnets, magnetic apparatuses, etc.

C H A P T E R XIII

STEELS AND ALLOYS FOR WORK AT HIGH TEMPERATURES

Contemporary aviation is characterized by high speeds of flight of jet aircraft.

During work of jet engines hot gases are formed which flow with great speed through structure, heating it. The highest temperatures are characteristic for such parts of jet engine as combustion chambers, turbine disks, turbine blades, and guide-vane devices. These parts during use, besides effect on high temperatures, experience large internal stresses.

At high speeds of flight are observed aerodynamic phenomena leading to heating of entire aircraft structure. Heating of aircraft under conditions of high-speed flight is connected with friction of particles of air against sheathing of wing and fuselage. The higher the speed of flight the more heat is generated as a result of the aircraft is overcoming resistance of air medium. This heat leads to increase of temperature first of sheathing and then of entire aircraft. At sufficiently high speeds of flight, exceeding the speed of sound by a few times, this temperature can reach several hundred degrees.

Thus for future successful development of aviation materiel are necessary materials able to resist for prolonged time the action of high temperatures and loads.

Thus, for instance, selection of alloys for jet engines is determined by operating temperatures of parts, by loads which they absorb, and by duration of work. For work at temperatures up to 300°C, when in steels there still is not observed phenomenon of creep, ordinary structural steels are applied. In interval of temperatures from 300 to 500°C are applied so-called heat-resistant steels, which

preserve their strength at these temperatures and resist gas corrosion. For work at temperatures higher than 600°C are applied heat-resistant and oxidation resistant steels and alloys. For temperatures to 650°C are used high-alloy complex steels of austenite type, and for temperatures over 650°C complex alloys based on nickel, cobalt, and iron find wide application.

§ 1. Requirements Imposed on Steels and Alloys Applied at High Temperatures

In connection with wide use in aviation of gas-turbine engines, steels and special alloys assume even greater value.

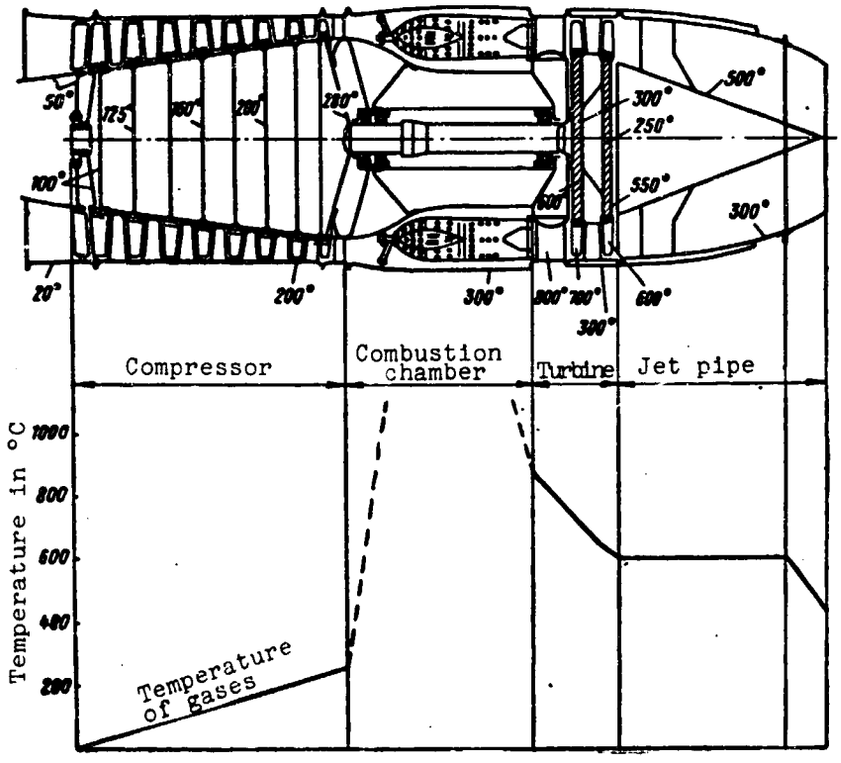


Fig. 13.1. Diagram of gas-turbine engine with axial-flow compressor.

For better understanding of requirements imposed on these materials it is necessary to consider conditions of work of basic parts of jet engines. In Fig. 13.1 is shown diagram of gas-turbine engine with axial-flow compressor with indication of maximum temperature of its parts and assemblies.

Through jet engine goes powerful gas flow of high temperature. Basic parts of engine are under severe conditions: they experience action of raised stresses at high temperatures.

The most vital parts of engine-rotor blades of gas turbine – experience simultaneous influence of static and sign-alternating loads. In the most stressed root part of blade total operating stress, due to extension, bend, and torsion, is approximately 250 MN/m^2 (25 kgf/mm^2). Here, it is necessary to consider that operating temperature of blade in this place reaches up to 650°C. Under such conditions ultimate strength of ordinary steels does not exceed 50 MN/m^2 (5 kgf/mm^2).

Disk of gas turbine, working under torsion and extension, at roots of blades is heated to 500-550°C and at nave approximately to 150°C. Shaft of turbine has temperature near 100°C. Jet pipe, cone, and jet nozzle have temperature of 450-550°C.

Stator blades of guide-vane apparatus and flame tubes of combustion chambers experience smaller external loads but are subjected to strong action of thermal stresses, appearing as a result of nonuniform heating and multiple thermal cycling.

Besides influence of high temperatures and stresses, parts of engine touching gas flow experience oxidizing action of this flow. Process of burning of fuel in jet engine occurs with considerable surplus of air. High operating temperature of parts favors their oxidation by hot gases containing excess oxygen and sulfurous products of combustion of fuel.

Requirements imposed on materials for parts of aircraft engines ensue from conditions of work of material. Since not all parts of jet engines work under equally severe conditions, it is always necessary to consider concrete conditions of service of part.

Depending upon conditions of work of parts of aircraft engines, on material from which they are prepared are imposed the following requirements:

Resistance to scaling or oxidation – high resistance to oxidation at high temperatures (resistance to gas corrosion).

Heat resistance – ability to resist deformations (resistance to creep) and destruction (stress-rupture strength) under action of mechanical loads.

Endurance – property of metals to endure large number of repeatedly varying loads without failing.

Thermal stability – resistance to influence of frequent thermal cycling (resistance to thermal fatigue). Thermal fatigue is process of destruction of metal due to repeated heatings and coolings.

Insensitivity to concentration of stresses – ability of material to redistribute stress in places of sharp transitions or notches in parts of complicated form through local plastic deformation without leading to destruction.

Erosion resistance – ability of material to resist wear during encounter with flow of gases carrying abrasive particles.

Technological properties, ensuring manufacture of parts and their assembling by contemporary methods.

Exploitational requirements, ensuring prolonged work of metal at high temperatures without change of structure and properties.

During selection of material working for prolonged time at high temperatures it is necessary to consider appearance of hot embrittlement, which leads with time to strong lowering of impact toughness. Nature of hot embrittlement has so far not been determined exactly. Basic factor of its appearance is time of exposure of steel at high temperatures. Especially inclined to hot embrittlement are chromium and chrome-nickel steels. Addition to these steels of molybdenum delays process of hot embrittlement.

§ 2. Oxidation Resistance and Heat Resistance of Steels and Alloys

Oxidation resistance. As it was shown, a number of parts of gas-turbine engine touching hot gases are subjected to gas corrosion.

Gas corrosion is destruction of metals and alloys under action of hot gases. Question about gas corrosion will be considered in greater detail in chapter "Corrosion of metals and alloys." Danger of gas corrosion consists in premature breakdown of parts. Oxidation resistance (scale resistance) of steel or alloy depends on impenetrability and strength of film of oxides formed on their surface in process of gas corrosion at high temperatures.

Basic method for increasing oxidation resistance is alloying of alloys with chromium, aluminum, silicon, and beryllium, which promote formation on surface of parts of tight film impenetrable for gases.

Heat resistance. Under conditions of heating at high temperatures strength of material depends not only on temperature but also on time of its action. Heating of metals and alloys to high temperatures causes reduction of their strength, which is explained by weakening of strength of interatomic bonds in crystal lattice. If

strength of steel at room temperature is almost independent of duration of test, this steel at temperatures higher than 300°C will display less strength the more the duration of test.

Prolonged loading of material at high temperatures leads to its destruction during stresses less than ultimate strength. Destruction is preceded by strong permanent deformations of material - so-called creep.

Creep is property of metals and alloys to slowly and continuously plastically deform at high temperatures under action of constant prolonged applied load. Physical essence of creep is explained by two processes occurring during high-temperature prolonged loading of metal and effective in opposite directions.

On the one hand, in process of plastic deformation at high temperatures occurs strengthening of metal (work hardening), which increases resistance to deformation.

On the other hand, if temperature of metal exceeds its recrystallization temperature, softening of metal occurs due to recrystallization, which facilitates deformation.

Under conditions of prolonged action of stresses exceeding elastic limit at temperatures exceeding recrystallization temperature, plastic deformation of metal will occur continuously as long as external loads and temperature act.

Rate of occurrence of creep depends on relationship of temperature and recrystallization temperature and also on operation stresses and strength characteristics of metal. As was already mentioned, creep is characterized by creep limit.

Creep precedes destruction of metal during its prolonged service. The longer the metal is under load the lower the magnitude of stress at which its destruction occurs. Ability of metal to withstand high-temperature loading for fixed time without destruction is called stress-rupture strength.

Ability of metals and alloys to resist plastic deformation and destruction during prolonged high-temperature loading is called heat resistance.

Heat resistance of steels and alloys, characterized by creep limit and stress-rupture strength, depends on following factors: nature of solid solution base; alloy elements; heat treatment; grain size; character of treatment of surface of part.

Influence of solid solution of base. It has been established that maximum

Heat resistance belongs to alloys whose structure consists of saturated solid solution and strengthening components carbides or metallic compounds. Such structure is obtained for alloys of very complex composition containing defined alloy elements.

Properties of heat-resisting alloys are determined by properties of solid solution of base and properties of intermetallic compounds and carbides.

Heat resistance of steel or alloy, in the first place, is connected with melting point, recrystallization temperature, and atomic bonds, which are determined by type of crystal lattice of base. The higher these characteristics the greater the heat resistance of alloy.

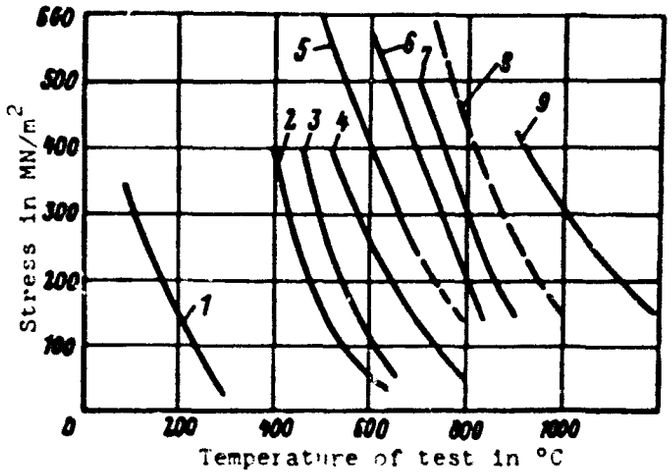


Fig. 13.2. Change of 100-hour stress-rupture strength for different materials with temperature of test. 1 – aluminum alloys, 2 – titanium alloys, 3 – ferrite steels with 1.25 Cr and 0.5 Mo, 4 – austenite steels 18-8, 5 – austenite steels with carbide hardening, 6 – austenite steels with intermetallic compound hardening, 7 – deformed nickel heat-resisting alloys, 8 – cast nickel heat-resisting alloys, 9 – molybdenum alloys.

In Fig. 13.2 are shown comparative curves of heat resistance of aluminum and titanium alloys, steels, and nickel and molybdenum alloys. Melting point, recrystallization temperature, and atomic bond for alloys based on iron are higher than for aluminum and titanium alloys and lower than for nickel and molybdenum alloys. In the same dependence is heat resistance of these alloys.

Influence of nature of crystal lattice on heat resistance may be shown by example of steels. Thus, austenite steels with tighter face-centered lattice

possess greater creep strength and stress-rupture strength that ferrite steels, having body-centered crystal lattice.

Influence of alloying. Alloying is basic method of increasing heat resistance of alloys and is used widely during development of new alloys. The biggest effect of increase of creep strength is obtained in that case when into composition of alloy are introduced large number of alloy elements, variously influencing behavior of alloy during its work. The more alloy elements are introduced into alloy, the more complex the alloy, the greater its heat resistance.

High heat resistance of steel is achieved by means of its alloying, mainly with chromium, nickel, molybdenum, tungsten, niobium, titanium, vanadium, cobalt, aluminum, and other elements.

Alloy elements introduced into alloy are distributed between solid solution and strengthening components. Being dissolved in basic metal, they increase thermal stability of crystal lattice of solid solution, and this means increase strength of alloy at high temperatures.

Such elements, forming solid solutions and possessing by nature high heat resistance, are nickel, chromium, cobalt, molybdenum, and tungsten.

Heat resistance of alloy is increased also as a result of its alloying with elements increasing recrystallization temperature of solid solution. Such elements are molybdenum and tungsten. Forming stable carbides and intermetallic compounds, alloy elements also lead to hardening of alloy. This is explained by the fact that hardening phase, being disposed in structure of solid solution of base prevents plastic deformation and promotes heat resistance.

Such elements as chromium, molybdenum, tungsten, niobium, titanium, aluminum, and vanadium form chemical compounds with carbon, iron, or with other metals. Grains of these chemical compounds, thermally stable and enlarged little when heated, are able to preserve mechanical properties of alloys at high temperatures for prolonged time.

Influence of heat treatment. Heat resistance of majority of alloys is created by heat treatment as a result of age-hardening. Age-hardening is based on aging of supersaturated solid solutions, which is accompanied by precipitation of finely-dispersed inclusions of hardening [illegible] (carbides, nitrides). This hardening phase exists both in the form of crushed big particles on grain boundaries and in

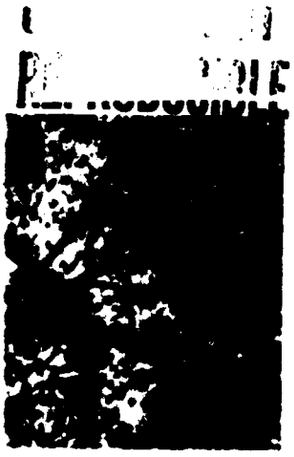


Fig. 13.3. Structure of heat-resisting steels. [4Kh15N7G7F2MS] + Xl + E/DT62MC) (EI388); ×500.

the form of fine particles evenly distributed within grains (Fig. 13.3), which increase resistance to plastic deformation at high temperatures, i.e., increase heat resistance.

At present heat treatment of dispersion hardening alloys consists of two sequential operations:

1) hardening from temperatures of 1000-1300°, for the purpose of transforming carbides and metallic compounds precipitated during preceding treatment to solid solution.

2) aging, i.e., prolonged holding at a temperature of 650-850°C, for the purpose of singling out of excess phases in small-dispersion form.

In order to ensure prolonged work of alloy to ensure stability of solid solution and to prevent structural changes leading to decrease of heat resistance, aging must be conducted at temperatures exceeding working temperature. Slow cooling of alloy after aging from such temperatures stabilizes precipitation of secondary phases from solid solution at working temperatures.

Influence of grain size. It has been established that alloys having more coarse-grained structure possess higher heat resistance than alloys having fine-grained structure. This occurs because at high temperatures grain boundaries are weakened, and destruction of alloys occurs on grain boundaries. Inasmuch as coarse-grained alloys possess smaller total length of grain boundaries than fine-grained alloys, the possibility of destruction (and this means heat resistance) for alloys with coarse-grained structure will be less than for alloys with fine-grained structure.

3. Heat-Resistant and Oxidation-Resistant Steels

Chrome-nickel austenite steels find application as oxidation-resistant materials in aircraft construction.

Chromium gives them heat resistance and nickel ensures obtaining of austenite structure. Oxidation-resistant chrome-nickel austenite steels contain little carbon; sometimes they contain additions of small quantities of titanium or niobium to eliminate inclination to appearance of intercrystallite corrosion. These steels, having high resistance to corrosion in aggressive media, possess good

resistance to formation of scale and are applied as maximal heat-resistant materials up to 900-1100°C.

The most widely applied in aircraft construction are heat-resistant dispersion hardening austenite steels. Depending upon type of hardening, they are subdivided into two basic groups:

1) austenite steels with carbide hardening; they include steels 4Kh15N7G7F2MS [EI388] (EI388), EI481, and others.

2) austenite steels hardened by metallic; they include steels [Kh12N20T3R] (X12H20T3P) (EI696), EI786, and others.

In steels of first group increase of heat resistance is connected with processes of hardening of γ-solid solution due to formation of carbide phases of high degree of dispersion. These hardening phases, being separated during aging or during work of alloy at high temperatures, block glide planes, thus increasing heat resistance.

In steels of second group increase of heat resistance is caused by formation of metallic compounds during aging or during work at high temperatures. Mechanism of increase by metallic compounds of resistance of alloy to plastic deformation at working temperatures is analogous to mechanism of hardening of alloy by carbide phases.

Hardening of heat-resistant austenite steels is carried out as a result of strain aging. For this they are subjected to heat treatment, consisting of hardening to austenite and subsequent prolonged aging at 700-750°C.

In those cases when for condition of work high heat resistance is not required, instead of expensive austenite steels there are applied cheaper ferrite steels, containing smaller quantity of alloy elements.

Heat-resistant ferrite steels are inferior to austenite steels in heat resistance, oxidation resistance, and weldability. But, in turn, they are more easily processed by pressure and cutting, and heat treatment of them is simpler. Besides this, they possess better physical properties (coefficient of thermal expansion and thermal conductivity), which has important value during manufacture of a number of parts working at raised temperatures.

In Table 27 are given compositions, and in Table 28 are given mechanical properties of heat-resistant and oxidation-resistant steels most widely applied in aircraft construction

Table 27. Chemical Composition of Heat-Resistant and Oxidation-Resistant Steels in %

Name of steel	Grade	C	Cr	Ni	Fe	Other elements
25-18	Х23Н18 (ЭИ417)	0,10	25	18	Base	Si1, Mn<2,0
20-35-3W	ЭИ703	0,16	20	35	.	W 3, Nb 1,5 or Ti 1,0
20-40-7W	ХНВА	0,25	20	40	.	W 7
15-7-7V-Mo	4Х15Н7Г7Ф2МС (ЭИ388)	0,42	15	7	.	Mn7; V1,7 Mo 0,7
10-20-3T	Х12Н20Т3Р (ЭИ696)	0,06	10	20	.	Ti 3; B 0,015
3Mo-W-V	20Х3МВФ (ЭИ415)	0,16—0,24	2,4—3,3	<0,5	.	V 0,60—0,85; W 0,30—0,50; Mo 0,35—0,55
16-25-6Mo	Х16Н25М6 (ЭИ395)	0,10	16	25	.	Mo 6; N 0,15
13-8-8V-Mo-Nb	ЭИ481	0,38	13	8	.	Mn 8; V 1,3; Mo 1,1; Nb 0,3
21-11-2,5W	21-11-2,5	0,20	22	11	.	W 2,5

Table 28. Mechanical Properties of Heat-Resistant and Oxidation-Resistant Steels

Name of steel	Grade	Heat treatment	Temperature of test, °C	Mechanical properties (not less)			
				σ_b kg/mm²	δ %	creep limit with respect to total deformation $\sigma_{0,2/100}$ kg/mm²	stress-rupture strength σ_{100} kg/mm²
25-18	Х23Н18 (ЭИ417)	[illegible]	20	670	35	230	—
			600	420	23	230	—
			700	330	22	150	170
			800	180	15	75	70
20-35-3W	ЭИ703	[illegible]	20	740	40	—	—
			800	250	58	—	90
			900	150	82	—	45
20-40-7W	ХНВА	[illegible]	20	500	7	—	—
			600	—	—	—	—
			700	380	5,5	—	—
			800	300	7	—	—
15-7-7V-Mo	4Х15Н7Г7Ф2МС (ЭИ388)	[illegible]	20	900	15	—	—
			600	700	10	230	300
			700	500	12	150	180
			800	300	8	70	100

Table 28 (continued)

Name of steel	Grade	Heat treatment	Temperature of test, °C	Mechanical properties (not less) σ_B MN/m²	δ %	creep limit (with respect to total deformation) $\sigma_{0,2/100}$ MN/m²	stress-rupture strength σ_{100} MN/m²
10-20-3T	X12H20T3P (ЭИ696)	Hardening from 1140-1180°C in air or water	20	1100	22	—	—
			600	850	23	—	—
			700	700	18	340	400
			800	400	26	—	—
3Mo-W-V	20Х3МВФ (ЭИ415)	Hardening from 1060°C in oil, tempering at [illegible]°C, holding 1 hour	550	580	12	320	350
			600	500	9.7	—	—
16-25-6Mo	X16H25M6 (ЭИ395)	Hardening from 1200°C in water and aging at 700°C, holding 25 hours	20	840	20	—	—
			600	650	20	345	405
			700	510	13	165	230
			800	350	11	100	—
13-8-8V-Mo-Nb	ЭИ481	Hardening from 1140°C in water, tempering at 650°C	20	940	16	—	—
			600	600	12	220	450
			700	620	13	158	310
			800	—	—	—	—
21-11-2,5W	21-11-2,5	Normalization at 1100°C, holding 3-6 hours	20	500	12	—	—
			600	390	24	—	360
			700	270	24	—	250
			800	190	30	—	170

Combustion chambers, as compared to other units of jet engines, are subjected to action of the highest temperatures. Under severe conditions work flame tubes, heated by gas flow to 900-1000°C, where there frequently occurs nonuniform heating, which leads to thermal stresses.

Under analogous conditions are parts of exhaust system (cone, extension pipe, jet nozzle); however, they are heated by gas flow to lower temperatures.

Basic requirements imposed on material of combustion chambers and exhaust system of jet engines is high resistance to gas corrosion. Of material of flame tubes is required also the ability to resist multiple fast heatings and coolings. For manufacture of parts of flame tubes and exhaust system are applied heat-resistant chrome-nickel austenite steels, and for manufacture of flame tubes are applied heat-resistant alloys based on nickel.

Steel Kh23N18 (EI417) has raised content of chromium and nickel as compared to steel [illegible] [EYa1] (Cl1), which leads to considerable increase of its heat resistance and oxidation resistance. After being hardened in water steel obtains austenite structure (Fig. 13.4), which gives it high ductility. It allows deep drawing and

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Fig. 13.4. Microstructure of steel Kh23N18; ×250.

other forms of cold stamping. Steel welds well by all forms of welding. Characteristics of heat resistance steel are given in Table 28. Steel is heat-resistant in oxidizing atmosphere to 1000°C. One of its main deficiencies is inclination to intercrystallite corrosion. Steel Kh23N18 is supplied in the form of sheets, rods, and rings. It is used for manufacture of parts of combustion chambers, flame tubes, and parts of ramjet engine working at temperatures of 900-950°C.

Steel EI703, as compared to steel Kh23N18 (EI417) has still higher content of chromium and nickel and is additionally alloyed with tungsten.

This explains its high heat resistance and oxidation resistance. Small quantity of niobium or titanium is introduced to eliminate the possibility of intercrystallite corrosion. Steel is subjected to hardening to austenite. After being hardened it becomes ductile, allowing application of cold stamping. Steel welds well by argon arc, arc, and resistance welding. Characteristics of heat resistance of steel are given in Table 28. Steel resists oxidation in air medium to temperature of 1200°C.

It is supplied in the form of sheets, tapes, and wires. It is used for manufacture of parts of flame tubes and afterburners.

Blades of guide-vane apparatus work at temperatures of 750-850°C and under the influence of gas flow are subjected to action of small bending stresses. Therefore metal of nozzle blades should possess high resistance to gas corrosion and erosion. Simultaneously, the material of nozzle blades must possess high resistance to gas corrosion and erosion. For manufacture of blades of turbine stator are applied heat-resistant foundry alloys based on iron or cobalt.

Alloy [VL7-45U] (ВЛ7-45У) as basic alloy elements contains chromium, nickel, and tungsten, with addition of manganese and boron for refining. Alloy is applied in cast form, possesses good foundry properties, parts are prepared by exact casting and machine satisfactorily. Heat resistance of alloy is high; values of creep limit and stress-rupture strength are given in Table 28. Alloy VL7-45U is heat-resistant to 1000°C.

Casting from it are subjected to heat treatment consisting of prolonged aging at 900°C and subsequent cooling in air.

Alloy VL7-45U is used for manufacture of blades of guide-vane apparatus of jet engines, intended for work at temperature of not more than 800-850°C.

Rotor blades are the most loaded parts of turbine engine. Although rotor blades work at temperatures approximately 100°C lower than nozzle blades, they are subjected to influence of large tensile stresses due to centrifugal forces, considerable bending stresses due to irregularity of pressure of gas flow, and also stresses from torsional oscillations.

Besides this, rotor blades are subjected to oxidizing action of hot gases.

Working for prolonged time under conditions of high temperatures and stresses, material of turbine blades should possess good oxidation resistance, high creep strength, and great endurance during action of repeatedly-variable buckling loads.

Material used for rotor blades of turbine must also possess toughness and ductility, allowing treatment of blades and rendering resistance to dynamic loads.

Such complicated complex of properties is satisfied only by high-alloy heat-resistant steels and under more stressed conditions of work by special alloys based on nickel.

Steel 4Kh15N7G7F2MS (EI388) contains as basic alloy elements chromium, nickel, manganese, and small quantities of vanadium and molybdenum. It belongs to group of austenite-carbide heat-resistant steels. Best properties for these steels are obtained after high-temperature hardening and prolonged aging, as a result of which it obtains structures of austenite, on grain boundaries of which are disposed small inclusions of complex carbides of chromium and vanadium, molybdenum and iron. Steel possesses good technological properties: weldability, hot pressure workability, machinability after heat treatment, and also high resistance to oxidation in air medium to 700°C.

For increase of scale resistance parts are nickel-plated or calorized. Characteristics of heat resistance of these steels are given in Table 28.

Steel 4Kh15N7G7F2MS (EI388) is supplied in the form of rods and is used for manufacture of lightly-loaded blades of gas turbines and for fasteners. After prolonged work under influence of high temperatures and stresses, steel becomes less heat-resistant, which is explained by change of its structure – impoverishment of solid solution.

Steel Kh12N20T3R (EI696) as basic alloy elements contains chromium, nickel, titanium, and aluminum; raised content of nickel gives it austenite structure.

Steel belongs to group of austenite heat-resistant steels. Hardening of this steel is caused by formation of metallic compounds of nickel with titanium, which is separated as a result of strain aging. After being hardened to austenite from 1100°C, this steel has very high ductility and moderate strength. As a result of prolonged aging at 700°C, steel is strengthened greatly and possesses high mechanical properties, which are preserved during prolonged work up to temperatures of 700°C (see Table 28). Steel is heat-resistant in oxidizing medium to temperatures of 850°C, processes well by pressure both in hot and cold states, welds well by all forms of welding, and does not need subsequent heat treatment.

Steel Kh12N20T3R (EI696) is released in the form of various semifinished products and is used for different parts working under loads at temperatures of not more than 750°C.

Thus, rods are used for rotor blades of gas turbines, guide vanes, rotor blades for compressors, and fasteners.

Sheets are used for manufacture of elements of such heat-resistant structures as afterburners and turbine bodies.

Forgings of this steel is used for turbine disks, annular parts of turbine, and others.

Turbine disks work under conditions of large and combined stresses. First, are stresses due to centrifugal forces, reaching considerable magnitudes. Then come somewhat smaller temperature stresses, caused by difference of temperature of rim and center of disk. The highest stresses appear in less heated central nave part of disk. Temperature of this part of disk is 100-150°C. Therefore material for turbine disks must possess high yield point and resistance to plastic deformation.

On rim of disk, heated to temperatures of 500-600°C, stability of material is determined by creep strength; therefore material must possess heat resistance and also high resistance to sign-alternating loads. Toughness and ductility of this material are necessary, so that redistribution of stresses in places of their concentrations is possible.

For reduction of temperature stresses appearing during work of disk material should possess smallest possible coefficient of linear expansion, since expansions, determining temperature stresses, will be bigger the greater the coefficient of linear expansion.

With increase of thermal conductivity of material of turbine disk, difference of operating temperatures between rim and nave decreases, and this means temperature stresses also decrease. And finally, resistance to gas corrosion in interval of operating temperatures is of important value.

For turbine disks working at 500-550°C are applied heat-resistant steel, and for work at high temperatures steels having high-temperature strength are used.

Steel [20Kh3MVF] (20Х3МВФ) (EI415) is medium-alloy steel belonging to ferrite class. Presence of chromium in it increases heat resistance. Tungsten and molybdenum give steel heat resistance. Addition of vanadium increases stress-rupture strength and creep strength.

This steel is well suited to pressure working and machining. Heat treatment of it consists of hardening in oil and high-temperature tempering. Here, steel obtains structure of acicular martensite with carbides.

Creep strength and stress-rupture strength of steel 20Kh3MVF (EI415) are given in Table 28. Steel is heat-resistant, i.e., preserving its mechanical properties at temperatures to 500°C.

This steel is supplied in the form of rods and forgings. It is used for manufacture of turbine and compressor disks working at 500-550°C.

Steel Kh16N25M6 (EI395) contains, besides basic alloy elements, a small quantity of nitrogen, introduced for full stabilization of austenite. It belongs to group austenite-intermetallic-compound heat-resistant steels. After hardening and aging it has structure of austenite, strengthened by metallic compound of complex composition (Fig. 13.5).

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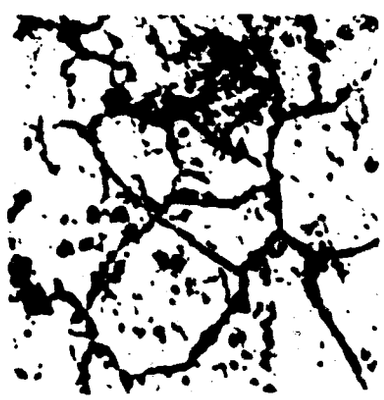


Fig. 13.5. Microstructure of heat-resistant steel Kh16N25M6 (EI395); ×250.



Fig. 13.6. Microstructure of heat-resistant steels EI481; ×500.

Steel is processed satisfactorily by pressure and welds well, it machines well, possesses high heat resistance (see Table 28), and is resistant to gas corrosion to temperature of 800°C.

Since heat treatment does not give sufficient increase of properties, steel for hardening is subjected to semihot work hardening. It is used for manufacture of turbine disks of jet engines of working at temperatures not higher than 800°C. At present steel Kh16N25M6 (EI395) is replaced by less scarce and more easily processed steel EI481.

Steel EI481 constitutes complex alloy chromium-nickel-manganese steel with addition of molybdenum, vanadium, titanium, and niobium. This steel belongs to group of austenite-carbide heat-resistant steels. To give it heat resistance, steel EI481 is subjected to hardening and tempering in process of which are separated finely-dispersed carbides of chromium and vanadium (Fig. 13.6).

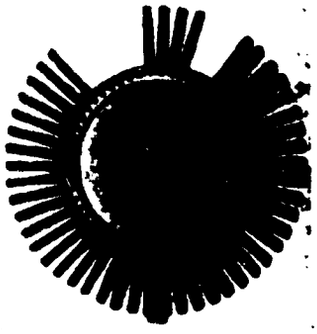


Fig. 13.7. Disk of turbine of jet engine prepared of steel of grade Kh16N25M6 with blades made from nickel alloy Kh20N80T3 (EI437B).

Creep strength and stress-rupture strength of steel are given in Table 28.

Steel EI481 is resistant to oxidation in air medium at temperatures to 700-750°C. It possesses good technological properties – ductility and machinability.

Steel is supplied in the form of rods and forgings. It is used for manufacture of turbine disks working at temperatures of 600-700°C (Fig. 13.7). Besides this, from it are prepared power rings and fasteners (bolts, studs, nuts) of gas turbines of jet engines.

Body of turbine and casing of turbine stator of jet engines are heated during work to 700°C and above. For their manufacture is applied chromium-nickel-tungsten steel of grade 22-11-2.5. Parts made from this steel are cast.

For production of uniform structure, removal of internal stresses, and improvement of properties, blanks for bodies of turbines and both guide-vane devices of turbine are heat-treated.

After normalization and prolonged aging occurs stabilization of dimensions of parts, which is important requirement imposed on these parts during work of engine.

Steel possesses high fluidity, satisfactory machinability, good weldability, and oxidation resistance to 1000°C.

Characteristics of heat resistance of steel 32-11-3.5 are given in Table 28.

As oxidation-resistant materials also are used earlier considered stainless steels Kh18N9 (EYa1), 2Kh18N9 (EYa2), Kh18N9T (EYa1T), and 0Kh18N10B (EI402).

§ 4. Heat-Resistant and Oxidation-Resistant Nickel and Cobalt Alloys

For manufacture of parts of jet engines working at high temperatures, along with heat-resistant and oxidation-resistant steels, nickel and cobalt alloys are widely applied.

As compared to alloys based iron, alloys based on nickel and cobalt possess high heat and oxidation resistance. It is necessary, however, to consider that nickel and cobalt alloys, in view of scarcity of nickel, and especially of cobalt, are considerably more expensive than heat-resistant steels.

High oxidation resistance of these alloys is explained by formation on their surface at high operating temperatures of a deuse protective film of oxides of chromium and aluminum.

Heat resistance of nickel alloys is due to formation of hardening metallic compounds of nickel with titanium and nickel with aluminum in solid solution. In distinction from steels, in nickel alloys carbides are not formed, since they contain small quantity of carbon.

Hardening of heat-resistant nickel alloys is carried out as a result of strain aging. For this they are subjected to heat treatment, consisting of hardening, for production of uniform solid solution of alloy elements in nickel, and subsequent prolonged aging at high temperatures, 700-800°C.

Here, as a result of disintegration of supersaturated solid solution, hardening metallic compounds are formed, increasing resistance to plastic deformation at high temperatures, i.e., increasing heat resistance of alloy. Prolonged holdings at high temperatures are accompanied by increase of particles of metallic compounds, which leads to softening of alloy and impairment of its heat resistance.

For production still more heat-resistant alloys are used alloying with refractory elements - molybdenum, tungsten, niobium, and also such elements as cobalt, and boron. Refractory elements complicate structure of solid solution and promote formation of stable particles of hardening phases. As was shown, complication of composition of alloy causes increase of its heat resistance. Aiding small quantity of boron to alloy strengthens grains and leads to considerable

increase of heat resistance. Still greater heat resistance can be obtained for alloys based on cobalt or molybdenum.

For production of optimum heat-resisting properties it is necessary also that alloy pcssess high degree of purity and that metallurgical defects be absent.

Heat-resistant and oxidation-resistant alloys on nickel and cobalt bases are subdivided into following groups:

1. Heat-resistant nickel-chromium alloys of Nichrome type. These include alloys Kh20N80T (EI435), EI602, and others. High resistance to oxidation in gaseous environment permits using them for manufacture of flame tubes of combustion chambers.

2. Heat-resistant nickel-chromium-titanium alloys of type 75-20-3. These include alloys Kh20N80T3 (EI437B) and EI617, possessing high resistance and applied for manufacture of rotor blades of gas turbines.

3. Cast complex-alloy heat-resistant alloys on nickel (EI618) and cobalt [LK4] (ЛК4) bases. These alloys are used for manufacture of cast rotor and nozzle blades of gas turbines.

Table 29. Chemical Composition of Heat-Resistant and Oxidation-Resistant Nickel and Cobalt Alloys in %

Name of alloy	Grade	C	Cr	Ni	Ti	Al	Co	Mo	Other elements
Nichrome 80-20	Х20Н80Т (ЭИ435)	>0,12	19—22	>75	0,15—0,35	<0,15	—	—	Mn 0,7; Si 0,8; Fe 1,0
Complex alloy	ЭИ602	<0,08	19—22	Base	0,35—0,75	0,35—0,75	—	1,8—2,3	Mn 0,4; Si 0,8; Nb 1,9—1,3
Complex alloy	ЭИ652	<0,1	26,5—28,5	.	—	2,8—3,5	—	—	Ba 0,08; Fe 1,0; C<0,03
Complex alloy	ВЖ98 (ЭИ868)	<0,1	23,5—26,5	.	0,3—0,7	<0,5	—	—	Si 0,8; Mn 0,5; W 13,0—16,0;
75-20-3	Х20Н80Т3 (ЭИ437Б)	<0,8	19—22	.	2,2—2,7	0,5—0,95	—	—	Mn 0,35; Si 0,65; Fe 1,0; B 0,01
Complex alloy	ЭИ617	<0,12	13—16	.	2	2	—	2—4	Mn 0,5; V 0,5; Si 0,5; Fe 8,0; W 5—7
Complex alloy	ЖС3 (ЭИ618)	<0,15	18,0	.	1,8	2	—	4	B 0,02; V 0,3; W5
63-27-6	ЛК-4	0,2—0,3	230—28,5	3,0—3,75	—	—	Base	4,5—5,5	Mn 0,6; Si 0,5; Fe 3,0

Table 30. Mechanical Properties of Heat-Resistant and Oxidation-Resistant Nickel and Cobalt Alloys

Name of alloy	Grade	State of material	Temperature of test, °C	Mechanical properties (not less)			
				σ_b MN/m²	δ %	creep limit (with respect to total deformation) $\sigma_{0,2/100}$ MN/m²	stress-rupture strength σ_{100} MN/m²
[illegible] -20	Х20Н80Т (ЭИ435)	Hardening from [illegible]°C in water or air	20	700	30	—	—
			700	400	—	—	120
			800	180	—	—	45
			900	110	—	—	15
[illegible] alloy	ЭИ602	Hardening from [illegible]°C, cooling in air	20	860	—	—	—
			700	560	—	61	16—17
			800	297	—	20	80
			900	180	—		29
[illegible] alloy	ЭИ652	Hardening from 1100°C, cooling in air	20	750	30	—	—
			700	420	—	—	—
			800	360	4	—	—
			900	150	57	—	—
[illegible] alloy	ВЖ98 (ЭИ868)	Hardening from 1200°C, cooling in air	20	750	30—40	—	—
			800	400	23	—	110
			900	230	25	—	52
[illegible]	Х20Н80Т3 (ЭИ437Б)	Hardening from 1050°C, holding 8 hours, cooling in air, ageing at 750°C for 16 hours	20	1000	19,3	—	—
			600	880	6,9	—	—
			700	680	3,3	220	302
			800	350	6,8	114	150
[illegible] alloy	ЭИ617	Hardening from 1050°C, holding 2 hours, cooling in air, then secondary hardening from 1050°C, holding 4 hours, cooling in air, and ageing at 750°C for 16 hours	20	1080	14	—	—
			700	900	12	300	480—520
			800	800	8	170	280—300
			900	550	8	—	130—150
[illegible] alloy	ЖС3 (ЭИ618)	Hardening from 1150°C in oil and ageing at 850°C for 5 hours	20	750	2	—	—
			700	570	—	—	—
			800	560	4	—	290
			900	400	—	—	100
[illegible]	ЛК4	Cast	20	700	8	—	—
			600	520	12,5	—	300
			700	470	10	—	250
			800	325	6,5	—	150
			900	270	9,0	—	70

In Table 29 are given chemical compositions most widely spread and in Table 30 are given mechanical properties of the heat-resistant and oxidation-resistant nickel and cobalt alloys in aviation industry.

Alloy Kh20N80T (EI435) belongs to group of alloys of Nichrome type. High content of chromium and aluminum give alloy good heat resistance. After being hardened, structure of alloy constitutes uniform solid solution. In hardened state at room temperatures alloy possesses moderate strength and high ductility, allowing it to be subjected to all forms of cold stamping. Alloy welds well by resistance welding and satisfactorily by gas and atomic-hydrogen method. Heat resistance of alloy is low (see Table 30). Alloy is supplied in the form of sheets and is used for manufacture of flame tubes of combustion chambers. If operating temperature does not exceed 800°C, alloy can be replaced by cheaper alloy EI417.

Alloy EI602 belongs to the same group of alloys and differs from alloy Kh20N80T (EI435) by the fact that in it are contained about 2% molybdenum and 1% niobium, which somewhat increases its heat resistance without impairment of ductility at operating temperatures. Alloy possesses high oxidation resistance and is used for manufacture of flame tubes and afterburners in engines more strained in a thermal sense. Alloy EI602 can be successfully replaced less scarce alloy EI703.

Alloy EI652 belongs also to alloys of Nichrome type. Introduction of up to 3% aluminum and up to 27% chromium considerably increases heat resistance of alloy but decreases its ductility at lowered temperatures. Here, its weldability and workability by pressure in cold state are worsened as compared to alloy EI435. Alloy possesses oxidation resistance to 1200°C. Alloy EI652 is supplied in the form of sheets and can be used for manufacture of parts of combustion chambers working at the highest temperatures.

Alloy [V2h98] (EP98) (EI868) is one of the high-strength alloys for combustion chambers. Its raised heat resistance as compared to alloy Kh20N80T (EI435) is ensured by high content of tungsten (13-16%). Characteristics of heat resistance of alloy are given in Table 30.

Alloy V2h98 stamps well and welds well by all forms of welding. Alloy is supplied in the form of sheets, rods, and tapes. It is used for manufacture of parts of combustion chambers and afterburners working at temperatures to 1100°C.

Alloy Kh20N80T3 (EI437B) belongs to group of heat-resistant nickel-chromium-titanium alloys. Presence in alloy of raised content of titanium and small addition of boron substantially increases its heat resistance as compared to nickel-chromium alloys but lowers their ductility. Alloy is subjected to strengthening by heat treatment, consisting of hardening with cooling in air and prolonged aging at 700°C, after which it has structure of solid solution, strengthened by singling out of phase into which enter nickel, titanium, and aluminum (Fig. 13.8).



Fig. 13.8. Microstructure of heat-resistant nickel alloy Kh20N80T3 (EI437B), ×500.

Characteristics of heat resistance of this alloy are given in Table 30. Alloy possesses high heat resistance; it is resistant to oxidation in air medium to 1050°C.

Alloy Kh20N80T3 (EI437B) is supplied in the form of rods and is used widely for manufacture of rotor blades of gas turbines working at 700-750°C (Fig. 13.9).

Alloy EI617 is complex alloy nickel-chromium-titanium alloy, into which are introduced molybdenum, tungsten, and increased content of aluminum. This still more increases heat resistance of nickel-chromium-titanium alloys. Together with this, for such alloys pressure workability and machinability are worsened. After heat treatment, consisting of heating at 1200°C with cooling in air and prolonged aging at 800°C, alloy EI617 possesses high heat resistance (see Table 30), exceeding heat resistance of alloy Kh20N80T3 (EI437B). Machining of alloy is hampered. It is processed only by cutters made from high-speed cutting high-tungsten steel. Alloy EI617 is processed satisfactorily by pressure.

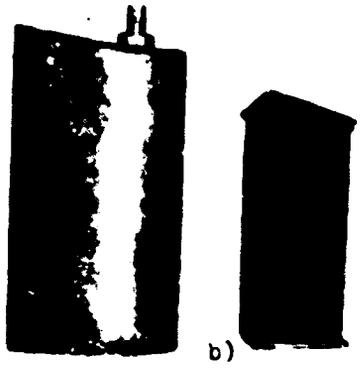


Fig. 13.9. Rotor blade of gas turbine made from heat-resistant alloy Kh20N80T3 (EI437B).

Alloy EI617 is supplied in the form of rods and is used for manufacture of rotor blades of gas turbines of working at 800-900°C.

Alloy [illegible] (EI618) constitutes complex nickel-chromium-[illegible]-tungsten alloy with addition of titanium, aluminum, and boron. It is necessary to note that introduction of large quantity of such alloy elements as aluminum, titanium, molybdenum, tungsten,

and others into alloys based on nickel increases their heat resistance still more but very strongly worsens ductility. Such alloys are applied in cast state mainly for manufacture of blades of turbine stators of jet engines and less often for rotor blades of gas turbine. Alloy ZhS3 is the most widely applied heat-resistant foundry alloy based on nickel. Alloy is heat-resistant at temperatures to 1000°C and possesses high heat resistance whose characteristics are given in Table 30. Alloy ZhS3 and other alloys of the same type at temperatures lower than 800°C possess very low ductility and are difficult to machine. Alloy ZhS3 is foundry alloy. It is used for manufacture of precision castings of nozzle blades of gas turbines for jet engires (Fig. 13.10a) and for turbostarters.



a) b)

Fig. 13.10. Cast blades of turbine stator of jet engine. a) prepared from nickel alloy ZhS3 (EI618), b) prepared from cobalt alloy LK-4.

Castings are subjected to heat treatment, consisting of hardening from temperature of 1150°C and cooling in air.

Alloy LK-4 constitutes complex cobalt-chromium-molybdenum alloy. Because this alloy does not respond well to pressure treatment or machining, parts made from it are prepared by method of precision casting.

Pouring of metal into hot ceramic forms is done by centrifugal method. Alloy possesses good fluidity. Castings of alloy LK-4 have structure constituting solid solution on cobalt base and complicated carbides. Alloy is not heat treated. This alloy is characterized by high heat resistance values for which are given in Table 30, and by high oxidation resistance. Parts made from this alloy can work without oxidizing to 1000°C.

This alloy is applied for manufacture of blades of turbine stator of jet engines (Fig. 13.10b). In view of scarcity and high cost, nickel-based alloy ZhS3 can be replaced by iron-based alloy VL7-45U.

§ 5. Refractory Metals and Alloys Based on Them

Above considered heat-resistant alloys based on iron, nickel, and cobalt possess satisfactory strength only to temperatures not exceeding 1000°C.

It is expedient to use as structural materials intended for work at temperatures

exceeding 1000°C either heat-capacitive or very refractory materials.

Use of heat-capacitive materials allows us to relieve temperature conditions of work of parts. As such material it is possible to use beryllium.

Use of refractory materials is due to the fact that they have strength at high temperatures exceeding strength of materials with lower melting points.

At present it is accepted to call refractory those metals whose melting point exceeds 1800°C.

In Table 31 are given properties of certain refractory metals.

Table 31. Properties of Certain Refractory Metals

Metal	Melting point °C	Specific gravity kN/m^3	Ultimate strength σ_B MN/m^2	Elongation δ %	Elastic modulus E MN/m^2
Tungsten	3410	193	500-4000	8-0	410,000
Rhenium	3180	200	–	–	430,000
Tantalum	3000	166	400-1800	10-2	188,000
Osmium	2700	225	–	–	–
Molybdenum	2625	102	450-1800	30-2	322,000
Iridium	2450	224	–	–	–
Niobium	2420	86	350-700	30-1	115,000
Chromium	1890	72	–	–	198,000

All refractory metals given in Table 31 have a series of essential deficiencies, being cause of their restricted use at high temperatures.

First, all of these metals but iridium and chromium readily oxidize at high temperatures.

Secondly, all of them but chromium and niobium have comparatively high specific gravity.

From considerations of cost and accessibility at this time the most promising metals in aircraft construction are considered molybdenum and niobium, then tantalum and tungsten.

Besides this, of interest is chromium, distinguished by high resistance to oxidation. However, high brittleness of chromium does not permit its use as basis of structural materials.

Molybdenum. At present molybdenum is produced by industry in comparatively

large quantities by two methods: powder metallurgy and fusion method. Process is conducted in high vacuum, which promotes the obtaining of pure metal. Contamination of molybdenum by nitrogen, oxygen, or carbon makes it brittle at low temperatures, which is an essential deficiency.

Application of molybdenum in structures subject to action of high temperatures presents interest thanks to its physical properties. Molybdenum has small coefficient of thermal expansion ($5.4 \cdot 10^{-6}$); this causes small thermal stresses in structure during thermal cyclings. Its high thermal conductivity ($1.47 \cdot 10^2$ W/m·deg or 0.35 cal/cm·s·deg) is important for rapid temperature balancing during nonuniform heating.

Molybdenum is plastic at normal and raised temperatures. Its modulus of normal elasticity, having large value during work of structure, decreases little with increase of temperature.

Molybdenum possesses considerable strength both at normal and at high temperatures. Strength of molybdenum at normal temperature is 400-450 MN/m^2 (40-45 kgf/mm^2) after work hardening is increased to 1300-1400 MN/m^2 (130-140 kgf/mm^2). This strength of work-hardened molybdenum decreases little up to temperature of its recrystallization, equal approximately to 1000°C.

Development of alloys based on molybdenum has been conducted especially actively in last decade. As alloy elements of molybdenum alloys are used small quantities of niobium, titanium, zirconium, chromium, silicon, and other elements forming solid solutions with molybdenum.

In spite of the fact that molybdenum alloys possess higher specific gravity than alloys based on iron and nickel, they have considerable advantage over them for work under conditions of high temperatures. Thus, for instance, alloy of molybdenum with 0.3% niobium has high hardness to 1100°C and with 0.5% titanium has this property to 1200°C. Alloy containing 0.45% titanium at 1000°C possesses stress-rupture strength equal to $\sigma_{100} = 350$ MN/m^2 (35 kgf/mm^2), while for alloys based on nickel it reaches only 100 MN/m^2 (10 kgf/mm^2).

Application of molybdenum alloys at high temperatures is expedient thanks to increase of strength, in spite of increase of specific gravity. Thus specific strength of molybdenum alloys at temperatures of exceeding 1000°C exceeds that of known heat-resistant steels and nickel alloys.

Molybdenum and its alloys could become very valuable structural material if it were possible to surmount their low resistance to gas corrosion. Molybdenum oxidizes very fast with increase of temperature and molybdenum oxide MoO_3 formed at high temperatures, starting from 750°C possesses great volatility. Prolonged heating in air leads to large losses of weight of molybdenum due to continuous formation and volatilization of oxide. Thus, molybdenum can work either in atmosphere of inert gas or with covering reliably protecting it from oxidation.

At present for increase of resistance to oxidation of molybdenum alloys metallic and ceramic surface coverings are applied.

Essence of protection of molybdenum alloys by metallic coverings consists in creation on surface of article of layer of metal or alloy possessing high resistance to oxidation. For work at temperatures to 1100°C are applied coverings of chromium and nickel, deposited by galvanic method by plating, or by sputtering method, using oxidation-resistant alloys containing aluminum, chromium, silicon, and nickel. Deficiency of these coverings is their loss of protective properties due to accelerated diffusion in molybdenum at temperatures, over 1050°C, of metals that resist oxidation well.

Ceramic coatings permit increasing temperature limit of applicability of molybdenum alloys. However, these coverings possess insufficient cohesion with basic metal. The most very promising is covering of molybdenum disilicide $MoSi_2$, which permits using molybdenum alloys to 1400-1500°C. It is possible to protect molybdenum to 2000°C with help of oxides. But these films are brittle and badly resist thermal shocks.

At present technology of processing molybdenum and its alloys is more improved than that of other refractory metals. They are released in the form of sheets, plates, bands, wire, and tubing. They are subjected to treatment by pressure and cutting.

Molybdenum and its alloys is used for parts of aircraft and their engines working for prolonged periods at temperatures higher than 1000°C. It is possible to use them briefly at temperatures to 2000°C.

Niobium is the most promising of refractory metals for high-speed aviation. Its production is increasing with every year. Thus, for instance, in 1958 in the United States were produced 12 tons of niobium, in 1959 – 20 tons, and in 1970 it is assumed that 800 tons will be smelted.

Pure niobium is very soft and plastic metal. It can be easily subjected to pressure treatment without intermediate annealing.

Contamination of niobium by small quantities of nitrogen, oxygen, and hydrogen leads to appearance of brittleness.

Niobium is distinguished by low modulus of normal elasticity, which is not changed with heating to 1100°C. Strength of this metal is low. Thus, in annealed state niobium has ultimate strength of σ_B = 350 MN/m^2 (35 kgf/mm^2), with elongation of δ = 30%. By work hardening it is possible to increase its strength to σ_B = 700 MN/m^2 (70 kgf/mm^2).

Deformed niobium loses practically no strength when heated to 1000°C, which is its recrystallization temperature.

For production of alloys based on niobium, as alloy elements are used molybdenum, tungsten, vanadium, and other elements forming solid solutions with it.

Ultimate strength of these alloys after work hardening is 950-1000 MN/m^2 (95-100 kgf/mm^2).

Niobium alloys have, as compared to pure niobium, higher recrystallization temperature, and this means higher heat resistance. In value of stress-rupture strength at high temperatures niobium alloys are somewhat inferior to molybdenum alloys. For instance, at 1200°C for niobium alloys stress-rupture strength is 300-350 MN/m^2 (30-35 kgf/mm^2) and for molybdenum alloys 400-450 MN/m^2 (40-45 kgf/mm^2). However, lower specific gravity of niobium compared to molybdenum permits obtaining for these alloys at temperatures of 1000-1200°C value of specific tenacity close to those of molybdenum alloys.

In corrosion resistance niobium and its alloys exceed molybdenum. Niobium possesses high corrosion resistance to 200°C and its alloys are stable to 400°C.

Niobium alloys are recommended for manufacture of parts of gas turbines and aircraft.

Without protective coverings niobium alloys can be used for brief work to 1500°C. Protective coverings permit them to work for prolonged periods at temperatures to 1100°C.

Tantalum. This is a very refractory metal of silvery-white color. Its specific gravity is almost twice that of niobium. Tantalum is characterized by low value of elastic modulus.

Tantalum is a soft and very plastic metal. It can, like niobium, be subjected to cold deformation without intermediate annealings. It permits carrying out rolling of sheets, forgings, and drawing of wire. Cold deformation strongly increases hardness and strength of tantalum. Thus, for instance, annealed tantalum has ultimate strength of 300-400 MN/m^2 (30-40 kgf/mm^2), which for work-hardened tantalum is 1700-2000 MN/m^2 (170-200 kgf/mm^2).

Influence of raised temperatures on mechanical properties of tantalum is still insufficiently investigated. It has been established that tantalum is completely recrystallized at 1300°C. It loses practically no strength approximately to these temperatures. Ultimate strength of tantalum at 1100°C is about 120 MN/m^2 (12 kgf/mm^2).

Tantalum possesses high resistance to corrosion and erosion. It is resistant to influence of different acids and alkalis. However, like other refractory metals, tantalum strongly oxidizes at high temperatures and needs protection.

In aircraft and engines tantalum and its alloys so far are not applied. However, obtained alloys of tantalum with tungsten show ability to withstand temperatures to 2000°C.

Tungsten. Of all known metals it possesses the highest melting point - 3410°C. In connection with this, it usually is obtained by method of powder metallurgy.

Tungsten has specific gravity (see Table 31) very exceeding that of nickel by 2 times, that of iron by 2.5 times, and that of aluminum by 7 times.

From this metal for a long time were extruded only filaments for incandescent lamps, and only recently has tungsten been used in the form of forged rods or sheets obtained by hot deformation.

Tungsten in great degree is inclined to work hardening, which strongly hampers its treatment.

By cold deformation it is possible to increase ultimate strength of tungsten from 450-500 MN/m^2 (45-50 kgf/mm^2) after annealing to 3000-4000 MN/m^2 (300-400 kgf/mm^2). Recrystallization temperature of tungsten is approximately 1500°C, and after being alloyed it is increased to 2000°C.

Of the refractory metals tungsten has the highest strength at temperatures exceeding 1500°C and the greatest modulus of normal elasticity; therefore during comparatively large stresses it has small elastic deformations.

Tungsten is subject to oxidation. At a temperature of 300°C its oxidation first becomes noticeable. At temperatures of 800-850°C starts sharp acceleration of oxidation, which is accompanied by strong evaporization of oxidize and losses of metal.

To be especially feared is intercrystallite corrosion of longeron profiles of aviation constructions, considerably lowering their strength.

Great specific gravity, strong oxidizability at high temperatures, and labor-consumingness of technology of manufacture of parts from tungsten delay present application of tungsten in aviation constructions.

It is considered that use of tungsten alloys will allow us to raise maximum temperature of application of heat-resistant alloys from 2000 to 2600°C. For higher operating temperatures one should apply graphite, ceramic, and cermet materials.

C H A P T E R XIV

CAST IRON

We distinguish white, gray, and malleable cast iron. In white cast iron all carbon is in bound state – in the form of cementite (iron carbide) Fe_3C. Gray and malleable irons contain carbon in free state – in the form of graphite. These cast irons differ from each other basically in form of graphite. Gray cast iron has laminar form of graphite, and malleable iron has flaky graphite.

§ 1. White and Gray Cast Iron

White cast iron is so-called for form of fracture. Structure of white cast iron, as was shown earlier, consists of perlite, ledeburite, and excess cementite (see Fig. 7.6). Therefore it is distinguished by high hardness, brittleness, low strength, and are poorly suited to machining. White cast irons are applied mainly for conversion to steel. From white cast iron also are made castings of subsequently annealed to malleable iron.

Gray cast iron in fracture has dark-gray color, owing to the fact that all or part of carbon is separated in the form of graphite. Nature of graphitization of cast iron has not been established finally, but it is considered that it occurs as a result of disintegration of cementite. It has been established that process of graphitization in gray cast iron depends basically on:

a) conditions of casting of cast iron, especially on rate of its cooling;

b) chemical composition of cast iron.

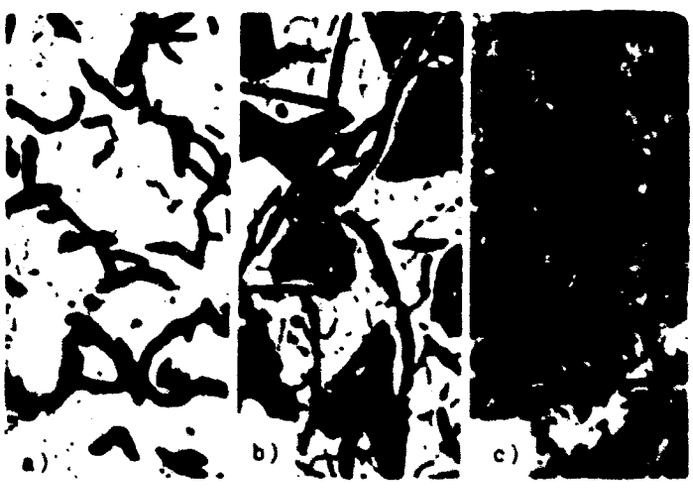
Influence of rate of cooling. By changing rate of cooling it is possible, with the same chemical composition of cast iron, to obtain structure both of

white and also of gray cast iron. High rate of cooling promotes formation in cast iron of cementite; delayed cooling, on the contrary, causes precipitation of carbon in the form of graphite. Thus, during fast cooling of cast iron disintegration of cementite will not occur and white cast iron will be obtained. During slow cooling disintegration of cementite disintegration occurs and structure of gray cast iron is obtained.

Influence of chemical composition. Essential influence on graphitization of cast iron is rendered by impurities in cast iron. Some of them, the so-called carbide-forming impurities, for example, manganese, chromium and molybdenum, increase stability of cementite and consequently promote formation of white cast iron. Others, the so-called graphite-forming impurities, for example, silicon, nickel, and aluminum, decrease stability of cementite and promote formation of gray cast iron.

Depending upon what part of cementite disintegrated, we distinguish ferrite, ferrite-perlite, and perlite cast iron.

Gray ferrite cast iron is obtained in that case when there occurs full disintegration of cementite contained in ledeburite, perlite, and also structurally free cementite. Structure of cast iron will consist of ferrite and graphite (Fig. 14.1a)



GRAPHICS NOT REPRODUCIBLE

Fig. 14.1. Microstructure of gray cast iron. X450. a) ferrite; b) ferrite-perlite; c) perlite.

Gray perlite-ferrite cast iron is characterized by smaller degree of graphitization as compared to ferrite cast iron, since to graphitization in this

cast is subjected cementite contained in ledeburite, secondary cementite and partially the cementite entering in composition of perlite. Here there forms structurally free ferrite, liberated from perlite. Structure of cast iron becomes perlite-ferrite with presence of graphite (Fig. 14.1b).

Gray perlite cast iron is obtained in that case when to graphitization is subjected only cementite contained in ledeburite and secondary cementite. Structure of perlite cast iron after final transformations will consist of perlite and graphite (Fig. 14.1c).

Thus, gray cast irons have structure of steel speckled with inclusions of graphite.

Properties of these cast irons depend on structure of metallic base and on form, dimension, and quantity of graphite inclusions. The less ferrite in metallic base of cast iron the greater its strength. Brittle and soft inclusions of graphite disturb continuity of metallic base. Small evenly scattered graphite inclusions weaken cast iron relatively little, which in this case in strength approaches that of metallic base – steel. Best mechanical properties are possessed by cast iron with perlite structure containing graphite in the form of small evenly distributed lamella.

Sometimes in structure of cast iron along with graphite is ledeburite. Such grayish-white cast iron is called mottled. It possesses high hardness, brittleness, and low strength. It finds no practical application.

Gray cast iron is designated by letters [SCh] (СЧ) plus two numbers: first number signifies ultimate tensile strength, the second denotes ultimate bending strength in MN/m^2 • 10 (kgf/mm^2).

For instance, designation SCh 18-36 shows that given cast iron should have $\sigma_в$ = 180 MN/m^2 (18 kgf/mm^2) and $\sigma_и$ = 360 MN/m^2 (36 kgf/mm^2). Mechanical properties of this gray cast iron are the following: $\sigma_в$ = 180-150 MN/m^2 (15-14 kgf/mm^2); $\sigma_и$ = 280-480 MN/m^2 (28-48 kgf/mm^2); HB = 1430-2410 MN/m^2 (143-241 kgf/mm^2); δ = 0.5-0.1%.

Gray cast iron has high foundry properties, is processed well by cutting tools, is less brittle than white cast iron, and has good antifriction properties. The last one is explained by porous structure and presence of graphite. It is applied in machine building exclusively for production of castings and therefore

is called foundry iron.

§ 2. Influence of Constant Impurities on Properties of Cast Iron

Constant impurities of cast iron are carbon, silicon, manganese, sulfur, and phosphorus.

Carbon is basic impurity determining structure and properties of cast iron. With increase of carbon content mechanical properties of gray cast iron are worsened, which is explained by increase of quantity of graphite inclusions, weakening metallic base of cast iron. At the same time carbon increases foundry properties of cast iron, allowing us to obtain high-quality thin-walled castings. Carbon content in cast iron must not exceed 4.5%.

Silicon belongs to graphite-forming impurities. Therefore for the casting of thin-walled parts we use cast iron with raised silicon content. In this case there can be obtained structure of gray cast iron with considerable precipitation of graphite, even with raised cooling rate. Promoting precipitation of graphite, silicon also promotes growth of plates of the latter, which worsens quality of castings. In virtue of this, the quantity of silicon should be held within defined limits. Thus, in foundry cast irons should be 1.0-3.0% silicon.

Manganese has opposite influence of silicon. Increase of manganese content is equivalent to acceleration of cooling and causes chilling of cast iron, i.e., increases quantity of cementite and promotes formation of smaller particles of graphite. Besides, manganese in both cast iron and in steels renders deoxidizing influence of metal, promotes removal of sulfur from liquid cast iron, and paralyzes harmful influence of sulfur remaining in hardened cast iron. But manganese also has negative influence on quality of cast iron: it increases its shrinkage and brittleness. Usually in gray cast iron is contained 0.5-1% manganese.

Sulfur. Sulfur worsens quality of cast iron - lowers fluidity, increases shrinkage, causes brittleness and inclination to formation of cracks. Therefore quantity of sulfur is held within limits of 0.08-0.12%. With small content of manganese sulfur renders chilling action on cast iron.

Phosphorus almost does not affect structure of cast iron, since it neither accelerates nor delays graphite formation. Hardness of cast iron due to presence of phosphorus in it in solid solution is increased, whereas ductility is lowered

considerably. Consequently phosphorus worsens mechanical properties of cast iron, but then it improves foundry properties and lowers melting point, increasing fluidity and promoting very good filling of form. In usual casting is contained 0.1-0.9% P; high-quality castings should contain not more than 0.4% P.

§ 3 Modified Cast Iron

It has been established that dimension and form of graphite inclusions depend on presence in liquid cast iron of centers of crystallization, rate of cooling, and content of graphite-forming impurities. Presence of large number of centers of crystallization in the form of different small particles insoluble in liquid cast iron promotes formation of structure of fine graphite.

Modified cast iron constitutes cast iron into whose composition are introduced elements (modifiers) promoting during crystallization formation of small inclusions of graphite. Modifiers in small quantity are introduced into liquid cast iron before it is poured, increasing quantity of centers of crystallization. As modifiers are applied aluminum, calcium, and silicon. For modification cast irons are smelted with content of 2.6-3.2% carbon and 1.1-1.6% silicon. As a result of modification strength of cast iron is increased and brittleness decreases. This is explained by the fact that crushing of plates of graphite shows up less negatively on weakening of metallic base of cast iron.

Mechanical properties of modified cast iron, on the average, are the following: σ_B = 300-350 MN·m^{-2} (30-35 kgf·mm^{-2}); $\sigma_{изг}$ = 500-600 MN·m^{-2} (50-60 kgf·mm^{-2}); HB = 1470-2450 MN·m^{-2} (150-250 kgf·mm^{-2}).

Modified cast iron is used for parts subject to wear.

High-strength cast iron. Gray cast iron with round (globular) form of graphite, attained through modification by magnesium or cerium, is called high-strength cast iron. Such form of graphite determines the greatest continuity of metallic base and consequently high strength, raised plasticity, and impact toughness.

High-strength cast iron is attained from usual gray perlite cast iron by means of addition to ladle with liquid cast iron of 0.3-0.6% magnesium (by weight of cast iron). High-strength cast iron has structure of ferrite and perlite with round inclusions of graphite (Fig. 134, a).

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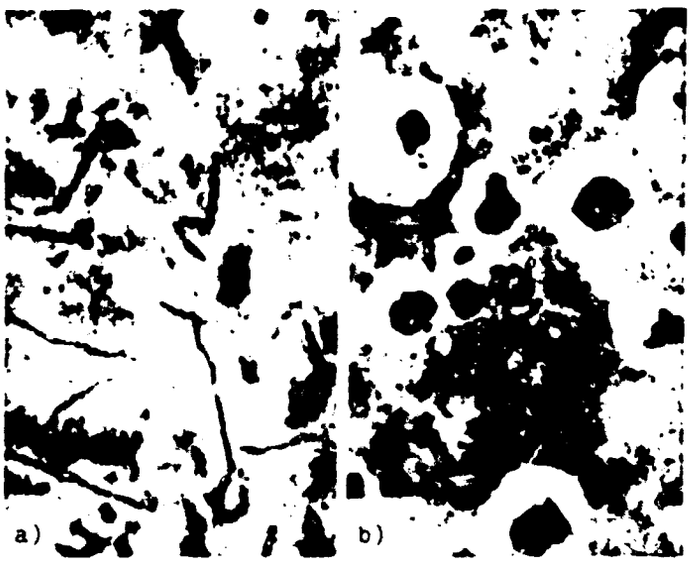


Fig. 14.2. Microstructure of cast iron with graphite of round form. ×300. a) before modification; b) after modification.

High-strength cast iron is designated by letters [VCh] (BCh) and two numbers: first number indicates ultimate tensile strength σ_B in MN/m^2 (kgf/mm^2) and second indicates specific elongation δ in %.

For instance, designation VCh 45-5 shows that given cast iron should have σ_B = 450 MN/m^2 (45 kgf/mm^2) and δ = 5%. Mechanical properties of high-strength cast iron are characterized by following data: σ_B = 400-600 MN/m^2 (40-60 kgf/mm^2); δ = 3 - 10% and HB = 1560-2550 MN/m^2 (156-255 kgf/mm^2)

At present high-strength cast irons are starting to find application instead of steel and malleable iron for manufacture of specially loaded parts.

§ 4. Malleable Cast Iron

Malleable iron is white cast iron graphitized by heat treatment (annealing). For production of malleable iron it is necessary to heat white cast iron to 950-1000°C and then, after prolonged holding, to cool it at slow rate to room temperature. Structure of malleable iron is characterized by presence of graphite in the form of flaky inclusions. Such form of inclusions of graphite in smaller degree lowers mechanical properties of cast iron than do lamellar inclusions characteristic for gray cast iron. Therefore mechanical properties of malleable iron are higher than those of gray iron. It possesses greater strength and raised plasticity although it is not suitable for forging. Depending upon degree of graphitization, malleable iron can be of ferrite or perlite type. Besides this,

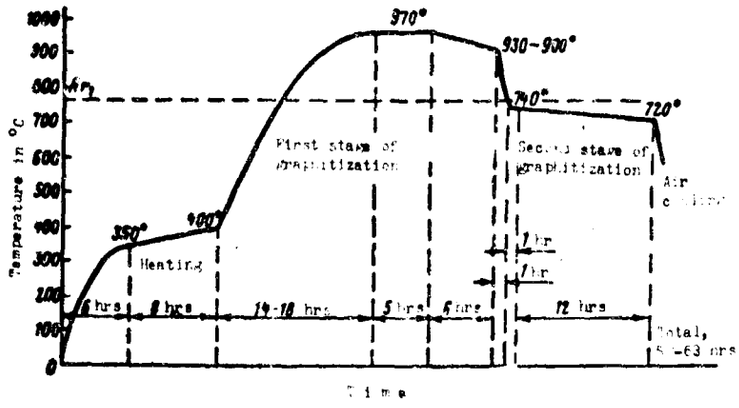


Fig. 14.3. Diagram of step annealing of malleable iron.

there can be obtained ferrite-perlitic malleable iron. Various degree of graphitization is attained by means of changing conditions of annealing. In Fig. 14.3 is given diagram of step annealing of malleable iron.

Ferrite malleable iron has structure consisting of ferrite and inclusions of flaky graphite (Fig. 14.4a), and perlite malleable iron has perlite and inclusions of flaky graphite (Fig. 14.4c).

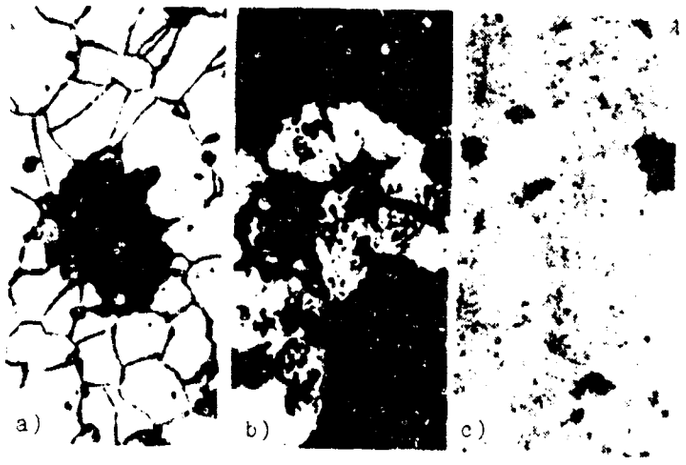


Fig. 14.4. Microstructure of malleable iron after annealing. ×250. a) ferrite; b) ferrite-perlite; c) perlite.

Distinction in structures of these cast irons is responsible for distinction in properties. Thus, ferrite malleable iron has lower hardness than perlite cast iron, but greater plasticity.

Malleable iron is designated by letters (КЧ) (КЧ) plus two numbers: first number indicates ultimate tensile strength σ_B in MN/m^2 (kgf/mm^2), and the second

designates specific elongation δ in %.

For instance, designation KCh 56-4 indicates that given cast iron should have σ_p = 560 MN/m^2 (56 kgf/mm^2) and δ = 4%.

Properties of malleable iron are characterized by following data: for ferrite iron: σ_B = 300-370 MN/m^2 (30-37 kgf/mm^2); δ = 6-12%; HB = 1490-1630 MN/m^2 (149-163 kgf/mm^2). For perlite iron: σ_B = 450-630 MN/m^2 (45-63 kgf/mm^2); δ = 2-6%; HB = 2010 MN/m^2 (201 kgf/mm^2).

Malleable iron finds application for manufacture of parts working under shock and vibration loads.

§ 5. Application of Cast Iron in Aviation Industry

Cast irons in aviation industry are used in small quantity as cheap foundry material possessing antifriction qualities, wear resistance, and thermal resistance. In structures of aircraft and engine are applied primarily gray and malleable irons of various grades. For manufacture of the most vital castings are used alloy cast iron.

Alloy cast irons contain, besides carbon and impurities, additional alloy elements – chromium, nickel, molybdenum, tungsten, copper, and others which improve physico-mechanical properties.

Alloy cast irons are designated by initial letters of alloy elements. For instance, cast iron [KhM] (XM) contains chromium and molybdenum; [KhMV] (XMB) contains chromium, molybdenum, and tungsten; [ChM 1.3] (ЧМ 1.3) contains copper (Figure 1.3 indicates copper content in %).

Chemical composition of cast irons most often applied for manufacture of parts of aircraft and engines is given in Table 32.

Cast irons shown in Table 32 have the following assignment. Antifriction cuprous gray cast iron [ChM 1.8] (ЧМ 1.8) is used for bushings and axle boxes of aircraft landing gears, for worm and other gears, for rings, washers, supports, inserts and other parts of aircraft, and for assemblies not bearing dynamic loads and working with lubricant.

Antifriction cuprous malleable iron ChM 1.3 is used for friction and support parts: landing gear struts, dampers, cylinders, bushings, axle boxes, nuts, rings, supports, step bearings, sliders, washers, inserts, levers, and other parts working with lubricant under conditions of static and dynamic loads.

Table 32. Chemical Composition of Cast Irons Used in Aircraft Industry in %

Grade	C	Si	Mn	P	S	Cr	Cu	Ni	Mo
ЧМ1,8	2,8—3,6	1,3—1,9	0,6—0,9	<0,3	<0,1	0,2—0,4	1,0—1,5	—	—
ЧМ1,3	2,3—3,0	0,5—1,1	0,6—1,2	<0,2	<0,08	<0,15	1,0—1,5	—	—
ЧНМХ	3,2—3,8	1,6—2,3	0,6—1,0	<0,3	<0,1	0,15—0,45	—	0,8—1,4	0,2—0,5
ЧНМ	3,2—3,8	1,6—2,3	0,6—1,0	<0,4	<0,1	<0,3	—	0,8—1,4	0,2—0,5
ПЧИ	3,7—4,0	2,4—2,8	0,6—0,9	0,6—0,9	<0,1	<0,2	—	<0,4	—
ПЧ	2,9—3,2	1,4—1,9	0,7—1,2	0,45—0,7	<0,1	<0,2	—	<0,4	—
ХН	2,9—3,2	1,4—1,9	0,7—1,2	0,45—0,7	<0,1	0,3—0,7	—	0,2—1,0	—
ХНВ	2,9—3,2	1,4—1,9	0,7—1,2	0,4—0,65	<0,1	0,3—0,6	W 0,25—0,7	0,6—1,4	0,05—0,35
ХМ	2,9—3,2	1,9—2,3	0,7—1,2	0,25—0,4	<0,1	0,6—0,9	—	<0,4	0,6—0,9
Х	2,9—3,2	1,7—2,2	0,7—1,2	0,45—0,7	<0,1	0,4—0,7	—	<0,4	—
ЧЯ	2,5—3,0	1,5—2,5	0,5—1,2	<0,3	<0,08	1,5—2,5	6,0—8,5	14—17	—

Frictional nickel-molybdenum-chromium cast iron [ChNMKh] (ЧНМХ) is used for drums of airplane wheels of all types.

Gray nickel-molybdenum-chromium cast iron [ChNM] (ЧНМ) is used for parts of jet engines: for instance, bodies of gas collectors, covers, and others.

Gray cast irons [PChI] (ПЧИ), [PCh] (ПЧ), [KhN] (ХН), [KhNV] (ХНВ), [KhM] (ХМ), and [Kh] (Х) are used for compression rings for engines of all types (cast iron of grades PChI, KhM, and KhNV) and for oil scraper rings.

Heat-resistant and acid-resistant cast iron [ChYa] (ЧЯ) is used for ball and socket joints of exhausts, bushings, and barrels of pumps and acid-resistant equipment.

S E C T I O N T H R E E

NONFERROUS METALS AND ALLOYS

In aviation technology wide application is found for nonferrous alloys based on aluminum, magnesium, titanium, and copper. Of especially great value are light alloys based on aluminum and magnesium and also alloys based on titanium, specific strength of which (strength referred to specific gravity) in most cases exceeds specific strength of steel.

Resolutions of XXII Congress of Communist Party on creation of material-technical base of communish provide for further considerable expansion of production of nonferrous metals and alloys. Thus, for instance, production of copper will be increased 1.9 times, that of aluminum 2.8-3 times, and that of nickel, magnesium, titanium, and other nonferrous metals will be increased significantly.

C H A P T E R XV

ALUMINUM AND ITS ALLOYS

§ 1. Properties of Aluminum

Aluminum is the most important aviation metal. It has silvery-white color, possesses low specific gravity of 27 kN/m^3 (2.7 gf/cm^3), and has melting point of 658°C.

Electrical and thermal conductivity of aluminum are very high. Aluminum and many of its alloys possess high corrosion resistance, which is explained by formation on their surface of oxidized film possessing good protective properties. It is quite resistant under atmospheric conditions and at raised temperatures. Concentrated nitric acid and organic acids do not act on aluminum, but alkali salt and sulfuric acid destroy it.

Aluminum possesses high plasticity in cold and hot states, is easily rolled, pressed, stamped, welds well, but has low foundry qualities and is processed poorly by cutting.

Cast aluminum has low strength and hardness but high plasticity: σ_B = 80-100 MN/m^2 (8-10 kgf/mm^2), δ = 27-30%, HB = 210 MN/m^2.

Through work hardening it is possible to increase strength and hardness of aluminum, but this lowers plasticity: σ_B = 160-180 MN/m^2 (16-18 kgf/mm^2), δ = 2-6%.

For removal of work hardening, obtained as a result of cold deformation, aluminum is annealed at a temperature of 350-360°C.

Aluminum is marked by letter A and figures 0, 1, 2, 3, showing conditionally the quantity of impurities in it from 0.4 to 2%. In Table 33 are given examples of industrial grades of aluminum.

Table 33. Content of Impurities in Pure Aluminum

Grade	Aluminum % (not less than)	Impurities in % (not more than)				
		Fe	Si	Fe + Si	Cu	In all
AV0000	99,996	0,0015	0,0015	—	0,001	0,004
AV000	99,99	0,0030	0,0025	—	0,005	0,01
AV00	99,97	0,015	0,015	—	0,005	0,03
AV0	99,93	0,04	0,04	—	0,01	0,07
A00	99,7	0,16	0,16	0,26	0,01	0,30
A0	99,6	0,25	0,20	0,36	0,01	0,40
A1	99,5	0,30	0,30	0,45	0,015	0,50
A2	99,0	0,50	0,50	0,90	0,02	1,0
A3	98,0	1,10	1,00	1,80	0,05	2,0

Inevitable impurities of aluminum are Si, Fe, and Cu. Increase of Si and Cu increases strength of Al but lowers plasticity and anticorrosive properties. The most harmful impurity is Fe, worsening pressure workability.

Application of aluminum as structural material is limited in view of its low strength. Aluminum is used mainly for manufacture of alloys having wide application in aircraft construction. For smelting of alloys of high strength is applied aluminum of high purity, AV0000, AV000, AV00, AV0; for smelting of foundry alloys – aluminum A1 or A2 is used. Aluminum A0 also is used for manufacture of spacers.

Pure aluminum is used for plating of duralumin and mainly in electrical industry for manufacture of wires, cables, rectifiers, capacitors, etc.

§ 2. General Information About Aluminum Alloys

Aluminum alloys possess a series of advantages as compared to other alloys. The most important merits of aluminum alloys are their low specific gravity of 26-28 kN/m^3 (2.6-2.8 kgf/cm^3), high mechanical properties, and comparative ease of technological processes of production of parts (treatment by pressure and casting).

Influence of alloy elements. Increase of mechanical properties of aluminum alloys is attained by introduction of such elements as copper, magnesium, silicon, zinc, manganese, and others.

Majority of these elements form with aluminum limited solid solutions and metallic compounds, which permits strengthening them with the help of heat treatment.

Let us consider influence of basic alloy elements on properties of aluminum alloys.

Copper with aluminum forms limited solid solutions and chemical compound $CuAl_2$, possessing high hardness and brittleness. In complex aluminum alloys copper enters into composition of ternary compounds.

In deformable aluminum alloys copper content usually does not exceed 5.5%. For these alloys copper is basic alloy element, giving it high mechanical qualities after heat treatment. However, copper worsens corrosion resistance of aluminum alloys.

Magnesium and silicon form limited solid solutions with aluminum. Besides this, magnesium forms with aluminum the compound Mg_2Al_3 and with silicon the Mg_2Si, possessing high hardness. This permits us to apply to aluminum alloys containing Mg and Si strengthening heat treatment.

In deformable alloys is contained up to 2% silicon, while foundry alloys contain no more than 13%. Magnesium in the majority of alloys is present in quantity to 3%; sometimes its content reaches 10-12%.

Manganese is introduced into aluminum alloys in small quantities - from 0.2 to 1.6%. It forms with aluminum limited solid solutions and compound $MnAl_6$. Manganese is applied cheifly for improvement of corrosion resistance of aluminum alloys.

Zinc is an important alloy element. It is introduced into new high-strength aluminum alloys in quantity to 7%. Zinc is dissolved in aluminum and with other elements of alloy forms a complex chemical compound. Zinc essentially strengthens aluminum alloys after their quenching and aging. However, zinc decreases their corrosion resistance.

Besides the above into aluminum alloys it is possible to introduce titanium, for production of finer-grained structure; chromium, for limitation of grain growth during heating; and nickel, to provide greater stability and improvement of thermal conductivity of alloys.

Iron for the majority of aluminum alloys is harmful impurity, since it worsens their corrosion resistance. However, in certain aluminum alloys up to 1.5% iron is introduced for increasing heat resistance.

Classification and grading of aluminum alloys. Aluminum alloys are subdivided into two basic groups: deformable alloys, subjected to pressure treatment (rolling, pressing, and others), and foundry alloys, applied in the form of castings.

Deformable alloys, after being cast, are pressure worked in hot state, after which they are subjected to heat treatment. In mechanical properties they exceed foundry alloys.

Foundry alloys are not processed by pressure. From deformable alloys they are distinguished by raised content of alloy elements, and in structure they have eutectic, which ensures their low melting point and fluidity.

Distinction in properties allows different fields of application of alloys of these groups. Thus, deformable alloys are applied for manufacture of parts whose configuration is not very complicated and which work under raised loads. Foundry alloys are used for manufacture of parts of complicated form working under smaller loads and also in cases when it is economically more profitable to prepare part not by pressure treatment but by casting.

Boundary between deformable and foundry aluminum alloys is limit of saturation of solid solution at eutectic temperature (Fig. 15.1).

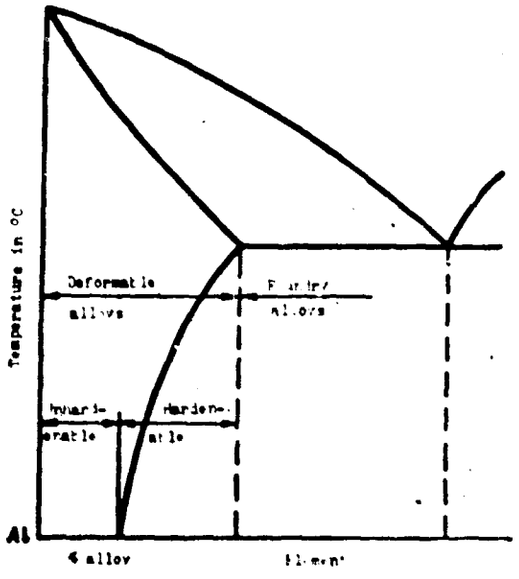


Fig. 15.1. Classification of aluminum alloys on constitution diagram Al-B (where B is alloy element).

Deformable aluminum alloys, depending upon composition of methods of treatment and application, are subdivided into the following groups:

1. Alloys not hardenable by heat treatment, characterized by the fact that concentration of component is less than limit of solubility at room temperature (Fig. 15.1). To this group belong: technical aluminum and alloys of aluminum with

magnesium. For designation of aluminum alloys is applied literal-numerical marking. Letters designate defined group of alloys and figures indicate either number of alloy or percentage content of basic alloy element.

Technical aluminum is designated by letters [AD] (АД) (aluminum, deformable). In case of use of purer aluminum the figure 1 is used.

Combinations of letters [AMg] (АМг) and [AMts] (АМц) signify alloy of aluminum (A) with magnesium [Mg] (Мг) and manganese [Mts] (Мц). For alloys of aluminum with magnesium figure characterizes percentage of magnesium (for instance, alloys of grades AMg3, AMg5, and AMg6 contain respectively 3, 5, and 6% magnesium.

State of semifinished product is designated by letters which are placed after grade of alloy: A signifies that alloy is of raised quality, from improved aluminum; M signifies soft, annealed alloy; P devotes partially work hardened alloy (degree of pressing 40%); N signifies work hardened alloy (degree of pressing 80%). For instance, for annealed alloys ([ADM] (АДМ), [AMtsAM] (АМцАМ)), for partially work hardened alloys ([AMgAP] (АМгАП), for work hardened alloys ([AD1N] (АД1Н), [AMg3N] (АМг3Н)).

II. Alloy hardenable by heat treatment. These alloys include the following basic subgroups:

1. Structural alloys of high strength: these include variety of duralumin and alloys of aluminum with zinc and magnesium.

2. Forging alloys intended for work at temperatures to 100°C.

3. Heat-resisting forging alloys intended for work at temperatures of 300°C.

Duralumin is designate by letter D and figure showing conditional number of alloy. For instance, alloys D1, D16, D18.

Certain alloys developed recently have another designation: for instance alloys V65, [VD17] (ВД17).

High-strength alloy of aluminum with zinc and magnesium is designated V95.

State of half-finished products of high-strength alloys and character of plating also have literal-digital marking:

M - soft, annealed; T - heat treated, hardened, and naturally aged; T1 - heat treated, hardened, and artificially aged; N - work hardened (cold hardening of sheets of duralumin type, of the order of 5-7%, and alloy V95 - 3%); N1 - intensively work hardened (cold hardening of sheets, of the order of 20%); V - raised quality

of rolling of hardened and aged sheets; [PN] (ПН) - raised quality of rolling of annealed sheets; B - sheets without plating (or with technological plating); [UP] (УП) - thickened plating (4% of sheet); [g.k] (г/к) - hot-rolled sheets, plates.

At the end of designation for sheet material is indicated its thickness in mm, and for profiles conditional digital designation of form of section and dimensions are given. For instance, [D16ATNV] (Д16АТНВ) L2.5 signifies plated sheet duralumin of D16 of raised quality, heat treated, work hardened and has raised quality of rolling, and thickness of sheet is 2.5 mm.

Alloys used for manufacture of rivets have in designation the letter P (alloy for wire). For instance, alloys [D3P] (Д3П), D16P, D18P, and [AMg5P] (АМг5П).

Aluminum alloys for forging and drop forging are designated by letters [AK] (АК) (aluminum forging) and figure - conditional number of alloy. For instance, alloys of grades AK4, AK4-1, AK6, AK6-1, AK8 (additional figure 1 shows that alloy is close modification of other alloy).

Recently developed forging alloys have nonstandard designation: for example, alloy of grade D20.

Foundry aluminum alloys are designated by letters [AL] (АЛ) (aluminum foundry) and figure showing conditional number of alloy. For instance, alloys AL2, AL4, AL9, etc. Only exceptions are new grades of foundry alloys [VI-11-3] (ВИ-11-3), V-3[illegible], V14-A.

Depending upon composition, all aluminum foundry alloys are subdivided into several subgroups:

- silumins, constituting alloys of aluminum and silicon (AL2, AL4, AL9);
- alloyed silumins, being alloys of aluminum and silicon with addition of copper (AL3, AL5, AL9) or magnesium (AL10, VI-11-3);
- al'mag, constituting alloy of aluminum and magnesium (AL8);
- alloys of aluminum with copper (AL7, AL19), etc.

For foundry aluminum alloys are applied the following designations of conditions of heat treatment: T1 - aging; T2 - annealing; T4 - quenching; T5 - quenching and partial aging; T6 - quenching and full aging to the greatest hardness; T7 - quenching and stabilizing temper; T8 - quenching and softening temper. For example, designation [AL8-T1] AL8-T1 shows that alloy AL8 is subjected to heat treatment per conditions T1, consisting of quenching and aging.

§ 3. Heat Treatment of Aluminum Alloys

Heat treatment of aluminum alloys is based on variable solubility of copper, magnesium, zinc, and other elements in aluminum, depending upon temperature (Fig. 15.2).

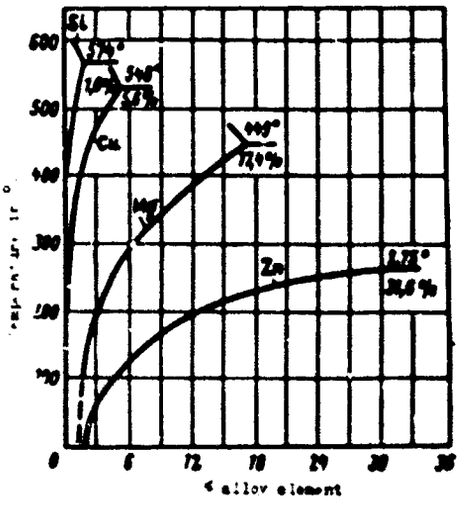


Fig. 15.2. Change of solubility of zinc, magnesium, copper, and silicon in aluminum.

Essence of process of heat treatment of aluminum alloys will be considered by example of duralumin. Duralumin as alloy elements contains copper, magnesium, manganese, and silicon.

Microstructure of duralumin in annealed state constitutes grains of complex solid solution on aluminum base with inclusions of chemical compounds $CuAl_2$, Mg_2Si, Al_2CuMg located about grain boundaries (Fig. 15.3). These components possess variable solubility in aluminum with change of temperature. Thus, for instance, with increase of temperature from room to 548°C, content of copper in solid solution on aluminum base is increased from 0.5 to 5.6%.



Fig. 15.3. Microstructure of annealed duralumin. ×300.

During heating of duralumin these chemical compounds are dissolved in aluminum, forming uniform solid solution. Subsequent fast cooling of alloy fixes this structure at room temperature (Fig. 15.4). However, obtained solid solution is unstable, and with time in it there start to occur processes leading to its disintegration. These processes are accompanied by hardening of alloy. Increase of temperature, accelerating these transformations, can lead to full disintegration of solid solution and obtaining of former stable structure which alloys had before hardening. Here occurs lowering of hardness and ultimate strength of duralumin.

Process of heat treatment of other aluminum alloys in principle do not differ



Fig. 15.4. Microstructure of hardened duralumin. ×150.

from considered processes of heat treatment of duralumin. Distinction can consist in that in creation of supersaturated solid solution there can also participate other alloy elements (for instance, zinc). Besides, diffusion processes for these alloys can show on selection of quenching temperature and duration of holding during heat treatment.

The following forms of heat treatment of duralumin exist:

1. Quenching with subsequent aging, serving for hardening of alloy.

2. Treatment "to recovery," having purpose of brief increase of plasticity of alloy.

3. Annealing, serving for prolonged increase of plasticity of alloy.

Quenching and aging. Quenching is produced by heating duralumin to temperature exceeding by 3-5°C temperature of line of limiting solubility, holding at this temperature, and subsequent fast cooling in water. Quenching serves for production of uniform alloy structure consisting of supersaturated solid solution capable of being strengthened in process of aging.

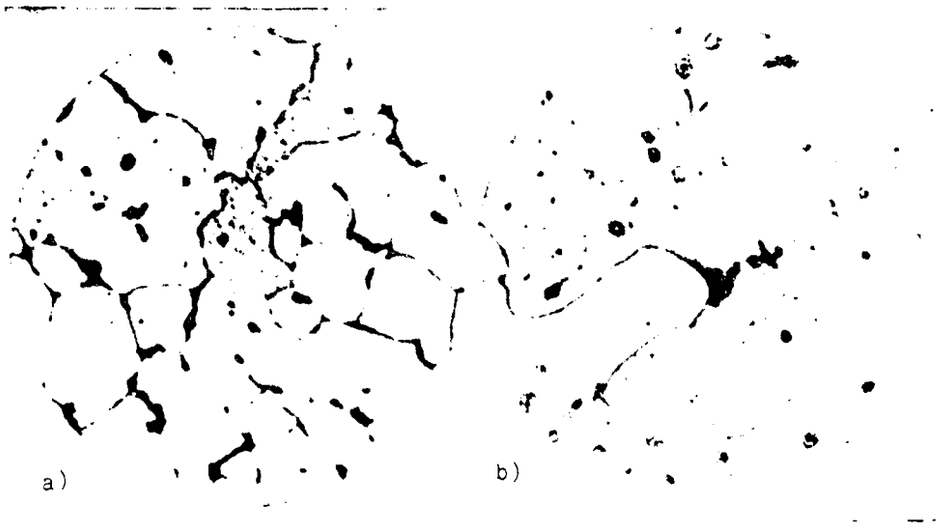


Fig. 15.5. Microstructure of overheated and burnt duralumin. ×300. a) burnt; b) overheated.

Temperature of heating before quenching should guarantee dissolution of

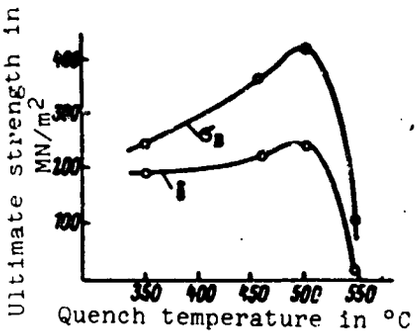


Fig. 15.6. Influence of quench temperature on mechanical properties of duralumin after hardening and natural aging.

chemical compounds and the obtaining of uniform solid solution. As already said, temperature of quenching of duralumin is determined from constitution diagram of aluminum – copper system. Here is considered influence of other alloy elements. Therefore different grades of duralumin have various quench temperatures. During the quenching of duralumin it is necessary to pay attention to temperature control, since quench temperature interval for duralumin is very narrow and its disturbance leads to sharp impairment of structure and properties of alloy. Thus, for instance, underheating will be connected with preservation in structure of undissolved metallic compounds, which decreases strength and plasticity of alloys after heat treatment. Especially dangerous is overheating accompanied by growth of grains of solid solution and strong oxidation of alloy about grain boundaries to large depth (Fig. 15.5a and b). Mechanical properties of burnt duralumin extremely are low (Fig. 15.6). Heating of duralumin before quenching is carried out in baths of molten saltpeter. Usually applied is 50% $NaNO_3$ and 50% KNO_3. This mixture melts at temperature of 218°C. Heating in saltpeter baths ensures fast and uniform heating of alloy and protects it from oxidation. Parts heated in saltpeter baths have to be dry and without grease spots, otherwise spraying of molten saltpeter or flaming oil is possible. Control of temperatures of heating before quenching is carried out by pyrometer. Besides saltpeter, for heating of duralumin are used forced air furnaces.

Duration of holding at quench temperature should be such that part is heated to needed temperature and that process of formation of uniform solid solution on aluminum base. Time of holding at quench temperature depends on thickness of duralumin. In Table 34 are given values of time of holding of sheet material of grades D16 and V95 during heating in saltpeter bath.

Time of holding during heating in electrical furnaces exceeds time of holding during heating in saltpeter bath. Thus, for sheet of the same materials with thickness of 0.5-1.0 mm, time of holding is 10-20 minutes; for sheet of 2-2.5 mm thickness, time is 80 minutes.

Cooling during hardening is produced in cold water, which ensures fixing of structure of uniform solid solution. To prevent appearance of cracks and warping of parts with large cross section, cooling is produced in heated water. Hardening of duralumin in air or hot water with temperature higher than 40°C is not recommended, since in process of such hardening on grain boundaries there starts disintegration of solid solution, which lowers corrosion resistance of alloy.

Table 34. Time of Holding During Quench Depending Upon Thickness of Duralumin Sheet

Thickness of sheet, mm	Time of holding, minutes
To 0.8	10
From 0.8 to 2.0	15
From 2.5 to 3.0	20
From 3.5 to 4.0	30
From 5.0 to 6.0	40
Over 6.0	60

After being cooled, parts are washed in warm water and dried, thus removing remaining saltpeter, which may cause corrosion. After being hardened, duralumin, having structure of uniform solid solution, possesses medium strength and high plasticity.

Plasticity of hardened duralumin is preserved at room temperature for certain time, which permits producing pressure treatment. Time during which freshly quenched duralumin at room temperature preserves plasticity is called incubative period. Increase of mechanical properties of hardened duralumin with time is called aging. Aging occurs spontaneously.

We distinguish natural artificial and aging. Natural aging occurs ordinary temperatures and continues for 5-7 days. Artificial aging occurs at raised temperatures (to 300°C) and lasts several hours. Curves of aging of duralumin are depicted in Fig. 15.7. Analysis of these curves shows that freshly quenched duralumin preserves its plasticity for a certain time. This is the incubative period. It permits carrying out different technological operations: correction, knockout, riveting, fitting, and others. Incubative period depends on composition of alloy. For low-alloy duralumin D1 during natural aging it is equal to 2 hours and for more alloyed duralumin of grade D16 – it is 20 minutes. Generally increase of strength of duralumin during aging occurs in first 15-20 hours. Strength and hardness of duralumin after natural aging are somewhat higher than after artificial aging. During artificial aging hardening is attained faster than during natural aging. The higher the temperature of artificial aging the earlier drops strength of duralumin after hardening. At temperature lower than 20°C aging is delayed

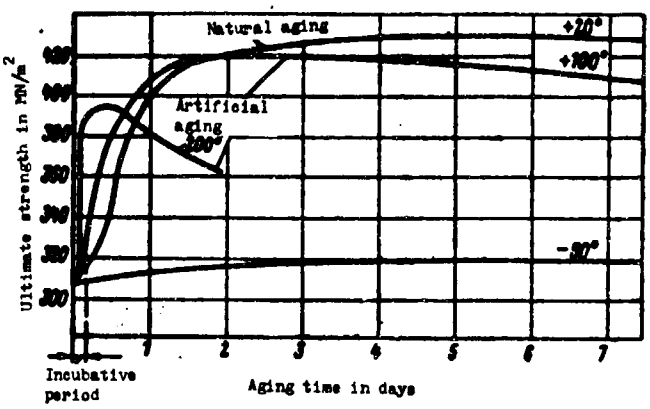


Fig. 15.7. Curves of duralumin.

strongly. This is used in aircraft building during the setting of rivets: held at a temperature of -50°C, rivets preserve high plasticity for any time after being quenched.

Mechanical properties of duralumin of normal composition after various technological operations are given in Table 35.

Table 35. Mechanical Properties of Duralumin of Normal Composition

Mechanical properties	State of alloy			
	after casting	after hot deformation	after quenching	after quenching and natural aging
σ_B in MN/m²	170	240	300	380—420
δ in %	1	15	20	20

Since corrosion resistance of duralumin after natural aging is higher than after artificial aging, plated duralumin is subjected to hardening only by natural aging.

Microstructure of duralumin after quenching and after natural aging remains without visible changes. Therefore it was long impossible to explain natural cause of hardening of duralumin during aging.

Only application of X-ray structural investigations of duralumin in process of heat treatment permitted Soviet scientists S. T. Konobeyevskiy and D. A. Petrov to develop theory of aging. According to this theory: in grains of supersaturated solid solution after quenching starts shift (diffusion) of copper atoms to defined

centers, with formation of so-called Guignet-Preston zones, enriched by copper. These zones have form of disk-like plates with thickness of 2-3 atomic layers and diameter of 5 nm (50 kXu), distant from each other by about 50 atom diameters. Plates are located on defined planes of lattice of solid solution, on grain boundaries, forming a whole with them, so that boundaries do not exist. As further investigations of duralumin showed, the process of formation of zones enriched by copper and other elements is finished in 5-7 days. Nonuniform distribution of atoms of copper in alloy with distinction of dimensions of atoms of aluminum and copper causes distortions of crystal lattice of solid solution. A microstrain state is created, leading to increase of strength and hardness. Raised plasticity of naturally aged duralumin is explained by the fact that zones enriched by copper are connected organically with solid solution. During artificial aging, thanks to high temperature, shift of atoms of copper and other alloy elements occurs considerably faster, and the process takes place differently than during natural aging. In first period of time during artificial aging, as also during natural, Guignet-Preston zones are formed, but their dimensions are larger than those of natural aging. With time these zones, with increase in them of copper content, are developed and pass into stable phase, close in composition to chemical compound $CuAl_2$.

With sufficient holding at high temperature on base of this phase are formed small $CuAl_2$ crystals, separated along grain boundaries of solid solution. Structure and properties of artifically aged duralumin become close to properties of alloy after annealing.

The biggest increase of strength of duralumin in process of artificial aging is observed during formation of Guignet-Preston zones enriched by copper, distorting crystal lattice of solid solution. Formation of intermediate phase and singling out of small crystals of $CuAl_2$ from solid solution leads to softening of alloy, which is explained by smaller distortion of crystal lattice. The fact that with increase of temperature of artificial aging time of achievement of maximum strength of subsequent softening decreases with sufficient holding is explained by faster formation of zones enriched by copper, by faster appearance and singling out of chemical compound $CuAl_2$. Lowering of value of maximum strength with increase of temperature of artificial aging may be explained by formation of zones enriched

by copper, of larger dimension, which leads to smaller total distortions of crystal lattice of solid solution.

For alloys of different composition there is experimentally determined most advantageous temperature of aging, at which is attained the biggest value of strength. For industrial alloys most advantageous temperatures of aging are within limits of 120-180°C. Time of holding during aging is several hours.

Processing duralumin "to recovery". Recovery is phenomenon of return of properties of hardened and aged duralumin to properties of freshly-hardened state by means of brief heating. Phenomenon of recovery was investigated for the first time in USSR by D. A. Petrov, and theory was worked out by S. T. Konobeyevskiy. Purpose of treatment to "recovery" is brief softening of duralumin after quenching and natural aging to facilitate cold pressure treatment. Treatment "to recovery" is produced by means of brief heating of article to temperature of 220-280°C with subsequent fast cooling in cold water. Alloy treated "to recovery" will preserve strength and raised plasticity for 2-3 hours. Treated "to recovery," duralumin ages naturally, and in 5-7 days recovers former mechanical properties obtained by it after quenching and natural aging.

Essense of theory of treatment "to recovery" consists in the following. As it is known, hardening of duralumin after natural aging is connected with formation of zones enriched by copper, which causes distortion of crystal lattice of solid solution. These zones are stable only at temperature of their formation. To every temperature are inherent unique stable critical dimensions of zones enriched by copper and alloy elements. During heating of duralumin zones formed at room temperature during natural aging become unstable and are dissolved in solid solution. With this occurs lowering of strength of duralumin, connected with sharp decrease of distortion of crystal lattice (Fig. 15.8, section 1-2). Length of time to full dissolution of zones, and this means recovery of plasticity also, is very brief. Thus, for sheet duralumin D16T, with thickness of sheets from 1.5 to 10 mm and temperature of treatment of 270°C, it is 30 sec. If one were to continue

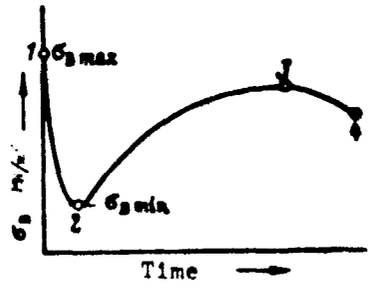


Fig. 15.8. Curve of treatment to duralumin "to recovery."

holding of duralumin at this temperature in solid solution, there grain are formed zones enriched by copper but of larger dimension (Fig. 15.8, section 2-3), which with time, as occurs during artificial aging, change to small crystals of chemical compound $CuAl_2$, located along grain boundaries (Fig. 15.8, section 3-4).

Holding time during treatment "to recovery" must be so selected as to fix structure of alloy with maximum plasticity, and this corresponds to moment of dissolution of primary zones enriched by copper (point 3 on Fig. 15.8). Treatment "to recovery" can be applied only for thin sheets and articles of thickness to 1.5 mm. To prevent appearance of prolonged softening of alloy, to treatment "to recovery" the same part may be subjected not than more 3-4 times in succession.

Annealing of duralumin. Annealing is heating of duralumin to defined temperature, holding, and cooling in furnace or in air. Annealing of duralumin is produced for the purpose of imparting to it high plastic properties necessary for execution of technological operations connected with deformation in cold state (bending, knockout, etc.). In Fig. 15.9 is shown microstructure of annealed duralumin. Against the background of grains of solid solution are conspicuous inclusions of chemical compounds $CuAl_2$, Mg_2Si, and Al_2CuMg.



Fig. 15.9. Microstructure of annealed duralumin. ×250.

Obtained plasticity of duralumin does not change with time, since after annealing aging does not set in. Annealing of duralumin is used mainly as intermediate heat treatment. We distinguish three forms of annealing: annealing of duralumin strengthened by work hardening in annealed state, annealing of quenched and naturally aged material, and annealing of duralumin strengthened by work hardening in quenched state.

Annealing of work hardened material removes stresses remaining after work hardening. Here occurs transformation of deformed grains into new recrystallized grains. Such annealing is carried out in saltpeter baths or electrical furnaces at a temperature of [illegible]; holding at this temperature is from [illegible] minutes.

Annealing of quenched and naturally aged duralumin is produced under the same

conditions. Here occurs disintegration of solid solution having concentration corresponding to quench temperature.

Annealing of duralumin work hardened in quenched state is produced according to the following conditions: heating to temperature of 450-500°C with holding for several minutes, further cooling to 350-370°C, holding for 30-90 minutes, and slow cooling.

It is possible to control state of duralumin after heat treatment by means of measurement of hardness. Brinell hardness of duralumin D1 and D16 after annealing on the average is 500-600 MN/m^2 (50-60 kgf/mm^2), after hardening it is 700-800 MN/m^2 (70-80 kgf/mm^2), after hardening and aging it is 1000-1100 MN/m^2 (100-110 kgf/mm^2).

§ 4. Aluminum Alloys Not Hardenable by Heat Treatment

For manufacture of aviation parts by deep stamping is applied technical aluminum AD and alloys of grades AMts and AMg, not hardenable by heat treatment.

In Table 36 are given chemical composition and mechanical properties of technical aluminum.

Table 36. Chemical Composition and Mechanical Properties of Technical Aluminum

Grade of alloy	Chemical composition in %			State of material	Mechanical properties (not less than)		
	Fe	Si	Cu		$\sigma_в$ MN/m^2	δ %	*HB* MN/m^2
АД	0,5	0,55	0,1	Annealed (ADM, AD1M)	80	35	250
АД1	0,3	0,35	0,05	Work hardened (ADN, AD1N)	140	6	320

Technical aluminum contains inpurities of iron, silicon, and copper.

Alloys given in Table 37, also containing constant impurities of iron, silicon, and copper, are applied in annealed or work hardened states and are not strengthened by heat treatment. Annealing of these alloys after work hardening is produced at a temperature of 350-420°C with cooling in air.

For all alloys not hardenable by heat treatment is characteristic low strength, high plasticity, good weldability, satisfactory or bad machinability, and high corrosion resistance.

Table 37. Chemical Composition and Properties of Deformable Aluminum Alloys

Grade of alloy	Chemical composition in %			State of material	Mechanical properties (not less than)		
	Mg	Mn	Other elements		σ_b MN/m^2	δ %	HB MN/m^2
AMn	—	1,0—1,6	Si 0,6 Fe 0,7	Annealed (AMtsM)	130	23	300
				Partially work hardened (AMtsP)	170	10	400
				Work hardened (AMtsN)	220	5	550
AMr	2,0—2,8	0,15—0,4	Si 0,4 Fe 0,4	Annealed (AMgM)	190	23	450
				Partially work hardened (AMgP)	250	6	600
AMr3	3,2—3,8	0,3—0,6	Si 0,5—0,8 Fe 0,5	Annealed (AMg3M)	200	22	500
AMr5B	4,8—5,5	0,3—0,6	Si 0,5 Fe 0,5	Annealed (AMg5VM)	260	22	650
				Partially work hardened (AMg5V)	300	14	800
AMr6	5,8—6,8	0,5—0,8	Ti 0,02—0,1 Si 0,4 Fe 0,4	Annealed (AMg6M)	320	20	800

On Fig. 15.10 is shown microstructure of welded seam of alloy AMts, consisting of grains of solid solution and inclusions of chemical compound $MnAl_6$ on grain boundaries.



Fig. 15.10. Microstructure of welded seam from aluminum alloy AMts. ×150.

In Fig. 5.11 are shown samples of certain parts made from aluminum alloys not hardenable by heat treatment. These alloys are released in the form of sheets, rods, profiles, pipes, plates, and wire. In accordance with their properties these alloys are used for parts of aviation structures prepared by deep upsetting, for welded parts, and also for articles working in corrosive media.

Technical aluminum of grades A1 and A11 possessed high corrosion resistance. It has high plasticity. It welds well by gas, atomic hydrogen, and resistance welding. It is processed unsatisfactorily by cutting. It is used for manufacture of structural elements and parts not bearing loads; protective tubes for electric wiring, spacers, parts of ventilation system of aircraft, etc.



GRAPHICS NOT REPRODUCIBLE

Fig. 15.11. Parts prepared from aluminum alloys by deep upsetting. 1 – housing for dive brake control rod; 2 – connecting tube of cabin heat air inlet, prepared from alloy AMts; 3 – tee of aircraft fuel system; 4 – stator blades of inlet duct of centrifugal compressor, prepared from alloy AMg.

Alloy AMts possesses high corrosion resistance. It was high plasticity in annealed state. Temperature of forging-stamping is 420-475°C; annealing is done at 350-410°C, with cooling in air. It welds well by gas, atomic hydrogen, and resistance welding. It is processed unsatisfactorily by cutting. It is used for manufacture of welded airplane tanks, air inlets, and other lightly loaded parts of complicated configuration, and also as wire for rivets. Rivets are supplied in annealed state.

Alloy AMg possesses high corrosion resistance. It has high plasticity in annealed state. Temperature of forging-stamping is 420-475°C; annealing is done at 350-410°C, with cooling air. It welds well by contact, point, and seam welding. Machinability is unsatisfactory. It is used for manufacture of lines for fuel, oil and hydraulic systems of contemporary aircraft. From it are also prepared parts of inlet apparatus for turbine compressors.

Alloy AMg3 possesses high corrosion resistance. It has high plasticity in annealed state. Temperature of forging-stamping is 450-480°C. Annealing is produced at 270-280°C, with cooling in air. It has good weldability by gas, argon arc, point, and seam welding. It is processed satisfactorily by cutting. It is used for manufacture of welded structures of medium strength and for parts obtained by cold stamping.

Alloys [AMg5V] (AMr5B) and AMg6 possess high corrosion resistance. They have satisfactory plasticity in annealed state. Annealing of alloy AMg5V is produced at 270-280°C, and alloy AMg6 is annealed at 300-350°C, with cooling in air.

Temperature of forging and stamping [illegible] They are used for manufacture of welded structures of load-carrying parts, [illegible], frame parts, and welded vessels.

§ 5. High-Strength Aluminum Alloys

High-strength aluminum alloys are the most wide-spread aircraft alloys. This is due to their low specific gravity, good workability, and high mechanical properties. They are applied for manufacture of load-carrying structural members of aircraft: frame parts, sheathing, frames, wing ribs, stringers, longerons, propeller blades, and also rivets, etc.

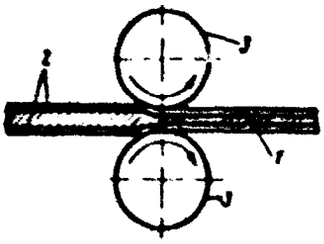
High-strength aluminum alloys include alloys with copper and magnesium (duralumin) and alloys with zinc and magnesium (V-95).

Raised plasticity in hot state ensures to these alloys good pressure workability. They are supplied in the form of sheets of profiles, rods, and tubes.

Profiles are prepared mainly by pressing, which substantially increases mechanical qualities of alloy. Increase of mechanical qualities in process of hot working for these alloys is explained by destruction of defects from casting, crushing of grains, destruction of lattice location of brittle component of alloy. High mechanical properties of these alloys are attained as a result of heat treatment: for duralumin, quenching and natural aging; for alloy V-95, quenching and artificial aging.

In a number of cases sheets of duralumin are [illegible] by means of combination of heat treatment and [illegible]

[illegible] part of increasing corrosion resistance of such materials. It is supplied from the mill part in plated state. Plating consists in covering both surfaces of sheet [illegible] aluminum with thickness [illegible] Fig. [illegible] very pure aluminum, [illegible] with thickness [illegible]



[illegible] Diagram of [illegible] plated sheet of duralumin: 1 — for [illegible] 2 — plating, 3 — pure aluminum

[illegible] especially in case of [illegible] of aluminum with [illegible] of high strength, [illegible] of high strength, [illegible]

Corrosion [illegible]

containing, besides manganese, iron and silicon. Copper and magnesium are introduced for hardening of alloy. Manganese is added to increase corrosion resistance. Iron is harmful impurity: it lowers strength and plasticity and also worsens corrosion resistance. Silicon partially removes harmful influence of iron.

At present are released duralumins of different composition and quality: normal composition (D1), high-alloy (D6, D16), low-alloy (D18, V65), and high-temperature (D19 and VD17).

In Table 38 are given chemical composition and typical mechanical properties of duralumins applied at present.

Table 38. Chemical Composition and Mechanical Properties of Duralumin

Grade of duralumin	Chemical composition %			State of material	Mechanical properties (not less than)		
	Cu	Mg	Mn		σ_b MN/m^2	δ %	HB MN/m^2
D1	3,8—4,8	0,4—0,8	0,4—0,8	Annealed (D1AM)	not over 210	12	450
				Quenched and naturally aged (D1AM)	380	12	1130
D6	4,6—5,2	0,6—1,0	0,5—1,0	Annealed (D6M)	not over 220	15	420
				Quenched and naturally aged (D6T)	400	15	1000
D16	3,8—4,5	1,2—1,5	0,3—0,9	Annealed (D16AM)	not over 200	10	420
				Quenched and naturally aged (D16AT)	430	10	1050

The biggest application in aircraft construction are duralumins of general assignment D1 and D16, rivet alloys D18 and V65, and high-temperature VD17 and D19.

Mechanical properties of duralumin depend not only on its composition but also on form of semifinished product and its treatment.

Duralumin D1, unplated, possesses low corrosion resistance, average plasticity, good weldability by spot welding, and satisfactory workability by cutting. It is subjected to strengthening by heat treatment consisting of quenching from [illegible] in water and natural aging for not less than four days. Annealing is done at [illegible], with cooling in air. Duralumin D1 is supplied in the form of sheets, rods, profiles, pipes, forging, stampings, and wire. Temperature of forging-stamping [illegible]

Duralumin D1 is used for manufacture of different parts and structural elements of medium strength, for fuselage sheathing, stamped hinges, and propellor blades.

Duralumin of raised strength D16 and D6. Alloy D16 possesses low corrosion resistance in unplated state. Plated sheets resist corrosion well. Alloy has medium plasticity in annealed and freshly-hardened states; however, it is not suitable for forging. Alloy D16 is subjected to strengthening by heat treatment consisting of quenching from 495-505°C in water and natural aging for not less than four days. Microstructure of quenched and naturally aged duralumin D16 is shown in Fig. 15.13. Artificial aging at 165-190°C for 6-16 hours is obligatorily used for parts working at a temperature of 150°C and above. Annealing of alloy is produced at 350-370°C, with cooling in air. Alloys wolds well by spot welding and is processed satisfactorily by cutting.



Fig. 15.13. Microstructure of duralumin D16. ×250.

Duralumin D16 is used for manufacture of basic supporting members of aircraft construction: parts of frame, sheathing, frames, wing ribs, longerons, rivets (alloy D16P), with the exception of stamping. Alloy D16 the strongest at temperatures higher than 120°C.

Alloy D6 is analogous to alloy D16. Recently its application has been reduced strongly in view of its lower high-temperature strength.

Alloys D16 and D6 are supplied in the form of sheets, plates, rods, profiles, pipes, and wire.

There recently were developed high-temperature duralumins designed for application in places of aviation constructions subjected to heating to 200°C and above. These alloys include: forging alloy VD17, for manufacture of turbine compressor blades, and alloy D19, for manufacture of heat-resistance rivets and sheets.

High-strength aluminum alloys with zinc and magnesium have recently found wide application in aviation industry. The most important of them are alloy V95,

forging alloy V95-1, alloy V94 for rivets, and the recently developed still higher-strength alloy V96.

In Table 39 are given chemical composition and mechanical properties of high-strength aluminum alloys.

Table 39. Chemical Composition and Mechanical Properties of High-Strength Aluminum Alloys

Grade of alloy	Chemical composition in %					State of material	Mechanical properties (not less than)		
	Zn	Mg	Cu	Mn	Cr		σ_b MN/m^2	δ %	*HB* MN/m^2
B95	5,0—7,0	1,8—2,8	1,4—2,0	0,2—0,6	0,1—0,25	Annealed (V95M)	Not over 250—280	10	—
						Quenched and artificially aged (V95T1)	490—580	6—7	1500
B96	8,0	2,8	2,7	0,3	0,2	Quenched and artificially aged (V96T1)	700—720	7—8	1900

These are the aluminum alloys of highest strength. Introduction of zinc, magnesium, and copper into these alloys ensures high mechanical strength after heat treatment. Manganese increases corrosion resistance and chromium promotes obtaining of fine-grained structure. The highest mechanical properties are obtained by these alloys after heat treatment consisting of quenching and aging. For production of best results after aging a necessary condition during the carrying out of heat treatment of alloys of this group is fast transfer of processed articles into cooling medium and sufficiently fast cooling.

Microstructure of alloy V95 (Fig. 15.14) constitutes solid solution of zinc, magnesium, and copper in aluminum and small inclusions of chemical compounds $MgZn_2$ and Al_2CuMg.

High-strength aluminum alloys with zince and magnesium possess low plasticity, raised inclination to stress corrosion, lowered static strength, and have low heat resistance.

In spite of these deficiencies, basic structural material of contemporary aircraft building is alloy V95.

Recently this alloy, as the stronger, has started to displace high-strength duralumin D16 for structures working at temperatures to 120°C. Wide application

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Fig. 15.14. Microstructure of aluminum alloy V95. ×250.

of alloy V95 in constructions of heavy aircraft has permitted weight reduction of aircraft of up to 2-5 t. Alloy V95, having greater high-temperature strength, can be applied for aircraft possessing high speeds.

Variety of alloy V95, alloy V95-1, possesses less strength but greater plasticity and is applied mainly for propellor blades. Alloy V94 is high-strength rivet alloy. There recently was developed an allow of higher strength, V96.

High-strength alloy V95, as compared to duralumin, possesses greater strength and better machinability. However, it has raised inclination to stress corrosion and lower plasticity. Alloy is strengthened by heat treatment consisting of quenching from 465-480°C in water and artificial aging at 120°C for 24 hours (for plated sheets) or at 140°C for 16 hours (for unplated parts). Machinability and weldability by spot welding are good; weldability by gas welding is unsatisfactory. It is supplied in the form of sheets, plates, rods, profiles, forgings, stamping, and pipes. Temperature of forging-stamping is 380-430°C. Alloy V95 is used for manufacture of basic supporting members of aviation constructions: longerons, stringers, frames, wing ribs, sheathings, etc.

Alloy V96 possesses lowered corrosion resistance and increased sensitivity to concentrations of stresses as compared to alloy V95. Alloy V96 is subjected to heat treatment as followings: quenching from temperature of 460-465°C in cold water and aging for 16 hours at 135-140°C. Alloy V96 has strength approximately 10% more than alloy V95. However, its plasticity is less (see Table 39). Alloy is processed well by cutting. It is supplied in the form of pressed profiles, panels, pipes, and is used for loaded elements of aviation constructions.

§ 6. Aluminum Alloys for Rivets

During manufacture and repair of aircraft structures rivets are widely applied. Number of them in contemporary heavy aircraft exceeds one million. Quality of rivet material is characterized by shear resistance and plasticity at the time of setting riveted. Therefore rivet can be prepared from almost all deformable aluminum alloys. However, special rivet alloys exist. This is explained by the following. As was noted earlier, certain aluminum alloys preserve their plasticity after hardening only for a small time. Thus, for instance, incubative period for alloy D1 is about 2 hours and for alloy D16 it is about 30 minutes. Setting of rivets from such alloys should be done in freshly quenched state within limits of incubative period, while they still preserve plasticity. This creates considerably inconveniences. Therefore special rivet alloys have to have either a very long incubative period, must allow riveting in aged state, or must not be strengthened by aging.

Table 40. Chemical Composition, Conditions of Riveting, and Properties of Aluminum Alloys for Rivets

Grade of alloy	Chemical composition in %					Conditions of riveting	Shear resistance τ_{cp} MN/m^2
	Cu	Mg	Zn	Mn	Ti		
АМг5П	—	4,7—5,7	—	0,2—0,6	—	In annealed state	190
Д18П	2,2—3,0	0,2—0,5	—	—	—	After natural aging	210
В65	3,9—4,5	0,15—0,3	—	0,3—0,5	—	After artificial aging	260
Д19	3,6—4,1	2,0—2,4	—	0,7—0,9	0,03—0,10	In freshly quenched state	280
В94	1,8—2,4	1,2—1,6	6,0—6,7	—	0,02—0,08	After artificial aging	320

As material for rivets in aircraft construction we apply the following grades of aluminum alloys: AMg5P, D18P, V65, and V94. Alloy AMg5P is of nonaging type. Remaining alloys are set after aging. The most important rivet alloys are D18 and V65, which may be riveted at any time after aging. In recent years was developed alloy D19, possessing, as compared to above-indicated alloys, raised high-temperature strength. This alloy is supplied also in the form of wire for rivets. Alloy D19 is strengthened during natural aging. It has long incubative period, allowing us to apply rivets made from it for up to 2-6 hours after quenching (depending upon diameter of rivets). For lengthening of above-indicated periods it is recommended

that after quenching they be stored at subzero temperatures (in refrigerators) in order to delay aging. Chemical composition, conditions of riveting, and properties of aluminum alloys for rivets are given in Table 40.

Alloy AMg5P possesses high corrosion resistance. It has high plasticity. It welds satisfactorily. Machinability is lowered. It is applied during manufacture of rivets for constructions from aluminum and magnesium alloys. Rivets are set in annealed state. Alloy is supplied only in the form of wire.

Duralumin rivet alloy of raised plasticity D18P. Corrosion resistance of rivets is low. Alloy possesses plasticity sufficient for setting of rivets in hardened and naturally aged states. It is strengthened by heat treatment consisting of quenching from 495-505°C in water and natural aging. Weldability and workability by cutting are the same as for alloy D1.

Alloy is supplied in the form of wire and is applied as rivets for constructions of medium strength working at a temperature of not more than 100°C.

Rivet duralumin of raised strength V65. Corrosion resistance of rivets is same as for rivets of alloy D18. Plasticity is sufficient for setting of rivets in hardened and aged states. It is strengthened by heat treatment consisting of quenching from 515-520°C in water and artificial aging at 75 ± 5°C for 24 hours. Microstructure of alloy V65 after heat treatment is shown in Fig. 15.15. Weldability and workability by cutting are the same as for alloy D1.


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Fig. 15.15. Microstructure of aluminum rivet alloy V65. ×250.

Alloy is supplied in the form of wire and is applied as rivets for constructions of raised strength working temperatures of not more than 100°C.

High-temperature duralumin D19 possesses same corrosion resistance as alloy D16. It has satisfactory plasticity, pressure workability, and machinability. It is strengthened by heat treatment consisting of quenching from 505 ± 3°C in water and natural aging for not less than five days. Alloy has satisfactory weldability.

Alloy D19P is supplied in the form of wire and is used for rivets as substitute

for alloys D16P, D18P, and V65 in constructions working at temperatures of from 125 to 250°C. Rivets of D19P, with diameter to 15 mm can be set up to 6 hours after quenching, those with diameter of 6 mm for 4 hours, and those with diameter of 8-9 mm for 2 hours. In the form of sheets alloy is applied in constructions working at temperatures of 150-250°C.

High-strength rivet alloy V94 possesses satisfactory corrosion resistance. It has plasticity sufficient for setting of rivets in hardened and aged states. It is strengthened by heat treatment consisting of quenching from 465 ± 5°C in water and step artificial aging for 3 hours at 100°C and at 165 ± 5°C. Alloy has satisfactory machinability.

Alloy V94 is supplied in the form of sheets and is applied as rivets for loaded constructions working at temperatures to 125°C.

§ 7. Aluminum Alloys for Forging and Hot Stamping

In contemporary aircraft construction for manufacture of different parts of aviation structures there are applied widely aluminum alloys for forging and stamping.

These alloys are distinguished by high plasticity in hot state, allowing us to produce hot pressure treatment. Its high mechanical properties allow us to apply them for manufacture of loaded parts working at ordinary or raised temperatures.

Forging aluminum alloys are divided into two groups:

1) alloys intended for work at ordinary temperatures, not exceeding 100°C;

2) heat-resisting alloys intended for work at raised temperatures.

Forging alloys for work at ordinary temperatures. These are alloys [AV] (AB), [AK6] (AK6), AK8, and V95-1. In chemical composition alloys AV, AK6, and AK8 are similar to duralumin of normal composition, with the same content of magnesium, manganese, and silicon. Content of copper changes from 0.4 to 4.4%, which increases strength but somewhat worsens productibility of these alloys. Alloy V95-1 is variety of alloy V95.

In Table 41 are given chemical composition and mechanical properties of aluminum forging alloys applied for manufacture of forgings and stampings.

Forging of parts from these alloys is conducted at a temperature of 400-470°C. Alloys AV, AK6, and AK8 are strengthened by heat treatment consisting of quenching and natural or artificial aging. Alloy V95-1 is subjected only to artificial aging.

Table 41. Chemical Composition and Mechanical Properties of Aluminum Forging Alloys

Grade of alloy	Chemical composition in %				State of material	Mechanical properties (not less than)		
	Cu	Mg	Mn	Si		σ_B MN/m²	δ %	HB MN/m²
AB	0,2—0,6	0,45—0,9	0,15—0,35 (plus Cr)	0,5—1,2	Annealed (AVM)	не более 150	17—20	300
					Quenched and naturally aged (AVT)	180—210	14—20	600
					Quenched and artificially aged (AVT1)	300	8—10	850
AK6	1,8—2,6	0,4—0,8	0,4—0,8	0,7—1,2	Quenched and artificially aged	360—420	8—12	1000
AK8	3,9—4,8	0,4—0,8	0,4—1,0	0,6—1,2	Quenched and artificially aged	420—460	8—10	1200
B95-1	0,3—1,0	1,2—2,0	0,3—0,8	7,0—8,0	Quenched and artificially aged	500	8	1400

In Fig. 15.16 is presented microstructure of alloy of grade AK6, consisting of solid solution and metallic compounds. Samples of certain parts from aluminum forging alloys are presented in Fig. 15.17.

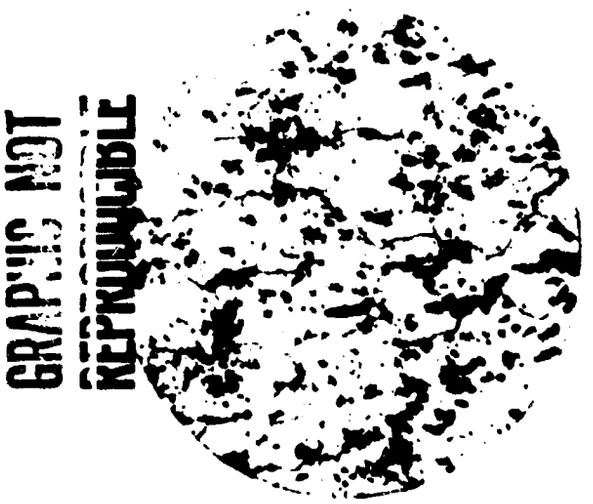

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Fig. 15.16. Microstructure of aluminum alloy AK6. ×200.

Forging alloy of raised plasticity AV (avial) possesses high corrosion resistance, has high plasticity in cold and hot states. It is strengthened by heat treatment consisting of quenching from 515-525°C in water with subsequent natural [AVT] (ABT) or artificial (AVT1) aging at 150-160°C for 12-16 hours. Annealing at 350-370°C. Forging and stamping at 470-475°C. To prevent lowering of effect of heat treatment, aging should be produced directly after quenching. Alloy welds well by point and atomic hydrogen welding and satisfactorily by gas. Workability by cutting in annealed state is unsatisfactory.

Alloy AV is designed for parts of aviation constructions of complicated configuration prepared by cold or hot stamping and forging. It is supplied in the form of sheets, pipes, profiles, rods, forgings, and stampings.

Forging alloy of medium strength AK6 possesses satisfactory corrosion resistance, has high plasticity in hot state, and machines well. It is subjected to hardening by heat treatment consisting of quenching from 500-515°C in water and artificial aging at 150-165°C for 12-15 hours. Forging and stamping are done at 380-470°C. Alloy welds well by contact, point, and seam welding.

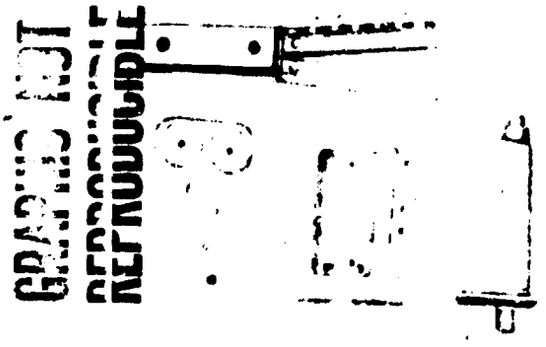


Fig. 15.17. Parts made from aluminum forging alloys. 1 – wing tip and 2 – rudder control rocker, prepared from alloy AK6; 3 – butt fitting for center part of wing with center section, prepared from alloy AK8; 4 – stator blade of axial-flow compressor; 5 – rotor blade of axial-flow compressor, prepared from alloy AK4-1.

With introduction into alloy of small additions of chromium and titanium its technological qualities are improved (alloy AK6-1).

Alloy AK6 is basic aluminum alloy for manufacture of aviation forgings and stampings. It is designed for manufacture of parts of complicated form of medium strength: joints of aircraft and parts of compressors for jet engines. It is supplied in the form of forgings, stampings, rods, plates, profiles, and sheets.

Forging duralumin of raised strength AK8 possesses low corrosion resistance, has low plasticity in hot state, which hampers its stampability. Alloy is strengthened by heat treatment consisting of quenching from 490-505°C in water and artificial aging at 150-165°C for 6-15 hours. It possesses good machinability and good weldability by contact, point, and seam welding.

Alloy AK8 is used for manufacture of highly loaded and forged aircraft parts: frames, fittings, brackets, and others. It is supplied in the form of forgings, stampings, rods, plates, profiles, and sheets.

High-strength forging alloy V95-1 possesses corrosion resistance, as does alloy V95. It has satisfactory plasticity in hot state, allowing us to produce stamping. Temperature of forging and stamping is 380-430°C. Alloy is subjected to strengthening by heat treatment as follows: quenching from 465-475°C in water and aging for 16 hours at 140°C. Alloy V95-1 possesses good machinability and is supplied in the form of forgings and stampings for manufacture of propeller blades.

Heat-resisting al. yo. [illegible] above decreases fast with increase of temperature. This shows especially after prolonged work at a temperature exceeding aging temperature. This is explained by the fact that majority of them are aged alloys. And, as it was shown earlier, with increase of temperature occurs further excess aging, leading to softening of alloy.

High-strength alloys of type D16 and V95 – the most important structural materials of aviation material – cannot be used in constructions of supersonic aircraft. For conditions of flight when there occurs aerodynamic heating of sheathing and frame to temperatures exceeding 150°C, other materials with raised heat resistance have to be used.

For manufacture of parts of aviation constructions working at raised temperatures we apply heat-resistant aluminum alloys AK4, AK4-1, VD17, and recently developed alloys D20 and D21.

Chemical composition and mechanical properties of heat-resisting aluminum alloys after strengthening by heat treatment are given in Table 42.

Table 42. Chemical Composition and Mechanical Properties of Aluminum Heat-Resisting Alloys

Grade of alloy	Chemical composition in %			Other elements	Mechanical properties (not less than)		
	Cu	Mg	Mn		σ_b MN/m²	δ %	HB MN/m²
AK4	1,9—2,5	1,4—1,8	<0,2	Fe 1,0—1,5, Si 0,5—1,2, Ni 1,1—1,6	360—380	3—8	1000
AK4-1	1,9—2,5	1,4—1,8	<0,2	Fe 1,0—1,5, Ni 1,0—1,5	380—400	4—5	1090—1480
VD17	2,6—3,2	2,0—2,4	0,45—0,7	Fe 0,3, Si 0,3	400—440	10	1050
D20	6,0—7,0	—	0,4—0,8	Ti 0,1—0,2	300—380	8—25	1000
D21	6,0—7,0	0,25—0,45	0,4—0,8	Ti 0,1—0,2	430	9	—

In alloys AK4 and AK4-1 manganese is absent, and for giving it heat resistance iron and nickel are introduced. Alloy AK4-1, thanks to decrease of quantity of silicon, is more heat-resisting.

Alloy VD17 belongs to duralumin group. Raised content of magnesium gives to it, along with increased strength, high heat resistance.

Alloys D20 and D21 possess higher heat resistance and better [illegible] than alloys considered above.

All known alloys are subjected to strengthening by heat treatment consisting of quenching from temperature of 515-535°C and artificial aging at a temperature of 170-190°C for 10-16 hours. After heat treatment they have structure of solid solution with inclusions of different metallic compounds, Al_2CuMg, $FeNiAl_9$, and others (Fig. 15.18).


GRAPHIC NOT REPRODUCIBLE

Fig. 15.18. Microstructure of aluminum alloy AK4-1. ×200.

To temperature of 300°C these alloys preserve sufficiently high characteristics of heat resistance.

In Table 43 are given typical mechanical properties of aluminum forging alloys at high temperatures after heat treatment. For alloys AK4, AK4-1, and VD17 it consists of quenching from 515°C in water and artificial aging at 170°C for 16 hours. Alloy D20 is quenched from 535°C in water and artificially aged 165°C for 12 hours.

Table 43. Mechanical Properties of Aluminum Heat-Resisting Alloys at High Temperatures

Grade of alloy	Temperature in °C	Mechanical properties (not less than)			Grade of alloy	Temperature in °C	Mechanical properties (not less than)		
		$\sigma_в$ MN/m²	$\sigma_{0.2}$ MN/m²	σ_{100} MN/m²			$\sigma_в$ MN/m²	$\sigma_{0.2}$ MN/m²	σ_{100} MN/m²
AK4	200	325	150	200	B.317	200	380	160	190
	250	280	90	100		250	240	75	100
	300	160	45	40		300	170	35	40
AK4-1	200	315	140	—	D20	200	300	80	180
	250	280	60	100		250	240	85	120
	300	100	30	45		300	180	55	80
						350	120	30	40

It has been established that during brief tests the greatest strength at temperatures from 125 to 220°C is possessed by alloy VD17, while at 300°C and above alloy AK4-1 has the advantage.

During prolonged tests, the alloy D20 has the best characteristics of heat resistance at 300°C.

Alloy AK4 possesses satisfactory corrosion resistance. It has plasticity in hot state. Temperature of forging - stamping is 350-480°C. Alloy welds well by contact, point, and seam welding and also machines satisfactorily. Warping of this



Fig. 15.19. Impeller of turbine compressor made from aluminum alloy AK4-1.

alloy, grade AK4-1, possesses somewhat better productibility and higher heat resistance.

Alloys AK4 and AK4-1 are used for manufacture of compressor blades, impellers, disks, rings, pistons, and other engine parts working at raised temperatures, to 300°C. These alloys are supplied in the form of forgings, stampings, and rods. In Fig. 15.19 is shown impeller of turbine compressor, made from alloy AK4-1.

Duralumin VD-17 has higher corrosion resistance than alloys AK4 and AK4-1. It has high plasticity during hot deformation. Temperature of forging-stamping is 350-450°C. Temperature of pressing should be 400-460°C. Alloy welds satisfactorily and machines well. In Fig. 15.20a is shown microstructure of alloy VD17, consisting of grains of solid solution with inclusions of metallic compounds Al_2CuMg and others.

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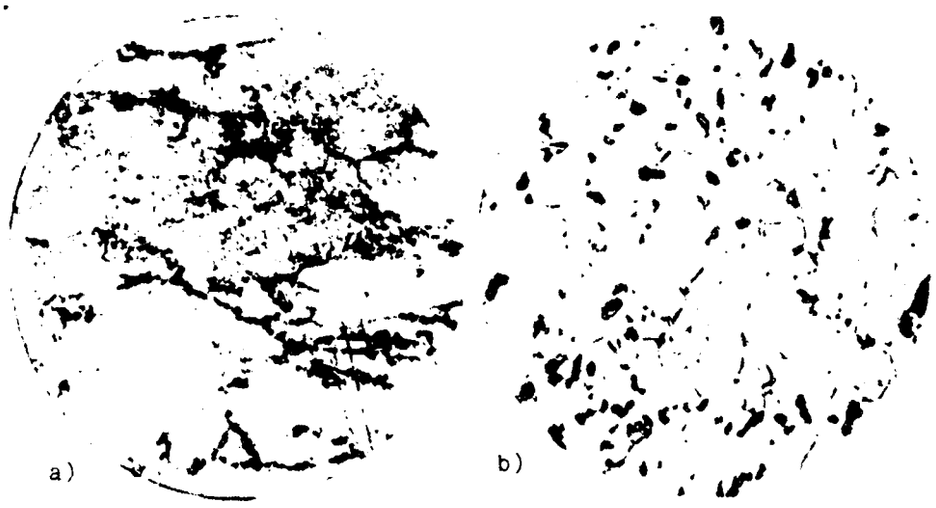


Fig. 15.20. Microstructure of heat-resisting aluminum alloys. a) alloy VD17. ×250; b) alloy D20. ×200.

Alloy VD17 is used for manufacture of blades and rear disks of axial-flow compressors and other parts of turbojet engines working at temperatures of 200-300°C. It is supplied in the form of forgings, stampings, and rods.

Heat-resistant alloy D2C possesses low corrosion resistance but has high plasticity in hot state. Temperature of forging-stamping is 400-460°C. Alloy is strengthened by heat treatment consisting of quenching from 530 ± 5°C in water

and artificial aging 200-220°C for 12 hours (for pressed semifinished products) or at 165-175°C for 10-16 hours (for forgings and stampings). Annealing is produced at a temperature of 350-370°C, with cooling in air.

At ordinary temperature this alloy is less strong than alloys D16 and VD17 but possesses the highest prolonged strength at temperatures of 250-350°C.

Alloy D20 welds well by point, roller, and argon arc welding and also possesses satisfactory machinability. It is used for manufacture of parts and elements of aviation constructions working at raised temperatures, to 250-350°C: blades of disks of axial-flow compressors and other parts of turbojet engines prepared from pressed and forged semifinished products and also parts welded from sheet material (vessels, hermetically sealed cabins, etc.). In Fig. 15.20b is shown microstructure of alloy D20, consisting of grains of solid solution with inclusions of metallic compounds.

Alloy is supplied in the form of forgings, stampings, rods, profiles, and sheets.

Heat-resisting alloy D21 possesses satisfactory corrosion resistance. It has high plasticity in hot state. Alloy is strengthened by heat treatment consisting of quenching from 520 ± 5°C in water and artificial aging at 185-195°C for 12-16 hours.

To temperature of 150-250°C alloy D21 possesses greater strength than D20 and greater prolonged strength than AK4-1. Alloy possesses satisfactory machinability, is not weldable, and is designed for manufacture of parts of aviation constructions of complicated form working at temperatures to 225-250°C. It is supplied in the form of forgings and stampings.

Heat-resisting material [SAP] (САП) is new deformable material, which is obtained by means of pressing and sintering of aluminum powder at a temperature of 500-600°C. Aluminum powder is prepared by method of pulverization of aluminum. From briquettes obtained thus are prepared different semifinished products (rods, pipe, profiles, sheets).

Basic physical properties of SAP (specific gravity, thermal conductivity, and coefficient of linear expansion) are close to properties of pure aluminum. This material possesses high corrosion resistance, is easily machined, welds well, and is suitable for pressure treatment.

Table 44. Mechanical Properties of SAP at Raised Temperatures

Temperature, °C	σ_B MN/m^2	$\sigma_{0.2/100}$ MN/m^2	σ_{100} MN/m^2
200	210	100	150
300	180	80	110
350	145	—	100
400	110	—	90

SAP at ordinary temperature possesses low mechanical properties: σ_B = 330 MN/m^2 (33 kgf/mm^2); δ = 7%. The most important property of SAP is high heat resistance, determined by presence of thin film of Al_2O_3 on particles of aluminum powder. SAP contains up to 20% Al_2O_3, the remainder being metallic aluminum. In Table 44 are given mechanical properties of semifinished products pressed from SAP, at raised temperatures.

From Tables 43 and 44 one may see that starting from 300°C SAP has greater strength than the most heat-resisting aluminum alloys. Application of SAP at temperatures below 300°C is inexpedient. SAP is used for manufacture of parts working at temperatures of 350-500°C.

§ 8. Aluminum Foundry Alloys

For manufacture of parts of complicated form not subjected to raised loads (boxes and housings for assemblies and instruments) in aircraft construction widely are applied aluminum foundry alloys.

These alloys possess low specific gravity of 25.5-29.3 kN/m^3 (2.55-2.93 gf/cm^3), high corrosion resistance, quite high mechanical properties, which in considerable degree depend on presence in them of harmful metallic and nonmetallic impurities. Thus, for example, for alloys of aluminum with silicon copper lowers corrosion resistance; zinc lowers mechanical strength; iron renders harmful influence on plasticity, etc.

Heat resistance of aluminum foundry alloys is low, with the exception of certain grades which can work to temperatures of 300°C.

Quality of foundry alloy is determined by fluidity, viscosity, density, inclination to hot cracks, shrinkage during crystallization, and so forth. These alloys basically possess good foundry qualities. Casting from these alloys are prepared in earthen forms, in chill molds, and under pressure. Aluminum alloys

are poured at 680-760°C.

Heat treatment of aluminum foundry alloys is done for removal of internal stresses appearing during casting, for levelling of chemical composition through cross section of casting, increasing strength or plasticity, and for stabilization of dimensions of parts.

Depending upon assignment of cast parts, aluminum alloys are subjected to different forms of heat treatment:

(1) T1 (aging) – somewhat increases mechanical properties of alloy; is used for parts bearing medium loads;

(2) T2 (annealing) – used for stabilization of dimensions of parts;

(3) T4 (quenching) – essentially increases strength and plasticity; is used for loaded parts experiencing shock influences;

(4) T5 (quenching and partial aging) – causes additional hardening of alloy as compared to treatment T4 at the expense of certain lowering of plasticity; is used for parts bearing high static loads and experiencing shock influences;

(5) T6 (quenching and full aging) – causes the biggest increase of strength of alloy at the expense of essential lowering of plasticity; is used for parts bearing high static loads and not experiencing impact loads;

(6) T7 (quenching and stabilizing temper) – is used for prevention of lowering of mechanical properties of alloy and change of dimensions of parts in case of work at raised temperatures;

(7) T8 (quenching and softening temper) – is used for parts cast from alloy AL3 for guarantee of increased plasticity with high content of magnesium.

Depending upon content of basic alloy components, aluminum foundry alloys are divided into several subgroups.

The most widespread aluminum foundry alloys are the Silumins. This is explained by the fact that along with good foundry properties they possess comparatively high mechanical qualities, corrosion resistance, low specific weight, and weldability.

Silumins are alloys of aluminum with silicon, containing up to 13% silicon (normal Silumin) and small quantities of copper, magnesium, and manganese (special Silumins).

As can be seen from aluminum – silicon constitution diagram presented in Fig. 15.21, in structure of Silumin is eutectic, improving foundry qualities of alloy.

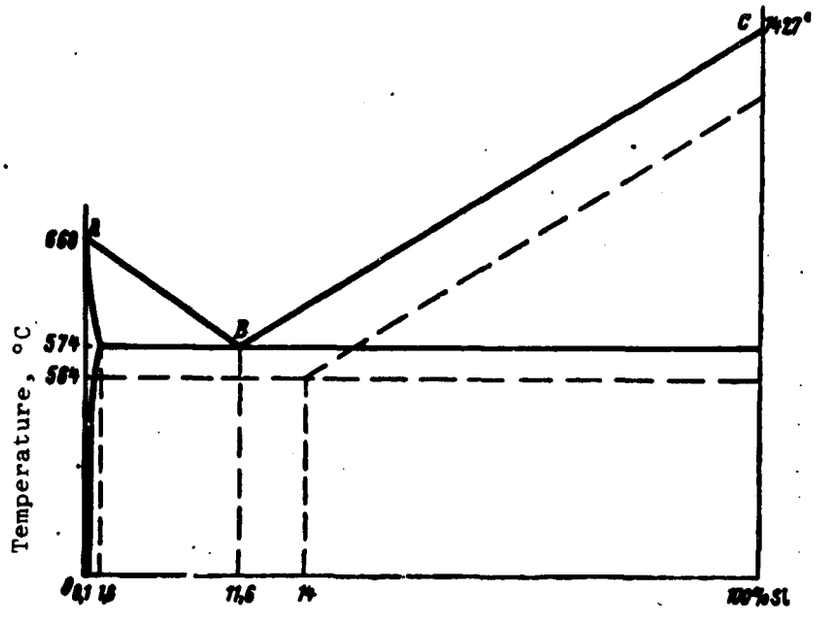


Fig. 15.21. Aluminum – silicon constitution diagram.

Coarse-acicular eutectic structure with brittle inclusions of primary silicon, obtained during casting of Silumin under usual conditions (Fig. 15.22), is characterized by low mechanical qualities.



GRAPHICS NOT REPRODUCIBLE

Fig. 15.22. Microstructure of Silumin. ×200.
a) unmodified; b) modified.

For improvement of structure and properties of Silumin we apply modification. Modification is process of artificial change of dimensions and form of grains, as a result of which is obtained fine-grained structure of alloy with high strength and plasticity. Modification of Silumin consists in introduction into melted alloy (before pouring) of a mixture of salts of sodium fluoride and sodium chloride.

As a result of modification, eutectic temperature of constitution diagram drops from 574 to 564°C, and content of silicon in eutectic is increased to 14% (see Fig. 15.21).

Structure of alloy after modification is characterized by fine-grained eutectic and plastic grains of primary aluminum (Fig. 15.22b). As a result of this, ultimate strength of alloy is increased by 40% and elongation is increased by 2-3 times.

It is necessary to note that before modification for removal of slag and gas pockets Silumin is subjected to refining by chlorine or chlorous salts ($ZnCl_2$).

One of deficiencies of Silumin is inclination to formation of porosity during casting in earth. For prevention of porosity of big castings (bodies of turbine compressors) we sometimes apply casting with crystallization under pressure.

Casting by this is produced in special steel autoclaves, which, after pouring of alloy, are fed compressed air at pressure of 0.5-0.6 MN/m^2 (5-6 at). Thus crystallization of alloy and its cooling occur under pressure.

In this case pressure prevents liberation from alloy of gases dissolved in it and small shrinkage cavities in casting are better filled by metal.

As a result of crystallization under pressure are obtained tight and nonporous castings with higher mechanical properties.

In Table 45 are given chemical composition and mechanical properties of aluminum foundry alloys after casting in earth (for Silumin AL2 and AL4 – after modification).

Normal Silumin (AL2) is not strengthened by heat treatment. If, however, to Silumin containing 4-10% silicon are added small quantities of copper, magnesium, and manganese, there are obtained special or alloyed Silumins (AL4, AL5, AL9), which can be strengthened by heat treatment. Such Silumins possess higher mechanical properties.

Heat treatment of special Silumins consists of quenching from 535°C in warm or hot water, to prevent appearance of internal stresses (T4). After quenching we sometimes apply artificial aging at a temperature of 175°C for 15 hours (T5).

The highest mechanical properties are possessed by foundry alloy of aluminum with magnesium – al'tmag (AL8). It has low specific gravity (25.5 kN/m^2 or 2.55 $gf/cm)^2$, high strength and corrosion resistance, but lowered density and bad foundry qualities.

Foundry alloys of aluminum with copper (AL7, AL19) as aviation alloys find limited application at present, since their corrosion resistance is worse than others, they are heavier, and are less plastic. Their application is conditioned

Table 45. Chemical Composition and Mechanical Properties of Aluminum Foundry Alloys

Grade of alloy	Method of casting	Chemical composition in %					Form of treatment	Mechanical properties (not less than)		
		Si	Cu	Mg	Mn	Other elements		σ_p Mn/м²	δ %	HB Mn/м²
АЛ1	З	0,7	3,7—4,5	1,2—1,7	—	Ni 1,7—2,2	Т1	220	0,5	850
	З						Т5	260	0,5	1000
АЛ2	ЗМ	10,0—13,0	—	—	—	—	—	180	6	500
АЛ4	ЗМ	8,0—10,5	—	0,17—0,3	0,25—0,5	—	—	180	3	600
	ЗМ						Т6	260	4	700
АЛ5	З	4,5—5,5	1,0—1,5	0,3—0,6	—	Ti+Cr 0,20	Т5	220	1	800
АЛ7	З	1,2	4,0—5,0	—	—	—	Т4	220	8	650
	З						Т5	250	5	800
АЛ8	К	—	—	9,5—11,5	—	Ti 0,07 Be 0,07	Т4	320	12	700
АЛ9	З	6,0—8,0	—	0,2—0,4	—	—	Т4	200	6	550
ВИ-11-3	З	0,8—1,2	—	10,5—13,0	—	Be 0,03—0,05 0,03—0,05	Т4	240	3	950
АЛ19	З	—	4,5—5,3	—	0,6—1,0	Ti 0,2—0,4	Т4	320	8	800
	З						Т5	360	5	1000
В300	З	—	4,6—6,0	0,8—1,5	0,2—0,3	Ni 2,6—3,6	Т2	180	0,6	—
	З					Cr 0,1—0,2	Т7	220	0,6	—
В14А	З	1,5—2,0	3,5—4,5	0,7—1,2	0,15—0,3	Fe 1,2—1,7 Cr 0,1—0,2	Т2	170	0,8	—
						Ti 0,05—0,1	Т7	210	0,8	—

Note: Methods of casting are designated in the following way: З — in Earth; [ЗМ] (ЗМ) — in Earth, modified; К — casting in chill mold.

by heat resistance and great convenience in a technological respect.

In aircraft construction are applied mainly aluminum foundry alloys of the following grades: for casting of aircraft parts, AL7, AL8, AL9; for big and medium-size engine parts, AL4 and less often AL5; for castings of medium-size and small assembly and instrument castings not subject to large loads, AL2.

New alloys of grades [V14A] (B14A), AL19, and V300 possess heat resistance and are designed for casting of parts working at raised temperatures, to 300°C.

Conditions of heat treatment of aluminum foundry alloys applied in aircraft construction are given in Table 46.

Table 46. Conditions of Heat Treatment of Aluminum Foundry Alloys

Grade of alloy	Form of heat treatment	Quenching			Aging	
		Temperature of heating, °C	Holding during heating, hours	Cooling medium	Temperature of heating, °C	Holding during heating, hours
AJ11	T5	515±5	2—4	Boiling water or air	220±10	2—4
AJ14	T6	535±5	2—6	Water 50—100° C	175±5	15
AJ15	T5	525±5	4	Boiling water	180±5	5
	T7	525±5	4	Water 50—100° C	230±5	5
AJ17	T4	515±5	10—15	Water 50—100° C	Natural aging	
	T5	515±5	10—15	Water 50—100° C	150±5	2—4
AJ18	T4	435±5	15—20	Water 80—100° C	—	—
AJ19	T4	535±5	2—8	Water 50—100° C	—	—
	T5	535±5	2—8	Water 50—100° C	150±10	1—3
BM-11-3	T4	430±5	15—20	Water 50—100° C	—	—
		Step heating				
AJ110	T4	535±5	8	—	—	—
		545±5	5—7	Water 80—80° C	—	—
		Step heating				
	T5	535±5	8			
		545±5	5—7	Water 80—80° C	175±5	3
B300	T2	Annealing 300	5—10	Air	—	—
		Step heating				
	T7	500	2			
		535	4—10	Water 80—100° C or oil 200—220°C	Temper at 300	3—5
B14A	T2	Annealing 280	10	Air	—	—
	T7	515±5	3—5	Water 80—100° C	Temper at 250	10

Table 47. Mechanical Properties of Heat-Resisting Aluminum Foundry Alloys at High Temperatures

Grade of alloy	Form of heat treatment	Temperature, °C	$\sigma_{0.2;100}$, MN/m²	σ_{100}, MN/m²
AL19	T4	175	90	185
		250	—	115
		300	—	65
	T5	175	90	185
		250	—	115
		300	—	70
AL30	T2	300	40	58
		350	20	35
	T7	300	40	65
		350	17	37
AL1A	T2	250	46	90
		300	31	60
	T7	250	55	90
		300	35	60

In Table 47 are given typical mechanical properties of heat-resisting aluminum foundry alloys at high temperatures after casting in earth.

Alloy AL1 possesses lowered corrosion resistance and low foundry properties. Heat treatment is conducted per conditions T5. Alloy has good machinability and high heat resistance.

Alloy is used for manufacture of pistons and cylinder heads of internal-combustion engines and other parts working at raised temperatures. Casting is conducted in earth or in chill molds.

Alloy AL2 possesses good corrosion resistance and high foundry properties. It is subjected to refining for lowering of gas porosity and modification for increase of mechanical properties. During casting of large parts it is necessary to apply crystallization under pressure in autoclaves. Alloy is not strengthened by heat treatment, for removal of residual stresses annealing per conditions T2 is recommended. It has good gas weldability and poor machinability.

Alloy AL2 is used for casting parts of complicated form and medium loading: parts of assemblies and instruments. Casting is conducted in earth, in chill molds, or under pressure.

Alloy AL4 possesses good corrosion resistance, good foundry properties, and raised strength. It is subjected to refining and modification. Strengthening heat treatment of alloy is produced under conditions T6.

Alloy is used widely for manufacture of big loaded parts of complicated



Fig. 15.23. Body of turbine compressor, cast from alloy AL4.

configuration for aircraft engines. Castings made in earth and in chill molds from it are used for engine bodies, housings of certain assemblies, and also separate aircraft parts (Fig. 15.23). However, alloy is not useful for manufacture of parts working at temperatures higher than 200°C.

Alloy AL5 possesses somewhat lower corrosion resistance and strength than alloy AL4. It has good foundry qualities. Strengthening heat treatment is produced per conditions T6, and for parts working at raised temperatures it is done per conditions T7. Alloy welds satisfactorily and machines well.

Alloy AL5, possessing great heat resistance, is used for manufacture of large engine parts working at raised temperatures: heads and crankcases of internal-combustion engines. Casting is conducted in earth or in chill molds.

Alloy AL7 possesses low corrosion resistance, low foundry properties, and high strength. Strengthening heat treatment is produced per conditions T4 and T5. It has good weldability and machinability.

Alloy is used for manufacture, by casting in earth, of medium-loaded small aircraft parts working to temperatures of 200°C.

Alloy AL8 possesses high corrosion resistance, high strength, and low foundry properties. It is subjected to strengthening heat treatment per conditions T4. Alloy has satisfactory gas weldability and good machinability.

Alloy AL8 is used for manufacture, by casting in earth or chill molds, of highly-loaded aircraft parts subject to corrosional influence and working at low temperatures.

Alloy AL9 possesses satisfactory corrosion resistance, good foundry properties, medium strength, and high plastiicty. Strengthening heat treatment of alloy is produced per conditions T4 and T5. It has good gas weldability and satisfactory machinability.

Alloy AL9 is used for manufacture, by casting in earth or chill molds, of aircraft parts of complicated configuration of medium loading: brackets, bracing joints, landing gear pistons, and other parts.

Alloy VI-11-3 possesses high corrosion resistance, good foundry properties,

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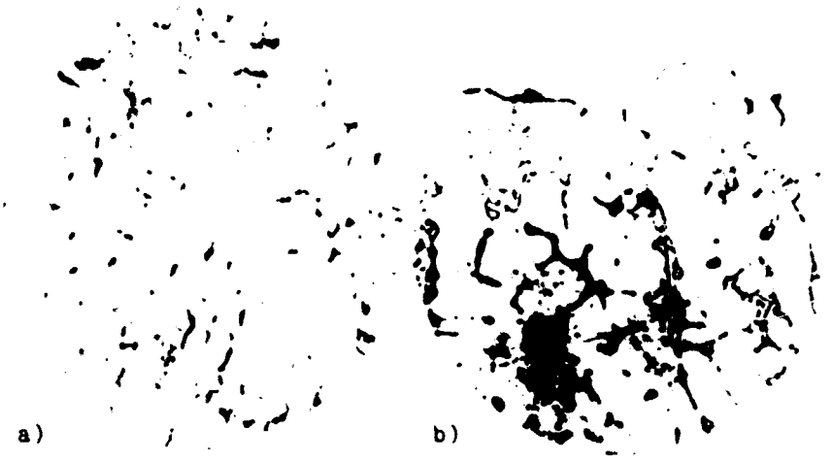


Fig. 15.24. Microstructure of aluminum foundry alloys. a) alloy V300. ×250; b) alloy V14A. ×250.

and raised strength. Strengthening heat treatment of alloy is done per conditions T4. It has satisfactory gas weldability and good machinability. Alloy is used for manufacture, by casting in earth, chill molds, or under pressure, of parts or raised corrosion resistance.

Alloy AL-19 possesses low corrosion resistance, low foundry properties, but high mechanical qualities and high-temperature strength.

Strengthening heat treatment of alloy is produced per conditions T4 and T5. It has good weldability and machinability. Alloy AL19 is used for manufacture, by casting in earth, of aircraft and assembly parts working at temperatures of 175-300°C.

Alloy V-300 possesses lowered corrosion resistance, satisfactory foundry properties, and raised strength and heat resistance. In Fig. 15.24a is shown microstructure of aluminum alloy V-300.

Strengthening heat treatment of alloy is conducted per conditions T2 for parts of complicated configuration and T7 for more heavily loaded parts. It has satisfactory weldability and machinability. Alloy V-300 is used for manufacture, by casting in earth, of parts working at a temperature of 200-350°C.

Alloy V14A possesses lowered corrosion resistance, satisfactory foundry properties, and raised strength and heat resistance. Heat treatment of alloy is produced per conditions T2 for parts of complicated configuration and per T7 for parts of bearing raised loads. It has satisfactory weldability and machinability.

Alloy V14A is used for casting of parts working at a temperature of 250-300°C. In Fig. 15.24b is shown microstructure of aluminum foundry alloy V14A.

C H A P T E R XVI

MAGNESIUM ALLOYS

§ 1. Properties of Magnesium

Magnesium is the lighest technical metal. It has silvery-white color, very low specific gravity (17.4 kN/m^2 or 1.74 gf/cm^3), and melting point of 651°C. Magnesium possesses low chemical resistance. When heated to 600°C, it easily ignites, which complicates technology obtaining of it. Technical magnesium and its alloys oxidize readily in air and in humid media; they are destroyed rapidly in sea water and from action of majority of acids and salts. Weak resistance to corrosion of magnesium and its alloys is explained by very low electrochemical potential and also by the fact that oxidized film of magnesium MgO does not possess protective properties. Therefore parts made from magnesium alloys must be protected from corrosion.

Magnesium has low fluidity but welds and machines well. Strength and plasticity of magnesium are low. After casting its mechanical properties are the following: σ_B = 120 MN/m^2 (12 kgf/mm^2), δ = 8%, HB = 300 MN/m^2 (30 kgf/mm^2).

Native industry releases two grades of technical magnesium: Mg1 and Mg2, containing respectively not more than 0.08 and 0.15% impurities.

Owing to bad complex of properties, magnesium is not applied in pure form as structural material.

§ 2. General Information About Magnesium Alloys

Magnesium alloys are finding ever greater application in aircraft construction. They possess low specific gravity of 18 kN/m^2 or 1.8 gf/cm^2, approximately one and

a half times less than for aluminum alloys.

In mechanical properties they are inferior to aluminum alloys, but in specific strength (strength per unit of weight) in a number of cases they are close to high-strength aluminum alloys and alloy steels. Magnesium alloys possess good machinability: alow the highest cutting speeds, rates of feed, and depth of cutting.

Magnesium alloys have a series of deficiencies. They possess low corrosion resistance in air and in many media. They oxidize readily when heated and ignite at temperatures over 600°C. Many magnesium alloys are inclined to corrosion cracking under stress.

Magnesium alloys are considerably less suited than those of aluminum to pressure treatment, especially in cold state. Production of castings of magnesium alloys, owing to their low foundry properties and spontaneous combustion in liquid form, presents considerable difficulties.

The most important alloy elements in aviation magnesium alloys are: aluminum, zinc, manganese, cerium, zirconium, and others. Majority of these elements form limited solid solutions and chemical compounds with magnesium.

Up to 11% aluminum is introduced into composition of magnesium alloys. It forms limited solid solutions and metallic compounds with magnesium, and increases strength and plasticity of alloys. With increase of content of aluminum foundry properties are improved; however, plasticity of alloy in hot state decreases and inclination to corrosion cracking under stress is increased.

Up to 5% zinc is contained in magnesium alloys. It forms limited solid solutions and metallic compounds with magnesium. Zinc improves mechanical properties, but in smaller degree than aluminum. Foundry qualities of alloy are improved in the presence of zinc. Besides, zinc increases corrosion resistance.

Improvement of mechanical properties through introduction into magnesium alloys of aluminum and zinc is explained by possibility of application of strengthening heat treatment – quenching and artificial aging. This is connected with the fact that aluminum and zinc form limited solid solutions with magnesium, their solubility in magnesium being increased with increase of temperature.

However, the effect of hardening of magnesium alloys as a result of heat treatment is less than for aluminum alloys. In practice heat treatment of them may

be produced only when content of aluminum is over 6% and of zinc is over 3%.

Strong oxidizability during heating and deceleration of diffusion processes in its alloys creates complexity of carrying out of heat treatment.

Content of aluminum and zinc in magnesium alloys higher than shown concentrations leads to impairment of strength and plasticity.

Manganese is introduced into magnesium alloys in quantity of 0.1-0.5% for increase of corrosion resistance and in quantity of 1-2.5% for increase of strength. Besides this, manganese promotes crushing of structure but worsens foundry properties of magnesium alloys.

Cerium is introduced in quantity to 0.25% in alloy of grade MA8 for improvement of mechanical properties.

Zirconium and titanium are introduced into malleable alloys in small quantities for increase of plasticity in hot state. Besides this, they somewhat increase strength and promote the obtaining of fine-grained structure.

Berylbium is introduced in small quantities (to 0.07%). It sharply decreases oxidizability of magnesium, which protects alloys from spontaneous combustion during casting.

Harmful impurities in magnesium alloys are: nickel, silicon, iron, and copper, worsening mechanical properties and corrosion resistance.

Magnesium alloys, just as aluminum, are subdivided into deformable and foundry types.

§ 3. Deformable Magnesium Alloys

Plasticity of magnesium alloys at ordinary temperature is lower than that of aluminum alloys; therefore they are not used for manufacture of parts by means of cold pressure treatment.

With increase of temperature, plasticity of magnesium alloys is increased somewhat, which permits producing pressure treatment of them at 300-400°C. For increase of plasticity, before being forged or pressed, magnesium alloys are held at 350°C for 18-24 hours. Hot working considerably increases strength and plasticity of magnesium alloys.

Deformable magnesium alloys are applied mainly in the form of stamping, secondly in the form of pressed semifinished products, and less often in the form of sheets.

Table 48. Chemical Composition and Mechanical Properties of Deformable Magnesium Alloys

Grade of alloy	Al	Chemical composition in %			State of alloy	Mechanical properties (not less than)		
		Zn	Mn	Other elements		σ_B MN/m^2	δ %	HB MN/m^2
MA1	—	—	1,3—2,5	—	Without heat treatment	210	8	450
MA8	—	—	1,5—2,5	Ce 0,5—0,35	Annealed	280	18	500
BM65-2	—	3,0—4,0	—	Zr 0,3—0,9	Annealed	270	18	—
MA2	3,0—4,0	0,2—0,8	0,15—0,5	—	Without heat treatment	250	5	450
MA3	5,5—7,0	0,5—1,5	0,15—0,5	—	Annealed	280	8	500
MA5	7,8—9,2	0,2—0,8	0,15—0,5	—	Quenched	340	12	650
BM65-1	—	5,0—6,0	—	Zr 0,3—0,9	Quenched and artificially aged	320	7	—
BM17	0,2	0,2	1,4—1,2	Zr 2,5—3,5	Without heat treatment	230	5	500

Magnesium alloys are less numerous than aluminum. For manufacture of loaded parts by drop forging are applied alloys of grades MA2, MA3, MA5, [VM65-1] (BM65-1), and VM17. Alloys of grades MA1, MA8, and VM65-2 are applied most frequently as sheet material.

With proper protection from corrosion magnesium alloys are widely applied in aviation constructions working under usual atmospheric conditions.

In Table 48 are given chemical composition and mechanical properties of deformable magnesium alloys.

Alloy MA1 possesses the greatest corrosion resistance and best weldability of all magnesium alloys. It has high plasticity in hot state. Alloy is processed by pressure at temperatures of 300-350°C. Alloy is not strengthened by heat treatment. For removal of work hardening is produced annealing at 300-360°C. Alloy welds well by gas, argon-arc, and spot welding and machines excellently.

Alloy MA1 is used for manufacture of lightly-loaded and welded parts: hoods, cowls, and fittings for fuel and oil systems. It is supplied in the form of sheets and rods, and less often as profiles and forgings.

Alloy MA8, owing to additional content of cerium, possesses greater strength and plasticity than alloy MA1. For improvement of mechanical properties it is subjected to annealing at 240-300°C, after which its structure consists of solid solution and inclusions of Mn (Fig. 16.1a). In other respects this alloy is like alloy MA1.

Alloy MA8 is designed for manufacture of medium-loaded elements of constructions of contemporary aircraft: cowls, rudder fins of aircraft, sheathing of helicopters, internal parts and fittings for fuel and oil systems.

It is supplied in the form of sheets, plates, tapes, profiles, and rods.

Recently alloys MA1 and MA8 have gradually been replaced by alloy VM65-2, which possesses somewhat lower strength than alloy MA8 but considerably exceeds it in plasticity in hot state.

Forging MA2 possesses satisfactory corrosion resistance and high plasticity in hot state. It is processed by pressure at temperatures of 375-400°C.

Alloy is not strengthened by heat treatment. Alloy MA2 welds well by argon-arc welding and machines excellently.

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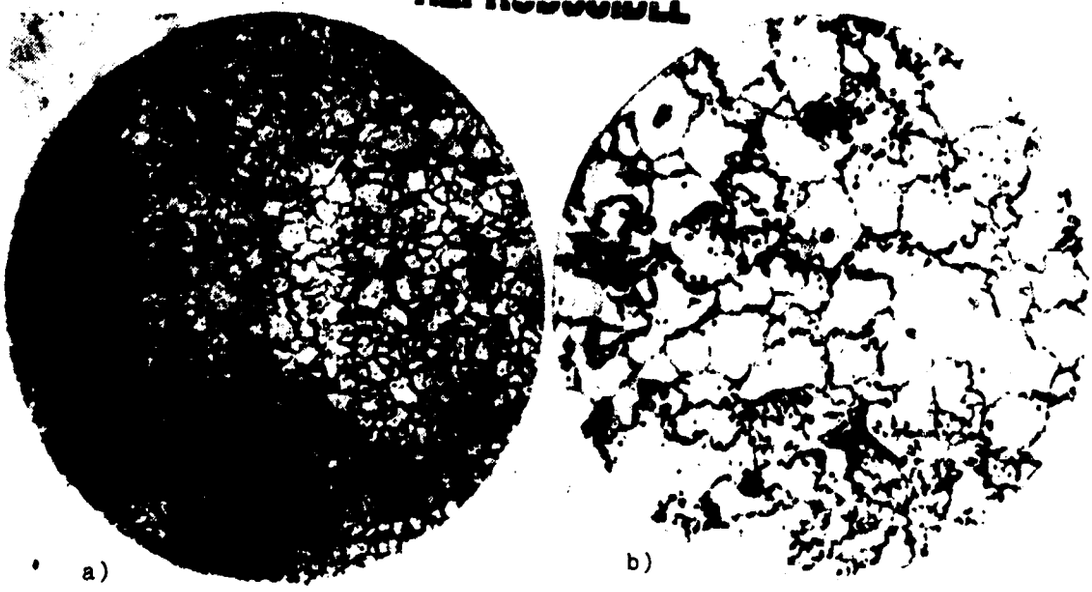


Fig. 16.1. Microstructure of deformable magnesium alloys. a) alloy MA8. ×300; b) alloy VM65-1. ×400.

Alloy MA2 is used for manufacture medium-loaded forged and stamped parts of complicated form: levers, brackets, bodies of assemblies, and other parts. It is supplied in the form of pressed semifinished products of forgings and stampings.

Variety of alloy MA2, alloy MA2-1, differs somewhat by large content of aluminum, zinc, and manganese. It possesses greater strength, which permits using it for manufacture of loaded parts of helicopters: empennage, hatches, doors, and also for internal parts of aircraft.

Forging alloy MA3 possesses lowered corrosion resistance (is inclined to stress corrosion). It has high strength and satisfactory plasticity in hot state. Alloy MA3 is processed by pressure at temperatures of 250-340°C. Alloy is not strengthened by heat treatment. Annealing of forgings and stampings is produced at 320-400°C for 4-12 hours, with cooling in air. Alloy MA3 machines excellently; its weldability is lowered.

This alloy is designed for manufacture of loaded aircraft parts: rockers, brackets, engine mountings, and so forth. It is supplied in the form of pressed rods, forgings, and stampings.

Forging alloy MA5 possesses raised inclination to stress corrosion. It has raised strength and lowered plasticity in hot state. It is pressure processed at temperatures of 300-400°C. Alloy MA5 is subjected to strengthening by heat treatment consisting of quenching from 410-425°C in air. Alloys welds

satisfactorily and machines excellently.

Alloy MA5 finds limited application: it is designed for manufacture of loaded parts of simple form. It is supplied in the form of rods, forgings, and stampings.

High-strength alloy VM65-1 possesses satisfactory resistance of corrosion and good plasticity in hot state. It is processed by pressure at temperatures of 300-420°C. Alloy is strengthened by artificial aging at 160-170°C for 10 hours (pressed semifinished products), or for 24 hours (forging and stamping). Microstructure of alloy is presented in Fig. 16.1b. It consists of grains of solid solution and inclusions of metallic compound $MgZn_2$. Alloy possesses unsatisfactory weldability and excellent machinability.

Alloy VM65-1 is used widely for manufacture of loaded parts working at ordinary temperature: fuselage stringers, etc. It is supplied in the form of rods, profiles, and stampings.

Heat-resisting alloy VM17, developed recently, is not strengthened by heat treatment. Alloy possesses satisfactory corrosion resistance and good plasticity in hot state. It is processed by pressure at temperatures of 350-480°C.

Alloy VM17 is supplied in the form of pressed rods and is designed for manufacture of parts working at temperatures to 200°C. Stress-rupture strength of this alloy σ_{100} = 80 - 90 MN/m^2 (8 - 9 kgf/mm^2).

Heat-resisting alloys MA13 and [ML14] (МЛ14) possess good short-term and stress-rupture strength at temperatures higher than 250°C.

These are magnesium-thorium alloys alloyed with other elements; they were developed recently. Alloy MA13 is deformable, and alloy ML14 is of foundry type.

Alloy MA13 at a temperature of 350°C has stress-rupture strength σ_{100} = 30 MN/m^2 (3 kgf/mm^2). It is supplied in the form of sheets, which after being quenched at 550°C are strengthened by cold hardening and aging at 200°C for 16 hours. Alloy MA13 welds satisfactorily by argon-arc welding and is used for manufacture of parts of aviation constructions working continuously at temperatures to 350°C and briefly to 400°C.

§ 4. Magnesium Foundry Alloys

Magnesium foundry alloys as compared to aluminum alloys have the worse foundry qualities and greater oxidizability.

However, low specific gravity, good machinability, and sufficient mechanical properties are responsible for their application in aircraft construction as structural materials.

Basic grades of magnesium foundry alloys, ML4, ML5, and ML6, exceed in specific strength high-strength aluminum foundry alloys of grades [AL4] (АЛ4) and AL5.

Ready oxidizability of magnesium alloys and inclination of them to ignition in melted state make it necessary to apply protective means.

To prevent ignition of molten magnesium alloys, melt is kept under protective layer of fluxes, as which are applied chlorides and fluorides of magnesium.

During the pouring of magnesium alloys into forms, for prevention of ignition the forms are coated with sulfur.

Application of vacuum during production of magnesium foundry alloys permits obtaining alloys of higher quality.

In Table 49 are given chemical composition and mechanical properties of magnesium foundry alloys (samples separately poured in sand form).

Table 49. Chemical Composition and Mechanical Properties of Magnesium Foundry Alloys

Grade of alloy	Chemical composition in %				Form of heat treatment	Mechanical properties (not less than)		
	Al	Zn	Mn	Other elements		σ_b Mn/м²	δ %	HB Mn/м²
МЛ12	0,1	—	1,0—2,0	—	—	90	3,0	300
МЛ14	5,0—7,0	2,0—3,0	0,15—0,5	—	—	160	3,0	500
					T4	220	5,0	500
					T6	230	2,0	600
МЛ15	7,5—9,0	0,2—0,3	0,15—0,5	—	—	150	2,0	500
					T2	150	2,0	500
					T4	220	5,0	500
					T6	230	2,0	650
МЛ16	9,0—10,2	0,6—1,2	0,1—0,5	—	—	150	1,0	500
					T4	220	4,0	600
					T6	230	0,5	650
МЛ17-1	5,8—6,5	0,3—0,7	0,3—0,6	Ca 0,2—0,5	—	160	4,0	550
МЛ111	—	0,2—0,7	—	Rare-earth metals 2,5—4,0 Zr 0,2—0,8	T6	—	—	—
МЛ114	—	1,7—2,3	—	Th 2,8—3,8 Zr 0,5—1,0	T1	200	6,0	600

In distinction from deformable alloys magnesium foundry alloys have higher content of alloy elements, and thus lower plasticity.

Presence of eutectic component in their structure promotes improvement of their foundry properties. To foundry magnesium alloys to a larger degree than to

deformable alloys it is possible to apply strengthening heat treatment. Magnesium foundry alloys, having nonuniform structure, may be improved considerably by means of prolonged holding at a temperature near 400°C, with subsequent cooling in air.

Designations of conditions of heat treatment for magnesium foundry alloys are the same as for foundry aluminum.

To strengthening heat treatment are subjected magnesium alloys ML4, ML5, and ML6. Most frequently for them are applied conditions T4, as a result of which mechanical properties of castings are improved. Conditions T6 are applied rarely, since they are accompanied by strong decrease of plasticity.

Alloy ML2 (without heat treatment) is designed for manufacture of medium-loaded parts. Alloys of grades ML4, ML5, and ML6 are designed for manufacture of highly-loaded cast parts. Heat-resisting alloys ML7-1 and ML11, developed recently, are used for manufacture of medium-loaded parts heated during work to temperatures respectively of 200 and 300°C. Latest alloy, ML14, possesses still greater heat resistance.

All magnesium alloys are poured in sand forms with the exception of alloys ML5 and ML6, castings from which besides can be obtained in chill molds or by pressure method.

Conditions of heat treatment of magnesium foundry alloys applied in aircraft construction are given in Table 50.

Table 50. Conditions of Heat Treatment of Magnesium Foundry Alloys

Grade of alloy	Form of heat treatment	Quenching			Aging	
		Temperature of heating, °C	Holding during heating, hours	Cooling medium	Temperature of heating, °C	Holding during heating, hours
ML74	T4	380±5	8—16	Air	—	—
	T6	380±5	8—16	"	175±5	16
ML75	T4	420±5	16—24	"	—	—
	T6	420±5	16—24	"	175±5	16
ML76	T4	380±5	3	"	—	—
	T6	380±5	3	"	190±5	4—8
ML711	T6	570±5	18	"	205±5	16
ML714	T6	570±5	18	"	315±5	16

Alloy ML2 possesses higher corrosion resistance than other magnesium alloys. It has low mechanical and foundry properties. It is not strengthened by heat treatment. Alloy welds well and machines well. It is used for casting of parts

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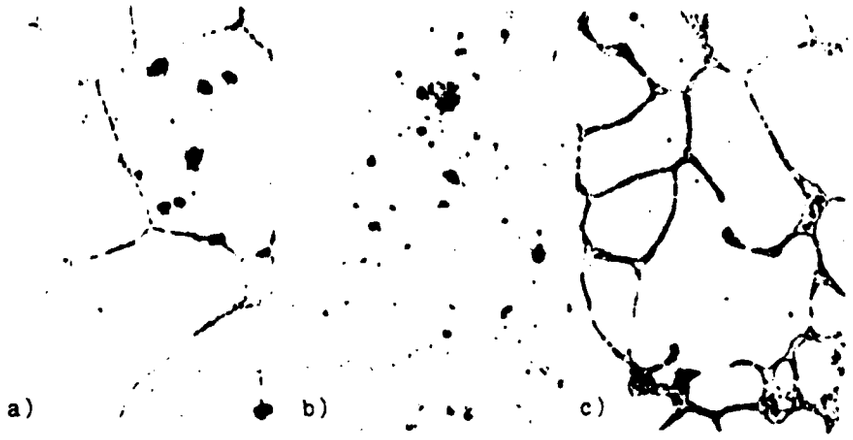


Fig. 16.2. Microstructure of magnesium foundry alloys. a) alloy ML5. ×250; b) alloy ML7-1. ×250; c) alloy ML11. ×200.

of simple configuration, for different fittings, and for parts of instruments requiring increased corrosion resistance.

Alloy ML4 possesses good corrosion resistance, high mechanical strength, and satisfactory foundry properties. Heat treatment of alloy is produced per conditions T4 and T6. It is used for casting of parts of engines and assemblies of simple form subjected to static and dynamic loads (housings of instruments, aircraft brake drums, and bodies of brakes).

Alloy ML5 has somewhat less corrosion resistance than alloy ML4 but better technological properties; it has high mechanical qualities after casting and strengthening heat treatment per conditions T4 and T6. Microstructure of alloy ML5 after treatment per conditions T4 is shown in Fig. 16.2a. It consists of grains of solid solution and inclusions of metallic compound Mg_4Al_3. Weldability of alloy is satisfactory, and machinability is excellent.

Alloy is applied for casting of vital parts highly-loaded and of complicated form for aircraft and engines, assemblies, and instruments: brake drums, blocks, steering wheels, rockers, pedals, brackets, and other parts.

Alloy ML6 possesses somewhat less corrosion resistance than alloy ML5, high strength, and good foundry qualities. It is strengthened by heat treatment per conditions T4 and T6. Alloy welds satisfactorily and machines excellently. It is used for casting highly- and medium-loaded parts when raised yield point is required: bodies and parts of instruments and equipment.

In Table 51 are given mechanical properties of heat-resisting magnesium alloys at raised temperatures after casting in earth (for separate samples).

Table 51. Mechanical Properties of Heat-Resisting Magnesium Foundry Alloys at Raised Temperatures

Grade of alloy	Temperature, °C	$\sigma_в$ kg/mm²	$\sigma_{0.2/100}$ kg/mm²	σ_{100} kg/mm²
ML7-1	150	160	55	90
	200	120	25	55
	300	80	—	—
ML11	200	130	55	110
	250	—	25	65
	300	110	7	30
ML14	300	80	—	65
	400	70	—	28

At temperatures of 150°C and above alloy ML7-1 exceeds all considered magnesium foundry alloys in creep and rupture strength. Alloys ML11 and ML14 are more heat-resisting than alloy ML7-1.

Alloy ML7-1 possesses satisfactory corrosion resistance, satisfactory foundry properties, medium strength, and raised heat resistance. It is not strengthened by heat treatment. For removal of internal stresses, after casting it is recommended that annealing be done at 325°C for 3-5 hours. Alloy welds badly and machines excellently. It is intended for manufacture of cast medium-loaded engine parts working at temperatures to 200°C, for instance, different parts of compressor bodies. In Fig. 16.2b is shown microstructure foundry magnesium alloy ML7-1.

Alloy ML11 possesses satisfactory corrosion resistance, satisfactory foundry properties, sufficient strength, and raised heat resistance. It can be subjected to heat treatment per conditions T6. However, here, with increase of ultimate strength heat resistance drops. Annealing for removal of internal stresses is produced at 325°C for 3 hours. Alloy welds satisfactorily and machines excellently. It is intended for manufacture of cast medium-loaded parts working continuously at temperatures to 300°C and briefly to 400°C. In Fig. 16.2 is presented microstructure of magnesium alloy ML11.

Alloy ML14 in foundry properties is analogous to alloy ML11 but substantially exceeds it in heat resistance. It can be subjected to heat treatment per conditions T6, which somewhat lowers its heat resistance. Alloy welds satisfactorily by argon-arc welding. It is intended for manufacture of cast parts working continuously at temperatures to 350°C and briefly to 400°C.

C H A P T E R XVII

TITANIUM AND ITS ALLOYS

§ 1. Properties of Titanium

Titanium is a promising new structural material, application of which in aviation industry continues to be increased. This is explained by the fact that titanium and its alloys possess low specific gravity, high mechanical properties at raised temperatures, and high corrosion resistance.

Titanium has silvery-white color, low specific gravity of 45 kN/m^2 (4.5 gf/cm^3), and high melting point of 1720°C.

Titanium has two allotropic modifications: to 882°C α-titanium, having hexagonal lattice; and at higher temperatures β-titanium, with body-centered cubic lattice.

Titanium and its alloys possess high corrosion resistance in various media, not inferior to that of stainless chrome-nickel steels. This is explained by good protective properties of oxidized film formed on its surface.

Titanium resists oxidation to 400-500°C in ordinary atmosphere, resists sea water and solutions of acids, alkalis, and salts.

However, high chemical activity of titanium in strong degree complicates production and appreciates its cost, necessitating that melting and treatment of titanium by produced in vacuum furnaces or furnaces with neutral gases.

Titanium actively interacts with oxygen, nitrogen, and carbon, forming stable compounds with them, which in considerable degree worsen its properties.

Main problem of metallurgy of titanium is avoidance of these harmful impurities, which make the metal brittle and hamper processes of its treatment.

At the same time oxygen, nitrogen, and carbon considerably increase strength of titanium. Therefore in small quantities (in sum not exceeding 0.2-0.3%), while satisfactory productibility is kept, they can be considered alloy elements.

Presence of hydrogen has especially negative effect, lowering impact toughness. With hydrogen content over 0.015% all semifinished titanium products are subjected to annealing in vacuum for several hours for decrease of content of hydrogen to minimum (0.003-0.005%).

For sponge titanium content of impurities in it must not exceed the following magnitudes:

Fe – 0.3%; Si – 0.15%; C – 0.06%; N_2 – 0.05%; O_2 – 0.2%; H_2 – 0.01%.

Mechanical properties of commercial titanium and titanium of high purity are the following:

Mechanical properties	99.6% Ti	99.9% Ti
Ultimate strength σ_B in MN/m^2.....	500-560	300
Yield point $\sigma_{0.2}$ in MN/m^2.....	450-500	190
Specific elongation δ in %.....	25-40	40
Transverse narrowing ψ in %.....	55	61
Brinell hardness HB in MN/m^2.....	1850-2000	1100-1200
Impact toughness a_H in MJ/m^2.....	1.7	-
Modulus of normal elasticity E in MN/m^2..	115,000	-

From given data one may see that mechanical properties of titanium depend on degree of its purification from inevitable impurities.

With considerable characteristics of strength titanium possesses high plasticity and toughness. However, low resistance to elastic deformation limits its application for highly-loaded elements of aviation constructions. Increase of modulus of normal elasticity of titanium is produced by means of its alloying.

During heating occurs considerable change of mechanical properties of titanium (Fig. 17.1). At raised temperatures titanium is weakened, but its properties are sufficiently high and exceed those of aluminum and magnesium alloys. Pure titanium can be applied at temperatures of not more than 350-370°C, at which other light alloys become absolutely unfit.

Titanium is subjected to all forms of hot and cold pressure treatment. As it was shown, workability of titanium in strong degree depends on its content of

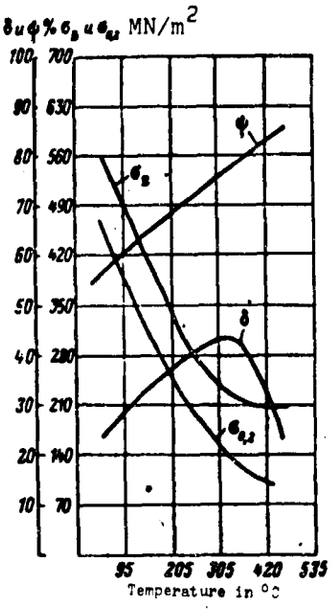


Fig. 17.1. Influence of temperature on properties of titanium.

harmful impurities of oxygen, nitrogen, and hydrogen. In process of cold pressure treatment titanium is easily work hardened, which increase its yield point with preservation of satisfactory values of plasticity and toughness. Annealing is produced in electrical hot-air furnaces 525 ± 5°C, holding for 1 hour, and cooling in air.

Titanium possesses good weldability by argon-arc, point, roller and seam methods. As compared to steel, titanium has lowered machinability, which in considerable degree depends on its carbon content. With carbon content over 0.2% are formed hard carbides, greatly hampering machinability.

High chemical activity of titanium forces us to take special measures of precaution during its treatment, storage, and transportation.

Native industry releases 4 grades of sponge titanium, differing from each other in content of impurities. Titanium of grade [TG00] (ТГ00) is designed for scientific investigations and grades TG0, TG1, and TG2 are intended for production of titanium alloys.

§ 2. General Information About Titanium Alloys

In specific strength titanium alloys differ profitably from alloy steels and aluminum alloys.

In heat resistance titanium and its alloys occupy central place between aluminum alloys and steel. Heat resistance of titanium alloys permits us to apply them in aviation constructions working at temperatures of 350-500°C.

As alloy elements in titanium alloys are used Al, Cr, Fe, Mn, Mo, V, Sn, and Zr. These elements are either dissolved in titanium or form metallic compounds with it. Alloying of titanium leads to considerable increase of strength but simultaneously is accompanied by lowering of its plasticity.

The most important alloy element is aluminum, found in almost all titanium alloys. It increases strength and heat resistance and gives it weldability.

Chromium, manganese, and iron promote increase of strength of alloys with preservation of good plasticity. However, during prolonged work under stress at temperatures higher than 400°C in alloys containing these elements; owing to disintegration of solid solutions, embrittlement is observed.

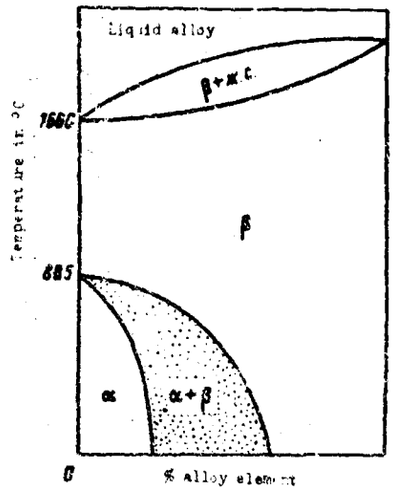
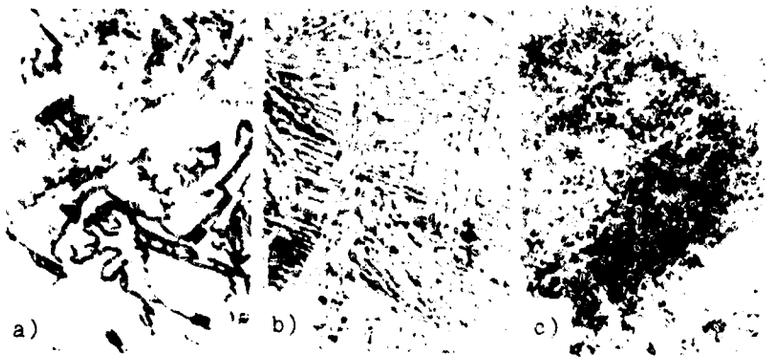


Fig. 17.2. Constitution diagram of titanium alloys.

Molybdenum and vanadium increase strength, stabilize structure, and remove danger of appearance of brittleness of titanium alloys.

In structure titanium alloys can be divided into the following groups (Fig. 17.2).

1. Single-phase alloys having structure of α-titanium. These include alloys of titanium with Al, Sn, O_2, N_2, and C, increasing temperature of allotropic transformation and increasing stability of α-phase. Example of alloy of this group is alloy [VT5] (BT5), microstructure of which is presented in Fig. 17.3a. These alloys preserve sufficient strength to 650°C, after heat treatment do not become brittle, and possess good weldability. However, alloys of this type, owing to low plasticity, require application of high pressure during treatment by deformation.



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Fig. 17.3. Microstructures of titanium alloys. a) alloy VT5. ×200; b) alloy VT6. ×300; c) alloy VT3. ×100.

2. Single-phase alloys having structure of β-titanium. These include alloys of titanium with Mn, Fe, Cr, Mo, and V, lowering temperature of allotropic transformation and increasing stability of β-phase. These alloys preserve their strength to 540°C, possess high plasticity, and do not need heat treatment for hardening.

However, alloys of this type have so far not been applied, owing to high content of scarce alloy elements and great sensitivity to contaminations in process of production.

3. Two-phase alloys, in structure of which are crystals of α- and β-phase. To these alloys belongs the majority of applied alloys of titanium. They contain from 3 to 6% aluminum and from 3 to 9% elements stabilizing β-phase.

Example of alloy of this group is alloy VT6, microstructure of which is presented in Fig. 17.3b. Alloys of this type possess high strength at room temperature and good plasticity. They are subjected to heat treatment. However, when control is insufficient, there can be observed brittleness of alloy. Essential deficiency of these alloys is that their strength is preserved only to 430°C.

Industrial alloys of titanium usually contain several alloy elements, with inevitable presence of constant impurities.

As it was shown, alloying is sufficiently effective means of increasing mechanical properties of titanium. Thus certain titanium alloys possess high strength with sufficient plasticity in annealed state also.

For many titanium alloys a further means of increasing strength is heat treatment consisting of quenching from 700-950°C in water and artificial aging at 480-550°C. Aging at a temperature lower than 430°C is impermissible, since it leads to sharp increase of brittleness. By changing quench and aging temperatures it is possible to change properties of titanium alloys within wide limits.

Titanium and its alloys are characterized by low antifriction properties and inclination to sticking on friction surface. Increase of wear resistance is attained by application of chemical-heat treatment, in particular carburizing and nitriding.

Titanium alloys yield to welding, soldering, machining and pressure treatment in cold and hot states. However, certain properties of titanium give these technological operations specific peculiarities, hampering them. Thus, inclination of molten titanium to absorb nitrogen and oxygen from the atmosphere hampers the obtaining of high-quality welded seam. Inclination to cold welding with surfaces of friction hampers machinability, owing to intense adherance of titanium to cutting edges of tool, etc.

Problem of obtaining shaped castings from titanium and its alloys on

industrial scales is still unsolved. So far wide application has been found only for deformable titanium alloys, from which are produced forgings, rods, pipe, wire, tape, sheets, plate, and shaped profiles.

§ 3. Deformable Titanium Alloys

At present titanium and its alloys are used mainly in aviation constructions, where from them are prepared various engine parts (alloys VT3, VT3-1, VT5, and VT6) and bodies of aircraft and vehicles with supersonic speeds (alloys VT1, VT4, OT4, VT5, and VT6).

In Table 52 are given composition and mechanical properties of commercial titanium.

Table 52. Chemical Composition and Properties of Commercial Titanium

Grade of titanium	Impurities in % (not more than)	Mechanical properties (not less than)		
		$\sigma_в$ MN/m^2	δ %	*HB* MN/m^2
BT1-1 BT1-2	0,1C; 0,15O_2; 0,04N_2; 0,3Fe 0,15Si; 0,015H_2	450—600 550—750	20—30 15—25	500 450

Alloy VT1 – technically pure titanium with small quantity of impurities, possesses high corrosion resistance, plasticity high in hot state and satisfactory in cold; it welds well by argon-arc and resistance welding. Alloy VT1 is used for manufacture of parts of aircraft working at temperatures to 350°C: sheathings, fuselage frames, longerons, and other parts. It is supplied in the form of sheets, rods, and wire. In Table 53 are given chemical composition and mechanical properties of deformable titanium alloys, and in Table 54 are given mechanical properties of certain titanium alloys at raised temperatures.

Alloy VT3 possesses high corrosion resistance and great strength, and also plasticity allowing treatment by method of hot deformation at 850-1050°C. After forging or stamping for removal of work hardening and levelling of properties through cross section, alloy is annealed at 700-800°C. Microstructure of alloy is shown in Fig. 17.3c. Alloy is applied for manufacture of engine parts working at temperatures to 350°C (at higher temperature appearance of brittleness is observed). It is supplied in the form of rods, stampings, and forgings.

Table 53. Chemical Composition and Mechanical Properties of Deformable Titanium Alloys

Grade of alloy	Chemical composition in % (Ti base)					Mechanical properties in annealed or hot-rolled states		
	Al	Mn	Cr	Mo	Other elements	σ_B MN/m^2	δ %	HB MN/m^2
BT3	4,0—6,2	—	2,0—3,0	—	—	950—1150	10—16	250—400
BT3-1	4,0—6,2	—	1,5—2,5	1,0—2,8	—	950—1150	10—16	250—400
BT4	4,0—5,0	1,0—2,0	—	—	—	800—900	15—22	200—300
OT4	2,0—3,5	1,0—2,0	—	—	—	700—900	15—40	250—550
OT4-1	1,0—2,5	0,8—2,0	—	—	—	700—850	15—40	250—550
BT5	4,0—5,5	—	—	—	—	800—950	12—25	300—450
BT5-1	4,0—5,5	—	—	—	Sn 2,0—3,0	800—950	12—25	300—450
BT6	5,0—6,5	—	—	—	V 3.5—4,5	900—1000	8—13	300—450
BT8	5,8—6,8	—	—	2,8—3,8	—	1050—1180	9—15	300—550

Variety of alloy VT3 – alloy VT3-1 – possesses higher heat resistance than VT3. It additionally contains 1-2% Mo, stabilizing its structure. From alloy VT3-1 are prepared disks and blades for turbine compressors working at temperatures to 450-500°C.

Alloy VT4 possesses high corrosion resistance, good plasticity, and high heat resistance. It is not strengthened by heat treatment. It has satisfactory weldability. Alloy VT4 is supplied only in the form of semifinished sheet products used for manufacture of parts and elements of structures working at temperatures to 400°C.

Alloys OT4 and OT4-1 are varieties of alloy VT4. They have still higher technological plasticity due to decrease of aluminum content. They possess greater heat resistance than alloy VT4. These alloys are not inclined to brittleness, which permits applying them for manufacture of welded and stamped parts working at temperatures to 500°C.

Alloy VT5 possesses high yield point and lowered technological plasticity, which hampers the obtaining of parts of complicated form. Temperature of hot forging and stamping is 1000-1150°C. It has excellent weldability of argon-arc and resistance methods. Alloy VT5-1 contains additionally 2-3% tin for guarantee

Table 54. Mechanical Properties of Titanium Alloys at Raised Temperatures

Grade of alloy	Form of semifinished product and state of material	Temperature, °C	σ_B MN/m^2	$\sigma_{0,2/100}$ MN/m^2	σ_{100} MN/m^2
BT1	Rods, annealed	350	700—750	140	—
BT3	Rods, annealed	400	680	290	560
		500	600	—	350
BT3-1	Rods, heat treated	400	600	300	660
		500	560	50	360
BT4	Sheets, annealed	250	620	—	—
		350	560	—	—
OT4	Sheets, annealed	350	435	—	—
		500	390	—	—
BT5	Sheets, annealed	300	580	140	560
		400	520	110	480
BT6	Rods, annealed	400	570—600	360	600
		500	500	55	210
BT8	Rods, annealed	400	750	370	750
		500	720	120	500

working to 400°C: sheathing and elements of frame, compressor bodies guide vanes of compressor, and others.

Alloy VT6 possesses raised heat resistance, good plasticity, allowing in hot state forging and stamping at temperatures of 950-980°C. After it is produced levelling annealing at 700-800°C.

Alloy VT6 is subjected to strengthening by heat treatment consisting of hardening and aging at 450-850°C. It welds satisfactorily and is machinable. It has stability of properties under stress to temperatures of 400-650°C. It is designed for manufacture of fasteners, sheathing, and other elements of structures working at temperatures to 400-450°C. It is supplied in the form of rods, stampings, and sheets.

Alloy VT8 possesses raised heat resistance as compared to other titanium alloys. It is deformed well in hot state at temperatures of 850-1100°C. Alloy welds well by resistance welding and machines satisfactorily. It is designed for manufacture of forged and stamped parts working at temperatures to 500°C. It is supplied in the form of rods, forgings, and stampings.

C H A P T E R XVIII

COPPER AND ITS ALLOYS

§ 1. Properties of Copper

Copper is a metal of pinkish-red color, high specific gravity of 89 kN/m^3 (or 8.9 gf/cm^3), and melting point of 1083°C.

Copper has high electrical and thermal conductivity, which explain its wide application in electrical engineering. Crystal lattice of copper is cubic with centered edges. Microstructure of copper with characteristic twins is presented in Fig. 18.1.

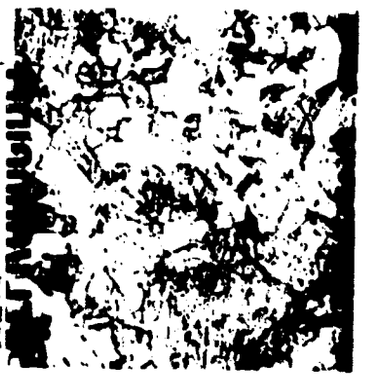


Fig. 18.1. Microstructure of copper. ×100.

Copper possesses resistance to atmospheric corrosion, but when heated it is subject to strong oxidation. Copper is resistant to action of acids and alkalis.

Copper has bad foundry qualities, since during hardening earlier dissolved gases are liberated, which imparts porosity to castings.

Copper is distinguished by high plasticity: it deforms well in hot (at 750-800°C) and in cold states, with intermediate annealing at 600°C. Annealing of copper is necessary for removal of work hardening obtained during cold pressure treatment.

Copper pipelines on aircraft are work hardened under action of vibration, which leads to increase of their brittleness and decrease of corrosion resistance. Annealing of copper pipelines, removing work hardening, restores toughness, plasticity, and corrosion resistance. Annealing is produced at a temperature of

600°C, with subsequent cooling in water.

Mechanical properties of copper depend on preliminary treatment. Thus, annealed copper has σ_B = 200-250 MN/m^2 (20-25 kgf/mm^2); δ = 40-45%. After work hardening mechanical properties of copper are changed: σ_B = 400 MN/m^2 (40 kgf/mm^2); δ = 5%.

Native industry releases 5 grades of copper (M0, M1, M2, M3, and M4), which differ by content of impurities (from 0.05% to 1%). Impurities in copper - bismuth, antimony, arsenic, sulfur, and phosphorus - lower plasticity and worsen by electrical conductivity.

Copper M0 is intended for manufacture of electrical wires and alloys of high purity. Copper M1, M2, and M3 in the form of sheets, tapes, bands, pipes, and wire is used for manufacture of electric wires, oil lines, gaskets, sealing rings, washers, and also for manufacture of deformable alloys. From copper M4 are prepared foundry bronzes and nonvital alloys.

In aircraft construction copper is applied basically in the form of different conductors and articles for instruments. In aviation industry of large value are copper alloys of brass and bronze type and also copper - nickel alloys.

§ 2. Brasses

Brasses are alloys of copper and zinc. They are the most widespread alloys on copper base, which is explained by their good complex of properties. Brasses possess following properties: high strength, especially after work hardening; good plasticity in annealed state; high corrosion resistance, exceeding that of copper. Brasses are distinguished by good technological qualities: cast well, are pressure workable, machinable, and weldable.

Brasses containing up to 10% zinc are called tombac, and those containing from 10 to 20% zinc are called semitombac. Aviation brasses contain up to 45% zinc.

In Fig. 18.2 is shown change of mechanical properties of brass depending upon zinc content. The greatest plasticity is displayed by brass containing 30-32% zinc, and the highest strength belongs to those containing 42-46% zinc. With larger content of zinc strength and plasticity of brass drop sharply.

Change of properties of brass with various contents of zinc is explained by change of its structure. In Fig. 18.3 is shown part of constitutional diagram of

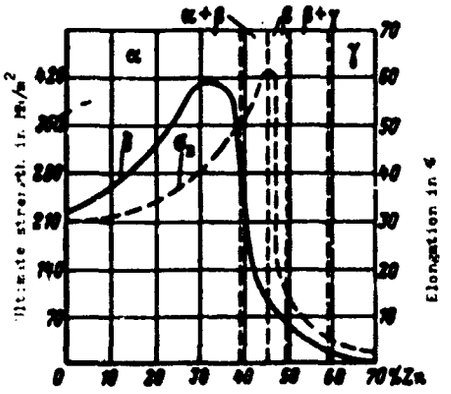


Fig. 18.2. Dependence of mechanical properties of brass on zinc content.

copper – zinc alloys. During hardening of copper – zinc alloys several solid solutions are formed: α, β, γ, etc., differing from each other by varied crystal lattices, and this means properties. The widest technical application is found for α-brass, containing to 39% zinc and α + β-brass, containing from 39 to 45% zinc.

α-brass possesses high plasticity, allowing pressure treatment in cold state. After cold deformation, for restoration of plasticity of work hardened brass recrystallizational annealing is applied at a temperature of 600-700°C, with cooling in air.

α + β-brass possesses high hardness and lower plasticity. They allow only hot pressure treatment, which is produced at a temperature of 750-850°C.

In Fig. 18.4 are shown microstructures of α and α + β-brasses.

For improvement of corrosion resistance of mechanical and technological properties brasses are alloyed with aluminum, nickel, manganese, tin, lead, and other elements. Such brasses are called special.

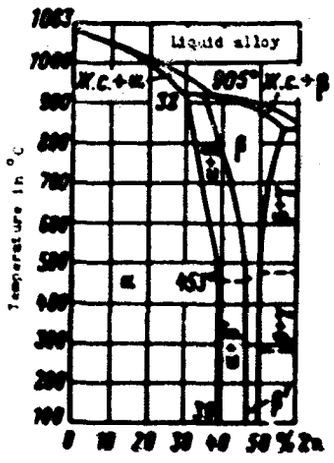


Fig. 18.3. Part of copper – zinc constitutional diagram.

Aluminum, tin, nickel, and manganese increase strength and corrosion resistance; silicon increases strength and foundry properties; lead improves machinability, etc.

Majority of brasses are subject to corrosion cracking, which is observed most frequently in work-hardened thin-walled stamped articles during joint action of internal stresses and external corrosive medium. For prevention of corrosion cracking brass is annealed after work hardening at 300°C for one hour.

Brass are designated by letter L. If brass is special, there follows letter designation of basic alloy elements in order of their decreasing [percentage]. After letter designation stand figure indicating content of copper and other alloy

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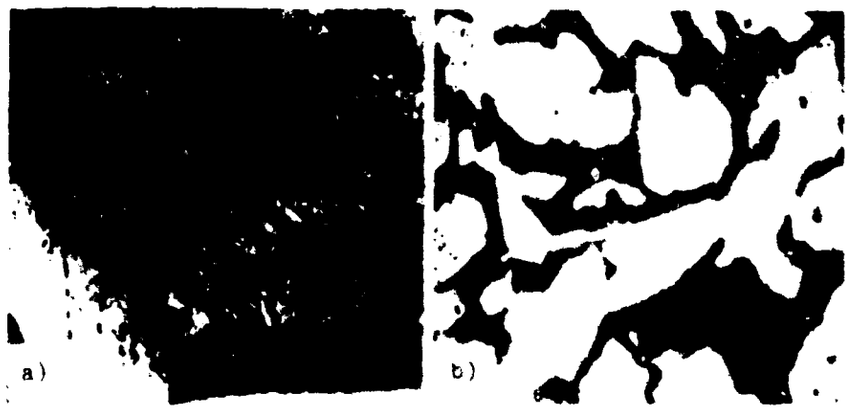


Fig. 18.4. Microstructure of brass. a) brass L62, α-solution; b) brass of LS59-1, α-solution (light) and β-solution (dark). ×250.

elements. For instance, L62 designates ordinary brass with 62% copper; [LS59-1] (ЛС59-1) denotes plumbous brass, containing 59% copper, 1% lead, and remainder zinc.

We distinguish deformable and foundry brasses. Brasses processed by pressure are supplied in the form of sheets, bands, tapes, pipes, wire, and other semifinished products. Pressure treatment can be produced in cold (for α-brasses) or hot (for α + β-brasses) states. Foundry brasses are applied in aircraft construction less often and usually are used as substitutes of stannous bronzes. Casting of brasses is produced in earth, in chill molds, or under pressure.

In Table 5a are given chemical composition and mechanical properties of deformable brasses; in Table 5b the same are given for foundry brasses.

Let us consider characteristics of basic grades of brasses applied in aviation industry.

Tombak L90 possesses high corrosion resistance (is not subject to corrosion cracking). It has high plasticity, allowing treatment by pressure in hot and cold states, good foundry and mechanical properties. It is designed for manufacture of pipelines and for radiator and condenser tubes.

Semitombak L85 is well suited to pressure treatment in hot and cold states, has good foundry and mechanical properties, and is designed for manufacture of filter screens and bellows of pressure regulators.

Brass L68 and L62 possess good resistance to corrosion, but they are subject to corrosion cracking. They are plastic, allowing pressure treatment in hot and cold states. They are designed for manufacture of parts by deep stamping and

Table 55. Chemical Composition and Mechanical Properties of Deformable Brasses

Grade of brass	Chemical composition in %						Mechanical properties (not less than)					
							σ_b MN/m²		δ %		HB MN/m²	
	Cu	Al	Fe	Mn	Zn	Other elements	soft	hard	soft	hard	soft	hard
Л96	95—97	—	—	—	Remainder	—	240	450	50	2	590	1370
Л90	89—91	—	—	—	"	—	320	640	52	5	530	1450
Л68	67—70	—	—	—	"	—	320	660	55	3	—	1500
Л62	60—63	—	—	—	"	—	330	600	49	3	560	1640
ЛС59-1	58—61	—	—	—	"	Pb 0,6—1,0	400	650	45	16	900	1400
ЛО62-1	61—63	—	—	—	"	Sn 0,7—1,1	400	700	40	4	—	—
ЛА77-2	76—79	1,7—2,5	—	—	"	—	400	650	55	12	600	1700
ЛМц58-2	57—60	—	—	1—2	"	—	400	700	40	10	850	1750
ЛЖМц59-1-1	57—60	—	0,6—1,2	0,5—0,8	"	Sn 0,3—0,7	450	700	50	10	880	1600

Note: Soft – annealed at 600°C; hard – deformable by 50%; for brasses LS59-1 and L062-1 degree of deformation is equal to 25%

Table 56. Chemical Composition and Mechanical Properties of Foundry Brasses

Grade of brass	Chemical composition in %						Mechanical properties (not less than)		
	Cu	Al	Fe	Mn	Zn	Other elements	σ_b MN/m²	δ %	HB MN/m²
ЛА67-2,5	66—68	2,0—3,0	—	—	Remainder	—	300—400	12—15	900
ЛК80-3Л	79—81	—	—	—	"	Si 2,5—4,5	250—300	10—15	950—1100
ЛМцЖ52-4-1	50—55	—	0,5—1,5	4—5	"	—	500	15—22	1000—1400
ЛАЖ60-1-1Л	58—61	0,7—1,5	0,7—1,5	—	"	—	380—420	15—18	900

drawing: pipelines, gaskets, washers, rings, rivets, and screens.

Brass L359-1 is processed well by pressure in hot state and machines excellently; it has good foundry qualities. It is designed for manufacture of parts by drop forging with subsequent machining (bushings, nuts, rings, cocks, fittings, screws, and other parts of special equipment and instruments).

Brass [L062-1] (Л062-1) possesses raised corrosion resistance in sea water, has satisfactory plasticity, and machines well. Brass L062-1 is intended for manufacture of pipelines and other parts coming in contact with sea water or gasoline.

Special brasses of grades [LA77-2] (ЛА77-2), [LMts58-2] (ЛМц58-2), [LZhMts59-1-1] (ЛЖМц59-1-1), alloyed with Al, Mn, and Fe, possess high strength. These brasses are designed for manufacture of parts of fittings and instruments and also for nonvital friction parts. Special brasses of grades LA67-2.5, [LK80-3L] (ЛК80-3Л), and [LAZh60-1-1L] (ЛАЖ60-1-1Л) possess high foundry properties and high strength. These alloys are designed for casting in earth or for precision casting of shaped parts of instruments and assemblies.

§ 3. Bronzes

Bronzes are alloys on copper base with additions of tin, aluminum, lead, silicon, and beryllium. Designation of bronze is determined by alloy elements contained in it. We distinguish stannous, aluminum, plumbous, siliceous, beryllium, etc., bronzes.

In certain bronzes for improvement of their properties we introduce additionally Zn, Pb, Ni, Mn, P and other elements. Thus in stannous bronzes zinc increases mechanical properties and fluidity, lead improves antifriction properties and machinability, and phosphorus increases antifriction properties and fluidity.

In aluminum bronzes iron and manganese improve mechanical properties and increase corrosion resistance. Nickel strongly improves mechanical qualities, imparts heat resistance and corrosion resistance.

Bronzes have literal-digital marking, indicating presence of some or other elements and their quantity. For instance, [BrAZhMts10-3-1.5] (БрАЖМц10-3-1.5) denotes bronze containing 10% Al, 3% Fe, 1.5% Mn, remainder Cu.

Basic components of bronzes have following letter designation: O – tin; Ts – zinc; F – phosphorus; B – beryllium; N – nickel; A – aluminum; Zh – iron;

[Mts] (Мц) – manganese; K – silicon.

Bronze possess high antifriction and mechanical properties, good corrosion resistance, high foundry properties, and good machinability. They are easily welded and soldered. Strengthening heat treatment is applied only to aluminum, beryllium, and siliceous bronzes.

We distinguish foundry and deformable bronzes. Majority of bronzes are used for casting friction parts, others being used to prepare corrosion-resistant part and fittings. Only certain bronzes possessing sufficient plasticity yield to pressure treatment. Wide application of bronzes is due to their antifriction properties and corrosion resistance.

Antifriction alloys are used for manufacture of friction parts, for decrease of friction, wear, and heating of friction surfaces. They are used for filling of sliding-contact bearings or manufacture of bushings.

On antifriction alloys are imposed the following special requirement: they have to possess low coefficient of friction, high thermal conductivity, and good run-in ability. During work under friction they should not themselves wear out and should not cause strong wear of shaft. Besides this, antifriction alloys have to possess low specific gravity and good technological qualities.

For satisfaction of so contradictory requirements antifriction alloys have to have heterogeneous structure, constituting soft plastic base in which small solid particles are evenly distributed (Fig. 18.5).

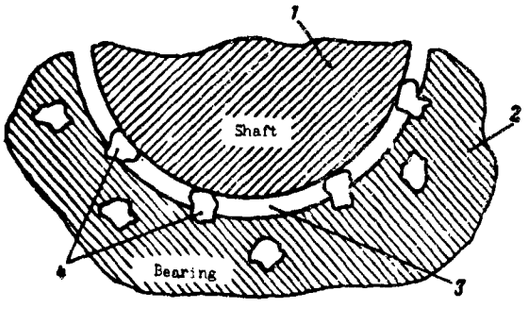


Fig. 18.5. Diagram of structure of antifriction alloy. 1 – shaft; 2 – soft base; 3 – space for lubricant; 4 – hard inclusions.

Solid particles serve to support shaft and decrease friction, and plastic base ensures run in. Besides this, soft base, being run in during friction, promotes

Table 57. Chemical Composition and Mechanical Properties of Bronzes

Grade of bronze	Chemical composition in %								State	Mechanical properties (not less than)		
	Sn	Pb	Ni	Al	Mn	Fe	Si	Other element		σ_b MN/m^2	δ %	*HB* MN/m^2
БрОФ7-0,2	6,0—8,0	—	—	—	—	—	—	P 0,1—0,25	Rods, annealed	370	55	700
БрОФ10-1	9,0—11,0	—	—	—	—	—	—	P 0,4—1,0	Cast in chill mold	250	3	900
БрОСН10-3-2	9,0—11,0	2,0—3,25	3,0—4,0	—	—	—	—	—	The same	250	5	750
БрАЖН10-4-4	—	—	3,5—5,5	9,5—11,0	—	3,5—5,5	—	—	"	600	5	1700
БрАЖМц10-3-1,5	—	—	—	9,0—11,0	1,0—2,0	2,0—4,0	—	—	"	500	20	120
БрБ2	—	—	—	—	—	—	—	Be 2,0—2,3	Pressed Pressed Annealed Hardened and tempered	550 600 1350	12 30 1	1100—1800 1000 1350
БрКН1-3	—	—	2,4—3,4	—	—	—	0,6—1,1	—	Hardened and tempered	600	20	1800
БрКМц3-1	—	—	—	—	1,0—1,5	—	2,7—3,5	—	Annealed. Work hardened.	380 750	45 2	1400 2000
БрС30	—	27—31	—	0,5	—	—	—	Sb 0,3	Cast in chill mold	60	4	250
БрОС5-25	4,0—6,0	23—27	2,0	—	—	—	—	—	The same	140	6	500
БрОС10-10	8,0—10,0	6,0—11,0	—	—	—	—	—	P 0,3	"	200	5	550

formation of tiny channels through which lubricant is distributed.

In Table 57 are given chemical composition and mechanical properties of bronzes applied in aircraft construction.

Stannous bronzes. These are alloys of copper with 2-14% tin, in which there usually, for improvement of properties, are introduced lead, nickel, and phosphorus. Addition of tin to copper strongly increases strength and hardness but lowers toughness and plasticity. Pressure treatment can be applied only to bronze containing not more than 6% tin.

Stannous bronzes possess good foundry and antifriction properties. Therefore they are applied for manufacture of cast shaped parts working under friction. Stannous bronzes have high corrosion resistance under atmospheric conditions and in water, they machine well, and are easily welded and soldered. Stannous bronzes are designed for manufacture of antifriction parts.

In Fig. 18.6a is depicted microstructure of cast stannous bronze, consisting of grains of solid solution and eutectoid.



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Fig. 18.6. Microstructure of bronzes. a) stannous BrOF 10-1. ×200; b) aluminum bronze BrAZhMts 10-3-1.5. X200; c) beryllium bronze BrB-2. ×250; d) plumbous bronze BrS30. ×250.

Tin-phosphorous bronze [BrOF7-0.2] (БрОФ7-0.2) possesses good pressure workability in hot state. It is subjected to annealing at 650°C. It is supplied in the form of drawn and pressed rods and is used for manufacture of friction parts working under medium loads and speeds of slip.

Tin-phosphorous bronze BrOF10-1 has excellent antifriction properties under conditions of high loads and speeds. It possesses good foundry properties. It is used for manufacture of different bushings, gears, dogs, flanges, spherical supports, and other parts.

Tin-lead-nickel bronze [BrOSN10-2-3] (БрОСН10-2-3) possesses good antifriction and anticorrosion properties. It is used for manufacture of support and guide bushings and for other parts of aircraft engines.

In view of high costs of stannous bronzes, bronzes in which tin is partially or completely replaced by other metals have been developed.

Aluminum bronzes. These are alloys of copper with 9-11% aluminum, containing additionally iron, nickel, and manganese for improvement of their properties; thanks to a series of valuable properties, they find wide application in aircraft construction.

Aluminum bronzes have high mechanical properties, possess raised heat resistance and corrosion resistance. Strengthening heat treatment consists of quenching from 850-900°C in water and subsequent tempering at 400-600°C for 1.5 hours. In Fig. 18.6b is shown microstructure of bronze BrAZhMts10-3-1.5, consisting of grains of α-solution (light) and (α + β)-eutectoid (dark).

Aluminum bronzes are well suited to pressure treatment, cast well, and weld and machine satisfactorily. These alloys are used for manufacture of antifriction parts working at raised temperatures. They are supplied in form of castings and in the form of rods, tapes, pipes, and bands.

Aluminum-iron-manganese bronze BrAZhMts10-3-1.5 possesses good plasticity, antifriction properties, and heat resistance. It is used for manufacture of antifriction parts working at low speed at increased temperatures: guide bushings, gears, castings and nuts of bearings, etc.

Aluminum-iron-nickel bronze [BrAZhN10-4-4] (БрАЖН10-4-4) possesses high mechanical properties, stability, and heat resistance. It is used for manufacture of responsible friction parts of engines working at temperatures to 600°C (oilsealing

rings, gears, different bushings).

Beryllium bronzes. These are alloys of copper with beryllium, containing 2-2.5% beryllium. In aircraft construction is applied beryllium bronze of grade [BrB2] (БрБ2). This bronze possesses high chemical resistance, wear resistance, and elasticity. After heat treatment consisting of quenching from 800°C in water and artificial aging at 350°C for 9 hours, beryllium bronze obtains high strength and hardness. In Fig. 18.6c is shown microstructure of beryllium bronze, consisting of grains of supersaturated solid solution.

Beryllium bronze welds well, machines well, and is suitable for hot pressure working.

Bronze is supplied in the form of bands, tapes, pipes, wire used for manufacture of specially responsible parts of aviation instruments and special equipment of aircraft: diaphragms, springs, spring contacts, and certain parts subject to abrasion.

High cost of beryllium limits application of beryllium bronzes and forces us to replace them by cheaper alloys.

Silicon bronzes. These are alloys of copper, containing 1-3% silicon and small quantity of nickel and manganese.

Silicon bronzes possess high elasticity and strength. They are distinguished by great corrosion resistance and antifriction properties. Silicon bronzes cast well and are processed by pressure in hot state. They weld and machine satisfactorily.

Silicon bronzes are strengthened by heat treatment or work hardening. They are supplied in the form of rods, tapes, bands, or wire.

Silicon bronzes are used as cheap substitute for stannous bronzes for manufacture of antifriction parts (bronze [BrKN1-3] (БрКН1-3)) or beryllium bronze for manufacture of springs and spring parts of radio equipment (bronze [BrKMts3-1] (БрКМц3-1)).

Plumbous bronzes. These are alloys of copper, containing up to 30% lead. They possess very high antifriction properties and are applied only for parts subject to friction.

Plumbous bronze [BrS-30] (БрС-30) is able to work at high specific pressures, has high fatigue limit and high thermal conductivity. It is used for filling of

highly-loaded sliding-contact bearings capable of work at temperatures to 350°C. However, in view of low strength of plumbous bronze, filling is done only on steel inserts. Plumbous bronze is insufficiently plastic, and it therefore is difficult to run in, which forces us to apply oil purified of mechanical impurities. Besides this, filling of bearings with plumbous bronze presents considerable difficulties owing to inclination of lead to liquation due to great difference in specific gravity of copper and lead. In Fig. 18.6d is shown microstructure of plumbous bronze, constituting grains of copper (light) and layers of lead (dark).

For improvement of run-in ability, into plumbous bronze we sometimes introduce up to 3% silver or plate surface with thin film of pure lead and indium.

Tin-plumbous bronzes [BrOS5-25] (BpOC5-25) and BrOS10-10. For increase of strength and wear-resistance of plumbous bronze, tin is added to it. However, antifriction properties are worsened somewhat here.

Bronzes BrOS5-25 and BrOS10-10 possess high corrosion resistance and machinability. They are used for castings of friction parts (bushings and bearings of aviation pumps and other units) working under high loads and at high speeds of rotation and coming in contact with different liquids.

§ 4. Copper-Nickel Alloys

Alloys of copper and nickel are divided into structural and electrical types. Structural copper-nickel alloys are distinguished by raised mechanical, anticorrosion, and heat-resisting properties, which permits applying them for manufacture of parts working at high temperatures and in corrosively active media.

Alloys containing up to 68.5% Ni are nonmagnetic at room temperature. Alloys containing 40-50% Ni possess the highest specific electrical resistance, thermoelectromotive force, and minimum temperature coefficient of electrical resistance.

Copper-nickel alloys are quite plastic and are processed satisfactorily by pressure in hot and cold states. They are prepared in the form of tapes, rods, and wire.

Chemical composition and mechanical properties of the most important copper-nickel alloys applied in aircraft construction are given in Table 58.

Cupronickel [MN19] (MH19) possesses high corrosion resistance under atmospheric

Table 58. Chemical Composition and Mechanical Properties of Copper-Nickel Alloys

Name of alloy	Grade of alloy	Chemical composition in %				Mechanical properties		
		Ni+Co	Cu	Other elements	Sum of impurities	σ_B MN/m^2	δ %	HB MN/m^2
German silver	MH19	18,0—20,0	Base	—	1,5	300—800	2,5—35	700—1280
Nickel silver	MNTs15-20	13,5—16,5	Base	Zn 18,0—22,0	0,9	350—800	1—35	700—1750
Monel	NMZhMu 28-2,5-1,5	65,4—69,2	27,0—29,0	Mn 1,2—1,8 Fe 2,0—3,0	0,6	450—700	1—30	700—1800

conditions and at raised temperatures. German silver is processed well by pressing, rolling, and drawing in hot and in cold states. It is supplied in the form of tapes, sheets, and wire.

This alloy is applied as corrosion-resistant material useful for work in vapor, fresh and sea water, media and also at raised temperatures for parts of precision instruments, for screens, and for chemically resistant parts working under severe conditions – raised pressure and temperature – where copper and brass tubes are inapplicable.

Argentan [MNTs15-20] (MNTs15-20) constitutes ternary alloy of copper, nickel, and zinc. It is externally beautiful, has high corrosion resistance, quite high mechanical properties, and is very economic. Argentan is processed by rolling, pressing, and drawing. It is supplied in the form of bands, tapes, rods, and wire.

Argentan is used for manufacture of parts of instruments, of springs for equipment working in humid or corrosively active medium, and also for electrical purposes.

Monel [NZhMts28-2.5-1.5] (NMZhMu28-2.5-1.5) is distinguished by high corrosion resistance. It is resistant to corrosion in solutions of alkalis, salts, and acids, and also in sea water and in atmosphere of dry gases. Monel is processed satisfactorily by pressure in hot and cold states. It is supplied in the form of tapes, bands, rods, and wire.

Monel is used for manufacture of parts working in aggressive media.

§ 5. Babbits

Babbits constitute white antifriction alloys based on tin or lead, designed

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Fig. 18.7. Microstructure of stannous babbit B83. ×200.

for filling of bearing inserts. They consist of plastic base, constituting solid solution based on tin or lead and hard inclusions of chemical compounds SnSb and Cu_6Sn_5 (Fig. 18.7). As stronger babbits in aviation are applied those of stannous variety. Besides tin they contain copper and antimony.

Grades of babbit are designated by letter B and figure showing percentage of tin. With increase of tin content plasticity increases but hardness of babbit drops. Composition and mechanical properties of aviation babbits are given in Table 59.

Table 59. Composition and Mechanical Properties of Aviation Babbits

Grade of babbit	Chemical composition in %			Mechanical properties (not less than)		
	Cu	Sb	Sn	σ_b MN/m²	δ %	HB MN/m²
B83	5,5—6,5	10—12	base	120	4	360
B87	2—4	9—11	base	100	6	300
B92	4—5	4—5	base	60	12	200

Stannous babbits possess high antifriction and foundry properties, do not give liquation, and run-in well.

However, lowered thermal resistance and thermal conductivity are responsible for their application only under conditions of low specific pressures at temperatures of not more than 120°C.

C H A P T E R XIX

BERYLLIUM

Beryllium constitutes silvery-gray metal with low specific gravity of 18.5 kN/m^3 (or 1.85 gf/cm^3) and quite high melting point of (1284°C). It has long been applied an alloy component. Additions of beryllium increase fatigue limit of steel, raise oxidation of magnesium alloys, and impart resistance high elasticity and wear resistance to bronze.

However, consumption of beryllium is low so far, which is explained by considerable high cost of its production and extraordinarily low plasticity. Thus, for instance, in 1959 in all capitalistic countries but 180 tons of beryllium were smelted.

Mechanical properties of beryllium are still insufficiently studied. They depend in strong degree on method of manufacture of beryllium. For instance, beryllium, after being cast in vacuum and pressed at a temperature of 1000°C, has ultimate strength of σ_B = 320 MN/m^2 (32 kgf/mm^2) and elongation per unit length of δ = 2.5%.

Beryllium possesses high hardness, which hampers its machinability. Owing to great brittleness, beryllium does not yield to rolling, forging, and drawing. Only when heated to dark-red incandescence can it be forged within small limits.

In corrosion resistance in air at room temperature beryllium is close to aluminum. The surface of beryllium appears thin oxidized film, possessing good protective properties. Noticeable oxidation of beryllium in air starts at temperatures higher than 700°C.

For increase of oxidation resistance is applied [illegible]

saturation of surface of steel with beryllium, which increases scale resistance of steel to 900°C.

Beryllium possesses rare nuclear characteristics. It combines low atomic weight, small magnitude of capture cross section of thermal neutrons, and relatively high scattering cross section. Therefore beryllium is irreplaceable material for nuclear power as a moderator or source of neutrons.

Beryllium is absolutely transparent for X-rays. Therefore it is applied for manufacture of "windows" of X-ray tubes in exchange for aluminum, applied earlier for this purpose.

Interest in beryllium as possible structural material in aviation appeared recently. This is explained by combination in beryllium of a series of useful properties. First of all, one should mention relationship of elastic modulus and specific gravity. Specific gravity of beryllium is almost equal to that of magnesium and is 0.7 that of aluminum. Here the modulus of normal elasticity is equal approximately to 310,000 MN/m^2 (3100 kgf/mm^2), which is 7 times more than for magnesium and 4 times more than for aluminum.

In specific strength beryllium exceeds high-strength steel, aluminum, and magnesium alloys, inferior only to titanium alloys. According to calculations, an aircraft prepared wholly from beryllium due only to decrease of weight will have 40% increase of range as compared to aircraft built from aluminum alloys.

Beryllium possesses high heat resistance. At a temperature of 400°C it decreases its strength only by 2 times, whereas aluminum alloys decrease by 5 times.

In spite of enumerated valuable properties of beryllium its application for manufacture of aircraft will be possible only under conditions of decrease of cost and achievement of sufficient plasticity at room temperature.

C H A P T E R XX

CERMET MATERIALS

§ 1. General Information on Cermet Materials

Cermet materials are mixtures composed of powders of metals and other substances, subjected to pressing and subsequent sintering at high temperatures.

Heating during sintering is produced without melting or with partial melting of the most fusible components of mixture. Process of manufacture of articles from powder materials is similar to production of ceramics; therefore powder metals and alloys are called cermets.

For the first time method of manufacture of metals and alloys from powders by means of their pressing and sintering was developed by the Russian engineer, P. G. Sobolevskiy, in 1827. At present this method is finding ever greater application. It is the only method of obtaining refract ory metals (tungsten, molybdenum, tantalum, and thorium) and also metals of high purity. Powder materials are used for manufacture of contact and magnetic alloys for electrical and radiotechnical industry; antifriction, friction, and cermet alloys are used for machine-building industry; high-temperature heat-resistant alloys are used for special assortment.

Powder materials have a series of advantages over [illegible] alloys. During their manufacture it is possible always to obtain [illegible] composition with defined grain size. For many [illegible] articles having exact [illegible] different parts [illegible] need machining or [illegible] possible to obtain [illegible] strength their hardness, [illegible]

and decreases waste of materials. Finally, from powder materials it is possible to obtain porous materials with refined pore dimensions, which is necessary for manufacture of bearings, filters, and other parts.

Wide development of cermet production is still limited by high costs and labor-consuming nature of manufacture of dies, by high cost of obtaining powders, by insufficient strength of obtained articles, and also by pressing parts of large dimensions and complicated form.

Basic elements of technology of cermet production are:

1) obtaining of powders;

2) manufacture of powdered blanks by means of pressing;

3) obtaining of finished article by sintering of pressed blanks.

It is possible to obtain powders by various methods, depending upon properties of materials. For mass production at present are applied basically reduction and electrolysis.

Reduction is carried out by influence of hydrogen, carbon monoxide, or other restorers on oxides of metals. As result of process are formed metal and water vapor. For instance, by this method are obtained powders of refractory metals and iron.

Electrolysis is carried out by means of transmission of d-c electrical current through aqueous salt solution. As a result of process metal settles in the form of powder on cathode. With the help of this method is obtained, for instance, powder of copper.

Besides this are applied mechanical methods of obtaining powders, to which pertain crushing of hard metals and alloys (cast iron, bronze magnesium, and so forth) and atomization of melted fusible metals (tin, lead, and so forth).

Before being pressed powders are examined for determination of form and magnitude of particles and bulk density.

Essence of pressing consists in compression of powder in steel die under pressure. Pressing is conducted at ordinary temperature. Pressure during pressing is from 10 to 100 GN/m^2 (from 1 to 10 T/cm^2), depending upon character of powder.

As a result of pressing powder obtains configuration of working space of die and preserves it due to forces of friction.

Sintering of pressed blanks is produced in atmosphere of protective gas at a

temperature of approximately 0.7 of melting point of the most fusible component of the material. Duration of sintering is 1-5 hours.

During sintering occur diffusion, recrystallization, reduction of oxides, and sometimes fusion of fusible components. As a result of these phenomena particles of powder are bound with each other and baked material obtains defined strength.

Basic forms of cermet materials are antifriction, friction, filtering, electrical, hard, and heat-resisting materials.

§ 2. Antifriction, Friction, and Filtering Cermet Materials

Antifriction cermet materials. Some of the most widespread objects of cermet production are porous antifriction articles – bearings and bushing.

Porous bearings are prepared from powders of iron, copper, tin, and other metals, with addition of earth. Pores in such bearings are filled with oil; therefore they are self-lubricating.

Porous cermet articles with antifriction properties have many advantages over antifriction articles cast from bronze and babbit.

Cermet antifriction materials with mechanical properties similar to cast antifriction materials have better run-in ability, lower coefficient of friction, and greater wear resistance. In cermet bearings is ensured automatic regulation of lubricant.

By method of powder metallurgy are obtained bronze-graphite and iron-graphite self-lubricating bearings.

Porous bearings on copper base consist of 9.5-10.5% tin, 1.5-3% graphite, and copper. Porous bearings on iron base consist of 2-3% graphite and 97-98% iron.

Process of manufacture of porous bearings consists of following operations: mixing of powders, pressing of mixture, sintering of articles at 750-780°C, and impregnation of bearings with oil at 70-150°C for 1-2 hours.

Pourous bearings are applied in aviation technology for different friction elements. In aviation industry have found application mainly materials on copper base.

It is recommended that bronze-graphite bearings be applied at average pressures and average speeds of shaft rotation. Under impact loads they work unsatisfactorily,

since they possess low dynamic strength.

It is recommended that bushings of bronze-graphite be used in those points where access of lubricating oil is hampered, since in such bushings lubrication is ensured by bearing itself.

Frictional cermet materials. Powder materials also have large advantages during manufacture of different frictional parts working in brake systems.

Frictional cermet materials cover disks, blocks, bands, and other articles for brake assemblies prepared of steel. Cermet frictional layers for brake disks on aircraft have thickness to 0.25-2 mm with thickness of steel support disk 1.5-3 mm. This layer is fixed on steel support base by multiple rolling of powder mixtures with subsequent sintering and calibration or pressing of frictional layer and sintering under pressure in protective atmosphere.

Steel support disks or bands prior to sintering of frictional layer based on copper are preliminarily copper plated; for sintering of frictional layer on iron base nickel plate is applied.

Working condition of frictional materials in contemporary high-speed machines are extremely severe. Initial speed of braking in them attains 30-50 m/sec at pressure to 200 MN/m^2 (20 kgf/cm^2), which leads to heating of friction surfaces to 1000-1100°C.

Cermet frictional material should possess high coefficient of friction and ability of work with low wear at operating temperatures. Besides this, it should have sufficient strength and good run-in ability.

Only by cermet method was it possible to prepare material from various components which ensured for ready article so contradictory properties. Usually mixtures for frictional parts are composed on the basis of powders of copper to which are introduced silica, increasing coefficient of friction, graphite, lowering wear, and other substances.

In aviation industry find application basically frictional materials of following chemical composition: 5-15% lead, 5-10% tin, up to 2% nickel, up to 2% iron, up to 0.5% silicon, 4-8% graphite, up to 0.5% silica, up to 0.3% asbestos, and remainder copper.

Filtering cermet materials. Porous powder materials are applied also for preparation of filters intended for purification of fuel and oil.

Powdered filters possess good filtering ability, do not contaminate filtered liquid, are durable, and are reliable in use.

For manufacture of cermet filters are used corrosion-resistant powder materials – bronze, nickel, brass, and stainless steel. Filters are prepared usually by sintering of free-poured and unpressed powders in special forms of having from of plates, cylinders, cones, disks, and so forth.

§ 3. Hard Alloys

For guarantee of specially high speeds of cutting of metal in industry special hard alloys are widely applied: these possess wear resistance tens of times greater than the most effective high-speed cutting steels.

Plates of hard alloys are soldered or welded to cutting tools of carbon steel, making it possible to conduct treatment of metals at high cutting speeds – to 150-200 rad/sec (1000-2000 m/min). This is explained by the fact that hard alloys possess high hardness, wear resistance, and red hardness.

Basic of hard alloys are carbides of refractory metals. Carbides can be obtained in the form of powder and in cast state. According to method of production, hard alloys are divided into cermet and cast types.

Cemented carbides constitute alloys of carbides of certain refractory metals (tungsten, titanium, tantalum) with additions of cobalt as cementing metal. Carbides of tungsten and titanium have high hardness; cobalt gives alloys toughness and lowers suitering temperature.

Cemented caribides are prepared by methods of powder metallurgy, by means of mixing powders of carbides and cobalt and pressing obtained mixture into articles of necessary form. Pressure of pressing is 15-20 GN/m^2 or 1.5-2 T/cm^2. Then pressed blanks are sintered at a temperature of 1350-1500°C for 1.5-2.5 hours in protective atmosphere or in vacuum.

According to structure of carbide components, cemented carbides are divided into two basic types: tungsten-cobalt (group [VK] (ВК)) and titanium-tungsten-cobalt (group TK). Alloys of group VK are distinguished by raised toughness and lower hardness. Alloys of group TK have higher hardness and wear resistance and less toughness.

Sintered alloys possess high hardness of 86-92 [illegible] and red hardness to 900°. The more carbides present the greater the hardness; however, with

this their brittleness is increased.

Composition and properties of cemented carbides are given in Table 60.

Table 60. Chemical Composition and Mechanical Properties of Cemented Carbides

Group of carbides	Grade of carbides	Chemical composition in %			Properties		
		WC	TiC	Co	specific gravity, kN/m³	hardness, HRA	bending strength, MN/m²
Tungsten	BK2	98	—	2	148	89,0	1000
	BK3	97	—	3	149	89,0	1000
	BK6	94	—	6	145	88,0	1200
	BK10	90	—	10	142	87,0	1350
	BK11	89	—	11			
	BK15	85	—	15	139	86,0	1600
Titanium-tungsten	T5K10	85	6	9	122	88,5	1150
	T14K8	78	14	8	112	89,0	1100
	T15K6	79	15	6	110	90,0	1100
	T15K6T	79	15	6	100	90,0	1100
	T30K4	66	30	4	95	91,0	900

Tungsten-cobalt alloys are used for manufacture of cutting tools applied for treatment of cast iron, bronze, and nonmetallic materials.

From cermet tungsten-titanium-cobalt alloys are prepared cutting tool applied for treatment of carbon and alloy steels.

Cemented carbides are applied also for manufacture of drawing dies, stamps, molds, and also other tools and parts.

Cast hard alloys. These alloys are divided into two groups: carbides and alloys of stellite type.

To first group belongs relit, constituting cast carbides of tungsten WC and W_2C. Relit has melting point of 3500°C and is smelted in electrical furnaces in which heating element is graphite pipe. Alloys of this type are distinguished by high hardness and wear resistance. Therefore they find application as bits for petroleum drilling. Pieces of relit are welded to tool with help of high-frequency currents or oxyacetylene flame.

To second group of alloys belong two forms of alloys: stellites and stellite-like.

Table 61. Chemical Composition and Properties of Cast Hard Alloys

Type	Grade of alloy	Chemical composition in %								Properties		
		Co	Ni	Fe	Cr	Mn	Si	W	C	hardness, HRA	specific gravity, kN/m^3	ultimate tensile strength MN/m^2
Cast carbides	Relit	—	—	Upto 0,25	—	—	—	Base	3,0—4,5	91—92	176—185	—
Stellites	B2K	47—53	Upto 2	Upto 2	28—33	До 1,0	1,0—2,0	13—17	1,8—2,5	46—48	88	600—700
	B3K	58—62	Upto 2	Upto 2	28—32	—	1,5—3,0	4,0—5,0	1,0—1,5	42—43	84	550—650
Tungsten-free	Cormite No 1	—	3,0—5,0	Base	25—31	1,5	2,8—3,2	—	2,5—3,3	49—54	74	350--370
	Cormite No 2	—	1,3—2,2	Base	13,0—17,5	1,0	1,5—2,2	—	1,5—2,0	40—45	76	420—430

Stellites constitute cobalt-chromium-tungsten alloys. They have melting point of the same order as that of steel. Stellites possess high hardness, wear resistance, and red hardness.

Structure and mechanical properties of stellites are influenced by cooling rate. The faster the cooling the finer the structure and the higher the mechanical properties.

Stellites also possess comparatively high corrosion resistance. High weldability permits using them for hard-facing on machine parts and tools subjected to wear, in consequence of which wear resistance of the latter is increased a few times.

For manufacture of cutting tools stellites are used in the form of plates or insertable knives. Thus stellite [VZK] (ВЗК) is used for hard-facing of exhaust valves for aircraft piston engines.

To stellite-like alloys belong sormite, constituting alloy of iron, chromium, nickel, carbon, and other elements. Sormite has lower hardness and red hardness than stellite. Red hardness of stellite attains 700-800°C and sormite 500-600°C.

Sormite, like stellite, is released in the form of rods, which serve for facing material for different fast-wear parts.

Chemical composition and mechanical properties of cast hard alloys are given in Table 61.

§ 4. Heat-Resisting Cermet Materials

Development of jet engineering and turbine engine building, and also the quest to obtain higher engine efficiency impose raised requirements on heat-resisting structural materials.

As was noted earlier, presently applied heat-resisting alloys based on nickel, cobalt, iron, chromium, and others with different alloy additions cannot work at temperatures exceeding 1000°C. Such high temperatures can be sustained by refractory metals, carbides and nitrides, oxides, silicides, and borides.

Alloys based on shown metals and compounds are heat-resisting cermet alloys. Articles from them are prepared chiefly by methods of hot pressing.

We distinguish three groups of heat-resisting cermet materials.

The first group belong alloys based on refractory metals: molybdenum, niobium, tantalum, and tungsten. Their characteristics were considered earlier. As it is

known, these materials possess insufficient scale resistance and cannot be used without protective coverings protecting them from oxidation. Application of presently known heat-resisting metals and alloys based on them is possible at temperatures of the order of 2000°C. Use of tungsten alloys will allow us to increase operating temperature to 2500-2700°C.

To second group belong materials based on refractory compounds of metallic character: carbides, borides, nitrides, and silicides with addition of ductile metals – cobalt and nickel. These materials are the most heat-resisting of known materials.

Among cermet materials useful for work at temperatures to 950°C of wide popularity are materials based on titanium carbide and nickel, titanium carbide and cobalt, titanium carbide and molybdenum, chromium carbide, and nickel. In all these materials metallic component serves as plasticizing addition, to promote increase of resistance to thermal shock.

For increase of heat resistance, to titanium carbide in certain compositions are added niobium carbide and tantalum carbide, and as binding metal are used heat-resistant alloys on nickel or cobalt bases.

For manufacture of articles working at higher temperatures are successfully applied so-called borolites. They constitute complex compositions containing up to [illegible] carbide and chromium boride or titanium boride.

Among all refractory cermet compounds the most promising are certain carbides of [illegible] and their mutual combinations. Thus, for instance, one of the most heat-resistant materials, having melting point of approximately 3900°C, is mixture of carbides of tantalum and hafnium in 4:1 relationship.

Application of heat-resisting materials of this group is very much hampered by their high sensitivity to cut, by absence of ductility, by great brittleness, and lack of resistance to thermal shocks.

To third group of materials belong cermet alloys based on refractory oxides with additions of metals. These materials sometimes are called cermets.

Cermets have high heat resistance, although they differ from [illegible] cermet materials by lower heat resistance. They possess sufficient thermal conductivity, but low resistance to thermal shocks. Industrial use of [illegible] materials of this group as refractory [illegible]

aluminum and aluminum oxide.

Requirements imposed on materials under working conditions of gas turbine and rocket ramps also preserves their value under conditions of work in atomic reactors, in systems of circulation of heat-transfer agents, etc.

However, upon them are added specific new requirements. Materials have to possess high corrosion resistance and must not interact with water, steam, and with liquid metals, which at present time are used as heat-transfer agents (sodium, alloys of sodium and potassium, or lead and bismuth).

Materials must not be noticeably subject to influence of various kinds radiation and must not noticeably absorb slow (thermal) neutrons.

Described heat-resisting cermet materials are applied with success and in atomic power engineering.

SECTION FOUR

CORROSION OF METALS AND ALLOYS

CHAPTER XXI

BASIC CONCEPTS OF CORROSION

§ 1. General Information

Corrosion is destruction (eating) of metals and alloys due to chemical or electrochemical influence of external medium on them. Destruction of metals starts from their surface and gradually spreads to the interior. As a result of corrosion, metals change their appearance: they lose luster and obtain rough surface covered by products of corrosion.

Exploitation of metal parts is connected with influence of external medium on them and with possibility of corrosion destruction. Examples of corrosion especially frequently encountered are rusting of steel, oxidation of aluminum and magnesium alloys, and formation of green spots on copper and its alloys.

Conditions of work of aviation structures are favorable for development of various types of corrosion. Exposed parts of aircraft, such as sheathing of wings, fuselage, empennage, and parts of undercarriage, are subjected to direct influence of air, moisture, dust, and chemically active gaseous products of combustion of fuel. Many engine parts during work are under influence of such aggressive media as hot gases. And finally, aviation structures are characterized by large number of joints of heterogeneous metals and alloys, which promotes appearance of [illegible].

Harm of corrosion consists, first of all, in decrease of mechanical strength of parts of aviation structures, which is especially danger[illegible] for thin-walled aircraft structures possessing small safety factors. [illegible] strength, [illegible] important in certain cases [illegible] of [illegible] with [illegible] [illegible].

Besides, corrosion leads to impairment of streamlining of parts of aircraft, to disturbance of airtightness of joints, to obstruction of feed systems by products of corrosion.

Corrosion brings huge damage upon the national economy, leading to yearly waste of a million tons of metal; therefore protection of parts from corrosion should be allotted the most serious attention.

Struggle with corrosion of metals during the last few years has obtained especially large value, since all the more widely applied are high temperatures and pressures, high speeds, and aggressive media, i.e., conditions favoring stronger rate of corrosion are being created.

Native science of corrosion was developed during the years of Soviet power. Soviet scientists, G. V. Akimov, V. A. Kistyakovskiy, N. A. Izgaryshev, N. D. Tomashov, and others, developed base of theory of corrosion of metals and solved a series of the most important practical questions connected with corrosion of metals and protection from it.

Depending upon conditions under which corrosion occurs, we distinguish:

(1) atmospheric corrosion, constituting destruction of metals in atmosphere and in any humid gas. It is the most characteristic for aviation structures. For instance, corrosion of sheathing of fuselage, wings, empennage, cowls, and parts of undercarriage under influence of deposits of fog, humid air contaminated by dust, and gases;

(2) liquid corrosion, constituting destruction of metals under influence of liquid aggressive media. For instance, corrosion of floats and hulls of seaplanes under action of marine and river water, corrosion of different pipelines, and internal parts of feed systems under action of hydraulic fluids, acids, and liquid coolants;

(3) gas corrosion, constituting destruction of metals as a result of their continuous oxidation under influence of dry hot gases. For instance, corrosion of parts of aircraft engines and aircraft of coming in contact with hot gases (blades of gas turbines and guide vane apparatus, combustion chambers parts of exhaust system, etc.).

Change of mechanical properties of alloys caused by corrosion in considerable degree depends on character of propagation of corrosion on surface, and especially to depth, of alloy.

Depending upon form of corrosion destruction, determined by structure of alloy and state of surface, we distinguish uniform local intercrystallite corrosion and corrosion cracking.

Uniform, or surface, corrosion is characterized by gradual destruction of metal over the entire surface (Fig. 21.1a). Through uniform corrosion is destroyed only surface layer of parts; destruction is insignificant, but mechanical strength is still lowered. Subject to it are aluminum alloys in solutions of acids and alkalis and steel in solutions of acids.

Practically, during exploitation of aircraft this form of corrosion destruction is encountered less often than remaining forms of corrosion.

Pitting is characterized by appearance of seats of corrosion on separate sections of part. Among varieties of pitting we distinguish point and ulcerous corrosion (see Fig. 21.1b). Basic cause of this form of corrosion is structural heterogeneity of alloy.

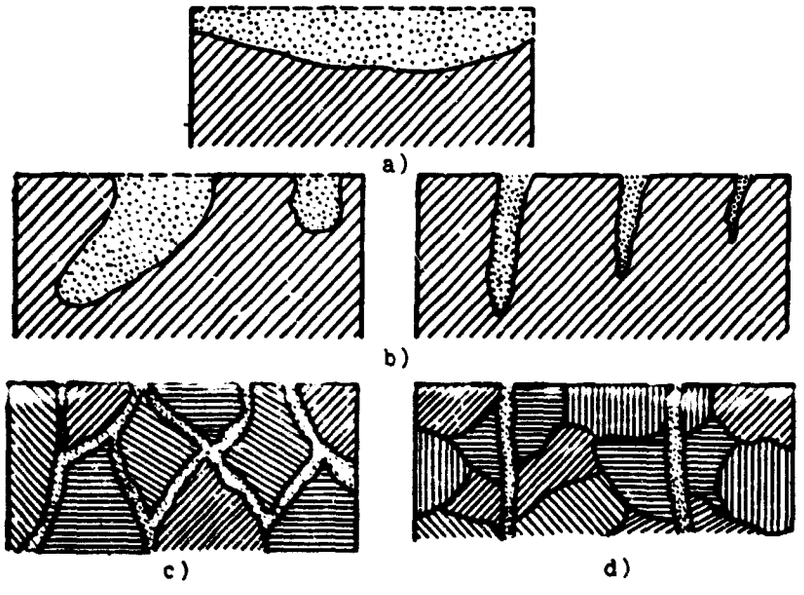


Fig. 21.1. Types of corrosion. a) uniform, b) local (point and ulcerous), c) intercrystallite, d) transcrystallite corrosion cracking.

In action pitting is similar to cuts - it decreases plasticity and fatigue strength of material. Besides this, when damage due to pitting is deep, lowering of mechanical strength is observed.

To pitting are subject aluminum, magnesium, and iron alloys under influence of humid atmosphere of fresh and sea water. Parts of aircraft are subject most

frequently to pitting.

Intercrystallite corrosion is characterized by destruction about grain boundaries of metal or alloy (Fig. 21.1c). It disturbs their bonding and sharply lowers strength of alloy.

To intercrystallite corrosion are subject duralumin (especially unplated) and stainless steel with incorrect heat treatment.

One should fear especially intercrystallite corrosion of longeron profiles of aviation structures, considerably lowering their strength.

Corrosion cracking is characterized by appearance of cracks, leading to strong drop of strength and even to destruction of parts (see Fig. 21.1d). Cause of corrosion cracking is simultaneous action of corrosive medium and internal stresses. To corrosion cracking are subject duralumin, high-strength alloy V95, certain magnesium alloys, stainless steel, and brass. Subject to it to a larger degree are sheets, pipe, profiles, and other articles of thin cross section.

Corrosion cracking and intercrystallite corrosion are the most dangerous forms of destruction, rapidly proceeding into depth of material. Upon external inspection these types of corrosion are difficult to detect, as a result of which destruction of parts can occur absolutely unexpectedly.

Corrosion of metals and alloys, depending upon essence of internal processes, can be divided into chemical and electrochemical. To chemical corrosion belongs corrosion in medium of dry hot gases or in liquids not conducting electrical current. To electrochemical corrosion belong processes of destruction of metals and alloys under influence of electrolyte.

§ 2. Theory of Corrosion Processes

Chemical corrosion. Chemical corrosion is process of destruction of metals or alloys as a result of purely chemical interaction of them with external medium.

As examples of chemical corrosion of aviation material can serve liquid corrosion of elements of fuel system of aircraft, appearing under action of active sulfurous compounds of fuel, corrosion of parts of liquid-fuel rocket engines under action of oxidizers, and also gas corrosion of aviation parts working in oxidizing medium of dry hot gases.

Let us consider essence of chemical corrosion on examples of oxidation of metals.

All metals under the influence of atmospheric oxygen are covered by thin film of oxides. Protective properties of films depend on their composition, structure, properties, thickness, and adhesion to basic metal.

Certain metals, as aluminum, chromium, and others, form durable oxidized films, reliably protecting metal from further oxidation. In this case process of corrosion is delayed sharply.

On other metals, for instance, on magnesium and iron, are formed oxidized films that are less perfect. They contain numerous pores and cracks, through which it is comparatively easy for gases to penetrate, provoking corrosion.

Initial stage of formation of films is purely chemical process, occurring on surface of metal. Basis of further process of oxidation is process of bilateral diffusion of atoms of metal, on the one hand, and of atoms of oxygen on the other (Fig. 21.2).

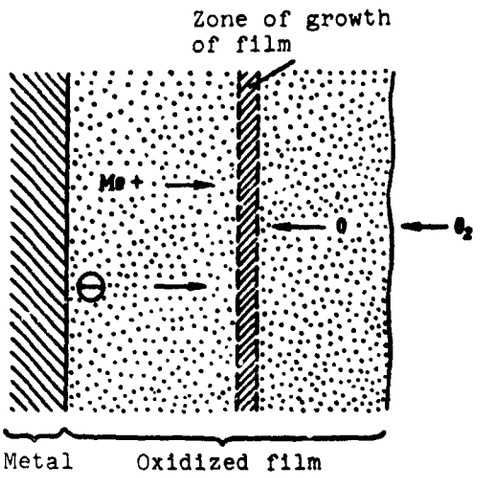


Fig. 21.2. Diagram of growth of oxidized film.

For those metals for which film of oxides possesses bad protective properties with increase of temperature, when rate of oxidation sharply increases, the process of formation of film is accelerated strongly. Thus, the essence of gas corrosion consists in continuous oxidation of metal in gaseous environment at high temperatures, as a result of which occurs decrease of strength of parts.

Gas corrosion is very dangerous for turbine-engine parts, since parts of exhaust system and flame tube of combustion chamber are prepared from light-gage sheet and rotor blades of gas turbine are highly-loaded parts.

However, the biggest harm to metallic structures is done by more widespread electrochemical corrosion.

Electrochemical corrosion. Electrochemical corrosion is process of destruction of metals and alloys appearing under action of electrolytes. By electrolyte is understood electrically conductive solution of acids, alkalis, and salts in water. Atmospheric moisture is also an electrolyte, since in it are dissolved salts and

gases (CO_2, SO_2, H_2S, NH_3).

As examples of electrochemical corrosion of aviation material can serve atmospheric corrosion of open parts of aircraft, liquid corrosion of floats and hulls of seaplanes.

Electrochemical corrosion appears as a result of interaction of two heterogeneous metals in electrolyte and touching among themselves. Metal immersed in electrolyte, as a result of interaction with it, obtains electrical charge, quantitatively expressed by its electrode (electrochemical) potential. Magnitude and sign of electrode potential depend on nature of metal, composition of electrolyte, and temperature.

Depending upon values of electrode potentials, for selected electrolyte all metals can be arranged in electromotive series (so-called series of metals, arranged in order of increase of their negative electrode potentials). Potential of hydrogen is conditionally taken as zero.

Electrode potentials of certain metals in 3% aqueous solution of NaCl at 18°C are given in Table 62.

Table 62. Electrode Potentials of Certain Metals in 3% NaCl

Metal	Electrochemical potential, v		Metal	Electrochemical potential, v	
	initial	final		initial	final
Silver	+0,24	+0,20	Iron	−0,34	−0,50
Copper	+0,02	+0,05	Cadmium	−0,58	−0,52
Chromium	−0,02	+0,23	Aluminum	−0,63	−0,63
Nickel	−0,13	−0,02	Zinc	−0,83	−0,83
Tin	−0,26	−0,25	Magnesium	−1,45	—

Relationships of potentials characterize comparative corrosion resistance of metals. From two metals located side by side in electromotive series that metal which possesses more negative potential will have lower corrosion resistance.

Thus, upon contact of two various metals being in contact with electrolyte, potential difference is created and electric current appears.

It is possible to consider such system as corrosional galvanic cell (galvanic pair). Metal with more negative electrode potential is called anode, the other, with more positive potential, is cathode. Process of electrochemical corrosion

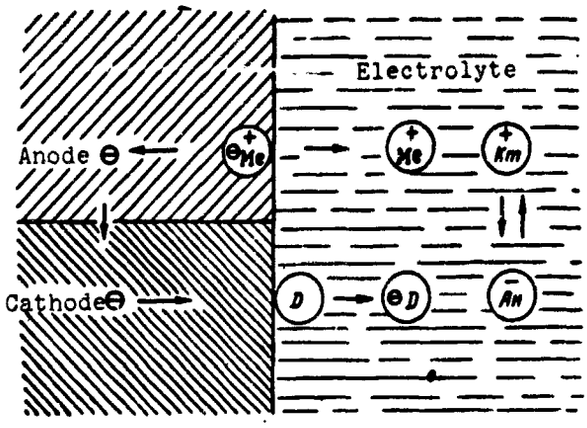


Fig. 21.3. Diagram of operation of corrosional galvanic cell.

is analogous to operation of galvanic cell.

Diagram of operation of corrosional galvanic cell is depicted in Fig. 21.3. Process of electrochemical corrosion, in distinction from chemical, is characterized by presence of two independent processes – anode and cathode. Electron conductivity of metal and ionic conductivity of solution permit occurrence of these processes in various sections of metal.

Anode process consists in that metal which has more negative electrode potential gives its positive ions (Me^+) to solution, where their hydration occurs. Since anode is always electrode from which to external circuit move electrons, the metal being anode of galvanic cell will be destroyed in process of work of galvanic pair.

Hydration constitutes phenomenon of interaction in electrolyte of ions of solute with molecules of water. Here energy generated, called energy of hydration (its presence confirms increase of temperature of water with addition of acid to). Owing to hydration every ion of dissolved metal turns out to be connected with larger or smaller quantity of water molecules.

Metal with more positive potential becomes cathode. It is not destroyed in process of operation of galvanic pair. On it occurs cathode process, consisting in connection of electrons to any depolarizer (Д) of solution, as a result of which occurs precipitation of metal from electrolyte or liberation of hydrogen.

Polarization is change of electrode potential in connection with physical and chemical changes near it. Restoration of initial value of potential of electrode is called depolarization, and substances promoting this are called

depolarizers. Phenomenon of depolarization promotes [illegible] anode. Depolarizer can be oxygen or hydrogen dissolved in water. Oxygen depolarization is characteristic for atmospheric corrosion of steel and aluminum alloys, and hydrogen depolarization is characteristic for corrosion of magnesium alloys.

Analyzing electromotive series, we can make the following conclusions:

1. In any pair of metals during corrosion will be destroyed metal with more negative potential (located lower in electromotive series). Thus, during contact of copper with iron iron will be destroyed, and during contact of iron with aluminum the aluminum is destroyed.

2. Destruction of anode in galvanic pair will be stronger the more the potential difference between metals (i.e., the further from each other they are located in electromotive series). For instance, during contact of copper with chromium, chromium with nickel, tin with iron, or iron with cadmium the rate of destruction of anode will be low. But, during contact of copper with iron, copper with aluminum, or copper with magnesium destruction of anode will occur with great speed.

3. During production and repair of aviation material it is necessary to select material for joined parts in such a manner that there is as little as possible potential difference between them. Thus, it is impossible to allow contact of aluminum alloys with copper alloys, nickel-plated and chrome-plated parts, high-alloy steels. Contact is not allowed between magnesium alloys and unprotected aluminum and its alloys, copper and copper alloys, carbon or carbon steels. For unalloyed and low-alloy steels (Cromansil) contact is not allowed with copper and its alloys, nickel-plated and chrome-plated steels and stainless steel.

§ 3. Corrosion of Alloys

Cause of electrochemical corrosion of alloys is their nonuniform structure, which in the presence of electrolyte will lead to formation on surface of alloy of large quantity microgalvanic cells (micropairs). Every micropair of alloy consists of two adjacent heterogeneous grains of various structural components (fig. 11.4).

Processes of electrochemical corrosion of alloy in electrolyte (so-called

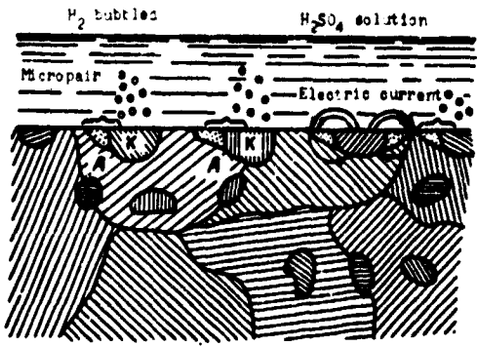


Fig. 21.4. Diagram of formation of microcells in alloy.

microgalvanic corrosion) differ in no way from processes occurring in galvanic cell.

It is possible to represent surface of alloy in this case as battery consisting of large number of microcells. Components of alloy having the lowest values of electrode potential will serve as anode sections, and metal in these sections will be destroyed. Components of alloy possessing higher values of electrode potential form cathode sections and will not be destroyed.

Structure of annealed duralumin constitutes grains of solid solution on aluminum base and inclusions of $CuAl_2$. Solid solution possesses more negative electrode potential than $CuAl_2$. Therefore during corrosion will be destroyed grains of solid solution, playing role of anodes in micropair, and inclusions of $CuAl_2$, forming cathode sections will not be destroyed.

Structure of annealed steel consists of alternating sections of ferrite and cementite. Ferrite possesses more negative electrode potential than cementite. During corrosion ferrite, playing role of microanodes, will be destroyed and sections of cementite, playing role of microcathodes, will not be destroyed.

Thus, alloys with uniform structure will be more resistant to corrosion than alloys with nonuniform structure.

Practically, metallic surface is nonuniform even for pure metals and alloys with uniform structure of solid solution owing to presence of impurities, nonuniform concentration of solid solution, nonuniform treatment, different degree of oxidation, and so forth. In this case also has place potential difference in various sections of surface. Therefore pure metals and alloys with uniform structure also are subject to process of microgalvanic corrosion, though in smaller degree.

Processes of electrochemical corrosion can appear in structures of aircraft and engines as a result of contact of parts prepared from various materials whose electrode potentials are different. In this case role of anode will be played by part prepared from material possessing smaller value of electrochemical potential.

Therefore during manufacture of metallic parts, in which various metals are connected, it always is necessary to consider possibility of harmful influence of different metals touching each other. As experience shows, contact of heterogeneous metals and alloys is most frequently the cause of corrosion destructions of aviation parts.

§ 4. Factors Influencing Corrosion

Intensity of electrochemical corrosion depends on a series of internal and external factors.

To intrinsic factors pertain: composition and structure of alloy, state of its surface, presence of internal stresses, and permanent deformations.

Uniform structure of metal or alloy, excluding possibility of formation on surface of microgalvanic cells, imparts corrosion resistance.

With nonuniform structure, alloy will be subject to corrosion, where rate of destruction of anode will be greater the more the potential difference of separate structural components. Heat treatment, as it is known, leads to change of structure of alloy, and this means to its corrosion resistance. If as a result of heat treatment structure becomes uniform, this increases corrosion resistance of alloy. If heat treatment disturbs homogeneity of structure, this reduces corrosion resistance of alloy.

Thus, hardening of duralumin and stainless steel, leading to the obtaining of uniform structure of solid solution, increases corrosion resistance of these alloys. During annealing of these alloys homogeneity of their structure is disturbed, which sharply lowers corrosion resistance. Hardening of carbon and low-alloy steels to martensite gives greater corrosion resistance in relation to structure than hardening to troostite or sorbite.

State of surface of alloy, determined by quality of machining of alloy and degree of its contamination, plays important role. Pure, even surfaces have high corrosion resistance. Presence of grooves and scratches, in which moisture is held, promotes corrosion. Besides this, in places of grooves, scratches, and nicks oxidized film is disturbed, which also leads to electrochemical corrosion.

Internal stresses and permanent deformation appearing during heat treatment or pressure treatment lower corrosion resistance of alloy. In this case role of anodes is played by more stressed sections of alloy.

In case of simultaneous influence of corrosive medium and internal stresses in metal is observed so-called corrosion cracking.

To external factors pertain: chemical composition of electrolyte, its concentration, and temperature.

Chemical composition of electrolyte strongly affects intensity of corrosion process. For instance, acid media are especially dangerous for magnesium, aluminum, iron, and zinc, and alkali media are dangerous for zinc, aluminum, and its alloys.

Humidity and contamination of air by dust and industrial gases are decisive natural factors provoking atmospheric corrosion. This is explained by the fact that dust, containing impurity of salts, and also atmospheric moisture, contaminated by certain industrial gases or salts of sea water, constitute very active corrosive media.

Concentration of electrolyte in strong degree affects destruction of anode; the biggest danger for metals is presented by electrolytes of average concentration. Of natural electrolytes very dangerous are sea water and atmospheric moisture contaminated by such industrial gases as sulfurous gas, hydrogen sulfide, hydrogen chloride, ammonia, and others.

Influence of temperature of electrolyte on intensity of corrosion is the following: the higher the temperature of electrolyte the higher the rate of destruction of anode.

§ 5. Corrosion Resistance of Aviation Alloys

Carbon and low-alloy steels differ comparatively little one from another in corrosion resistance: they are easily subjected to corrosion in humid atmosphere, marine and fresh water, and solutions of acids. In diluted solutions of alkalis these materials are stable. Heat treatment does not render essential influence on their corrosion resistance.

Stainless steels possess better corrosion resistance in humid atmosphere and alkalis than in sea water. For increase of corrosion resistance of stainless chrome - nickel steels they are subjected to hardening.

Titanium alloys possess good corrosion resistance, not inferior to that of chrome - nickel stainless steels. They are resistant to corrosion in humid atmosphere, in sea water, and in solutions of acids and alkalis.

Aluminum alloys are actively destroyed in alkalis, acids, and sea water, [illegible] actively in humid atmosphere. For increase of corrosion resistance of duralumin and other aluminum alloys containing copper they have to be applied in hardened and naturally aged state. In annealed state these alloys possess low corrosion resistance.

Magnesium alloys, as compared to aluminum alloys, to a larger degree are subject to corrosion destruction in sea water, in acids, and humid atmosphere. In alkalis these alloys are stable. Recently methods have been developed for protection of magnesium alloys from corrosion, allowing us to apply these alloys quite widely in aircraft building.

Copper alloys resist corrosion well in atmospheric conditions, somewhat worse in sea water and weak solutions of acids; in alkalis they darken.

C H A P T E R XXII

PROTECTION OF AVIATION ALLOYS FROM CORROSION

§ 1. Basic Methods of Protection from Corrosion

For preventing of breakdown of aviation materiel all important assemblies and parts of aviation constructions are protect from corrosion.

Selection of methods of protection from corrosion is determined by nature of metals by assignment and conditions of work of parts and assemblies made from them.

For reliable protection of aviation parts from corrosion on their surfaces are created special films, insulating metal from aggressive environment. Films can be metallic, oxidized, and varnish and paint. Besides this, there can be applied other methods of protection: alloying, diffusion saturation of surface by special elements, protection by protectors, and others.

Protection by alloying consists in addition to alloy of elements increasing its corrosion resistance.

Corrosion resistance of high-alloy steels and special alloys is explained by formation of uniform structure (for instance, austenitic structure in chrome – nickel stainless steels or in heat-resisting alloys on nickel base) or creation on surface of thin protective oxidized films of alloy elements (for instance, in stainless steels alloyed with chromium, silicon, aluminum).

Besides this, increase of corrosion resistance through alloying also is explained by increase of electrochemical potential obtained as a result of alloying steel or special alloy.

In a number of cases introduced alloy element does not completely remove possibility of appearance of corrosion but shifts intercrystallite form of corrosion to one less dangerous – surface type (for instance, magnesium and manganese in

certain aluminum alloys).

Protection from corrosion by alloying is widely applied in aircraft construction for protection of elements of aircraft structure, engine, or instrument from influence of hot gases or other aggressive media. For instance, protective sheets in places of flow of hot gases - shafts, pins, mushroom valves, guide vanes, and rotor blades of turbines - are prepared from stainless or heat-resistant steels and alloys.

Besides alloying, as protection of steels from gas corrosion there is deposited on part a layer either of heat-resistant material or protective diffusion layer is created.

Protection by metallic coverings consists in deposition on surface of part of film of metal possessing higher corrosion resistance than basic metal.

Metallic coverings can be deposited on protected part by following methods: galvanic, metallizing, plating, diffusion, and hot methods.

This method of protection is basic in aircraft construction for protection of steel parts (bimetalic wire and zincing) and sheet semifinished products from certain aluminum alloys (duralumin, high-strength aluminum alloy V95).

We distinguish two forms of metallic coverings: anode and cathode.

Anode covering has more negative electrochemical potential than basic material, i.e., is anode with respect to basic metal. As examples can serve coverings of steel parts by zinc or cadmium or plating of duralumin with aluminum.

With local disturbance of anode covering, for instance, due to scratch and effect there of electrolyte, covering will be destroyed through corrosion. Diagram of corrosion of metal with anode covering is shown in Fig. 22.1a.

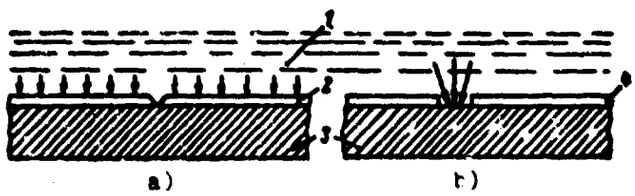


Fig. 22.1. Diagram of corrosion of metal. a) with anode covering, b) with cathode deposition. 1 - corrosive medium, 2 - anode covering, 3 - basic material, 4 - cathode deposition. Pointers show destroyed metals.

Thus, anode coverings create mechanical and electrochemical protection of parts.

Anode coverings are widely applied in aviation for protection of loaded responsible parts.

Cathode deposition has more positive electrochemical potential as compared to basic material, i.e., is cathode with respect to basic metal. As examples can serve coverings of steel parts with chromium nickel, copper, tin, and lead.

Cathode deposition well protects part from corrosion while it is solid. With disturbance of cathode covering on damaged section intense destruction of basic material starts.

Diagram of corrosion of metal with cathode deposition is shown in Fig. 22.1b.

Thus, cathode depositions create only mechanical protection of parts. Therefore they are applied in aircraft construction less often – mainly for decorative purposes.

Protection by oxidizing consists of artificial thickening of oxidized film or creation of thin protective film of salt-like compounds on surface of parts. This method of protection from corrosion in aviation applied especially widely is for aluminum and magnesium alloys and also for certain steel parts.

Protective film of oxides or salt-like compounds on surface of parts is created with the hlep of electrolysis (for instance, anodidizing of aluminum alloys) or by chemical means (for instance, oxidizing of magnesium alloys).

Electrochemical protection is protection based on the fact during contact of two heterogeneous metals only that one having more negative electrochemical potential will be destroyed.

Essence of this method consists in creation of artificial galvanic pair, consisting of protected part and protector fastened to it with rivets or bolts.

Material of protector must have negative electrochemical potential and be anode with respect to protected metal. However, potential difference must not be very great, in avoidance of very fast destruction of protector.

Protectors constitute small plates, adjoint to protected part. For instance, to floats of seaplane are joined zinc plates. Besides this, protector can constitute small linings, placed near or between contacting parts of different alloys. Thus, for instance, for protection of connections of parts made from Silumin and steel or Silumin and bronze reliable protectors will be linings of zinc or cadmium.

Electrochemical protection is used for parts fully submerged in electrolyte.

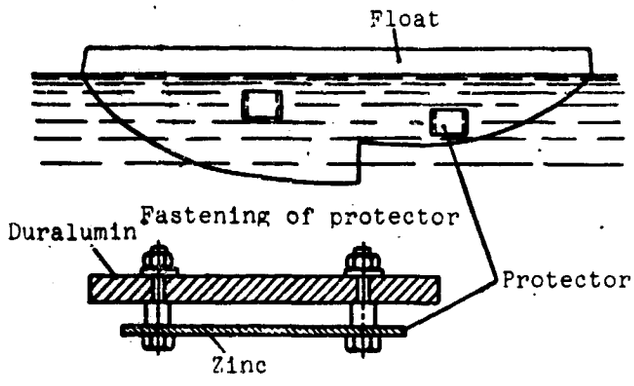


Fig. 22.2. Diagram of protector arrangement on float of seaplane.

Thus, in aviation it is used for protection of sheathing of hulls and floats of seaplanes, parts of hydraulic retraction system of landing gears, etc. In Fig. 22.2 is presented diagram of protector arrangement on float of seaplane.

Protection by nonmetallic coverings consists in creation on surface of parts of watertight varnish and paint film or layer of lubricant.

Protection by varnish and paint covering is the cheapest and most widespread method, widely applied in aviation for aluminum, magnesium, and steel parts.

Application of varnish and paint coverings is produced manually by brush, by dipping part in solution of paint, or by atomization of paint with help of paint sprayer.

In view of insufficient reliability, varnish and paint coverings usually are applied in combination with some other method of proteciton: thus, sheathing of duralumin is painted after being plated and anodized; part of magnesium alloys are painted after chemical oxidizing; and steel lines are painted after parkerizing.

For protection of aviation materiel from corrosion during transportation and storage we apply temporary anticorrosive protection, consisting of preservation and packing.

§ 2. Protection of Steels from Corrosion

Carbon and low-alloy structural applied in aircraft construction possess low corrosion resistance.

From all structural components of steels ferrite has the most negative electrode potential. Therefore it is anode, and cementite and other carbides are

cathodes. However, distinction in their potentials is small, and in practice microcorrosion of steel occurs as a result of different degree of oxidation of separate sections of surface. Here anodes will be slightly oxidized sections and pores of metal and cathodes will be strongly oxidized sections.

As a result of corrosion, unprotected steel parts will be covered by products of corrosion - rust. Rust constitutes brown friable deposit of ferric hydroxide, easily separated from basic metal. Rust does not protect steel from further corrosion but even promotes its development, since in it are condensed vapors of moisture.

For protection of steels from corrosion we apply metallic coverings, protective oxidized films, paint, and protective lubricants.

Protection by Metallic Coverings

Depending upon what metal is deposited on steel part, we distinguish: zincing, cadmium plating, nickel plating, chromium plating, copper plating, lead plating, tinning (covering with tin), indium plating, etc.

Deposition of protective metals on steel parts is carried out mainly by galvanic means and also by metallizing.

Galvanic method is one of basic methods of deposition of metal coverings on steel parts. Essence of this method consists in deposition on article of layer of protective metal with help of electrical current. For this, article is dipped in electrolyte bath and to it, the cathode is connected, d-c generator, while as anode serves plate of covering metal, or lead.

Under action of d-c electrical current of defined density and voltage on cathode (on part) occurs deposition of layer of protective metal. Diagram of installation for galvanic plating is given in Fig. 22.3.

Into composition of electrolytes of galvanic baths enter following components:

1) salts - sources of ions of precipitated metal. For instance, for zincing such salt is zinc sulfate, for chromium plating, chromic anhydride, etc.;

2) conducting salts or acids, increasing electrical conductivity of electrolyte. These include for instance for zincing and nickel plating, Glauber's salt;

3) buffers, holding acidity of electrolytes at constant level. These include boric acid, aluminum sulfate, and others.

Before being galvanized, parts are given preliminary treatment, consisting of mechanical purification, degreasing, and etching.

Mechanical purification of parts is produced by one of such methods as sandblast, grinding, or wire-brush (so-called scratching). At present at native plants is allotted much attention of mechanization and automation of processes of grinding and polishing before deposition of protective-decorative coverings.

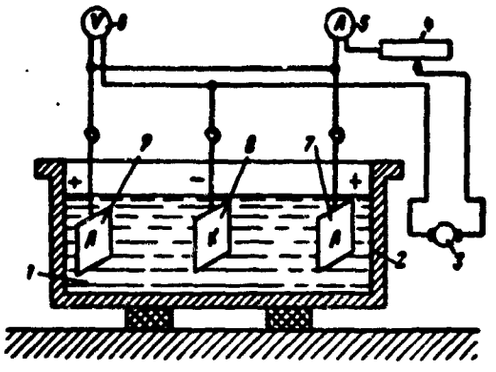


Fig. 22.3. Diagram of installation for galvanizing. 1 – electrolyte, 2 – bath, 3 – d-c generator, 4 – rheostat, 5 – ammeter, 6 – voltmeter, 7 – anodes, 8 – cathode (article galvanized).

In recent years in addition to mechanical preparation we are starting to apply electrolytic of chemical polishing, giving the greatest effect during treatment of small parts of complicated configuration. Essence of these processes consists in gradual smoothing of surface of part by means of dissolution of microroughness.

Degreasing is produced for full removal of all fatty contaminations. We distinguish preliminary and final degreasing. Preliminary degreasing is produced in organic solvents – kerosene or gasoline. In view of their inflammableness, for large quantity of parts we apply chemical degreasing in hot alkali solutions. Final degreasing has recently been produced by electrolytic method or with help of ultrasonics.

Electrolytic degreasing, recently finding wide use, is conducted in alkali solutions of approximately the same composition as chemical degreasing but with application of electrical current, considerably increasing intensity of process.

For purification of small parts of complicated configuration or parts prepared from dielectrics a new method of degreasing in ultrasonic field, which is starting to be applied at native plants is of great interest.

Etching is produced for removal from surface of part of oxidized films and products of corrosion. Steel parts are etched in solutions of sulfuric and hydrochloric acid. For acceleration of process is applied electrochemical (anodic) etching.

Pickling (mild etching) is last preparatory operation. It serves for removal

from surface of part of thin oxidized films appearing on parts under influence of atmosphere in periods between separate operations of preparation.

Pickling considerably increases strength of cohesion of electrolytic coverings with article. Chemical pickling of steel parts is carried out in 5% solution of sulfuric acid and lasts not more than one minute.

Recently at native plants technology of galvanic processes has been improved as followings:

1) acceleration of process by means of increase of current density; this causes necessity for increase in electrolyte of concentration of salts of precipitated metal and work with preheating and mixing of solution;

2) acceleration of process by means of application of reversible current, where covering takes on raised corrosion resistance.

3) obtaining of brilliant deposits directly in bath, which excludes process of mechanical polishing, reduces industrial cycle, and decreases loss of precipitated metal;

4) replacement of poisonous cyanogen electrolytes.

Most frequently for protection steels from corrosion in aircraft construction we apply metallic coverings of cadmium, zinc, chromium, nickel, etc.

Cadmium and zinc plating. Cadmium and zinc coverings are anode coverings for steel; therefore they are used widely for protection of responsible and loaded steel parts of aircraft and engines. Period of service of these coverings depends on character of environment. Thus, zinc coverings are more resistant in water-free media: oil, gasoline, kerosene, and also in atmosphere contaminated by different gases, products of combustion, etc.

Cadmium coverings are stabler in humid media, especially under conditions of marine atmosphere.

Thickness of protective covering of zinc reaches to 25 μ, and that of cadmium reaches 15 μ.

Best quality zinc and cadmium coverings are obtained in poisonous and expensive cyanogen electrolytes. Therefore for covering of small fasteners, when on quality of coverings no high requirements are imposed, where this is possible, we use noncyanogen electrolytes - acid, alkali, and others.

Galvanized and cadmium-plated parts, for increase of corrosion resistance,

are subjected to chemical treatment by so-called passivation.

In process of deposition of galvanic platings of zinc or cadmium, on cathode, along with deposition of metal, is liberated hydrogen, which, partially diffusing into surface layer of part, increases its brittleness.

For removal of brittleness due to saturation by hydrogen in process of galvanic plating we produce heat treatment of steel parts. For this, after deposition of covering, they are subjected to additional heating to 180-250°C with holding for two hours.

In connection with the fact that brittle rupture due to saturation by hydrogen after zincing is more probable than after cadmium plating, it is preferable to cadmium plate loaded steel parts. Galvanic zincing or cadmium plating of parts of high-strength steel [30KhGSNA] (30ХГСНА) is not permitted as prevention for sharp increase of brittleness owing to penetration of hydrogen.

Chromium and nickel plating. Chrome and nickel coverings with respect to steel are cathode depositions. They give beauty to appearance of part and therefore are basically decorative.

Chrome covering is deposited in thickness from 5 to 50 μ, and nickel is upto 30 μ (thick).

Chromium and nickel plating are produced in acid electrolytes. Chromium plating with protective-decorative purpose is carried out with underlayers of copper and nickel, and nickel plating is done over underlayer of copper. Complexity of covering is explained by the fact that with direct deposition on steel is obtained porous covering, not possessing good protective properties. Such coverings are used for protection of small parts not subject to friction.

Besides this is applied thickened covering of chromium over steel, deposited directly on steel without underlayer and attaining thickness of 0.7 mm. This covering can ensure heat resistance and also high wear resistance of parts subject to friction. Wear-resistance chromium plating is used for restoration of dimensions of parts during repair of aviation materiel.

On surface of part it is possible to create purposely a layer of porous chromium for improvement lubrication and decrease of wear. Porous chromium plating is used for parts working under conditions of friction at low specific pressures for the purpose of improvement of lubrication and decrease of wear (piston rings, landing-gear shock struts, etc.).

Recently for parts subject to friction (rods of hoist cylinders and gear struts) was introduced nonporous chromium plating. Such treatment of surface in considerable measure increases wear resistance and protects from corrosion in moderately aggressive media. For a number of steel parts having friction surfaces combined covering of chromium and cadmium has been introduced.

Recently work has been conducted on application of chemical nickel plating, which permits deposition of covering on articles of the most complicated profile and obtaining of uniform and brilliant deposits.

Essence of process consists in deposition of covering on metallic parts with help of reduction of nickel salts by hypophosphorite without application of electrical current.

Heat treatment after chemical nickel plating sharply increases strength of cohesion of nickel - phosphorous layer with basic metal and considerably increases hardness of covering.

Lead and indium plating. Basic assignment of lead coverings consists in improvement of run-in ability of parts (inserts, bushings, faces of rotors, plunger pumps, gears, etc.). Besides this, lead coverings are used to fill depressions and easing assembling of conjugate parts.

In connection with low corrosion resistance of lead to products of oxidation, lubricating oils, and also because of its low hardness, lead is covered with indium, with subsequent heat treatment.

As a result of heat treatment occurs formation of alloy of lead with indium, possessing best antifriction and anticorrosive properties. Thickness of indium covering is 0.06 the thickness of layer of lead.

Basic merits of electrolytic method of covering are high quality of deposited layer, possibility of exact control of its thickness, and low cost of precipitated metal.

However, this method has following deficiencies: impossibility of deposition of covering on parts of large dimensions, difficulty of obtaining even layer on parts of complicated form, and increase of brittleness of part due to saturation of its surface by hydrogen.

In certain cases, when for protection of steel parts it is difficult to apply galvanic method of deposition, we use metallizing method.

Metallizing consists in that we cover surface with thin layer of metal (metal spray gun) by spraying protective metal. As a result of spraying, surface remains uniform layer of metal. This method has wide application in aviation plants, since it permits covering large parts and assemblies. Metallizing is used with success for protection of large steel parts or parts of complicated configuration by zinc and aluminum.

Diffusion method consists in that surface layer of part is saturated by elements increasing corrosion resistance, for instance, chromium, aluminum, beryllium, nitrogen, and others. Part is placed in medium containing an element. Saturation is produced at high temperatures (to 1000°) by diffusion method.

Hot method consists in that metal is deposited on part during its submersion in bath with molten protective metal. This method is useful only for deposition of coverings on sheets and small parts.

Protective by oxidized films. For production of artificial protective films on steel parts we most frequently apply oxidizing and phosphorizing.

Oxidizing (bluing) consists in artificial creation on steel parts of protective film of iron oxides. There exist several methods of oxidizing. At present steel parts are oxidized mainly in hot water solutions of alkalis in presence of certain oxidizers. Before being oxidized, part is degreased and pickled. After being oxidized, part is washed in water and processed in soap solution. Then parts are oiled, which is done to increase protective qualities of film. Thickness of obtained films does not usually exceed 1-2 μ.

Deficiency of oxidizing is brittleness of film and its unstableness in water; therefore oxidizing is applied for protection of internal parts of engines and assemblies protected from direct influence of atmosphere and moisture (for instance, shafts, bushings, springs, gears, and others). Only in combination with lubricant does oxidizing reliably protect from corrosion under action of atmospheric air and gases.

Recently there have been developed new improved methods of oxidizing steel parts, which provide resistance to gas corrosion.

Phosphorizing consists of artificial creation on steel parts of protective film of phosphates of zinc, iron, and manganese.

Phosphorizing of aviation parts is produced in hot zinc - phosphate water.

Before being parkerized, part is specially prepared to increase protective qualities of covering. After being parkerized, coverings are processed in aqueous solution of bichromate, then colored or oiled.

Phosphate film possesses good protective properties in humid atmosphere but insufficient strength. Besides this, phosphate film serves as good base for application of varnish and paint coverings.

Parkerizing with color is applied widely, since it gives parts ability to resist well the action of atmosphere of fresh and sea water.

Parkerizing is used for protection of steel parts subjected to painting (lines for feed systems of aircraft) or parts of instruments (with subsequent oiling). Besides this, parts of high-strength steels 30KhGSNA are parkerized.

Other Methods of Protection of Steel

Painting. Application of protective layers of primer, enamel, and varnish is used for insulation of parts from direct influence of atmosphere and moisture. Most frequently for painting of aviation steel parts we apply butyric or vinyl chloride varnish and paint materials. Parts working under conditions of raised temperatures are covered with thermoresistant enamels: glyptal, siloxane, and others.

Lubricant. In case of necessity for brief or prolonged storage of steel parts in storehouses or during transportation they are covered with anticorrosive lubricants. Most widely used for protection from corrosion of steel parts are universal gun lubricant or lubricant consisting of mixture of machine and cylinder oils, technical vaseline, and rosin.

§ 3. Protection of Aluminum Alloys from Corrosion

Aluminum alloys, as is pure aluminum, oxidizes in presence of oxygen and are covered by thin oxidized film, possessing good protective properties. Any damage of film and disturbance of its continuity leads to lowering of corrosion resistance.

Of all structural components of aluminum alloys the most negative electrode potential belongs to pure aluminum and solid solution based on aluminum, while metallic compounds $CuAl_2$, $FeAl_3$ and so forth, have more positive potential.

Therefore in process of corrosion of aluminum alloys grains of solid solution in sections not having oxidized film are destroyed, since as cathodes sections covered by oxidized film and also metallic compounds. As a result of electrochemical

corrosion, surface of aluminum alloy is covered by products of corrosion — a loose friable deposit of aluminum hydroxide.

Of aluminum alloys less resistant to corrosion are those of duralumin type and V95; the more resistant alloys are those aluminum with silicon, magnesium, or manganese.

Aluminum alloys are subject to all forms of corrosion destruction: uniform corrosion is inherent to all forms of aluminum alloys; local and intercrystalline corrosion are most frequently encountered in alloys hardened by heat treatment; corrosion cracking is encountered in deformed thin articles from alloys of duralumin type and V95.

For protection of aluminum alloys from corrosion we apply protective oxidized films, metallic coverings, varnish and paint coverings, lubricant protection by protectors, and others. In aircraft building the most widely applied are protection by oxidized films and metallic coverings of aluminum or alloys of aluminum with zinc.

Protection by Oxidized Films

As it is known, oxidized film Al_2O_3, which appears on aluminum and its alloys under natural conditions, has porous structure and nonuniform thickness. Series of methods for protection of aluminum alloys is based on artificial thickening of oxidized film and removal of its porosity.

Artificial creation of durable protective film on articles of aluminum alloy is carried out mainly by electrolytic method and method of chemical etching. Electrolytic method of creation of oxidized film on aluminum alloys is called electrochemical oxidizing or anodizing, and chemical method is called chemical oxidizing.

Before being oxidized, parts made from aluminum alloys are subjected to preparation consisting in degreasing, etching in alkaline bath for removal of contaminations, and purification in solution of nitric acid.

Anodizing (anodic oxidation) consists in artificial creation on surface of part, by means of electrolysis, of stable protective film of aluminum oxides.

Part to be anodized is placed in bath with electrolyte and connected to anode of direct current. As cathodes serve lead plates or container of bath (Fig. 27.4). Under influence of electric current from surface of part is liberated oxygen,

oxidizing metal and forming oxide film on it.

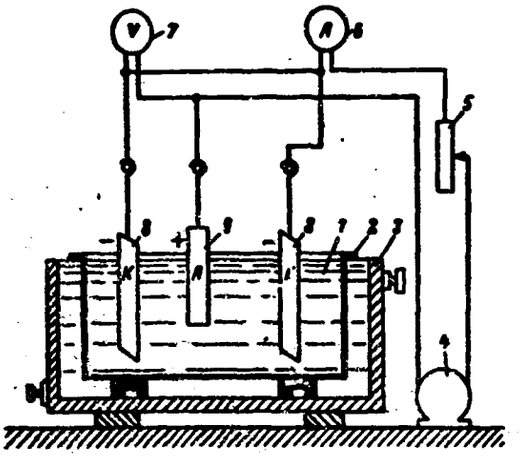


Fig. 22.4. Diagram of installation for anodizing. 1 – electrolyte, 2 – bath for electrolyte, 3 – bath for cooling water, 4 – electric generator, 5 – rheostat, 6 – ammeter, 7 – voltmeter, 8 – cathodes, 9 – anodes.

Several methods of process of anodizing exist. Most frequently for anodizing we apply direct current. Use of alternating current as compared to direct is connected with large difficulties of process and large expenditure of electrical current.

As electrolytes during anodizing are applied solutions of sulfuric or chromic acides. Basic is sulfuric acid method, which, owing to cheapness and simplicity, has found greater application that the chromate method.

Deficiency of sulfuric acid anodizing is aggressiveness of electrolyte and impermissibleness of treatment of parts of complicated configuration and also riveted and welded elements. This method is used for treatment of sheet material, profiles, etc.

Deficiences of chromic acid method of anodizing are somewhat worse quality of oxide film, great difficulty and lesser economy of process than those of sulfuric acid method. This method is used for treatment of welded parts and parts of complicated configuration.

As a result of anodizing, article is covered with hard and colorless oxidized film with thickness to 12 μ. In Fig. 22.5a is shown diagram of structure of oxidized film on aluminum or its alloys. Thanks to its porosity, film is well

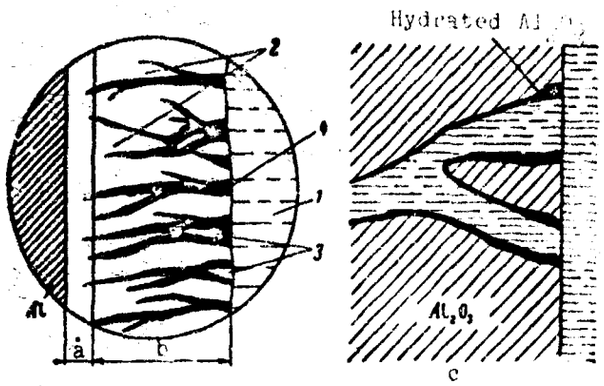


Fig. 22.5. Structure of oxidized film on aluminum. a) dense layer with thickness of 0.01-0.1 μ, b) friable layer with thickness of 10-100 μ, c) structure of channels in oxidized film, 1 – electrolyte, 2 – aluminum oxide, 3 – aluminum hydroxide, 4 – capillary channels.

impregnated by oil, is colored well by water-base dyes, and is good base for varnish and paint. After being anodized, parts are washed and passivated for improvement of protective properties of film.

The most widespread method of passivation is treatment of film in hot solution of bichromate or in hot water acidified with sulfuric acid. Here pores of film, through which can penetrate moisture and gases, provoking corrosion of metal, are filled in first case with bichromate, in the second with aluminum hydroxide (Fig. 22.5b).

After filling in solution of bichromate, oxide film obtains yellow-green nuance, and after filling in hot water, it becomes lightly-dull. Thus obtained film possesses high protective properties.

In those cases when application of anodic oxidation is hampered by complexity of configuration of parts, we apply chemical oxidizing. Protective film is obtained here as a result of chemical interaction of aluminum alloy with alkali solution containing oxidizer.

Chemical oxidizing of aluminum alloys is used since it gives less satisfactory protective films of insignificant thickness. It is used for semifinished products made from alloys of aluminum not containing copper (for instance, pipe, welded containers, and parts of complicated configuration made from alloys [AMg] (AMr) and [AMts] (AMu).

Most frequently oxidized parts are covered with butyric base and are colored by enamel of needed color.

After being oxidized, parts may be given needed color by means of impregnation of oxide film by water-soluble dyes. For this it is necessary to treat parts freshly-oxidized by sulfuric acid method, after neutralization in ammonia and washing, with water solution of corresponding dye. For coloring of anode films we apply different organic dyes or inorganic compounds. After that parts are covered with colorless oil, varnish, or lubricated with hot spindle oil, depending upon assignment of parts and conditions of their work.

Anodic oxidation and coloring of articles made from aluminum alloys increases their corrosion resistance, gives them decorative appearance and required color. Most frequently it is applied during treatment of parts of instruments.

In recent years has been introduced method of deep (thick-layered) anodizing, allowing us to obtain oxidized film with thickness to 150 μ.

Thick oxidized films obtained on aluminum and its alloys during anodizing in sulfuric acid possess great hardness, good heat resistance, and high electrical and thermal insulation properties. Film is brittle but very securely connected with metal and is well impregnated by oil, in view of its great porosity.

Thick oxidized film is applied in the first place for creation of surface with raised hardness and resistance to wear on parts made from aluminum alloys subject to friction and experiencing erosional influence (different cylinders and frontal part of wings) and also for production of thermal insulation layer and electric insulating covering.

Expedient thicknesses of films for these cases are the following: for parts subject to friction, 50-60 μ; for guarantee of necessary thermal insulation properties, 100-150 μ; for electric insulating, 20-40 μ (depending upon needed resistance).

Methods of obtaining thick oxidized films on aluminum and its alloys do not have fundamental distinction from methods widely applied in industry for obtaining oxidized films for protection of metals from corrosion, but they essentially differ from conditions of anodizing.

Technology of deep anodizing differs from usual anodizing in solution of sulfuric acid by operating conditions and strongly lowered temperature (-6 to -8°C).

Cooling is necessary for direct removal from metal of heat of separation during anodizing. The fact is that building up of oxidized film and liberation of heat during anodizing occurs not on external surface of article but under layer of oxide formed earlier on metal – film boundary. In view of this, in the presence of thick film, being good heat insulator, for its further buildup cooling of part only in electrolyte becomes insufficient.

Intensity of cooling is determined by desired thickness of oxide film. The greater the thickness of film which it is necessary to obtain the lower should be operating temperature. As refrigerants during treatment of small parts are applied ice, dry ice, and mixture of ethylene glycol and water. During treatment of big parts cooling is produced by freon installation.

Obtaining of thick films is connected also with composition of aluminum alloy. With application of additional cooling the most thick (to 200 μ) and hard film can be obtained on pure aluminum and its uniform alloys (AMg, [AV] (AB)); well anodized are aluminum – silicon alloys [AL2] (AJ2), AL4, AL9; on alloy D16 can be obtained film with thickness to 80 μ; considerably better anodized is high-strength alloy V95. For alloys of type of duralumin D1 and D6 deep anodizing is not recommended, since they are thereby etched.

On parts subjected to deep anodizing is not allowed presence of acute angles and edges, burrs, and other pointed places, since on them occurs concentration of current, provoking strong local heating, which can lead to burning of parts.

Protection by Metallic Coverings

Aluminum alloys may be reliably protected from corrosion by metallic coverings, since large part of metals applied for this purpose possess higher electrode potentials and their contact causes corrosion of aluminum alloys. Besides this, in view of fast oxidizability of aluminum alloys, it is difficult to achieve good cohesion of covering with alloy.

Of metallic coverings most frequently for aluminum alloys is applied plating; less often, galvanic plating. Sheets of alloy of duralumin type are plated with pure aluminum, and for alloy V95 we use alloy of aluminum with 1% zinc. In both cases are obtained anode coverings protecting metal not only from mechanical but also electrochemical corrosion. Process of plating duralumin and alloy V95 was considered earlier.

Difficulty of depositing galvanic platings on aluminum alloys limits their application. Nevertheless in aircraft building for parts made from aluminum alloys we apply galvanic plating of nickel, chromium, zinc, and other metals.

Sequence of technological operations and composition of electrolyte are established depending upon form of covering and material of part. The most widespread in industry is zincate method of preparation of aluminum and its alloys for galvanic platings. Essence of this method consists in that during submersion of aluminum in solution of sodium zincate there occurs dissolution of oxidized film with simultaneous displacement from solution of metallic zinc.

After zincate treatment of aluminum alloys, it is possible to produce galvanic nickel plating, chromium plating, copper plating, or deposition of any other covering. For instance, in aircraft building are applied tight and porous chrome coverings for parts made from alloys AK4, D16, and V95.

Porous chrome covering with thickness of 150 μ is securely connected with material of part and holds lubricant well. Tight chrome covering is obtained during subsequent holding after chromium plating of part at 300°C for two hours. In the presence of chrome covering parts made from aluminum alloys sustain heating to 300°C, which permits expanding field of application of these alloys in construction of contemporary high-speed aircraft. Recently developed was method of deposition on aluminum and its alloys of new protective-decorative covering – ematal' film – which is being introduced in native production. As a result of ematalizing is obtained dull film similar to varnish and paint or plastic covering. This film colors well in water solutions of aniline dyes and possesses good anticorrosive, electric-insulating, and wear-resisting properties. Besides this, covering of ematal' film is considerably lighter than varnish and paint (1 m^2 of film weighs upto 10 g in all).

Other Methods of Protection

Anode treatment with subsequent coloring is applied widely in aircraft construction for protection of majority of parts of aircraft and engines prepared from aluminum alloys (sheets, profiles, rivets, tubes, forgings, and castings). Thus, for instance, part made from unplated materials (pressed profiles, stampings from alloy AK6, and castings from alloy AL9) after coloring oxidized are covered with

lacquer primer [illegible] (AEP-1), [illegible], [illegible] obligatory hot drying. Internal surfaces of structural [illegible] are also [illegible] covered with the same primers.

Plated sheathing of contemporary high-speed aircraft, after being anodized, is covered with light, quick-drying lacquers and enamels based on synthetic resins, which are produced at present by native industry. For these purposes we apply butyl methacrilate enamel of grade A-624 and lacquers: alkyd of grade 138T and pentaphthalic of grade 170A.

For protection from corrosion of parts made from aluminum alloys we apply covering of neutral technical vaseline. In its absence can be used mixtures of aviation oil MK or [MS] (MC) with 4-10% ceresine.

For protection of parts made from aluminum alloys from corrosion in liquid media is applied also electrochemical protection by protectors, essence of which was considered earlier.

§ 4. Protection of Magnesium Alloys from Corrosion

Aviation magnesium alloys possess very low corrosion resistance. This is explained by very small value of electrode potential of magnesium; in electromotive series it is the lowest of all technical aviation metals. Besides this, film of oxides on magnesium alloys does not possess good protective properties.

Essential deficiency of majority of magnesium alloys is their inclination to corrosion cracking under stress. Cast malleable alloys are subject to it to a larger degree than foundry alloys.

Of all structural components magnesium alloys the most negative electrode potential belongs to solid solution based on magnesium, and metallic compounds have more positive potential. Therefore in presence of corrosion of magnesium alloys grains of solid solution will be destroyed. As a result of electrochemical corrosion surface of magnesium alloys is covered with products of corrosion - white deposit of magnesium oxyoxide.

[illegible] of magnesium with [illegible] small [illegible] sharply increases its corrosion resistance. Thus introduction into magnesium alloys of manganese and zinc as main [illegible] small [illegible] that it ensures industrial use of these with application of [illegible] for protection from corrosion. Therefore [illegible] contain [illegible] (3.5-4.5%) Mn, [illegible] reduced quantity of manganese,

are the most resistant to corrosion of all magnesium alloys.

Since obtaining of galvanic plating on magnesium alloys is conjugate with large difficulties and contact of them with all metals causes, in presence of moisture, intense corrosion of alloy, basic methods for their corrosion protection are chemical or electrochemical oxidizing in combination with varnish and paint coverings.

Oxidizing treatment alone, considerably increasing resistance of magnesium alloys to corrosion, cannot completely ensure safety of articles in conditions of exploitation of aviation materiel.

Despite the fact that quality of protective oxidized film after electrochemical oxidizing is somewhat higher than after chemical oxidizing, in view of large complexity and cost of technological process, anode treatment has lesser application.

To anode oxidizing are subjected mainly parts made from magnesium alloys limited in tolerances, since this process does not change dimensions of processed parts.

Chemical oxidizing of magnesium alloys is similar to chemical oxidizing of aluminum alloys. It consists of artificial creation on surface of part of protective film of oxides and salt-like compounds by means of etching.

Before application of chemical oxidizing, parts are prepared: degreasing in alkaline solution and removal of remainders of fluxes in solution of chromium anhydride, capable of subsequently of being seats of corrosion.

Protective film on parts made from magnesium alloys is obtained as a result of chemical interaction of alloy with sclution. There exist several compositions of solutions for chemical oxidizing. However, the greatest application is found for acid baths, not provoking etching surface and therefore not affecting in practice change of dimensions of parts after oxidation.

Obtained film has thickness of upto 3 μ and color from golden to grayish-brown. Its protective properties are fully satisfactory. For increase of protective qualities of oxidized film, as on aluminum alloys, film is filled by means of treatment of articles in 10% solution of bichromate. After being washed and dryed, oxidized parts made from magnesium alloys are subjected to coloring by two layers of lacquer primer ALG-1 or glyptal ALG-7 and two layers of glyptal or green perchlorvinyl enamel.

Oxidized and colored parts made from magnesium alloys well resist action of atmosphere but are nonresistant to action of sea water.

Effective but more costly method of protection of magnesium alloys is treatment by selenious acid. This method gives salt-like film not inferior in protective properties to oxidized film. However, owing to high cost of selenious acid, it is applied basically for local oxidizing during repair of sheathing.

As it is known, at contacts of parts made from magnesium alloys with steel, copper, and aluminum alloys, rate of their corrosion considerably increase. Therefore at connections of magnesium alloys with other alloys we apply active measures for decrease of harmful influence of contact.

Low corrosion resistance of magnesium alloys imposes stringent requirements on aircraft maintenance, especially under conditions favorable for formation and development of corrosion (high humidity and raised temperature).

§ 5. Corrosion Protection of Aviation Materiel During Work Under Tropical Conditions

In a number of cases of aircraft equipment is exploited in regions with tropical or maritime climate. Here for guarantee of normal work considerable attention should be allotted to anticorrosive measures.

As it is known, rate of atmospheric corrosion is determined by mutual influence of relative humidity and contamination of atmosphere by impurities of sulfurous compounds, by evaporations of hydrochloric acid, and by salted sea water. Atmospheric corrosion is the strongest in industrial regions and near the sea and is moderate in dry atmosphere.

Tropical climate is characterized by following atmospheric phenomena: high absolute humidity, due to frequent rains; raised temperature and intensity solar light; large variations of relative humidity and temperature; and strong contamination of atmosphere by aggressive gases and dust.

Under conditions of raised temperature and humidity corrosion processes are considerably more intense than under conditions of moderate climate. Under these conditions period of service of nonmetallic materials also is reduced. High humidity creates favorable conditions for development of various kinds of microorganisms (mold and bacteria), which may cause corrosion of metallic parts, rotting and destruction of nonmetallic materials.

It has been established that, in spite of peculiarities of atmospheric phenomena, corrosion in tropical countries is influenced by the very same factors as in countries with moderate climate. Thus, in countries with tropical climate it is possible to supply that equipment which resists corrosion under difficult conditions of moderate climate.

Anticorrosion resistance of articles in tropical regions depends on correct selection of structural materials of anticorrosive covering and its thickness, on quality of finishing of surface, and on thorough carrying out of temporary protection.

During the designing of articles and parts intended for work under conditions of tropical climate a series of circumstances should be considered.

During selection of structural materials it is necessary to give preference to materials possessing high corrosion resistance. Thus, for instance, in case of impossibility of protection from corrosion for conditions of exploitation and design features of parts, for their manufacture one should apply stainless instead of low-alloy steel.

To prevent appearance of microgalvanic cells in joined parts it is necessary to select materials ensuring least difference of electrode potentials between them. Thus, for instance, harmless contacts for aluminum alloys are cadmium coverings. Also allowed is mutual contact of aluminum alloys of different chemical composition. For magnesium alloys impermissible contacts are those with unprotected steel, nickel, copper, and copper alloys.

It is necessary to anticipate possibility of carrying out of anticorrosive protection of parts and assemblies. During deposition on article of anticorrosive coverings it is necessary to observe thoroughly the rules of technological process of deposition.

For protection from destruction under tropical conditions of parts and articles made from nonmetallic materials it is necessary to carry out the following recommendations. It is necessary to use materials having raised fungusproofness; for increase of resistance to rotting application of antiseptic is recommended. Thus, for instance, for increase of resistance to molds textile materials are impregnated with 0.5% alcohol solution of pentachlorophenol. For protection from influence of microorganisms we apply treatment by such antiseptics as oksidifenil

and al'bikhtol.

For increase of water resistance of nonmetallic materials it is necessary to use lubricant, high temperatures of drying, and so forth. Dry atmosphere inside article is created by means of its hermetic sealing and application of such drying substances as silica gel.

Construction of articles exploited under conditions of tropical climate should facilitate application of temporary protection and not prevent thorough care of them and purification from mud.

Best effect of anticorrosive protection of aviation materiel designed for work in tropics is given by: for steels, electrolytic covering of cadmium or phosphating; for aluminum alloys, anodizing for magnesium alloys, chemical oxidizing in combination with varnish and paint coverings.

For these purposes were developed varnish and paint materials based on synthetic resins, stable under conditions of aggressive medium of tropics. For instance, varnish and paint materials based on alkyd and acrylic resins (primers [AU10s] (АГ10с) and [VL-02] (ВЛ-02), varnish 9-32f, enamel [PF-28] (ПФ-28)); based on phenol resins (primer [FL-03] (ФЛ-03), varnish AO, enamel FL-76); based on perchlorvinyl resins (enamel [KhV16] (ХВ16) and [KhVE] (ХВЭ)), and others.

Under conditions of humid tropic climate stainless steels behave satisfactorily. Application of them is allowed without finishing. Corrosion resistance of parts made from stainless steels essentially depends on heat treatment and quality of finishing. The highest corrosion resistance belongs to parts with polished surface. Parts made from titanium alloys have high corrosion resistance and do not need protective coverings.

As it was shown above, during transportation and storage of articles ensure temporary anticorrosive protection, consisting in preservation and packing. Preservation is carried out by acetobutyrate films, easily removed from surface by plastic and different lubricants, and consists in application on surface of articles of insulating compositions. It is necessary to consider that applied preserving lubricants cannot be protective layer for prolonged time. Lubricant allows passage of moisture, which may cause corrosion. Therefore for prevention of corrosion it is necessary to replace lubricant periodically.

For aircraft on the whole or for its separate big units we use packing in the

form of hermetic cases, with use of special siccatives. As material for protective cases we apply polyvinyl chloride, polyethylene, and certain thermally sealable or self-sealing fabrics. Inside case is placed siccative. Usually for this we use special powder (silica gel), able to actively absorb water vapor. These methods ensure safety of articles used in regions with tropical and maritime climate during prolonged period of storage.

S E C T I O N F I V E

NONMETALLIC MATERIALS

Development of contemporary aviation materiel would have been inconceivable without new materials, among which a special place is occupied by nonmetallic materials, and, first of all, synthetic polymeric materials.

For creation of aircraft operating at supersonic speeds under high-attitude conditions are required materials of new type: thermoresistant unbreakable glass for cabins; heavy-duty heat insulators will low volumetric weight; flexible hoses and seals, preserving plastic properties over wide range of temperatures from -100°C to +400°C and above; structural parts of airplane fuselages made from fiberglasses, possessing strength of steel with 25-30% less weight, not corroding, and not requiring varnish and paint coverings; internal upholstering of poroplasts, considerably lowering weight and making effective heat and sound proofing.

In nature there are no materials with such specific exploitational characteristics. Therefore new compositions of synthetic materials with preplanned complex of necessary properties can be obtained only by artificial means.

In aircraft construction synthetic materials have long been applied, since without them it is impossible to create new technology. As a matter of fact, high-quality varnish and paint coverings based on synthetic resins; synthetic glues, sealers, and consolidators, organic glass, polymeric materials for internal finishing, plastic insulation for electrical communications, plastics for bodies of radio and television receiving and transmitting devices, and also different special equipment and instruments, and many other, have long been widely used in aviation industry.

Introduction of contemporary chemical materials in aircraft construction is given especially important value in connection with decisions of XXII Congress of our Party and also November (1962) and December (1963) plenums of Central Committee Party of the Soviet Union.

At present in aviation industry is applied large quantity of forms, types, and grades of different nonmetallic materials: plastics, rubber, varnish and paint, hermetic sealers and packings, glues, textile, and wood.

Here volumes, proportions, and role of separate nonmetallic materials utilized in aircraft construction are changing considerably, owing to effective replacement of natural materials by the most economic chemical materials. Thus, paramount value belongs in contemporary industry to plastics, rubber, chemical fibers and fabrics, synthetic sealers, and coverings, whereas in the past the most important of the nonmetallic materials were natural wood and textile materials.

C H A P T E R XXIII

PLASTICS

§ 1. General Information

Plastics occupy special place among nonmetallic aviation materiels.

Separate forms of plastics have such valuable properties as high specific strength, fricational properties, transparency, electric insulating properties, heat and sound insulation properties, chemical resistance, and many others.

The fact that plastics have at present large value during creation of aviation equipment confirms the fact that in constructions of contemporary jet engineering find application over 120 thousand different plastic parts.

Plastics are synthetic materials obtained on the basis of organic substances or their mixtures with different substances, possessing ability to be molded under certain conditions.

Plastics usually are complex compositions consisting of several substances. Required complex of properties is attained by selection of separate components and their defined relationship in composition of plastics.

Common component of all plastics is binding substance (usually high-molecular organic compound), which gives to plastics their plasticity and ability to be molded and then to harden, preserving obtained form. Certain plastics consist only of binding substance.

For increase of mechanical strength, thermal resistance, and electric insulating properties of majority of plastics, into their composition is introduced another very important components – filler, in the form of different powdery, fibrous, and laminar materials, which, after impregnation with binding substances, are pressed

into a uniform mass.

Besides binding substances and fillers plastics include plasticizers (for increase of thermoplasticity), dyes (imparting defined color), and other additions.

As binding substance in plastics are applied mainly synthetic resins and, in certain cases, cellulose esters.

Synthetic resins are obtained from substances with low molecular weight and also from natural or previously obtained substances with high molecular weight by means of various further chemical transformations. Obtaining of high-molecular synthetic resins can be accomplished basically by methods of polymerization or polycondensation. Essence of polymerization consists in combination of initial (uniform or heterogeneous) substances, monomers, with subsequent formation of new high-molecular substance, polymer (without yield of by-products). Polymerization is a continuous (chain) or step process. During polycondensation (or simply condensation)formation of new high-molecular substance, polymer, is accompanied by yield of by-products. Polycondensation is step process when intermediate products formed in every step can be separated. Besides this, high-molecular compounds can be obtained by methods of different chemical transformations.

Depending upon properties of binding and its behavior during heating, plastics are divided into thermosetting and thermoplastic types.

Thermosetting (thermoirreversible) substances when heated to defined temperature are first softened, then, as a result of irreversible chemical reactions, harden.

Of greatest application as binding substances are the following thermosetting resins:

Phenol-formaldehyde, products of polycondensation of phenols (phenol, cresol, resorcin) with formaldehyde or furfurol. These resins have long been known and are widely used for power and nonload-bearing plastics. They possess thermoresistance to 300°C.

Aminoformaldehyde (carbamide), products of polycondensation of amines (urea - thiourea, melamine) with formaldehyde. Used for electric insulating and as auxiliary and decorative plastics. They have thermoresistance to 145°C.

Anilinoformaldehyde, products of polycondensation of aniline with formaldehyde. Used for high-frequency electric insulating plastics. Possess thermoresistance to 110°C. Applied usually in combination with phenol-formaldehyde resins. Have

raised water-resistance, chemical stability, and electric insulating properties.

Epoxies, reaction point product of polymerization of epichlorohydrin and polyatomic phenol (diphenylpropane, resorcin, and others). They are thick, viscous liquids soluble in alcohol and acetone. Used for high-strength structural plastics.

Polyester, product of polymerization or polycondensation of esters of dibasic acids (maleic, sebacic, adipic), anhydrides (phthalic, maleic), and polyatomic alcohols (ethylene glycols, propylene glycols, diethylene glycols).

Applied for high-strength structural and electric insulating plastics. Have thermoresistance to 300°C. Together with good properties, can be molded at low pressures.

Polyorganosiloxanes, products of polycondensation of polysilicone compounds. Used for thermoresistant and electric insulating plastics. Have thermoresistance to 400°C; possess high elasticity and chemical stability.

Thermoplastic (thermoreversible) high-molecular compounds when heated gradually obtain plasticity and when cooled again pass into solid state.

Thermoplastic resins are used for manufacture of cast masses and sheet or film plastic materials not containing filler.

The biggest application as binders is found for the following thermoplastic resins:

Polyethylene, product of polymerization of ethylene and its derivatives. Used for electric insulating plastics.

Polyvinyl, product of polymerization of chlorine derivatives of ethylene. Used for electric insulating, chemically resistant, heat resistant, and decorative plastics.

Polyfluoroethylene, product of polymerization fluorine derivatives of ethylene. Used for thermoresistant, chemically resistant, and high-quality electric insulating plastics.

Polystyrenene, product of polymerization of styrene (phenylethylene). Used for electric insulating plastics.

Polyacrylate, product of polymerization of acrylic and methacrylic acid and their derivatives. Used for transparent window plastics.

Polyamide, product of polycondensation of diamines with dicarboxylic acids and also addition polymerization of lactans of amino acids. Used for high-strength thermoresistant and other plastics.

Polyurethane, product of polycondensation (polymerization) diisocyanates with polyatomic alcohols or diamines. Used for high-strength plastics.

Cellulose esters. Cellulose is basis of all vegetable cells (cotton, wood, straw, etc.) and constitutes natural high-molecular compound. As a result of treatment of cellulose with concentrated acids, we obtain cellulose esters: cellulose xanthate (alkali cellulose treated with carbon bisulfide), nitrocellulose (cellulose treated with mixture of nitric and sulfuric acid), and cellulose acetate (cellulose treated with acetic acid).

Xanthogenate dissolves well in weak solutions of alkalis; this is used in production of cellophane films. Nitrocellulose is stabler than xanthogenate and is independent material. It is soluble in acetone, ether, and other organic solvents. It is used for production of celluloid and elastic films. Cellulose acetate also is soluble in organic solvents. It is applied in production of films and articles obtained by pressing or casting.

All cellulose esters are hygroscopic, possess low chemical stability. More stable are the simple cellulose esters of ethyl cellulose type (cellulose treated with ethyl alcohol) and benzyl cellulose (cellulose treated with benzyl alcohol). They dissolve well in organic solvents and at raised temperature pass into viscous-fluid (resin-like) state. They are used for manufacture of films and plastics.

Plasticizers. Plasticizer are introduced into plastics for increase of elasticity of ready article and to facilitate drop forging. As plasticizers are apply different organic substances: stearin, castor oil, oleic acid, dibutyl phthalate, and others.

Increase of plasticity of thermoplastic resins is dictated by the fact that the majority of them have reduced plasticity, hampering their workability. This is why for more effective molding to composition of plastics are introduced special (usually low-molecular) substances, plasticizers, which promote increase of plasticity and fluidity of resins, especially at raised temperatures.

With use of thermosetting resins increase of plasticity may be obtained through introduction of plasticizer. Therefore increase of elasticity is attained by preliminary fusion of thermosetting resins with high-plastic resins or rubbers.

Fillers are important component of plastics and are introduced for improvement of physico-mechanical properties and reduction of costs of plastics.

According to origin, fillers are divided into organic and inorganic types. Fillers of organic origin are materials based on cellulose. They lower brittleness of resins and preserve low specific gravity. However, they increase hygroscopicity and decrease thermoresistance of plastics.

Fillers of inorganic origin increase brittleness of plastics, increase thermal resistance, and improve electric insulating properties. During molding plastics with mineral fillers display considerably less shrinkage than plastics with organic fillers.

Depending upon structure, in plastics can participate fillers: powdery (in the form of powdery crumbs), fibrous (in the form of different fibers), lamellar (in the form of sheet materials).

As powdery fillers are used wood meal, cellulose, mica, quartz, meal, soot, graphite, and certain others.

In thermosetting pressed composition the filler is an obligatory component, where its quantity attains 50% of total weight of mass. In thermoplastic pressed compositions or cast masses when necessary we use certain mineral fillers, which are introduced in small quantities.

General properties of plastics with powder-like fillers are their comparatively low mechanical strength and high brittleness. However, positive quality is their good fluidity and, consequently, the ability of such plastics to be molded into thin-walled articles of complicated configuration.

As fibrous fillers we use cotton waste, asbestos fiber, and glass fiber; besides these, there can be used cuttings of fabric, paper, cardboard, plywood, and others.

Fibrous fillers increase mechanical properties of plastics (including impact toughness); however, in virtue of lower fluidity (than in the in case of plastics with powdery fillers), they hamper processes of molding and possibility of manufacture of articles of complicated configuration.

As laminar fillers are applied the following homogenous-sheet materials: paper, cotton fabric, glass and asbestos fabric, and plywood.

Application of sheet (leaf) fillers gives possibility of obtaining plastic with the highest mechanical properties (strength, wear resistance, etc.) and also a whole series of special properties. Such plastics are called load-bearing and structural.

In certain cases we prepare plastics without fillers. There usually are transparent plastics of organic-glass type or separate opaque compositions.

Additional components. Besides basic components (binding substances, fillers, and plasticizer), into composition of plastics can be introduced different additional components, giving them special properties. Into composition of plastics, to impart defined color, are introduced corresponding coloring substances. Dyes are applied either in the form of crushed mineral pigments (Prussian red, and others) or in the form of organic dyes (nigrosine, methyl red, methyl blue, and others). In certain cases we introduce a duller to reduce transparency of plastic.

In powdery plastics as additions participate fusible, wax-like high-fluid, substances of lubricant type, facilitating extraction of articles from forms after pressing.

For acceleration of solidification of thermosetting plastics into their composition before molding we introduce catalysts (peroxides, acids, or salts).

For production of plastics having porous or cellular structure, into their composition we introduce special substances - expanding agents.

As additions in composition we introduce age-resisters (antioxidants).

§ 2. Classification of Plastics

Depending upon nature of their base (binding substances), all plastics can be of organic or inorganic origin. The biggest application in aviation industry is found for plastics of organic origin.

Depending upon behavior when heated, we distinguish thermoplastics and thermosetting plastics. To thermoplastics pertain plastics constantly preserving ability to be repeatedly molded at defined temperature and pressure. To thermosetting type pertain plastics able to be molded once, only in defined stage of production at determined pressure.

According to type of filler entering into composition of plastics the latter are subdivided into powder, fibrous, and laminar plastics, and also plastics without filler.

Plastics consisting of binding substance without filler or with powdery filler are designated according to kind of binder with addition of termination "layer".

Plastics, depending upon base - kind of binder - are divided into the following groups:

phenoplastics – plastics based on phenol-formaldehyde resins;

aminoplasts – plastics based on aminoformaldehyde resins;

anilinoplasts – plastics based on anilinoformaldehyde resins;

esterplasts – plastics based on polyester resins;

ethyleneplasts – plastics based on polyethylene resins;

vinyl plastics – plastics based on polyvinyl resins;

teflons – plastics based on polyfluoroethylene resins;

styrenes – plastics based on polystyrene resins;

acrylics – plastics based on acrylic resins;

epoxies – plastics based on epoxy resins;

amides – plastics based on polyamide resins;

urethanes – plastics based on polyurethane resins;

silicones – plastics based on silicone resins;

cellulose – plastics based on cellulose esters.

Plastics with lamellar fillers, physico-mechanical properties of which are determined basically by properties of filler and not properties of binder, are named according to the character of filler;

textolite – plastic with filler in the form of cotton or linen fabric;

fiberglass laminate – plastics with filler in the form of glass cloth;

asbestos laminated – plastic with filler in the form of asbestos fabric;

getinaks (laminated paper) – plastic with filler in the form of paper or cardboard;

asbolite – plastic with filler in the form of asbestos cardboard;

wood-laminated plastics (drevolit) with filler in the form of plywood.

Plastics with fibrous fillers also are named according to kind of filler;

voloknit – plastic with filler in the form of organic fiber;

steklovoloknit – plastic with filler in the form of glass fiber;

asbovoloknit – plastic with filler in the form of asbestos fiber;

tekstо- (bumago-, drevo-) voloknit – plastic with filler in the form of textile crumbs or cuttings of fabric, paper, cardboard, or plywood.

According to physico-mechanical properties at normal temperature (20°C), all plastics are divided into:

rigid, constituting hard elastic substances with high elastic modulus and

low ultimate elongation, preserving form during external stresses at normal or raised temperatures;

semirigid, constituting hard elastic substances with average elastic modulus, high ultimate elongation and tension set;

soft, being soft and elastic substances with low elastic modulus, high relative elongation, and low tension set;

elastic, constituting soft and elastic substances with low elastic modulus, yielding to nigh stretching strain, where all deformation, or the larger part of it, is reversible and instantly disappears at normal temperature.

Among plastics it is customary to refer only rigid, semirigid, and soft types.

Plastics with powdery fillers (just as plastics without fillers) are released in the form molding powders (for pressing), injection compounds (for casting), and sheet materials (for machining, bending, stamping, and blowing). Soft and elastic plastics, released in the form of sheets, tapes, etc., are designated as masticated rubbers. Materials released in the form of thin films (thickness to 0.5 mm), regardless of degree of softness and extensibility, are designated as films.

Materials with low specific gravity having porous cellular structure, with specific gravity of from 0.3 to 3 kN/m^3 (0.03 to 0.3 gf/cm^3), are designated as foam materials, and those with specific gravity over 3 kN/m^3 (0.3 gf/cm^3) are called porous materials.

For practical purposes it is most convenient to classify plastics according to application and assignment. In this case plastics are divided into structural, friction, antifriction, special, chemically resistant, electric insulating, transparent, heat proof, soundproof, sealing, and insulating types.

§ 3. Basic Properties of Plastics

Basic technical characteristics of moulding and injection compounds are their technological properties.

Appearance - controlled by type of resin and fillers applied. Thus, aminoplastics are colorless and can obtain any color, depending upon pigments; phenoplastics have brown nuance, and therefore it is recommended that they be colored in dark tones, etc.

Content of volatiles and moisture should be minimum. Their raised content worsens quality, lowers electric insulating properties, complicates process

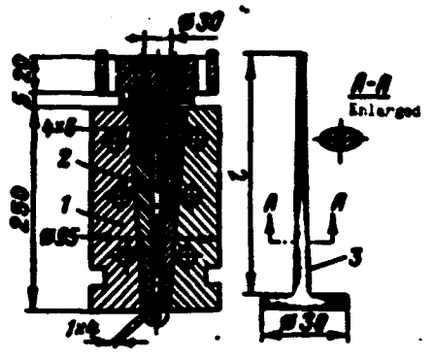


Fig. 23.1. Mold for determination of flowability. 1 – body, 2 – detachable cone, 3 – geometry of material after test for flowability.

molding, and leads to lowering of strength.

Pelleting property – ability of material to be packed during processing on pelleting machines without sintering or fusion. It is determined by puncture on pelleting machines (density, accuracy of weight, and possibility of pelleting).

Determination of flowability. Flowability – this ability of plastic to fill form under defined conditions (temperature, pressure, and time of holding). One can determine it by the following method: pelleting material is placed in mold and held for 2-3 minutes at temperature of 150°C and pressure of 30 MN/m^2 (300 kgf/cm^2). Flowability of molding powders is judge by depth of flow into channel of mold (Fig. 23.1).

Rate of hardening is determined by pressing samples with different hold times in mold. Rate of hardening is characterized by holding in minutes per millimeter of thickness of pressed sample. So, for phenoplastics rate of hardening at 150° ± 5°C is 48 - 210 m·sec/m (0.8-3.5 min/mm).

Basic characteristics of articles formed from plastics are the following:

Water-, gasoline-, kerosene-, and oil-saturation capacity are determined by submersion for 24 hours of suspended standard sample as follows: in distilled water (at 20°C), in gasoline, kerosene, or oil (at 105°C). Then upon the expiration of necessary time samples are removed and weighed. Water-, gasoline-, kerosene-, and oil-saturation capacity are determined by magnitude of change of weight of sample after swelling of 1% of initial weight.

Determination of thermal resistance. Thermal resistance is characterized by maximum temperature at which samples under loads preserve their form (are not deformed). Thermal resistance is determined with help of Martens instrument (Fig. 23.2) on standard samples under load of 5 MN/m^2 (50 kgf/cm^2). Thermal resistance of phenoplastics and aminoplasts is 100 - 150°C, and that of silicone plastics is over 300°C.

Chemical resistance of plastics is high. They are insoluble in organic

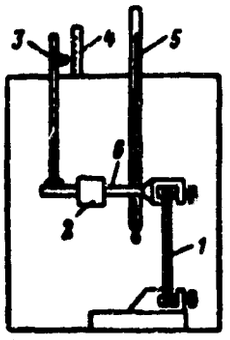


Fig. 23.2. Instrument for determination of thermal resistance. 1 – sample, 2 – load, 3 – pointer, 4 – scale, 5 – thermometer, 6 – 240 mm level.

solvents, oils, and fuel, are acid-resistant but are destroyed by alkalis, concentrated acids, and oxidizing mediums.

Mechanical properties. Determination of short-term cleavage strength, short-term shear strength, ultimate tensile strength, compression strength, transverse strength, Brinell hardness, and also specific viscosity is conducted on corresponding equipment per defined methods on samples of standard dimensions analogously to tests on metals and alloys.

Mechanical properties of plastics depend on temperature. So, with lowering of temperature brittleness is increased, tensile elongation is lowered, etc.

Electric insulating properties are determined with help of high-frequency generator. The highest electric insulating properties for samples with mineral fillers. Owing to great hygroscopicity, phenoplastics and aminoplasts with organic fillers have low dielectric properties. Polyethylene, polystyrene, fiberglass laminate, and others have better dielectric properties (dielectric constant not over 3-8).

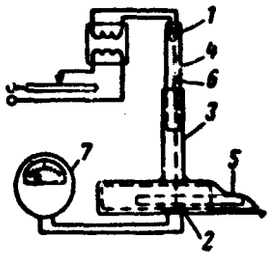


Fig. 23.3. Diagram of photometer for determination of translucence of plastics. 1 – source of light; 2 – photocell; 3 – stationary tube; 4 – sliding tube, serving for moving source of light toward photocell during passage of light through tested sample; 5 – tested sample; 6 – scale for measurement of distance from source of light to photocell; 7 – galvanometer.

Translucence of transparent plastics is determined according to method of [VIAMa] (ВИАМа) with help of photometer (Fig. 23.3). Photometer is equipped with a selenium photocell, illuminated by source of light. Intensity of illumination of photocell is determined with the help of galvanometer. Translucence is expressed in percent.

§ 4. Plastics with Powdery Fillers

We distinguish molding powders and injection compounds. Molding powders usually are thermosetting materials. They are designed for processing into articles by methods of hot pressing: ordinary and injection (casting under pressure). Injection compounds in most cases are unfilled thermoplastic compositions. They are designed for

processing into articles by methods of ordinary and injection pressing and also by extrusion methods (extrusion – sinking).

Depending upon kind of composition (thermosetting or thermoplastic), conditions change, as in certain cases does technology of processing of molding powders into articles. However, in most cases there is community of technological methods of processing thermosplastics, and thermosetting materials into articles, of applied equipment (presses and machines), accessories (molds), etc.

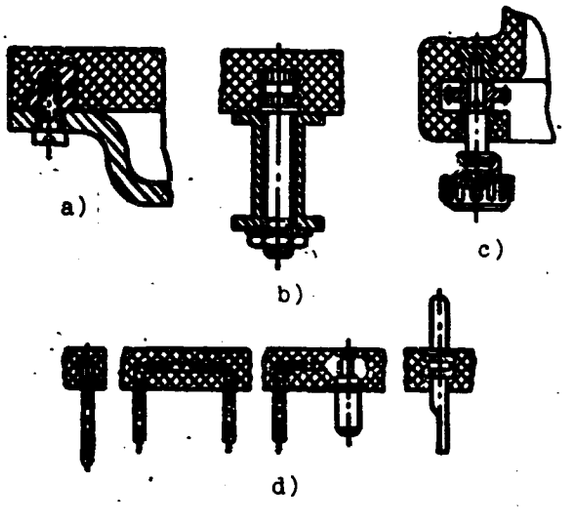


Fig. 23.4. Reinforcement of plastic parts. a and b) threaded metal bushing or bolt for attaching adjacent part, c) metal bearings for installation of pins, d) conductors and contacts.

Manufacture of articles from molding powders is composed of following stages: production of binder (resin), preparation of materials from resins with filler and other components (plasticizer, dyes, etc.), and not processing of them into articles by methods of pressing and casting. In process of manufacture of parts to materials (for strengthening) may be added fittings (Fig. 23.4).

Thermosetting Molding Materials

Thermosetting molding compositions are prepared usually on base of phenol-formaldehyde, aminoformaldehyde, anilinoformaldehyde, and polyorganosiloxane synthetic resins. In aircraft building is applied series of grades of plastics with powdery fillers, based on phenol-formaldehyde resins.

Molding powders K-15-2, K-17-2, K-18-2, K-19-2, K-20-2, K-110-2, K-220-23 of black, or K-21-22 and K-211-2 of brown color, consist of 52% two-stage or one-stage formaldehyde resins, 48% sawdust, dyes, and pigments.

Owing to comparatively low water-resistance of all molding powders, their electric insulating properties worsen after stay in humid atmosphere. Here their dimensions change and warping of articles is observed. Physico-mechanical and electric insulating properties are lowered considerably when they are heated.

Parts made from molding powders of given grades are prepared by ordinary or injection molding. During the molding process materials may easily be reinforced with metallic fittings.

These are used for manufacture of various lightly-loaded reinforced and unreinforced parts for general and electrical assignments working at temperatures of +60°C (in separate cases up to 80-100°C) and relative atmospheric humidity of no more than 60% (bodies of aircraft and electrical instruments, terminal panels, knobs, plates of electrical instruments, bases of radio tubes, junction boxes, electrical sockets, and so forth).

From materials K-21-22 and K-211-2 are prepared mainly parts for electrical assignment (part of magnetos distributors of current, and so forth), use of which is permissible in gasoline and oil.

Molding powders K-15-202, K-17-202, K-20-202, K-110-202, K-214-203 (one-colored) and [K-15-202TsS] (K-15-202TsC), K-17-202TsS, K-20-202TsS, K-110-202TsS, K-214-203TsS (colored) are used for manufacture of unloaded, reinforced, and unreinforced parts of general-technical assignment and for decorative parts (knobs, electrical fittings) working in medium of atmospheric air with relative humidity of not more than 60% and parts which have to have decorative or identifying color.

It is not recommended that shown materials be applied for parts working in contact with nonferrous metals, in hermetically closed articles, or in humid atmosphere.

Molding powder K-114-35, yellow in color, consists of 40% modified phenol-formaldehyde resin and 60% ground quartz. Thanks to low hygroscopicity, electric insulating properties are practically unchanged during prolonged stay in water and in conditions of humid tropic climate; they are changed little with heating to 100°C. Material is not subject to fungus growth in conditions of tropical

climate and does not corrode. Part made from this material preserve dimensions well.

Parts are prepared by ordinary or injection methods in molds. They are easily reinforced. Material is difficult to machine.

Molding powder K-114-35 is used for manufacture of various electric insulating parts, mainly high-quality radio equipment working at temperatures to 100°C with brief overheating to 150°C (printed-circuit boards, junction boxes, distributor caps, and so forth) and also parts working under conditions of tropical climate (high humidity and sharply variable temperature).

Aminoplasts

Molding powders K-211-3, K-211-4, and K-211-34, yellow or brown, consist of 40% anilinoformaldehyde resin and 60% quartz flour (K-211-3); mica and 55% quartz and wood flour (K-211-4); 60% mineral filler with addition of phenol-formaldehyde resin of two-stage type (K-211-34).

Electric insulating properties of materials in practice are changed little from prolonged stay in water and in humid atmosphere. Physico-mechanical and electric insulating properties are lowered considerably at 70-90°C. All these materials possess raised brittleness.

Parts are prepared by ordinary or injection methods. Heating material directly before loading mold is obligatory.

Table 63. Basic Properties of Thermosetting Molding Powders

Designation of material	Specific gravity kN/m³	Ultimate strength in MN/m² during			Specific viscosity, kJ/m²	Heat resistance in °C
		Compression σ_p	Extension σ_z	Bend σ_B		
Molding power(s) K-15-2, K-17-2, K-18-2, K-20-2	14	160,0	30,0	55,0	4,5	110
Molding power(s) K-21-22	14	150,0	—	60,0	4,2	100
Molding power(s) K-211-3	18,5	—	—	50,0	3,0	150
K-211-4	18,5	—	—	55,0	4,0	140
Molding power(s) K-211-2, K-110-2	14	150,0	35,0	65,0	5,1	110
Molding power(s) K-114-35	18	190,0	60,0	90,0	6,2	120

Molding materials of given grades are used mainly for manufacture of unloaded and unreinforced parts of radiotechnical assignment and high-frequency insulation working in medium of atmospheric air with raised humidity and at temperatures to 100-120°C. Material K-211-34, in particular, is used for molding of mica capacitors. In Table 63 are given physico-mechanical properties of certain thermosetting molding powders.

Thermosplastic Molding Compositions

Thermosplastic molding compositions are prepared usually on base of binders (resins) only, i.e., they are unfilled materials. Of greatest value are materials of this type based on polystyrenene, polyethylene, polyfluoroethylene, polyamide, and polyurethane synthetic resins, and also on base of cellulose esters.

Polyfluoroethylene Plastics (Ftoroplasty)

Ftoroplast-3 constitutes uniform, friable, easily-slugged, fine powder of white color, consisting of emulsion polymer, trifluorochloroethylene.

With increase of temperature mechanical strength of this material is lowered sharply. Hardening (i.e., sharp cooling from melting point to temperature below 100°C) sharply increases mechanical strength ftoroplast-3 and especially increases its impact strength (by 3-5 times) and ultimate elongation (by 5 times). In connection with poor thermal conductivity obtaining of well hardened materials and parts is possible only in the form of thin films. Ftoroplast-3 possesses increased elastic properties and is unyielding, i.e., it is, able after deformation under load, to return to initial form after removal of load. Dielectric properties depend on frequency and temperature, worsening with increase of the latter.

Ftoroplast-3 is resistant to action of aggressive media, including concentration nitric acid, aqua regia, alkalis, and oxidants. It is not moistened by water. It is destroyed in molten alkali metals, chlorine trifluoride, and elementary fluorine.

As fillers are applied such materials as glass and asbestos fibers or mineral powder products (quartz flour, kaolin, slate, and also graphite, ground coke, and so forth). As plasticizers are applied liquid low-molecular polymers of trifluorochloroethylene.

Processing of ftoroplast-3 into articles is possible to different methods of pressing (ordinary pressing, press-casting, die casting, and extrusion).

Coverings of ftoroplast-3 adhere well to aluminum and its alloys, to steels, zinc, nickel, and also nonmetals – glass, porcelain, ceramics, and so forth. Tear propagation strength of ftoroplast-3 on polished metal is equal to 0.5-0.8 MN/m^2 (5-8 kgf/cm^2) and on sandblasted metal is 2.5-3.0 MN/m^2 (25-30 kgf/cm^2).

Ftoroplast-3 is used for application of anticorrosive coverings to metals and other materials and for manufacture of parts supplied with metallic fittings, with large quantity of holes, and so forth, and also for linings, sleeves, value parts, frames for viewing glasses, films, etc., able to work in temperature interval from -195°C to +70°C – +100°C.

Ftoroplast-4 constitutes uniform, friable easily-slugged powder or granules of white color, consisting of emulsion polymer of tetrafluoroethylene. It is a comparatively soft and flexible material. When heated, its strength properties are lowered; with lowering of temperature its hardness increases. Ftoroplast-4 does not become brittle even at sub-zero temperatures.

Ftoroplast-4 possesses low coefficient of friction. That it is a stable lubricant makes possible application of ftoroplast-4 as packing for stuffing boxes working under pressures of up to 10 MN/m^2 (100 kgf/cm^2) at temperatures from -195 to +250°C.

Ftoroplast-4 is absolutely nonhygroscopic and is water-resistant. It is the most chemically resistant of all known organic materials and plastics: is insoluable, does not swell, and does not oxidize either in solvents, acids, or alkalis. It is destroyed by molten alkali metals chlorine trifluoride, and elementary fluorine (at high temperatures). Ftoroplast-4 is transparent to visible light in thin films).

Electric insulating properties of ftoroplast-4 in practice are not changed with change of frequency and temperature.

By method of pressing with subsequent heat treatment there can be obtained from ftoroplast-4 livers and antifriction parts resistant to acids, alkalis, organic solvents, and strong oxidizers, and also dielectric parts for high-frequency technology. By pressing it is possible to obtain plates with thickness of 1.5-25 mm, sealing rings for flanges with diameter of 10-500 mm, rods with diameter of 6-100 mm and length up to 100 mm, and so forth.

Ftoroplast-4 can be applied in the form of oriented and unoriented insulator

and capacitor films. Films must not have cracks, folds, holes, corrugations, or rents. Ftoroplast-4 can be slotted and cut out. It is released in the form of tapes with thickness of 10-200 μ, width of 10-120 mm, and lengths of 40, 100, and more meters. It is used for interlayer insulation of equipment working at temperatures from -60 to +250°C.

Ftoroplast-4 is used for manufacture of parts possessing resistance to strong aggressive media and high dielectric indices (plate, disks, rings, film, tape, pipe, flexible hoses, thin-walled sleeves, reactors, valves, cocks, porous plates, and others) working at temperatures to 250°C.

Styrenes

Polystyrene Д and Т constitutes coarse-grained powder fine granules based on polymer of styrene, obtained by block polymerization.

Articles made from block polystyrene are absolutely water resistant and under normal conditions possess high mechanical strength. With increase of temperature material assumes raised elasticity. Electric insulating properties of block polystyrene almost do not depend on frequency of current but worsen with increase of temperature.

Prolonged influence of sunlight causes yellowing of articles made from block polystyrene. Decomposition of polystyrene starts at +200°C and is very intense at 300°C. Polystyrene is the most resistant to radioactive irradiation of all plastics.

Block polystyrene will dissolve in aromatic hydrocarbons, in gasoline, and in such esters as butyl acetate, ethylene glycol acetate, and others. In obtaining of pressed parts is allowed application of different mineral fillers. From block polystyrene in softened state it is possible by extrusion and extraction to obtain tubes, rods, and also film, tape, and thread. Oriented polystyrene film and thread are distinguished by high tensile strength and eleasticity. Block polystyrene can be mixed with nitrile rubber and other high polymers, forming new varieties of materials.

Polystyrene of grade Д is used for manufacture of parts of electric insulating assignment, that of grade Т is used for parts of general-technical assignment. From polystyrene are prepared tubes and plates, which can be subjected to all forms of machining and bonding.

Polystyrene tubes are prepared in tinted form by extrusion, pressure molding, and are used for insulation of high-frequency conductors, parts of radar equipment, coil forms, insulators, and so forth.

Polystyrene A, B, and B are fine powders of white color with grains to 2.5 mm based on polymer of styrene, obtained by aqueous-emulsion polymerization.

With increase of temperature its mechanical properties are changed thanks to transition to elastic state. Polystyrene emulsion will dissolve in benzene, toluene, and xylene. Electric insulating properties are practically independent of frequency of current.

Action of moisture causes yellowing of parts made from polystyrene. It is somewhat less resistant to radioactive irradiation than block types but more resistant than other types of plastics.

Polystyrene emulsion of grade B is used for parts of high-frequency insulation of radar assignment and other moistureproof electrical parts (tube sockets, bases for capacitors and others); grade A is used for articles of general-technical assignment; and grade B is used for manufacture of foam plastics of type [PS-1] (ПС-1) and [PS-1U] (ПС-1У).

Ethyleneplasts

Polyethylene (usual and cable). Polyethylene constitutes hard horn-like particles with dimensions to 100 mm^3, white, gray, and yellow in color, based on polymer of ethylene and stabilizers, or without them. Cable polyethylene in the form of mass, sheets, and blocks for insulation is composition of polymer of ethylene with polyisobutylene and stabilizers.

At normal temperatures polyethylene for 30 days resists: nitric acid of low concentration, distilled water, formalin, caustic soda, sulfuric acid, hydrochloric acid, ethyl alcohol, acetone, and transformer oil. However, polyethylene is not resistant to benzene diethyl ether, carbon tetrachloride, toluene, chloroform, and ethyl acetate.

Polyethylene is subject to processes of aging under influence of heat, ultraviolet rays, and atmospheric oxygen, leading to impairment of its physico-mechanical and dielectric properties. Cable polyethylene ages under atmospheric conditions at higher rate than ordinary polyethylene. Hot molding of parts from

polyethylene and their subsequent cooling are combined with phenomena of shrinkage. Magnitude of shrinkage for polyethylene is equal to 1.0-2.5%. Repeated heating of finished parts again leads to their shrinkage, which can attain 1.0-2.5%.

Softening point of polyethylene is 108-130°C. Pressure molding is done at 150-260°C in forms heated to 50-70°C with specific pressure of 7-20 MN/m^2 (70-200 kgf/cm^2). During processing of polyethylene by method of hot pressing we first must roll it at 110-120°C for 10-15 min into solid sheet, which is then crushed and pressed at a temperature of 140-160°C and pressure of not below 3 MN/m^2 (30 kgf/cm^2). Holding time is from 2 to 5 min per 1 mm thickness.

Molding of polyethylene sheets by methods of stamping or bending over pattern should be done in state of full flowability at temperatures of 120-135°C, with preliminary heating of blank for 3 min per 1 mm thickness.

Welding of polyethylene is carried out by simultaneous heating to 250°C ends of material to be joined (in the form of plates, bars, and so forth) and welding rod of polyethylene by hot air, nitrogen, or carbon dioxide. Strength of welded seam sharply decreases at raised temperatures, being 80°C only 20% of strength at normal temperature.

Machining of articles from polyethylene is carried out on usual machines applied for treatment of metals. It is necessary to use high cutting speeds with low feed rate. Blocks of cable polyethylene can be sliced into sheets.

Polyethylene is used for insulation of wires and protective shells of cables, for preparation of parts of high-frequency radio equipment, production of pipes, films, tapes, and other parts, this being a chemically resistant material.

Cable polyethylene is applied as electric insulating corrosion resistant material for insulation of wires and cables of high-frequency equipment: power and supply cables, housings, coil forms, and as dielectric in capacitors.

Amidoplasts

Polyamide resins Nos. 54, 68, and 548 constitute, hard, horn-like crumbs or granules with dimensions of 10-20 mm or braids with mass to 500 g, of white to light-yellow and light-brown color.

Polyamide resin No. 68 is characterized by high melting point (213-220°C), considerable impact strength of 100 kJ/m^2 (100 $kgf-cm/cm^2$), bending strength of

70 MN/m^2 (700 kgf/cm^2), and also dielectric strength of 15 MV/m (15 kV/mm), and volume resistivity of the order of 0.1 $T\Omega \cdot m$ (10^{13} $\Omega \cdot cm$).

The most widely used polyamide resins are polycaprolactam or capron (foreign name perlon) and condensation products of dibasic acids and hexamethylenediamine, known under name amide or nylon.

Polyamides, along with positive properties, possess a series of deficiencies: impairment of electric insulating properties in process of heat aging, relatively high water absorption, inclination to thermal degradation when melted in air medium, and comparatively high shrinkage of articles obtained by method of pressure molding.

Atmospheric oxygen, especially during heating, worsens strength of polyamides (increases brittleness); therefore articles made from them should be used at temperatures to 100°C in air medium and at 135-140°C during submersion in oil and other liquid media. Negative effect on properties of polyamides is rendered also by sunlight and water at raised temperatures.

Polyamides possess good wear resistance and small value of coefficient of friction.

Polyamides of nylon type are widely applied as wear-resistant coverings on metallic friction surfaces in sliding bearings and gears.

Polyamides are not soluble in ordinary solvents but are dissolved well in phenol and hot acetic acid. They are practically incombustible.

Polyamide resin No. 68 is used for manufacture of different electrical machine-building parts and articles possessing high mechanical and electric insulating properties and resistance to action of gasoline, benzene, oils, alkalis, and water. Resins No. 548 and No. 54 are used for obtaining of films and molding compound.

Cellulose

Cellulose acetate molding materials Д-1, [illegible] (ЭЦТ-43), and 2ЭТ-65 (black and colored) constitute pieces with dimension to 8 mm of different color, based on secondary cellulose acetate, plasticizers (dimethyl- and dibutyl phthalate), fillers (kaolin, soot, etc.), and pigments (dyes).

Cellulose acetate molding materials are resistant to weak acids, alcohol, gasoline, and oil. At temperatures of 100°C they pass into plastic state. It is practically incombustible.

Table 64. Basic Properties of Thermoplastic Powder Materials

Designation of material	Specific gravity, kG/m³	Ultimate strength in kG/cm² units: Compression σ_c	Extension σ_e	Bend σ_b	Impact strength, J/m²	Thermal resistance per Martens, °C
Fteroplasty:						
Fteroplast-3	21,6	53,0	33,0	70,0	25	Working temperature from -196 to +100°
Fteroplast-4	23	20,0	20,0	12,0	100	Working temperature from -269 to +260°
Styrenes:						
Polystyrene A,B,V	11	100,0	36,0	65,0	15	75
Stiglomeplasts	0,1	—	13,0	12,0	—	Flow point 50
Amideplasts						
Resin No. 68	11,3	80,0	48,0	80,0	100	60
Cellulose:						
Cellulose acetate molding materials	14	53,0	33,0	46,0	23	40
Nitrocellulose etrol	19	100,0	28,0	36,0	3,2	45
Ethyl cellulose etrol	12	30,0	30,0	40,0	28	33

Cellulose acetate molding of grade 2DT-43 is used for controls, radio equipment, and decorative trim. Grade 2DT-55 is used for steering wheels and seals for pneumatic systems. Grade D-30 is used for transparent parts.

Nitrocellulose etrol consists of pieces of 8-10 mm dimensions of different color, based on nitrocellulose, fillers (diatomite, cotton combings), and pigments (dyes).

With reduction of temperature brittleness of material increases. Strong acids, alkalis, and organic solvents destroy it. Sunlight causes darkening and turbidity and increases brittleness.

It is used for production of steering wheels and handles for speed-levers switching, and other technical articles.

Ethyl cellulose etrol constitutes fine, friable powder or pieces of different size of white to yellow color, based on ethyl cellulose of plasticizer (debutyl phthalate), fillers (kaolin, cotton combings, and others), stabilizers (zinc oxide), lubricants (stearic acid), softeners, and pigments. It is used for manufacture of

different technical parts. In Table 64 are given physico-mechanical properties of certain thermoplastic molding powders.

§ 5. Plastics with Fibrous Fillers

Manufacture and processing of molding materials with fibrous fillers (organic and inorganic) are similar to production and processing molding materials with powdery fillers. As binder for plastics with fibrous fillers are usually applied thermosetting resins: phenol-formaldehyde and their derivatives, aminoformaldehydes, epoxides, polyorganosiloxanes, and others.

Filler in these cases is not powder but fibrous mass. Thorough impregnation of fibrous fillers is attained by application of lacquer solutions of resins (in water or alcohol, and benzene for phenol-formaldehyde; in water for melamine-formaldehyde; in toluene for polyorganosiloxane resins, etc.). Besides fibrous fillers (cotton fiber, asbestos fiber, and others), they can also include mineral fillers, in the form of powders such as talc, lime, kaolin, etc., pigments (dyes), and accelerators. Articles with fibrous fillers possess, as compared to articles made from plastics with powdered fillers, less brittleness and higher impact strength. Impact strength, depending on fillers, is from 10 (cotton fiber) and 21 (asbestos fiber) to 80 and more kJ/m^2 (glass fiber).

Thermal resistance for plastics with cotton filler is up to 130°C and for compositions with asbestos and glass fibers is 200-250°C, where maximum thermal resistance belongs to mass based on polyorganosiloxane resins with filler in the form of glass textile fiber - asbestos fiber.

Polyorganosiloxane compositions is characterized by high mechanical strength, heat resistance, and good electric insulating properties. Molding of articles from plastics with fibrous fillers requires pressures of the order of 30-40 MN/m^2 (300-400 kgf/cm^2); however, in case of polyester and epoxy resins in combination with fiberglass specific pressures of [illegible] are sufficient, which is very effective.

Steklovolokni[illegible]

Molding material [AG-4] [AG-4] of grades B [illegible] constitute friable fibrous material (grade B) or glued strands of unidirectional [illegible] fibers, with strand width of 1.5-4 mm; (grade G) and also [illegible] of resins [illegible]

yellow-brown color, based on 40% modified phenol-formaldehyde resin of resol type, 59% glass fiber, and 1% lubricant.

Physico-mechanical and electric insulating properties of material depend on temperature and duration of heating.

After natural aging for 2 years under conditions of moderate climate, physico-mechanical and electric insulating properties of material are practically not changed.

Owing to low water- and moistureabsorptivity, electric insulating properties of material are changed little during prolonged stay in water in humid atmosphere at 20°C and in atmosphere of tropical climate. Material is not subject to fungus growth in conditions of tropical climate.

Material is thermosetting. Preparation of parts from it is produced by pressing in molds at temperature of 145-155°C and pressure of 3-70 MN/m^2 (300-700 kgf/cm^2) or by pressure casting at temperature of 145-160°C and pressure of 85-120 MN/m^2 (850-1200 kgf/cm^2). Holding time during pressing is 1-1.5 min per 1 mm of thickness of part. In process of pressing material is easily reinforced. Material is easily machined. Molding material AG-4 is used for manufacture of highly-loaded reinforced and unreinforced parts for structural, radio, and electronic assignment, and also for parts working in conditions of raised temperature (to 175-200°C) and in conditions of tropical climate. Brief overheating of parts is allowed to 250°C for 3-5 hours and to temperature of 1500-2000°C for 10-15 s for articles of one-time use.

Asbovoloknit

Molding material K-6 constitutes fibrous petals with thickness of 1.5-2 mm, of gray color, based on 32% phenol-formaldehyde emulsion resin K-6 of resol type and 68% combed asbestos fiber.

Mechanical strength sharply drops in dependence upon duration of heating at 200°C. It is not water-resistant and is subject to mold in humid atmosphere. Electric insulating properties in humid medium also are lowered.

Molding material is thermosetting. Ordinary molding is conducted at 170-180°C with specific pressure of 30-45 MN/m^2 (300-450 kgf/cm^2) and holding time of 90 Ms/m (1.5 min/mm). Transfer molding is applied rarely. During storage molding material loses moldability (flowability). This is why it is recommended that after

preparation it be processed as soon as possible into articles. Shrinkage during molding is 0.3-0.5%.

Owing to low moistureproof nature of material, electric insulating parts made from it usually are covered with bakelite varnish and subjected to heat treatment for certain stabilization of properties.

It is used for manufacture of electric insulating parts: mainly junction and terminal panels with raised strength, working at raised temperature in air medium.

Molding materials for friction parts [KF-3] (КФ-3), [6-KKh-1] (6-КХ-1), 6-KKh-15, "22" and [FK-16L] (ФК-16Л) (retinaks) are pieces or petals with thickness of 3 mm and dimension of 8 mm (in cross section based on 32% phenol-formaldehyde resin K-6 of resol type and 68% asbestos fiber and additions (KF-3); 21-28% artificial resin and 79-72% asbestos and other mineral fillers (6-KKh-1 and 6-KKh-15), 25% modified (rosin) phenol-formaldehyde resin, 40% asbestos, 35% barite, and 16% brass (in wire form) (FK-16L - retinaks), artificial resin, asbestos, and other mineral fillers ("22").

Manufacture of friction parts is accomplished by method of ordinary molding in molds of closed type at pressure of 45-80 MN/m^2 (450-800 kgf/cm^2), temperature of 165-210°C, and holding time of ~1.5 min per 1 mm thickness of part.

These materials are used for manufacture of friction parts ([brake] disks, blocks, and so forth). From material of grade KF-3 are prepared, in particular, blocks for lightly-loaded brakes of airplane wheels, and from grades FK-16L and "22" are made parts for strongly-loaded brakes of airplane wheels.

FK-16L does not burn. It is resistant to acids, alkalis, solvents, gasoline, kerosene, and oils. Under normal conditions it does not cause corrosion of ferrous and nonferrous metals in contact with it. FK-16L effectively replaces compositions "22" and 6KKh-1.

Voloknit

Voloknit molding material constitutes friable braids of fibers glued with resin, having brown or black color. Base if 52% phenol-formaldehyde resin of resol type and 48% cotton combings, magnesium oxide, and talc.

Owing to low water and moisture resistance material, its electric insulating properties are sharply reduced after stay in water or humid atmosphere. Moistened

Table 65. Basic Properties of Fibrous Plastics

Designation of material	Specific gravity, kN/m^3	Ultimate strength in MN/m^2 during			Impact strength, kJ/m^2	Thermal resistance per Martens, °C
		compression $\sigma_в$	extension $\sigma_р$	bend $\sigma_и$		
Voloknit	14	120,0	30,0	50,0	9	110
Fibrous materials:						
КФ-3	17	100,0	—	70,0	21	200
КГ-6	18	110,0	—	70,0	20	200
Molding material АГ-4						
grade B	17	130,0	80,0	100,0	25	300
grade C	17	130,0	200,0	200,0	100	300
Molding material of grade К-6	19	110,0	30,0	75,0	19	300

parts made from voloknit are subject to warping and change of dimensions. Physico-mechanical properties are worsened considerably at temperatures of the order of 70-90°C.

Voloknit is thermosetting material. Preparation of parts from it is carried out mainly by means of ordinary molding. Transverse molding may be used to prepare only certain parts. In process of molding material is comparatively easily reinforced.

Voloknit is used for manufacture of parts of general-technical assignment with raised impact strength. Nonvital parts of electrical assignment before assembly are subjected to heat treatment and covered with bakelite varnish for certain stabilization of properties and dimensions. In Table 65 are given physico-mechanical properties of certain thermosetting voloknits.

§ 6. Plastics with Laminar Fillers

Widely applied in aviation industry are plastics with laminar fillers in the form of homogenous sheets of cotton, asbestos, glass or synthetic fabrics, paper, paper or asbestos cardboard, plywood, etc.

Physico-mechanical properties of plastics with laminar fillers to a larger degree are caused by properties of applied fillers than properties of binder (resins).

Manufacture of plastics with laminar fillers is based on impregnation of continuous tape of initial material (fabric, paper, plywood), or of sheets cut

from them, with prepared solution of binder resin.

Thus impregnated and dried material is sliced into identical sheets and is packed in rows in multilayer (two and more) packs of different thickness.

After that packs are pressed at defined temperatures and pressure (without application of molds) between warmed plates of hydraulic multi-bank presses. Duration of pressing depends on thickness of pack, i.e., on thickness and quantity of simultaneously pressed sheets.

After termination of hot pressing article is sustained under pressure for certain time for cooling or hardening, depending upon kind of binder resin (thermplastic or thermosetting). Pressed plates or sheets are extracted in cold state.

Most widely applied in aviation industry are the following laminar plastics: getinaks, textolites, fiberglass, laminates, asbestos laminates, and wood-laminated plastics.

Getinaks possesses high electric insulating properties and sufficient mechanical strength. Pressing of them is conducted under pressure of 6-10 MN/m^2 (60-100 kgf/cm^2) at 120-160°C and holding of 180-420 Ms/m (3-7 min/mm).

Getinaks electrical insulation sheet grades А and Б is composition of 45-50% phenol-, cresol-, xylenol- formaldehyde resins and 50-55% sulfate-impregnated paper. It possesses good oil resistance (stay in transformer oil at 130°C for 4 hours does not cause distending or separation of material). Its thermal resistance is within limits of 130-150°C. It is produced in the form of sheets with thickness of 5-50 mm and is applied in electrical equipment of aircraft for parts working at frequency of not over 50 Hz and also for aviation instrument and accessory building.

Getinaks structural sheet grade В constitutes the same composition as for grades А and Б. It is produced in the form of sheets with thickness of 0.2-50 mm and is applied in electrical equipment of aircraft for parts working at frequency no higher than 50 Hz and also for aviation instrument and accessory building.

Getinaks moistureproof structural sheet grades Г and Д is the same composition as grades А and Б. It is supplied in the form of sheet with thickness of 10.4-50 mm and dimensions of 400 × 400 mm and more.

Getinaks grade Г is used for manufacture of parts of electrical equipment working under conditions of increased humidity; grade Д is used as panel material.

Getinaks high-frequency electrical sheet grades $А_В$, $Б_В$, $В_В$, $Г_В$, and $Д_В$ constitutes same composition as grades А and Б. It is supplied in the form of sheets with thickness of 0.4-6.0 mm and is used for parts of radio equipment.

From electrical getinaks it is possible to prepare, with help of stamping, tubes and cylinders applied as coil forms for high-frequency radio equipment.

Getinaks decorative facing constitutes composition based on aminoformaldehyde resin, used to impregnate it special types of paper, with additional fillers or without them.

Decorative facing laminated plastic is subjected to all forms of machining under conditions close to those of treatment of getinaks and textolite. It can be fastened to elements of construction by screws, rivets, and other mechanical methods, and also by bonding.

It is produced in the form of single-layer or multilayer sheets with thickness to 3 mm and plates of 3-10 mm, obtained by method of not pressing at 140 ± 5°C and pressure of 11 MN/m^2 (110 kgf/cm^2).

It is applied as decorative material for finishing cabins, instruments, and internal equipment of aircraft, for manufacture of cases for radio receivers, television sets, and other radio and electric equipment; for pressing of diagrams, drawings, and maps; for typographical printing impressions, and for trim simulating costly varieties of wood and stone.

Textolites are characterized by higher water-resistance, compressive strength, and impact strength. Molding is conducted under pressure of 6-7 MN/m^2 (60-70 kgf/cm^2) at 150-160°C and holding of 300 Ms/m (5 min/mm).

Structural textolite [PTK] (ПТК) is composition of 48-54% phenol-, cresol-formaldehyde resin of resol type, or their mixture, and also 52-46% cotton fabric (calico or coarse calico) of mass to 0.18 kgf/m^2 (180 g/m^2).

Textolite is subjected to all forms of machining (sawing, drilling, grinding, turning). It does not have to be stratified and crumbled. Textolite also is bonded, both to itself and to other materials: duralumin, steel, glass textolite, and delta-wood glues [VIAM-B3] (ВИАМ-Б3) and [BF-2] (БФ-2) after proper preparation of surface and at proper temperature.

Textolite PTK is supplied in the form of sheets with thickness of 0.5-70 mm, of different dimensions, and is used for levelling liners, wing tips, damping

linings, loaded bosses, electric insulating parts working with low (to 50 Hz) frequency current at temperatures not higher than 120-125°C.

Textolite panel grade Г constitutes composition of 58-50% phenol- or cresol-formaldehyde resin and 42-50% cotton fabric (coarse calico or calico) of mass to 0.18 kg/m^2 (180 g/m^2). Textolite of grade Г is subjected to all basic forms of machining. Textolite of grade Г is produced in the form sheets and plates with thickness of 0.5-50 mm and is applied as panel material for work in air at ambient temperature of -60 to +70°C.

Building textolite grade [PT] (ПТ) constitutes composition of 45-50% phenol-, cresol-, xylenol- formaldehyde resin of resol type, or their mixture, and also 50-55% cotton fabric (coarse calico or gingham) of mass to 0.21 kg/m^2 (210 g/m^2).

Textolite is subjected to all forms of machining. It also is subjected to bonding, to itself and in combination with other laminates and metal.

Textolite of grade PT is supplied in the form of sheets with thickness of 0.5-70 mm, of different dimensions, and is used for simplest parts prepared by machining and also for levelling and damping linings and other similar parts.

Flexible lining textolite grade MA constitutes composition of 40-30% resin of grade MA, based on acrylic ester and 60-70% cotton fabric (chiffon). It is supplied in the form of sheets with thickness of 0.2-35 mm and is used for manufacture of linings used for hermetic sealing of flanged joints working in air, oil, kerosene, or gasoline.

Structural electrical textolite grades A and Б constitutes composition of 55-60% phenol- or cresol- formaldehyde resin of resol type and 45-50% cotton fabric (calico or coarse calico) of mass to 0.18 kg/m^2. It is supplied in the form of sheets with thickness of 0.5-50 mm. Textolite of grade A is used for parts of electric insulating and structural assignment working in transformer oil and in air at ambient temperatures from -60 to +70°C, obtained by method of machining. Textolite of grade B is used for parts working in air at temperatures from -60 to +70°C.

Electric insulating textolite grade [VCh] (ВЧ) constitutes composition of 55-50% phenol- or cresol- formaldehyde resin of resol type and 45-50% cotton fabric (chiffon). It is supplied in the form of sheets with thickness of 0.5-8.0 mm. It is used for electric insulating parts of radio equipment working at ambient

temperatures from -60 to +70°C.

From textolite are prepared tubes for different assembly parts, wound tubes for protection of wires and control cables of aircraft, electric insulating rods, etc.

Fiberglass laminates possess, as compared to textolite and getinaks, greater mechanical strength. Fiberglass laminates absorb vibration loads well, have insignificant coefficient of linear thermal expansion and high dielectric properties. Deficiencies of fiberglass laminates are low relative elongation, low resistance to crumpling, and low elastic modulus.

Sheet structural fiberglass laminate of grade [KAST] (КАСТ) constitutes composition of 32-26% binder BF-3 (modified phenol-formaldehyde resin) and 68-74% fibre of grade T with thickness of 0.25 mm (from alumoborosilicate low-alkali glass).

Fiberglass laminate KAST is subjected to all forms of machining and also bonding and riveting. Conditions of mechanical treatment are close to conditions of processing of metal. It is supplied in the form of sheets with thickness of 0.5-1.2 mm. Fiberglass laminate of grade KAST is used for containers of fuel tanks and similar devices working at temperatures not higher than 120-130°C.

Plate structural fiberglass laminate grade [KAST-V] (КАСТ-В) constitutes composition analogous to sheet glasstextolite KAST-V. Technological data on plate fiberglass laminate are analogous to properties of sheet glasstextolite. It is supplied in the form of plates with thickness of 15-30 mm.

Fiberglass laminate KAST-V is applied for parts prepared by mechanical means, chiefly for heat-insulating linings in different structures working for prolonged periods at temperatures to 200°C briefly (to 3 h) at temperatures to 300°C. It can be substitute for sheet textolite if thermoresistance of the latter does not satisfy imposed requirements.

Structural plate fiberglass laminate grade [KAST-K] (КАСТ-К) and fiberglass laminate of building grade [KAST-P] (КАСТ-П), consisting of 32-26% binder BF-3 or BF-7 and 68-74% glass cloth of grade T with thickness of 0.25 mm. They are subjected to all forms of machining, bonding, and riveting. Conditions of treatment are close to conditions of processing of metal. Fiberglass laminates KAST-K and KAST-P are supplied in the form of plates with thickness of 15 mm and are applied as armoring and heat-insulating material for cockpit of certain types of heavy aircraft, in

exchange for metallic duralumin armor, and also for building purposes.

Fiberglass laminate of grade [STM-1] (СТМ-1) consists of 45-40% resin [VF] (ВФ) or [IF] (ИФ) and 55-60% fibre of grade Э (from low-alkali glass) with thickness of 0.08-0.11 mm.

It sustains temperatures from -50 to +130 in air medium without stratification, swelling, and cracking, and endures prolonged stay in kerosene. Fiberglass laminate possesses good mechanical strength, elastic and plastic properties, and is suitable for cold stamping. It is supplied in the form of sheets with thickness of 0.55-0.70 mm and is applied for elastic diaphragms of fuel assemblies of jet engines.

Sheet electrical fiberglass laminate of grade [ST] (СТ) consists of 60-65% phenol-formaldehyde resin IF of resol type and 35-40% glass fibre of grades Э or [AS] (АС). It is released in the form of sheets with thickness of 0.5-30 mm and is designed as electric insulating material for aircraft instruments and special assemblies.

Asbestos laminates are heat-resistant plastics. In all other properties they are inferior to textolites and getinaks. Molding is done under pressure of 1.5-10 MN/m^2 (15-100 kgf/m^2) at 150-160°C and holding of 900 Ms/m (15 min/mm).

Asbestos laminate constitutes composition of 54-48% phenol-formaldehyde resin of resol type, bakelite catalyst, and 46-52% asbestos fabric of grade 35D. It is supplied in the form of sheets and plates with thickness of 9 mm. It is used for blades of rotary gasoline pumps for aircraft engines, for friction drive disks of two-speed hydraulic drives for heaters of piston engines, and for other parts, and also as material for electrical panels working with low current, and as thermo-insulation material.

Wood-laminated plastics have higher ultimate tensile compression strength and but lower water-resistance than all others. Molding is done under pressure of 10-15 MN/m^2 (100-150 kgf/cm^2) at 150-160°C and with holding of 30 Ms/m (5 min/mm).

Delta-wood structural plate grade [DSP-B-a] (ДСП-Б-а) constitutes composition consisting of 15-24% thermosetting phenol- and cresol- formaldehyde resins and 76-85% birch plywood with thickness of 0.5-0.6 mm. In plate every 10 layers, is one transverse layer.

Table 66. Basic Properties of Laminar Plastics

Designation of material	Specific gravity, kN/m³	Ultimate strength in MN/m² during			Impact strength, kJ/m²	Heat resistance per Martens, °C
		compression σ_c	extension σ_e	bend σ_u		
Getinaks:						
A	13,5	—	80,0	100,0	16	150
B	13,5	—	100,0	130,0	20	150
A_g	13,5	—	80,0	100,0	—	—
Textolites:						
ПТК	13,5	250,0	100,0	160,0	35	125
ПТ	13,5	230,0	85,0	145,0	35	125
A	13,5		50,0	80,0	20	130
Fiberglass laminate of grade, КАСТ-В	18,5	300,0	270,0	350,0	60	—
Delta-wood of grade ДСП-10	13,5	175,0	270,0	—	30	—

Delta-wood layers, after being machined and having its surface cleaned with acetone to remove oil spots and dust, are glued together (better in combination with wood and plywood) with resinous and casein glues. Delta-wood is subjected to all forms of mechanical treatment on machines used for processing of wood but at lowered speeds and somewhat higher cutting angles than used for natural wood. It is supplied in the form of short (to 1450 mm) and long (to 5700 mm) plates with width to 1200 mm and thickness of 16-18 mm.

Delta-wood in the form of short plates is used chiefly for shanks of propeller blades. Long plates of first grade are used for structural load-bearing parts of aircraft: longerous, bulkheads, and so forth. Second grade is used for dies intended for cold stamping of sheet aluminum and magnesium alloys and can be used for manufacture of vital fixtures.

Delta-wood of all grades based on alcohol resins can be applied as electric insulating material in electric equipment working in dry medium at frequency of 50 Hz.

Sheet structural delta-wood grade [DSP-V] (ДСП-В) constitutes composition of 15-22% thermosetting phenol- and cresol- formaldehyde resins and 78-85% birch plywood with thickness of 0.40-0.55 mm (layers of plywood are placed mutually perpendicularly). It is subjected to treatment by cutting, bending, and gluing.

Delta-wood DSP-V is produced in the form of sheets with thickness of 1-5 mm and dimensions of 1000 × 1100 mm. It is applied as substitute for structural textolite PTK, PT, and getinaks B; for damping linings, as strengthening layers in bolted joints of wooden constructions, as levelling liners for instrument panels, and for other similar parts of electric insulating assignment working in dry air medium; for panels, hatches, loaded bossess, wing tips, and so forth.

In Table 66 are given physico-mechanical properties of certain thermosetting laminar plastics.

§ 7. Unfilled Sheet Plastics

In distinction from filled plastics (with powdery fillers and laminar fillers) unfilled plastics do not contain fillers.

As the only and basic component of unfilled plastics usually participates binder – synthetic resins, cellulose esters, and others. This is why properties and characteristics of unfilled plastics are dependent on properties of initial binder and on methods of manufacture of articles from them.

Acrylics. In aircraft construction and instrument making considerable application is found for acrylic glass of organic origin, polymethylmethacrylate.

Polymethylmethacrylate organic glass sheet possesses high translucence, low thermal conductivity, ideal thermoplasticity, ability to be molded easily, satisfactory strength, etc.

Such successfully combined properties and quality of organic glass have made this material basic and irreplaceable as glass for aircraft.

Organic glass is easily machined. By very simple technological methods it is possible to mold from it parts of simple and complicated form, of any curvature.

Organic glass, being polymer of methacrylic methylester, is obtained in result of polymerization reaction and constitutes a thermoplastic.

Organic glass applied as window material under operational conditions is subjected to influence of a series of factors: first of all, stresses, temperature changes, moisture, ultraviolet radiation, and others, effective in the most diverse combinations. These factors, influencing organic glass, essentially change its properties.

Organic glass possesses low thermal conductivity and considerable thermal coefficient of linear expansion: during sharp temperature changes in it there

appear internal stresses, leading to formation on surface of small cracks (so-called silvering phenomenon).

Along with organic glass, at present for windows of pressurized cabins are applied laminated safety glass and oriented organic glass.

Glassing of pressurized cabins, besides permitting observation through it, also executes function of preservation of pressure inside pressurized cabins; therefore behavior of glossing material during shock loads is of special interest.

If, as a result loading there occurs local destruction of a glass, that particular composition should be given preference as compared to more brittle compositions.

Existing organic glass is quite brittle, which is clearly displayed under shock loads, especially under conditions of one-sided pressure drop. Lanterns glassed with glass under such conditions are destroyed over their entire area. Oriented organic glass and laminated safety glass when punctured display local destruction.

Oriented glass has considerable advantages as compared to ordinary organic glass. Essence of orientation consists in the following: during the drawing of organic glass in highly elastic state (above flow point) molecules are oriented with direction of action of external force, which leads to strengthening of organic glass, to increase of its toughness.

Uniaxial drawing strengthens glass only in direction of orientation: in perpendicular direction indices of mechanical properties are even lowered somewhat as compared to unoriented organic glass. Biaxial (plane or radial) drawing of organic glass leads to hardening of material in any direction in plane of sheet.

Glass parts prepared from biaxially-oriented organic glass have raised static strength and also localness of defeat during puncture. Optical properties of this glass are no lower than those of nonoriented organic glass. During the forming of such glass it is necessary to prevent possibility of its disorientation.

Organic laminated safety glass constitutes composition of two sheets of organic glass glued to transparent butvar film. Properties of organic laminated safety glass close to properties of organic glass. Its advantage consists in highly local nature of failure during punctures. In technical optical properties laminated safety glass almost does not differ from organic glass.

Optical deficiency of organic laminated safety glass is its inclination to formation of bubbles in glued layer when heated before molding. Cause of this is presence of moisture in butvar film. The less moisture contained in film the fewer bubbles formed at raised temperatures. During manufacture of laminated safety glass moisture can get into gluing layer owing to insufficient drying of film and also to absorption of moisture from air. Causes of formation of bubbles have to be removed.

Of glassing materials of inorganic origin are applied silicate and quartz glasses in the form of laminated safety glass, consisting of two sheets of silicate glass glued with butvar film. This is so-called safety or shatterproof glass.

Organic glass of aviation grade [SOL] (СОЛ) constitutes polymer of methacrylic methyl ester.

It is released in the form of sheets with thickness of 2-20 mm.

Organic glass is molded at a temperature of 105-150°C and welded at 140-145°C with holding for 20-30 min at pressure of 0.5-1.0 MN/m^2 (5-10 kgf/cm^2). It is glued by glue based on dichlorethane and is machinable.

Organic glass SOL is used for glassing pressurized and nonpressurized aircraft cabins. Its operating temperatures are -60 to +60°C.

Aviation organic glass [ST-1] (СТ-1) constitutes unplasticized polymer of methacrylic methyl ester with addition of phenyl solicylate. This organic glass possesses high thermal resistance. It is used for glassing of nonpressurized and pressurized cabins of aircraft with operating temperatures from -60 to +140°C.

Biaxially-oriented organic glass [DOR-16] (ДОР-16) constitutes polymer of methacrylic methyl ester. It machines well, can be glued and molded.

Organic glass DOR-16, supplied in the form of sheets with thickness to 10 mm and diameter to 1900 mm, is used for glassing of pressurized cabins of high-altitude aircraft. Its operating temperatures are -60 to +60°C.

Laminated organic glass OT-16 is composition of two sheets of organic glass with thickness of 4-6 mm glued with butvar film of 2 mm thickness. It is machinable, can be glued, welded, and molded.

Glass OT-16 is produced in the form of sheets of different dimensions and is used for glassing pressurized cabins of aircraft. Its operating temperatures are from -60 to +60°C.

Vinyl plastics constitute plastics without fillers. Basis for production of vinyl plastics is polyvinyl chloride resin.

Sheet vinyl plastic is obtained as a result of fusion on heated rollers of powdered polyvinyl chloride resin at a temperature of 160-165°C in presence of stabilizer (calcium carbonate, calcium stearate). Powdered resin with such heating on rollers is plasticized, and then, with help of multi-roll calenders, is rolled into thin uniform tape. Thus obtained continuous tape is cut into sheets and packed in the form of packs of different thickness, depending upon desired thickness of sheet vinyl plastic. Molding of sheet is conducted on multi-bank hydraulic press at 120°C and pressure of 2.5-3.0 MN/m^2 (25-30 kgf/cm^2).

Vinyl plastic can be also processed into profiled parts by means of hot molding at a temperature of 175-190°C, so-called impact or rapid molding of preprepared tablets. It is supplied in the form of hot-molded sheets with thickness of 2-20 mm. Articles made from vinyl plastic have high impact strength and resistance to aggressive media. Under conditions of raised temperature its mechanical properties are lowered sharply and creep sets in.

Vinyl plastic is used for manufacture by hot molding at 175-120°C of profiled parts of structural, electric insulating, and anticorrosion assignment.

Vinyl blend constitutes composition of emulsion polyvinyl chloride with plasticizer, stabilizer, fillers, and dyes.

We distinguish the following vinyl blends: liner, cable, heat-resistant, and special. They are released in the form of tubes and tapes and are used for manufacture by hot molding at 120-150°C and specific pressure of 2.5 MN/m^2 (25 kgf/cm^2) of different packing, lining, and hermetically sealing parts working at temperatures of from 0 to +50°C and high pressures, and also for chemically resistant parts and electric insulating parts, etc.

Tubes and tape of polyvinyl chloride are subject to processes of aging under action of atmospheric factors. During use is observed decrease of elasticity, increase of rigidity, and appearance of cracks.

Packing film polychlorine grade B-118 consists of 66.6% polyvinyl chloride resin, plasticizer (dibutyl phthalate and others), stabilizer (calcium stearate), and pigments. It is released in thickness of 0.19-0.27 mm, width of not less than 700 mm, and length of not less than 5 m.

Table 67. Basic Properties of Sheet Thermoplastic Masses Without Fillers

Designation of material	Specific gravity, kN/m³	Ultimate strength in MN/m² during			Impact strength, kJ/m²	Thermal resistance per Martens, °C
		compression σ_s	extension σ_r	bend σ_u		
Organic glass	11,8	110,0	65,0	95,0	12	~80
Vinyl plate	13,8	80,0	40,0	100,0	120	65

From film V-118 are manufactured packing cases for preservation of aircraft engines, accessories, and parts. During manufacture of cases film is cut, and then with special attachment ends of cut blanks are welded, i.e., connected by heating them under pressure. In Table 67 are given basic properties of sheet thermoplastic masses without fillers.

§ 8. Expanded Plastics (Foam Plastics)

Considerable application in aircraft construction is found for specially light plastics of cellular structure, based on synthetic resins, called foam plastics.

Along with low volumetric weight of 40-350 kg/m^3 (0.04-0.35 g/cm^3) plastics of this group possess good dielectric properties and radio wave permeability, low sound and thermal conductivity, and fair vibration resistance.

For production of foam plastics binder (resin) is mixed in powdery state with gas developing agent (foaming agent), able when heated to decomposed, liberating a considerable quantity of gaseous substances. Cellular structure of foam plastic is formed by closed pores. If cavities are not interconnected, plastic becomes gastight (so-called porous material). As foaming agents are applied sodium bicarbonate, ammonium carbonate, and nitrous compounds.

Gas developing agents can also be the resins (binders) themselves if their transformation when heated is accompanied by liberation of volatile substances. These are so-called self-foaming materials.

After mixture is prepared, it is pressed (molded) and foamed (in case of thermosetting types) or press and then foamed (in case of thermoplastics).

For production of foam and porous plastics are applied thermoplastic binders of polystyrene and polyvinyl chloride types. For foam plastics of thermoplastic

type with increase of temperature occurs, with increased diffusion rate of gas, fast packing and increase of volumetric weight. Besides this, thermoplastic foam plastics suffer from raised brittleness.

As thermosetting binders in production of foam plastics are applied phenol-formaldehyde, polyester, and polyorganosiloxane resins. Thermosetting foam plastics harden directly during molding, and this increases stability of structure of foam plastics. Such foam plastics are not affected by prolonged exposure to raised temperatures.

In aircraft building have found application the following forms of plastics: PS-I and PS-IV (based on polystyrene resin) [PKhV-I] (ПХВ-I) (based on polyvinyl chloride resin), [FF] (ФФ) (based on phenol-formaldehyde resin), [FK-20] ФК-20) and FK-40 (based on phenol-formaldehyde resin and rubber), K-40 (based on polyorganosiloxane resins), and [PU-101] (ПУ-101) (based on polyurethane resins).

Foam plastics are released in the form of rectangular plates of various thickness. Plate foam plastics are used as light fillers in aviation constructions of load-bearings rad'otechnical, and heat-soundproofing assignment. For example, they are used as filler for laminar and reinforced constructions of ailerons and control surfaces, for creation heat and sound insulation of aircraft cabins, for cowls of radar antennas, and for manufacture of buoyant articles. Elastic foam plastics are used as heat and soundproofing and damping materials.

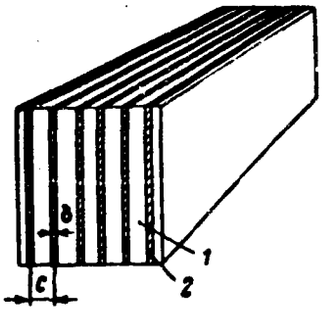


Fig. 23.5. Diagram of structure of reinforced foam plastic. δ – thickness of reinforcing material, c – spacing of reinforcing material, $K = \frac{\delta}{c}$ – degree of reinforcing. 1 – foam plastic, 2 – reinforcing element.

To give high strength and rigidity to multilayer structures, foam plastic is reinforced with help of sheets of plywood or metal.

Reinforced foam plastics are prepared on the basis of considered types of foam plastics and are load-bearing structural materials consisting of alternating layers of foam plastic and reinforcement – plywood, plastic, or metal (Fig. 23.5).

Characteristics of strength and rigidity of reinforced foam plastics vary widely. For structural purposes 5-7% reinforcing of foam is sufficient. In Table 68 are given properties of certain foam plastics.

Table 68. Basic Properties of Foam Plastics

Designation of material	Volumetric weight, kg/m^3	Ultimate strength in MN/m^2 during		Impact strength, kJ/m^2	Linear shrinkage in 24 hours at 60°C %
		compression $\sigma_в$	extension $\sigma_р$		
Polystyrene foams:					
ПС-1	60—220	0,3—3,0	4,2	1,7	0,7
ПС-IV	50—80	0,4	1,0—1,4	1,0	0,8
Polyvinyl chloride foam grade ПХВ-1	70—2200	0,4—1,5	1,8—4,6	4	0,9
Phenol-formaldehyde foam grade ФФ	190—220	1,0	1,2	0,12	1,3
Polyurethane foam grade ПУ-101	100—120	0,8—0,9	1,0	0,4	1,0

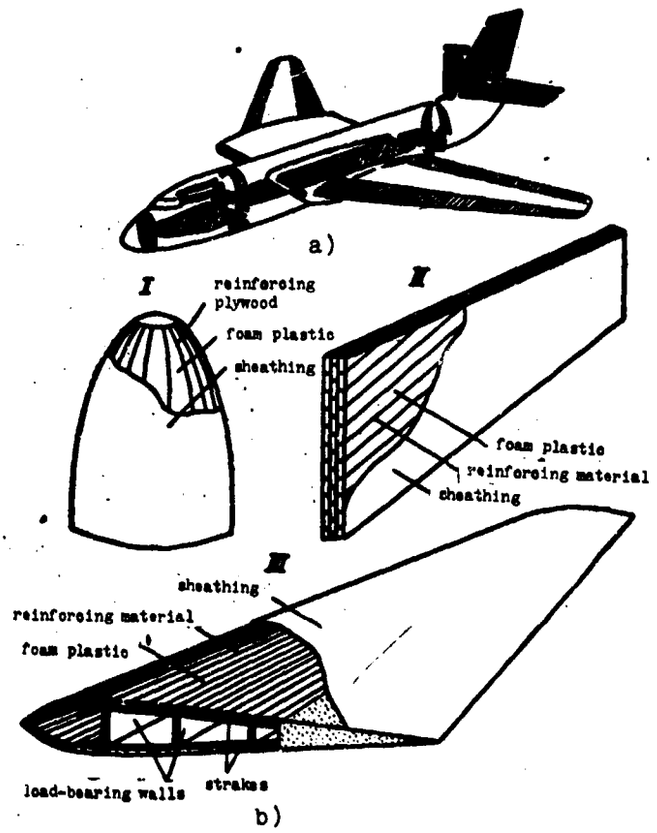


Fig. 23.6. Various application of reinforced foam plastic. I – load-bearing thermal insulation layer on article, II – load-bearing wall, III – profiled construction. a) diagram of application of foam plastic in construction of contemporary aircraft, b) diagram of structural parts of aircraft.

Machining of surface of unreinforced and reinforced foam plastics before bonding is produced on ordinary woodworking machines. Foam plastics can be subjected to following forms of treatment: sawing, planing on surface and sides, with observance of parallelism of processed sides or conicity over length; milling; drilling of lightening holes, etc.

Reinforced foam plastics are glued to each other and to wood materials with cold-polymerized glue VIAM-B3. Gluing of reinforced foam plastics with metal is executed just as foam plastic with metals.

Reinforced foam plastics, being load-bearing and structural materials, can be applied as filler, reinforcing thin skin and walls and also executing role of heat insulation, especially in those cases when reinforcing is done with nonmetallic materials (Fig. 23.6).

Most widely applied foam plastics in aviation industry, grades PS and PKhV, can be used at temperatures of from -60 to +60°C. At higher temperatures these foam plastics have to be replaced by more thermoresistant materials (for instance, FK-20, FK-40, and others).

C H A P T E R XXIV

RUBBER MATERIALS

§ 1. General Information

Rubber is an artificial material obtained as a result of special processing caoutchouc; it possesses a series of valuable properties which have made it an irreplaceable material in technology. These properties are high elasticity, resilience, damping ability, resistance to abrasion and multiple bend, stability to action of liquid fuels and oils, good sealing ability, gas- and waterproofness, electric `ating properties, and others.

Thar.. .o this, rubber materials have found considerable application in aviation industry for manufacture of aircraft tires and damping components, fuel tanks, hoses, deicers, and also as lining, sealing (for hermetic sealing of detachable connections), and electric insulating material.

Composition and basic components of rubber mixtures. Rubbers are complex compositions, consisting of many components, having defined assignment. Besides basic component, caoutchouc, the composition of rubber includes vulcanizers, fillers, plasticizers, accelerators, antioxidants, dyes, and others. Properties of rubber depend on what caoutchouc is basis of rubber and also on what components and in what quantities are added to it.

Caoutchouc is the basis of every rubber mixture. Content of it reaches up to 95%. Both raw caoutchouc and reclaimed rubber are applied, in some cases partially replacing raw caoutchouc. Depending upon origin, we distinguish natural and synthetic caoutchoucs.

Natural caoutchouc is obtained from tropical plants. Caoutchouc in considerable

quantity (up to 4-5%) is found in the tropical Hevea tree. It is contained in the form of lacteal latex sap. Extracted and processed latex is turned into a dense mass - natural caoutchouc. Film caoutchouc, coagulated after being rolled into packs of dull-cream color, is called crepe. Caoutchouc processed and freed of proteins by fumigation method darkens and takes on lower properties and characteristics - this is so-called smoked sheet rubber. Specific gravity of natural rubber is 9-9.1 kN/m^3 (0.90-0.910 g/cm^3). Elasticity of rubber depends on temperature. Thus, with lowering of temperature below +4°C, it hardens, and at lower temperatures it becomes brittle. At +70°C rubber is softened, loses its elasticity, becomes plastic-flowing, and at 200°C and higher melts, being decomposed and turned into a dough-like mass.

Natural rubber swells in gasoline, benzene, and oils but is resistant to diluted acids and alkalis. With time, under the influences of solar beams and atmospheric oxygen, rubber loses its valuable properties, becomes brittle. This is connected with its aging.

An important property is the ability of rubber to be vulcanized. In most cases this process is carried out in the presence of sulfur, where, as a result, rubber is turned into strong, insoluble, heat-resistant, nonsticky material of varying elasticity (depending upon sulfur content). Natural rubber is used for manufacture of cured rubber, applied for production of aircraft tires.

It is clear that natural rubber, encounted in certain plants in insignificant quantities, is very expensive, scarce, and its application is limited for a number of technical considerations. This is why production of cured rubber is based on rubbers obtained by artificial, synthetic, means.

Synthetic rubbers. The process of obtaining synthetic rubbers usually is connected with the reaction of polymerization (butadiene, nitrile, and styrene rubbers) or with condensation (thiokol and polysiloxane rubbers). As a result of copolymerization of butadiene and acrylonitrile, we obtain nitrile rubbers. Through polymerization of butadiene and styrene we obtain styrene rubbers.

Synthetic rubber was created for the first time by Soviet scientist-academicians S. V. Lebedev, A. Ye. Favorskiy, and Professor B. V. Tyzov.

Synthetic rubber in chemical structure, chemical and physico-mechanical properties is close to natural rubber.

Initial raw material for production of synthetic rubber by the S. V. Lebedev method is ethyl alcohol. Rubber obtained by this method is called sodium batadiene [SKB] (СКБ). Initial raw material for production of rubber by the A. Ye. Favorskiy method is acetylene, obtained from calcium carbide: raw material can also be petroleum or natural gases. Raw materials for production of rubber by the B. V. Byzov method are certain petroleum products. In process of obtaining rubber is applied diazoaminobenzene.

Diazoaminebenzene rubber [DAB] (ДАВ) has high frost-resistance (to -55°C).

However, not all synthetic rubbers are close in chemical structure to natural rubber. Certain synthetic rubbers are close to natural in physico-mechanical properties but differ considerably from it in chemical structure.

In the aviation industry of greatest application are natural rubber [NK] (НК) and also synthetic rubbers. Sodium-butadiene SKB, chloroprene (neutral neoprene), butadiene-nitrile [SKN] (СКН), polysiloxane [SKT] (СКТ), styrene-butadiene [SKS] (СКС). Basic characteristics of different types of rubbers are given in Table 69.

Table 69. Basic Characteristics of Certain Types of Rubbers

Designation of rubber	Tensile strength, MN/m²	Ultimate elongation in %	Permanent elongation in %	Swelling in % (not over)		
				gasoline	oil	water
Natural	24,0—36,0	600—800	20—40	120—200	40	5
Sodium butadiene (SKB)	13,0—16,0	800—900	50—70	100	60	8
Butadiene-styrene (SKS)	24,0—28,0	500—600	15—25	40	20	3
Butadiene-nitrile (SKN)	22,0—25,0	400—500	15—20	15	10	1
Chloroprene (neutral neoprene)	20,0—6,5	600—700	12	—	—	—
Polysiloxane (SKT) thiokol	3,5—6,0	300	4	100	60	8

Characteristics of rubbers in essential degree determine properties of vulcanized rubbers prepared from caoutchouc of some or other form.

Having comparatively great strength, natural rubber is considerably inferior to synthetic in frost-resistance and resistance to solvents.

Rubbers made from sodium-butadiene rubber (SKB) are used for parts working in

hot water or air at temperatures from -30 to +140°C. They are used for manufacture of seal and damping parts.

Rubbers based on butadiene-styrene rubber (SKS) possess good working properties at low temperatures (when not exposed to fuel or oils). They are used for manufacture of covers, seals, and damping parts.

Nitrile rubbers based on butadiene-nitrile rubber (SKN) possess high gasoline and oil resistance, raised mechanical strength, and high thermal resistance. They are used for manufacture of flexible hoses and special parts. Chloroprene rubber (neutral neoprene) is used for parts working in fuel and oil media at temperatures to +120°C. Polysiloxane (silicone) rubbers are distinguished by low strength, wide interval to operating temperature (from -60 to +250-300°C), which makes them thermoresistant sealing rubbers.

Thiokol polysulfide rubbers are used little for production of rubber articles, since in strength, frost-resistance, and thermal resistance they are inferior to rubbers made from NK or from synthetic butadiene rubbers. However, they possess high resistance to water, oil, gasoline, and atmospheric oxygen. Gastightness of thiokols is considerable. This makes them high-quality sealing materials.

Vulcanizers. As vulcanizing substance sulfur finds greatest application. Usually in rubber is contained up to 3% sulfur. However, for ebonite its content is increased to 25-30%. Vulcanization by sulfur occurs during heating to 120-150°C.

For acceleration of the vulcanization process, into composition of rubber are introduced lead litharge and other organic substances (captax and thiuram). Vulcanization accelerators are introduced in quantity of 0.1-2.5% of weight of rubber.

Fillers are solids giving rubber defined mechanical properties and cheapening it. Usual content of them in rubber is from 10 to 50%. We distinguish powdered and sheet (in the form of fabrics) fillers. Powdered fillers can be active and passive. Active fillers considerably increase mechanical properties of rubber. They include soot, silicon oxide, kaolin, titanium oxide, zinc oxide, and magnesium oxide. To every type of rubber corresponds a best combination of defined fillers.

Cheap rubber mixtures are prepared with application of cheap passive fillers (chalks, talc, and barium sulfate). These fillers increase strength very little; however, they lower elasticity and increase rigidity and weight of rubber. Talc

and barium sulfate increase acid resistance of rubber.

As sheet fillers, increasing strength of rubber, are applied fabrics (rubberized articles, sleeves, drive belts, conveyer belts, and others). Strong fiber fillers (woven cotton, viscose and capron cord, sleeve fabrics, and others) are used for strengthening tire casings. Cotton sleeve fabrics are used for different sleeves, etc.

Plasticizers (softeners) – facilitate mixing of caoutchouc with other components of rubber mixtures, improve plasticity of mass during molding, etc. However, softeners can give rubber defined new properties or fulfill added functions, increase frost resistance and elasticity (dibutyl phthalate), can be activators, accelerators, (fatty acids), lower combustibility (tricresyl phosphate), lower gas penetrability (glycerophthalates), decrease oxidizability – aging (phenol paraffin), change color, etc. Plasticizers are introduced in quantity of from 2 to 25% of weight of rubber.

Age resistors (antioxidants). It is known that with time rubber decreases in elasticity – ages. Aging of rubber articles depends on conditions of storage and use. Main cause of aging is oxidation of rubber by atmospheric oxygen. Aging is increased with increase of temperature and also in as a result of action of solar beams. Deceleration of processes of aging is attained by introduction of special substances in quantity of 1-3.5% of weight of rubber. Antioxidants are phenols, amines, paraffin, wax, and ceresine.

Besides these basic components, the composition of rubber includes dyes, serving to give rubber defined color. Sometimes into rubber mixtures we introduce reclaimed rubber – product of processing of old rubber.

Production of rubber consists of three basic operations of preparation of rubber mixture, molding, and vulcanization.

In the beginning there is prepared a rubber mixture called raw rubber, which is obtained by mixing caoutchouc with all remaining components, usually by means of two rollers revolving in different directions. It is possible also to produce it in closed mixing chambers.

Then from raw rubber parts are molded. Depending upon form of article, we apply various methods of molding. Thus, for instance, to obtain sheets, we apply calendering – treatment of raw rubber on calenders, working part of which consists

of rollers revolving in different directions. For production of tubes, rods, various profiles we apply extrusion – crushing of raw rubber with help of a worm press through fillers of defined form. Besides this, rubber articles are prepared by molding or injection molding.

Vulcanization is the final process of manufacture of rubber articles. In process of vulcanization by sulfur (or other vulcanizer) interaction with raw rubber causes formation of three-dimensional molecules with net-like structure. Properties of rubber are improved here: softness and plasticity decrease, elasticity and strength increase, and resistance to aging and action of solvents are increased.

We distinguish hot and cold vulcanization. The majority of rubber articles applied in aircraft construction is subjected during manufacture to hot vulcanization, with heating of articles to temperature of 120-150°C in hot air or steam and holding at this temperature for 10-150 min. For vulcanization we apply special boilers or individual vulcanizers.

Cold vulcanization is applied basically for thin-walled articles and imparts to them lower qualities than hot vulcanization. Cold vulcanization consists in that part of raw rubber (not containing sulfur) is dipped for a few minutes in a solution of sulfur chloride, gasoline, carbon bisulfide, or carbon tetrachloride at room temperature.

Certain synthetic rubbers, when heated, even without vulcanizing substances, are turned into rubber. These are used for manufacture of aircraft wing fuel tanks.

Classification of rubber. All rubber materials are classified according to a number of criteria:

– depending upon hardness: porous (sponge) rubber, soft and especially elastic; medium hardness; hard and high-hard; rigid (ebonite);

– depending upon assignment: universal and special (oil- and fuel-resistant, chemical-resistant, light-, ozone-, frost-, and heat-resistant, gastight, electrically-resistant, and others);

– depending upon form of initial raw material: rubber from natural and synthetic rubber;

– depending upon technology of manufacture: glued, molded, cast;

– depending upon type and construction of articles: tire, chamber, sleeve, protector, etc.

Depending upon basic properties and assignment, rubbers applied in aviation industry are divided into a series of classes and groups.

Class 1. To group A belong soft rubbers and those of medium hardness of grades 922, 1432, 2005, and 1448, working under low compression as seals in water, air, and alcohol-glycerine mixtures at temperatures from -30 to +80°C. To group B belongs rubber of medium hardness of grade 3827, working as profiled lining in water and air at temperatures from -45 to +80°C.

Class 2. This includes colored rubbers of medium hardness of grades 3853 1Ж, and 6Ж, which are used for molding ends of electrical leads.

Class 3. To group A belong rubbers of medium hardness of grades 3109 and 2961, working under conditions of considerable compression in medium of gasoline and oil. Group B includes hard rubbers of grades 4061, 551, 3465, and 2542, intended basically for work as linings and seals under conditions of considerable friction in medium of air, gasoline, kerosene, or oil. Group C includes oil- and gasoline-resistant rubber of medium hardness of grade 3063, working in connection with metal fittings. To group D belong rubbers of grades [VIAM-103] (ВИАМ-103) and VIAM-106, oil- and gasoline-resistant and with raised frost resistance. To group E belongs rubber of grade 3508, soft, of high oil and gasoline-resistance, working as seal rings, under conditions of low compression, and as diaphragms.

Class 4. This includes rubber of grades 2671, 2651, 2667, and 3909 of medium hardness and raised frost resistance, used for manufacture of profiles for sealing hatches, doors, and windows, as unreinforced shock-absorbing linings and rings, working in medium of water, air, or alcohol-glycerine mixture. They may be used at temperatures from -40 to +80°C.

Class 5. Group A includes rubber of grades 3949, 3701, and 56, of medium hardness and hard, intended for work under conditions of compression and extension in medium of water, air, or alcohol-glycerine mixture. Group B includes rubbers of grades 3701, 3311, and VIAM-2, soft and especially elastic, working under conditions of extension and insignificant compression in the same medium as group A.

Class 6. It includes rubber of grades 1847, 2959, and 2462, soft, medium, and hard, basically intended for work in conjunction with metal as shock absorber.

Class 7. Rubber of grades 3491, 4094, and 2696, of great hardness, working under conditions of high compression in interval of temperatures from -30 to +80°C.

Class 8. Rubbers heat-resistant and of medium hardness of grades 3687 and 5168, intended basically for work as linings for hot water and steam. They withstand heat to temperature of +150°C.

Class 9. Embraces rubber of raised frost-resistance of grades B-14, 98-1, 4326-1, 4327, and 4410, working under conditions of compression and friction as sleeves, rings, and linings at temperatures from -55 to +100°C.

Class 10. To group A belong rubbers of grades 3819, 3823c, 3826, 3824, 9722, and 3834, oil- and gasoline-resistant, intended for work as linings and seals in medium of water, air, gasoline, kerosene, or oil. In groups B includes rubber of high hardness of grades 3825, 4004, and 4008, working in medium of water, air, gasoline, kerosene, or oil. Group C includes rubber of grades 3838, 3683, and 4069, oil- and gasoline-resistant, with cork filler, intended for work as seal material in medium of water, air, oil, or kerosene. Besides the above, there are especially light rubbers: foam and porous elastomers.

§ 2. Basic Properties of Rubber Materials

Basic standard tests of rubbers consist in determination of ultimate tensile strength and ultimate elongation, hardness, coefficient of aging, thermal resistance, frost resistance, and resistance to oils, gasoline, and kerosene.

Determination of ultimate tensile strength of rubbers and of their ultimate elongation is made on tension testers -- dynamometers. Samples are first cut to proper form and dimensions; then samples are stretched at defined speed. At maximum load corresponding lengthening of working part of sample is noted.

Ultimate strength is determined by dividing maximum load by area of initial cross section of sample.

Ultimate elongation is determined as a percentage of initial length of sample.

Permanent elongation after break is determined as a percentage of initial length of sample with respect to length of working section by combining torn halves of sample.

Hardness of rubber (Jones) is determined with the help of ball-type hardness tester. Hardness is characterized by depth of submersion of ball in rubber. Load

on ball is 10 N (1000 gf) and its diameter is 5 mm. Depth of pressing in of ball is determined after 30-second test and is measured by indicating micrometer.

Coefficient of aging of rubbers (Geer') is determined as a result of heating standard sample in a heat cabinet for 144 h at a temperature of 70°C. Index of aging of rubber is the ratio of the value of ultimate elongation of sample after its heating to its initial magnitude.

Determination of thermal resistance of rubber. Thermal resistance is characterized by change of elongation of sample at raised temperatures to its elongation at normal temperatures, under identical loads.

Determination of frost resistance of rubber is conducted in interval of sub-zero temperatures to the beginning of loss of its elasticity. Frost resistance depends on character of state of strain and rate of loading.

Usually the frost resistance of rubber is characterized by establishing change of elongation of sample at low temperatures and determination of temperature at which brittleness appears. Coefficient of frost resistance is determined from ratio of elongation of sample when frozen to elongation at normal temperature, under conditions of identical loading.

Resistance of rubber to different liquids (oil, gasoline, kerosene) is determined from change in weight of standard sample of defined form and dimensions after it has been held for 24 hours in given liquid and is characterized by increase of weight as a percentage of initial weight of sample.

§ 3. Rubber Articles Applied in Aircraft Construction

Aircraft tires. Aircraft tires are designed for absorption of shocks during takeoff, landing, and taxiing of aircraft. They consist of rubber inner tubes and casings. Inner tube serves for damping of blows. It is made from raw rubber profile (hose) as a result of its gluing and vulcanization in special molds. Casing is the load-bearing part of the tire. It has complicated structure (Fig. 24.1). Manufacture of casing consists in preparation of its separate parts, their assembly, vulcanization of complete casing, and its finishing.

Rubber fuel tanks. On contemporary aircraft soft tanks find wide application. Soft tanks (Fig. 24.2) are not sensitive to vibration, better resist blow of liquids, are light, are airtight, convenient, and simple. Walls of soft tanks consist of

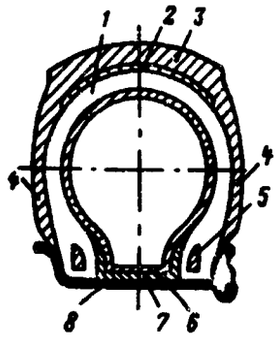
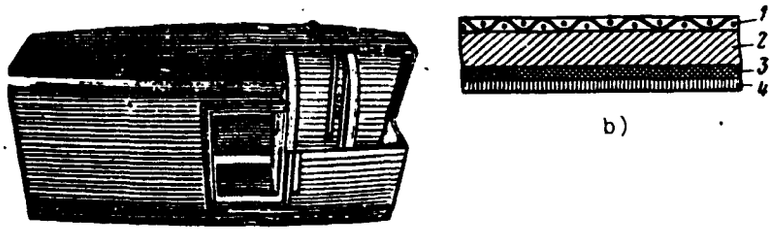


Fig. 24.1. Structure of aircraft tire. 1 – carcass; 2 – breaker; 3 – protector; 4 – slides; 5 – aircraft wheel; 6 – inner tube; 7 – rim tape; 8 – rim of wheel.

two layers of fuel-resistant rubber and an external layer of rubberized canvas. In certain tanks in lateral and lower walls, between fuel-resistant rubber and canvas, are inserted 1-2 layers of swelling rubber. When punctures occur, this protector swells as first portions of fuel strike it and closes hole this preventing further out flow of fuel.

Soft tanks are made from blanks preliminarily cut per patterns and assembled by bonding. Assembled tanks are subjected to vulcanization.

Soft tanks are placed in special containers, for instance of fiberglass laminate, to which they are held by special pins molded into tanks. Sometimes wall of tank are pressed from within against walls of container by special collapsible frames, introduced inside tank.



a) b)

Fig. 24.2. Soft fuel tank. a) external view of soft fuel tank; b) diagram of construction of wall of soft fuel tank. 1 – external load-bearing layer of rubberized fabric; 2 – sponge; 3 – swelling sheet rubber; 4 – kerosene- and gasoline-resistant sheet rubber of film.

Rubber sleeve (flexible hoses) are designed for flexible connection of lines for fuel, oil, hydraulic and air systems. We distinguish two forms of rubber sleeves: lined and braided construction. Rubber sleeve of lined construction are otherwise called by durite hoses. They constitute a cylindrical rubber chamber with a layer of rubberized fabric (Fig. 24.3). Depending upon assignment of hose, kerosene- and oil-resistant and other sorts of rubber are used. Hoses of lined construction can work at pressures of not more than 1.3 MN/m^2 (13 kgf/cm^2) and

temperatures from -45 to +80°C.

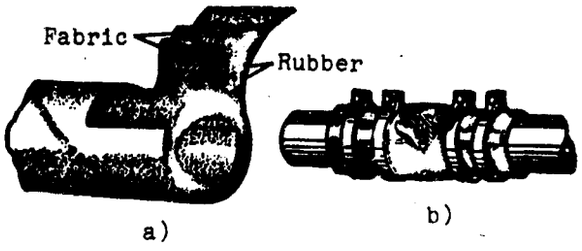


Fig. 24.3. Rubber sleeve of lined construction. a) structure of sleeve; b) method of connecting lines.

Rubber sleeve of braided construction, in distinction from durite type, have yarn or wire braiding, which increases strength of sleeves and ensures preservation of required flexibility. They are used for connection of rigid lines in the form of short sleeves or in the form flexible lines for air, hydraulic fluid, fuel, or oil. Sleeve of braided construction are released in three forms: for low pressure of not more than 1.5 MN/m^2 (15 kgf/cm^2) [RND] (РНД); for medium pressure of not more than 5 MN/m^2 (50 kgf/cm^2) [RSD] (РСД); for high pressure of not more than 12 MN/m^2 (120 kgf/cm^2) [RVD] (РВД).

Damping cord constitutes a bundle of stretched rubber threads of rectangular cross section bound tightly by cotton braiding (Fig. 24.4). It is used for damping parachutes, skis, and for other purposes.



Fig. 24.4. Damping cord. 1 – rubber threads; 2 – cotton braiding.

Rubber-metal reinforced parts and articles constitute rubber mixtures with metal fittings (Fig. 24.5). Such articles include different shock absorbers, dampers, suspension brackets, instrument panels, and panels for electrical and radio equipment. They must effectively absorb vibration and shocks negatively affecting operation of assemblies, instruments, and mechanisms.

Profiled rubber seals are used for sealing hatches, windows, and doors of pressurized cabins and others. These parts are obtained by method of pressing from rubber with high vibration resistance, based on sodium-butadiene rubber SKB.

Ebonite articles. Ebonite constitutes hard electric insulating material. In aviation industry from ebonite are prepared accumulator tanks, different parts for electrical equipment, etc.

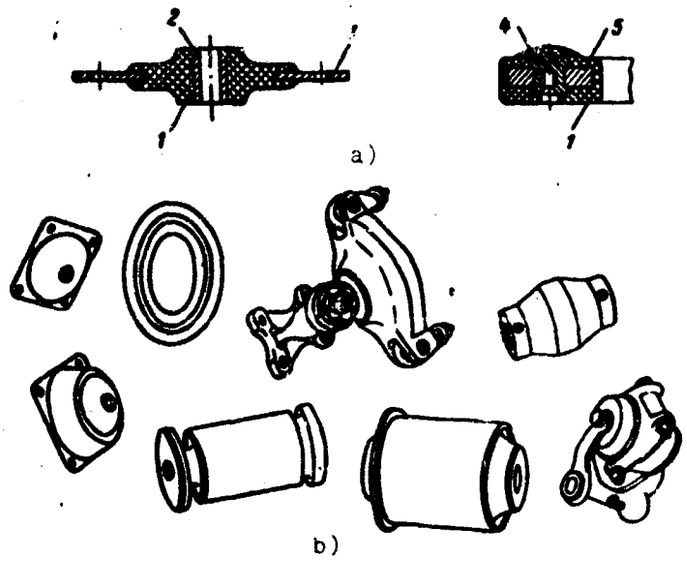


Fig. 24.5. Rubber-metallic aircraft parts. a) diagram of reinforcing; b) samples of rubber-metal parts. 1 – elastic rubber; 2 – steel bushing for suspension of electric motor; 3 – steel flange for mounting to frame; 4 – steel-rubber bushing for mounting flange; 5 – duralumin flange (for rigidity).

Conditions of storage of rubber materials. In process of storage of rubber raised temperature, sunlight, atmospheric oxygen, moisture, acid vapors, and others render destructive effect on it. Here occurs impairment of physico-mechanical properties of rubber and change of form of articles. Therefore it is necessary to store rubber materials in dry locations at air temperatures from 5 to 20°C and relative humidity from 40 to 65%. For every rubber material technical specifications include period and conditions of storage which it is necessary to observe strictly.

CHAPTER XXV

WOOD MATERIALS

§ 1. General Information

At present wood materials have very limited application and are used in light training aircraft, helicopters, gliders, and target drones, and also as building material for manufacture of equipment (mockups, patterns and lofting, etc.).

The most important positive properties of wood are: relatively high strength with low volumetric weight (in tensile strength wood is not inferior to high-carbon steel and duralumin); excellent machinability (thanks to low hardness); method of assembly of wooden constructions (gluing); presence of large natural reserves of wood.

Along with this, wood also has negative properties: hygroscopicity (moisture absorptivity), susceptibility to rotting, and combustibility.

Wood is able absorb moisture from the atmosphere, which leads to increase of weight and volume, decrease of strength, and change of form and dimensions. Damp wood in warm air rots comparatively fast and is destroyed. Basic method of protection of wood from rotting in aircraft building consists in protecting it from moisture with the help of varnish and paint. For more reliable protection from rotting wood is treated with poisons for mold (so-called antiseptics). Antiseptics have to remain stable with time, harmless to wood, glues, metal, and varnishes, and not to increase weight of wood considerably. As antiseptic in aircraft construction are applied oxydiphenyl, [AZ] (A3) (Zbarskiy antiseptic), and ethylmercuric phosphate. In view of toxicity of these substances it is necessary to observe measures of precaution in their use.

To give wood fire resistance, it is impregnated with substances (so-called antipyrenes), which reduce combustibility of wood. As antipyrene for aircraft wood we apply a mixture of borax and boric acid.

§ 2. Properties of Wood

Physical properties. Outward appearance of wood is characterized by its color, luster, and texture. Wood is colored with dyes and tanning substances, resins, etc. It can have color from white (asp or fir) to black (ebony). Under the influence of air and light graying of wood is observed. Damage by mold (fungus) and influence of temperatures over 100°C cause darkening. Certain varieties of wood (beech and others) in natural state possess luster. By texture we understand the grain peculiar to cuts of wood. It depends on width of rings and difference in color of early and late wood, on medullary rays, vascular [rays], direction of fibers, and plane of cut.

The most important physical properties of wood are moisture content, shrinkage, swelling, and volumetric weight. Wood is characterized by high moisture content. Part of moisture (upto 2%) is connected chemically with substances entering in composition of wood, and it is impossible to remove it without destruction of material. Besides this, there are capillary moisture (in capillaries of cells) and hygroscopic moisture (in walls of cells). This moisture is about 30%.

When moistened, wood swells, where mechanical properties are lowered and electrical conductivity is increased.

For determination of moisture content wood samples are dried in a special drying cabinet at 100-105°C to absolutely dry state (permanent weight), after which loss in weight is calculated (in percentage of weight of sample in absolutely dry state). Distinguish absolute and relative moisture content of wood.

With decrease of moisture content of wood there occurs a decrease in its dimensions - shrinkage. Increase of moisture content of wood leads, owing to swelling, to increase of dimensions.

As a result of heterogeneity of structure of wood, during shrinkage or swelling there occurs a nonuniform change of dimensions in various directions. This leads to warping and cracking of wood.

In production of wooden structures moisture content of wood in period of manufacture should be 7-10%, which is lower than that in period of use of these

structures (usually from 10 to 20%). This is achieved through elimination of possible shrinkage of wood in finished article and weakening of bonds between wooden elements. Specific gravity of cellulose, a component wood, does not depend on variety of wood and is approximately 15.4 kN/m^2 (1.54 gf/cm^3). Volumetric weight of wood in its natural state depends on its porosity, i.e., on moisture content, variety, conditions of growth, width of annual rings, age, and position of wood in trunk. For 15% moisture content volumetric weight is within limits of 370-1060 kg/m^3 (0.37-1.06 g/cm^3).

Mechanical properties. Mechanical properties of wood in different directions, in virtue of nonuniform structure of wood, are different. Wood resists loads best of all with the fibers. Mechanical properties of wood depend on moisture content and variety.

In Table 70 are given physico-mechanical properties of basic varieties of wood applied in aircraft construction.

Table 70. Physico-Mechanical Properties of Basic Varieties of Wood

Designation of wood	Volumetric weight, kgf/m^3	Ultimate strength in MN/m^2 during					Proportional limit during compression perpendicular to layers, MN/m^2	Modulus of tension, with fibers, MN/m^2	Resistance to bending shock, MN/m^2
		compression with fibers	extension with fibre	static bend	shear	torsion			
Pine	530	35.0	83.0	65.0	5.0	8.0	3.5	11000.0	1.30
Spruce	470	32.0	75.0	60.0	5.0	8.0	3.0	11000.0	1.00
Fir	440	34.0	72.0	58.0	5.0	7.5	3.5	10000.0	1.20
Larch	600	42.0	98.0	75.0	7.0	10.0	4.0	12000.0	1.00
Ash	710	40.0	110.0	82.0	8.5	12.0	6.0	12000.0	—
Oak	700	40.0	100.0	74.0	7.0	10.0	6.0	10000.0	—
Beech	680	38.0	98.0	73.0	7.5	12.0	6.0	10000.0	—
Linden	480	27.0	80.0	47.0	5.0	7.5	4.0	9000.0	—

§ 3. Wood Materials Applied in Aircraft Construction

In aircraft construction can be applied both natural wood, in the form of lumber, and a varied assortment of different wood materials based on it.

Natural wood. The most important wood in aircraft construction is pine. Substitutes for it can be ordinary spruce and fir.

Of the hard deciduous varieties best aviation wood is ordinary ash; second place is occupied by oak. Substitutes for these scarce varieties are beech, yellow and black birch, and also Manchurian ash, requiring considerable rejection of weak wood. Ordinary birch is used chiefly in the form of veneer for plywood, wood laminated plastics, and articles of double curvature. Linden is used in auxiliary parts of bracing.

During use of structural varieties of wood one should pay attention to its differentiated application in parts depending upon degree their loading. Wood is easily subjected to different forms of machining and gluing. Bending is produced by hot (with application of hydrothermal treatment) and cold methods.

Wood of normal and raised quality can be applied for manufacture of load-carrying parts of certain constructions of gliders, targets, and aircraft (in accordance with variety):

pine, ordinary spruce, Ayan spruce, and Caucasian fir - for fuselage longerons, beam flanges of wing, center section, empennage, stringers, propellers, and skis;

Siberian larch - for beam flanges of fin post, keelsons, stringers, and skis;

ordinary and Manchurian ash, oak and beech - for bent structural elements, of parts of fuselage, wings of hull, propellers, and skis;

yellow and black birch - for beam flanges of wing, center section, fuselage longerons and stringers.

It is recommended that wood lower quality be used for noncritical parts for the purpose of lightening structure. Besides this, it is used widely for manufacture of models, mockups, and equipment.

Wood materials. A deficiency of wood important in a technical sense is heterogeneity of its structure, leading to anisotropy of physico-mechanical properties. For decrease of this deficiency special wood materials based on wood veneers have been developed. These include plywood, delta wood, and other wood materials.

Veneer is a thin layer of wood, obtained by milling, planing, or paring of specially prepared logs.

In wider use in aircraft building is hulled veneer, which goes for manufacture of aviation plywood.

Plywood constitutes wood material obtained by gluing an odd number of sheets of veneer, as a rule, with perpendicular direction of fibers in adjacent layers.

In aircraft building is applied birch plywood of aviation grades [BP-1] (БП-1), [BS-1] (БС-1), and [BPS-1] (БПС-1). Plywood BP-1 consists of sheets of veneer glued with bakelite film (thin paper impregnated with phenol-formaldehyde resin). In BS-1 plywood veneer is glued with phenol-formaldehyde resin. Quantity of layers is from 3 to 11. Thickness of plywood is 1-12 mm.

Thicknesses of 15 mm and more are called plywood plate. Plywood BPS-1 is weatherproof and of raised rigidity.

Plywood is well suited to different forms of machining and gluing; bending is produced by hot method (with application of hydrothermal treatment). Plywood is supplied in the form of sheets with dimensions of upto 1500 × 1500 mm, thickness of 1-12 mm (BP-1 and BS-1), and 2-6 mm (BPS-1).

Plywood of grades BP-1 and BS-1 of first sort is used for load-carrying parts, and structures and that of second sort is used for lightly-loaded parts and structures.

Weatherproof plywood BPS-1 is applied as external load-bearing sheathing with single curvature.

Facing-decorative plywood is prepared from aviation plywood and veneer in combination with texture paper and aminoformaldehyde resin by method of hot pressing on hydraulic presses at a temperature of 140°C.

Facing-decorative plywood possesses raised weatherproofness. Its surface is not changed during brief exposure to aviation oils, fuel, and alcohol.

Plywood constructions and articles are prepared from mechanically treated blanks by means of mechanical fastening and riveting.

Veneer and plywood are subjected to tests for tensile strength with the fibers, for shear, moisture content, and strength of gluing.

Facing-decorative plywood is supplied in the form of sheets and plates with thickness of 1.5 mm and more and dimensions not less than 1500 × 725 mm.

It is applied as decorative material for finishing cabins, instruments, and internal equipment of aircraft.

C H A P T E R XXVI

TEXTILE MATERIALS

§ 1. General Information

Assortment of textile materials applied in aviation industry is varied. These include textile fibers and yarn on their basis, twisted articles (threads, cords, rope, and cable), fabric, material (fabric with surface films), and felt.

Textile materials can be applied in aircraft construction both directly and in production of plastics and special rubber articles.

Forms of textile fibers. Basis of textile materials is textile fiber. Properties of textile materials depend on chemical composition, nature, and structure of fibrous raw material, and also on methods of its processing and finishing of end produce. Depending upon origin, all textile fibers are divided into natural, artificial, and synthetic types.

Natural fibers are divided into three groups:

1. Vegetable fibers of cellulose composition (cotton, flax, and jute). They possess strength and weatherproofness and are used for manufacture of textile materials working under atmospheric conditions.

2. Animal fibers of albumin composition: these include deer wool, possessing high heat-shielding properties, and natural silk, having high strength and high dielectric properties.

3. Mineral fibers. These include asbestos, obtained by splitting certain minerals of fibrous structure. Asbestos possesses chemical- and thermal resistance and electric insulating properties. It is used for manufacture of heat- and electric insulating materials and also for frictional parts.

Table 71. Physico-Mechanical Properties of the Most Important Textile Fibers

Properties	Designation of fibers							
	cotton	flax	viscose silk	natural silk	wool	asbestos	glass	polyamides (capron, nylon)
Length in mm	12—55	5—55	Continuous	Continuous	30—160 and more	9—18	Continuous	Continuous
Thickness in μm	8—48	4—120	15—20	6—29	10—125 and more	0,5—9	5—7 and more	20
Specific gravity in kN/m^3	15,20	15,0	15,20	13,70	13,20	21,0—28,0	26,0	11,40
Normal moisture content in %	8,5	12	11	11	15—17	1,0	0,2	4,5
Heat resistance in °C	120° C	120° C	150° C	150° C	110° C	200—400° C	200° C	60° C
Tensile strength in MN/m^2	24—80	35—95	45	50—60	14—25	80—210	140—220	52—55
Ultimate elongation in %	6,5—9,8	2,5—4,0	9—17	13—20	30—54	—	2—3	25
Breaking length in km	16—53	23—63	30	36—43	10—19	28—100	53—85	45—50
Resistance to atmospheric influence	Resistant	Resistant	Less resistant than cotton	Nonresistant	Less resistant than cellulose	Resistant	Resistant	Nonresistant to light

Artificial fibers are obtained from wood cellulose and glass mass. As cellulose fibers are applied are viscose fibers, less often acetate and cuprammonium fibers. These fibers, owing to their insufficient stability in atmosphere, are applied mainly as electric insulating and decorative-finishing materials.

Glass fiber is obtained by extruding or blowing of molten glass mass. It possesses high mechanical strength, heat resistance, chemical resistance, incombustibility, and good electric insulating properties. Glass fiber is used for manufacture of different structural, electrical-, heat-, and soundproof, and filter materials.

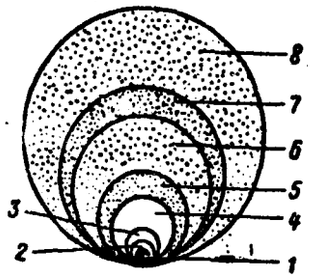


Fig. 26.1. Relative dimensions of different fibers. 1 – cuprammonium silk; 2 – acetate silk (3-5 μm); 3 – viscose silk (7-15 μm); 4 – capron (10 μm); 5 – cotton (15 μm); 6 – natural silk (18 μm); 7 – natural wood (29 μm); 8 – human hair (60 μm).

Synthetic fibers are obtained from different synthetic resins. Most important of the synthetic fibers are capron, nylon, and terilen. These fibers are obtained from melted polyamide and polyester resins by extruding similarly to glass fiber extrusion. Polyamide fibers possess sufficient strength, elasticity, and at the same time low light resistance. They are used for manufacture of fabrics and twisted articles for parachutes and internal finishing of aircraft and also for manufacture heat- and soundproof materials.

In Fig. 26.1 are given relative dimensions of certain fibers.

Properties of textile fibers. In Table 71 are given basic properties of fibers applied for manufacture of textile articles of aviation assignment.

§ 2. Textile Materials Applied in Airplane Construction

Felt

Felt is prepared by matting (packing) wadding from fibers of wood, usually with admixture of cellulose or capron fibers. Thanks to porosity, volume of felt is filled by air, which ensures low volumetric weight (200-430 kg/m^3) and high heat- and soundproof properties. Felt is applied as heat- and soundproof, packing-sealing, damping, filtering, stuffing box, wick, and polishing material. Usually are applied high-quality fine-wool grades of technical fiber: airplane industrial, electroindustrial, and pianograde. Besides the above, we use special friable felts [ATIM] (ATVM) (aviation heat and sound insulation material). Thus, for instance,

materials ATIM-8 and ATIM-9 are used for thermal insulation of pipelines and for heat and sound insulation of cabin sections.

Yarn and Thread

Yarn constitutes twisted (spun) short fibers. Thread constitute continuous strands of infinite length.

Basic characteristics of yarn are number of yarn, degree of twist, tensile strength, and breaking length. Thickness (fineness) of yarn is impossible to measure practically. Yarn has different thickness and is designated by numbers. This is why it is characterized indirectly by ratio of length of yarn (in m) to its weight (in g). This value is called the number of the yarn. Number of yarn shows length of thread with mass of 1 g in meters. The higher the number the thinner the yarn. For twisted yarn the number is indicated by a fraction: is numerator is placed number of single yarn and in denominator the quantity of threads.

For continuous threads of infinite length (natural silk, artificial and synthetic fibers) thickness is characterized by the so-called titer. Titer shows weight (in g) of thread of 9000-m length. Breaking length constitutes that minimum necessary length at which freely suspended thread is broken under action of gravity. It is determined by ratio of tensile strength to weight of unit length and characterizes specific strength.

Yarn and thread are applied for manufacture of fabrics and twisted articles. Besides this, they are used as winding and braiding material for insulation of electric wires and cords.

Twisted Textile Materials

We distinguish the following twisted materials: threads, string, cords, ropes, woven cords, rope, and cable.

Threads may or may not be subjected to special finishing - dressing. Of greatest application in aircraft building are cotton and linen threads.

Cotton sewing threads are released under numbers 00, 0, 1, 3, 4, 6, 10, 20, 30, 40, and 50.

Strings constitute thick hemp thread, prepared by twisting two threads of yarn. String is subjected to dressing and polishing. Strength of string varies from 120-800 N (12 to 80 kgf).

Cords are materials obtained by mutual twisting of several threads of twisted

yarn (cords) or string ("otboyka"). Twisting is produced in direction opposite direction of twisting of threads of twisted yarn and string. Cotton and linen cords are released in diameters of 1-3.6 mm and strengths from 145-1100 N (14.5 to 110 kgf).

Linen ropes constitute three or four twisted threads of cord. They are released in diameters from 4 to 14 mm strengths from 1250-12,200 N (125 to 1220 kgf).

Woven cords are materials obtained as a result of interlacing of several (usually eight) threads of twisted yarn. Cotton and linen cords are released in diameters from 4 to 12 mm and strengths from 550-4050 N (55 to 405 kgf).

Cords, otboyka, and ropes are applied for winding parts of undercarriage and control wheel for holding canvas sheathing to fuselage and seats of aircraft, for mounting heat and soundproofing, lacing partitions and covers, and others.

Ropes constitute three- or four-strand twisted articles of flax, hemp, or cotton with diameters from 3 to 19 mm and strengths from 570-16,500 N (57 to 1650 kgf); they are applied for various auxiliary technical purposes.

Ropes are twisted materials of large diameter made of hemp, manila, sisal, or cotton yarn. Diameter of ropes is 25-65 mm. Strength is 36-195.6 KN (3600-19,560 kgf). Recently we have applied ropes of raised strength made from capron and terilen. Ropes are applied for towing gliders, targets for aerial gunnery, for manufacture of floating anchors for seaplanes, etc.

Fabrics

Fabrics are prepared from yarn. Frequently fabrics of raised quality are prepared from twisted yarn. Fabric is produced on loom as a result of weaving warp (longitudinal) and weft (transverse) threads.

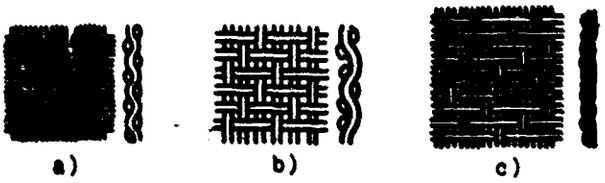


Fig. 26.2. The most important forms of fabric weave. a) card weave; b) serge weave; c) satin weave.

During production of fabric on loom warp threads can be woven with weft threads by different methods. The simplest and most widely used weaves for production of fabrics used in aircraft building are the following: card, serge, and satin (Fig. 26.2).

Card weave (calico or linen) is characterized by highest possible frequency of alternation of warp and weft threads, which ensures greatest strength of fabric to tear and extension, and provides minimum flexibility and softness of fabric.

Serge (twill) weave is characterized by regular diagonal location of warp and weft threads and gives softer and more flexible fabric. Such fabrics are weaker than card fabrics in tensile strength.

Satin (sateen) weave is characterized by least frequency of alternation of warp and weft threads, which provides smoothest surface and softest fabric.

Untreated fabric, taken directly from loom, is called raw fabric. To increase mechanical properties, atmospheric resistance, luster, and smoothness, cotton fabric is processed in alkaline solution with subsequent washing in water. This treatment is called mercerization and fabric is said to be mercerized.

Besides the above, raw fabric, depending upon assignment, can be subjected to different forms of treatment: waterproofing, vermifuge or fire-retardant impregnation, application of coatings, etc.

The most characteristic indices of fabrics are: moisture content, width, thickness, closeness of weave, weight, breaking strength, and ultimate stretchability.

Determination of moisture content is made by drying sample in drying cabinet at 105-110°C to constant weight, after which loss in weight is calculated (as percentage of weight of sample in absolutely dry state).

Width of fabrics. The most widespread widths of fabrics are: 45-75 cm, narrow; 75-100 cm, medium-wide; 100-150 cm, wide; 150-200 cm and more, very wide. Fabrics with width of 0.5-7.5 cm and more are called woven tapes. Width is measured by the meter in several places on fabric.

Thickness of fabrics. Thickness of different fabrics is 0.025-3.0 mm. Thickness is determined by thickness gauge.

Closeness of weave of warp or weft is characterized by number of threads (warp or weft) over length of sample of 100 mm. Determination of closeness of weave is made by direct counting of number of threads with help of weaving magnifier or special counter.

Weight of 1 m^2 of fabric is from 20 g to several kg. Fabrics with weight of upto 0.1 kg/m^2 (100 g/m^2) are light; those from 0.1-0.4 kg/m^2 (100 to 400 g/m^2) are medium; fabric weighing over 0.4 kg/m^2 (400 g/m^2) are heavy.

Tensile strength and ultimate elongation of fabrics are determined on pendular dynamometers chiefly on several samples of weft and base. Strength of fabrics is characterized by breaking load and varies within wide limits, depending upon nature of raw material and quality of treatment of fabrics. Ultimate elongation varies for different fabrics from 2 to 40%.

Materials for Linen Sheathing

Linen sheathing of wings, fuselage, and empennage is characterized by lightness, cheapness, and convenience of repair. It was applied on the majority of aircraft of wooden and mixed construction and is applied at present on gliders, empennage, and ailerons of the majority of small aircraft.

Table 72. Basic Characteristics of Aircraft Fabrics

Designation of fabric	Grade	Tensile strength, N		Ultimate elongation, %		Weight of 1 m^2 in kg
		base	weft	base	weft	
Aviation, from raw yarn No. 100/4, heavy weight	АСТ-100	2280±70	2200±100	<90	<90	0,185±0,010
Aviation linen of highest strength	АЛВК	2000±100	1000±100	90	90	0,220±0,010
Aviation, from mercerized yarn No. 93/2	АМ-93	<3000	<2900	70	70	0,180
Aviation linen, light	АЛЛ	2320	2400	60	60	0,165
Aviation, from mercerized yarn No. 100/2	АМ-100	3280±80	3220±140	60	57,5	0,127±0,007

Linen sheathing constitutes a highly durable fabric of card weave, prepared from linen or cotton yarn. Fabric sheathing has comparatively low strength, is easily soaked, and is subject to rotting. For increase of tautness of fabric, increase of mechanical properties, imparting waterproofness and weatherproofness, after being fastened to frame of structure, it is impregnated and painted with cellulose ester lacquer and paint products.

In Table 72 are given basic characteristics of linen and cotton aircraft fabrics.

Aircraft linen and cotton fabrics are mutually interchangeable. Fabric [ALL] (АЛЛ) is mutually interchangeable with fabric АМ-100 and fabric [ALVK] (АЛВК) is

interchangeable with fabrics [AST-100] (ACT-100) and AM-93. Fabrics ALL and AM-100 are used for sheathing of aircraft with speeds upto 5 km/s (300/h).

More durable fabrics ALVK, ACT-100, and AM-93 are used for sheathing of high-speed aircraft. However, fabric AM-93 is applied only for more durable fastening to frame (for instance, wire instead of threads).

For covering wings, empennage, and fuselage of aircraft with fabric we apply winding, strengthening, and surface woven tapes and also cotton and linen threads. For instance, tapes of cotton (calico), twill, and "two-sided." They are produced from cotton yarn: calico (card) twill and two-sided (serge) weaves.

Tapes of aviation percale [LAP] (ЛАП) and [LAPZ] (ЛАПЗ) constitute strips of cotton fabric – percales – with straight (LAP) and toothed (LAPZ) edges. They are used for gluing seams and fastening points of linen sheathings of wings, fuselage, and empennage of aircraft.

Fabrics for Use Over Wooden Sheathing of Aircraft and Propellors

For covering plywood sheathing of aircraft and propellors are applied special coverings of linen and cotton fabrics. These are light fabrics with low strength, being thin and loosely woven. They are impregnated well by glue, varnish, and paint coverings, protecting them from premature cracking and breaking away from sheathing.

In Table 73 are given properties of fabrics applied over sheathing of wooden aircraft.

Table 73. Basic Characteristics of Covering Fabrics

Designation of fabric	Grade	Tensile strength, N		Ultimate elongation, %	
		warp	weft	warp	weft
Aviation, for covering wood	АОД	200	200	5	9
Aviation linen, thinned	АЛР	400	400	2	9
Aviation cotton, twisted yarn, thinned	АЛКР	400	400	5	3
Aviation linen, twisted yarn, thinned	АХКР	600	600	14	10

Fabrics [AOD] (АОД) and [ALR] (АЛР) are used for covering wings, fuselage, and empennage of wooden aircraft and gliders. Besides this, fabric ALR is used for facing felt parts of engine fuel filters. Fabric [ALKR] (АЛКР) is used for covering wooden propeller blades. Fabric [AKhKR] (АХКР) is used for the same purpose and also for manufacture of rubber anti-icers for wings of aircraft and for cargo parachutes.

Fabrics for Covers and Parachutes

For covers for aircraft and engines we apply close-weave linen and cotton fabrics.

Linen fabrics are given vermifuge and waterproofing impregnation and cotton is given only waterproof impregnation. For manufacture of parachutes avizent cotton fabric is applied.

In Table 74 are given properties of fabrics for covers and parachutes.

Table 74. Basic characteristics of Fabric for Covers and Parachutes

Designation of fabric	Tensile strength, H		Ultimate elongation, %		Weight of 1 m² in kg	Thickness of fabric in mm
	warp	weft	warp	weft		
Linen, waterproof, external (ALR-1)	1080	720	15	6	0,235	0,8
Cotton, waterproof camvas	980	880	22	14	0,280	0,82
Cotton fabric, avizent	<1180	<1180	<17	<14	0,490	0,77

New Textile Fabrics Based on Synthetic and Glass Fibers

On the basis of capron fibers we prepare fabrics [MEK] (МЭК), AlT, and tape [LKT] (ЛКТ). Fabric for aileron tabs, MEK, consists of two layers of capron glued with polyisobutylene glue. It is airtight, frost-resistant, resistant to moisture, and nonresistant to gasoline and solar beams.

Fabric AlT is used for facing of thermal insulation. Tape MEK is used for soft mounting of aircraft canopies.

On the basis of glass fibers are prepared fabrics and tapes. Glass fabric is used for covering thermal insulation mats [ASIP] (АСИП) and [ATIPS] (АТИПС).

Tape [LAS] (ЛАС) is used for thermal insulation of pipelines and for electric insulating winding.

Materials (Leather Substitutes and Varnished Cloth)

Materials are fabrics with waterproof covering of special film. Usually film is applied to face of fabric (cotton, linen, capron, or glass). In aircraft construction of materials are applied for upholstering furniture, facing of walls, ceilings, and floors of aircraft cabins, and for other assignments.

We distinguish several forms of materials. Those with films based on vegetable oils (with pigments and fillers) are considered oilcloths. Those with nitrocellulose films (with plasticizer, pigments, and fillers) are called dermatins and lederins [leatherettes]. Those with polyvinyl chloride film are called tekstovinits. Incombustible material prepared as a result of application to one side of glass fabric of paste-like polyvinyl chloride covering is called pavinol.

Besides the above, we prepare noninflammable and waterproof materials by means of applying to one side of cotton or capron fabrics an antipyrene nitrocellulose covering.

Varnished cambrics are prepared from fabrics of cord weave as a result of their impregnation by special electric insulating varnishes. Basis for these is thin cotton and also special silk and glass fabrics. Varnished cambrics are used for insulation of electrical machines, transformers, and instruments.

C H A P T E R XXVII

VARNISH AND PAINT MATERIALS

§ 1. General Information

Varnish and paint materials constitute liquid compositions which, after application and drying, form a film which adheres to surface.

Varnish and paint coverings, as compared to other forms of coverings obtained after application of varnish and paint materials to articles, find greatest use. Advantages of varnish and paint coverings are: simplicity of technology of application, large variety for covering both metallic and nonmetallic materials, absence of harmful influences to articles covered, and also relative economy.

Varnish and paint coverings are designed for protection of metallic and nonmetallic parts, assemblies, and sheathings of aircraft from destruction under influence of atmosphere and aggressive media and also for improvement of aerodynamic properties of their external surface. Application of coverings on wood and textile materials protects them from rotting and lowers combustibility. Besides this, varnish and paint coverings give fabric sheathings additional strength and tautness and improve appearance of articles. Decorative varnish and paint coverings are used for coloring cases of instruments, instrument panels, for finishing cabin furniture, etc.

Varnish and paint coverings are applied in instrument making as electric insulating materials for impregnation of coils, of windings of plates, and for other parts.

Component Parts of Varnish and Paint Materials

Varnish and paint compositions in most cases constitute compositions of

different components: base of film-forming substance, solvent pigments, fillers, siccatives (drying accelerators), and plasticizers.

Film-forming substances are the basic component. They create film possessing good cohesion with coated surface, which simultaneously is binder for powdered components (pigments and fillers). Film-forming substances have to be stable and durable under conditions of use and chemically neutral. In nature film-forming substances in most cases are substances of organic origin. Film-forming substances under noraml conditions constitute solids or viscous liquids, which it is necessary to dissolve preliminarily to defined viscosity. In aircraft construction are applied varnish and paint materials based on water-insoluble film-formers; they do not cause corrosion of metals and form higher-quality coverings. These include vegetable oils, resins, and cellulose esters.

Vegetable oils are extracted from plant seeds. We distinguish drying (linen, hemp, tung), semidrying (sunflower, cotton), and nondrying (olive, castor) vegetable oils. Drying of oils at ordinary temperature consists of their self-oxidation and polymerization. There are chemical methods of treatment and transformation of nondrying and semidrying oils to drying type.

Resins. Of resins as film-forming substances are applied only soluble, so-called varnish resins. Their number includes both natural resins (amber, copal, dammar, shellac, and colophony) and synthetic resins (phenol-formaldehyde, alkyd, polyorganosiloxane, epoxy, polyvinyl chloride, and others).

Esters and cellulses applied as film-forming substances can be complex (nitrocellulose or cellulose acetate) and simple (ethyl cellulose and benzyl cellulose).

Solvents constitute colorless liquids of organic origin. Solvents are used for dissolution of film-forming substances. After application of varnish and paint materials to surface of coated article, solvents have to be evaporated. Depending upon nature of film-forming substances, as solvents we apply gasoline, turpentine, alcohols, acetone, and other organic liquids.

For preparation of economic mixtures and rational use of scarce solvents to them is added some volatile liquid not a solvent for given film-forming substance. Such liquids are called diluents. As diluents we use benzene, alcohols, and others.

Pigments constitute nonferrous, finely pulverized powders of oxides or salts and metals not soluble in film-forming substances and solvents. Pigments give to covering needed color and increase protective and mechanical properties of film.

At present the following pigments are applied: white (zinc and titanium white), yellow (ocher, lead and zinc chromate), blue (azure, ultramarine), green (chromic oxide), brown (rouge, iron minium), black (soot). Of greatest application of the powdered metallic pigments is aluminum powder.

Besides mineral pigments there also are applied organic pigments, which give film defined color and preserve its transparency.

Fillers are applied in varnish and paint compositions instead of part of pigments for the purpose of preparation of economic mixtures. Introduction of fillers can increase strength of film. As fillers we apply certain salts and oxides of metals. The most frequently applied fillers are chalk (gypsum), kaolin, talc, and others. Separate fillers give films dullness. As such dulling additions serve talc, kaolin, magnesia, and calcium and zinc stearates.

Plasticizers increase plasticity and flexibility of films. Plasticizers can be soluble and insoluble in film-forming substances. Widely used soluble plasticizers are dibutyl phthalate, tricresyl phosphate, triphenyl phosphate; a typical insoluble one is castor oil. Excess quantities of plasticizers make film sticky and prevent its drying.

Classification of Varnish and Paint Materials

Depending upon assignment, all varnish and paint materials are divided into basic and auxiliary types. Basic varnish and paint materials include varnishes, paints, and enamel (for final coverings). Auxiliary materials include washing and neutralizing compositions, pastes, etc. (for treatment of surface before painting), washing (for removal of old coverings before repainting), primers, fillers, and sealers (for guarantee of strong cohesion of coat, levelling and removal of certain defects and unevenness of colored surface), and also solvents, diluents, and thinners (for dilution and thinning varnish and paint materials to required viscosity before use).

Depending upon nature of film-forming substance, all varnish and paint materials are divided into: butyric (on the basis of vegetable oils), cellulose ester (on

the basis of different cellulose esters), and resinous (on the basis of different resins).

Varnish and paint coverings can be single-layer and multilayer. Multilayer coverings constitute system of coverings (primer-like, intermediate, and final layers).

Basic Properties and Methods of Testing Varnish and Paint Materials and Coverings

Tests of varnish and paint materials and coverings are made for the purpose of establishment of conformity of properties to requirements of technical specs or to requirements determined by their assignment.

Viscosity of liquid varnish and paint materials should correspond to methods of their application on surfaces (brush, spray, dip, etc.). Viscosity is determined by viscosimeter [VZ-1] (B3-1) and is expressed by time of flow (in seconds) of 50 mℓ of tested material through nozzle of viscosimeter at a temperature 20° (Fig. 27.1).

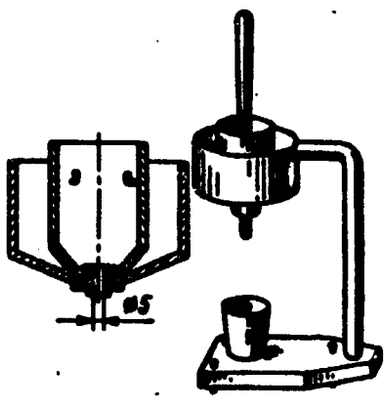


Fig. 27.1. Viscosimeter VZ-1.

Covering power of paints consists in ability to make color of painted surface invisible. Covering power is determined by application of paint on "chess" or glass plate with dimensions of 20 × 20 cm, traced similarly to a chess board in white and black squares. As a result, we determine minimum necessary quantity of varnish and paint material required to completely cover the board in such a manner that black and white squares cease to be different. Covering power is expressed quantitatively in kg/m^2.

Expenditure of varnish and paint materials during their application is characterized by weight of them expended for normal painting of surface with defined area. Expenditure also is expressed in kg/m^2.

Drying time. We distinguish drying time "from dust" and time of full drying.

Drying "from dust" exists when covering has not hardened completely but has lost stickiness (dust will not adhere to it).

Achievement of this moment is determined by blowing on a cotton tampon dropped on film, where fibers of cotton must not adhere to covering.

Full drying occurs when film solidifies so much that it is possible to carry out further technological operations. Achievement of such moment is established by pressing cotton tampon against film or covering under pressure of 20 kN/m^2 (200 g/cm^2) for 30 s, where cotton must not adhere.

Appearance of paint films is characterized by color, gloss, degree of cleanness (contamination). This is determined by their comparison with standard samples.

Dry residue. Dry residue is considered quantity of varnish and paint materials remaining in film of varnish and paint covering after its drying. Dry residue is expressed in percentage of mass of initial liquid varnish and paint material. Dry residue permits determining increase obtained as a result of varnish and paint coverings. This has great value during weight calculations of structures.

Thickness of film is determined by [TLKP-1] (ТЛКП-1) instrument. Determination of thickness of film of metal coverings is carried out with help of double microscope [MIS-11] (МИС-11).

Hardness of film. Hardness of film is determined with help of pendular instrument, as a result of measurement of time of damping of oscillations of pendulum bearing on glass and time of damping of its oscillations when support is tested film. Ratio of second value to the first is index of hardness.

Elasticity of film can be determined by alternate curving of painted metallic plate around steel rods of elasticity scale [NIILK] (НИИЛК), having different diameters (20, 15, 10, 5, 3, and 1 mm). Elasticity is characterized by diameter (in mm) of last rod of least diameter on which cracking of film occurs. Elastic film sustain bend on rod of 1-mm diameter.

Adhesive ability of film (strength of cohesion) is determined by making a cross-like cut with subsequent pressing of an "Э" press and determination of depth of pressing, in mm, at which film starts to scale at point of cut.

Heat resistance of film is determined as a result of holding film in heat cabinet at different temperatures with subsequent inspection and test for hardness, elasticity, and other properties.

Water, gasoline, and oil resistance of covering are determined by submersion of painted plate in corresponding liquid for defined time under conditions of defined temperature, after which resistance of film is evaluated from external appearance, weight, and hardness.

Weatherproofness. Tests under natural conditions are conducted by placing samples of varnish and paint coverings on special testing stations in open air and making observations of state of coverings from 1 to 3 years. In view of duration of such test, it is used for checking varnish and paint materials newly introduced into production.

Accelerated test is conducted by [VIAM] (ВИАМ) in an artificial weather apparatus, simulating change of seasons in 48 or more hours.

§ 2. Oil Varnish and Paint Materials

Oil varnish and paint materials are such for which film is formed in the process of transformation of drying vegetable oil from liquid to solid state. For production of defined properties of films of coverings, into varnish and paint materials we introduce different substances: resins, fillers, pigments, and others. Diagram of composition of oil varnish and paint materials is shown in Fig. 27.2. These materials form durable water-resistant and elastic film.

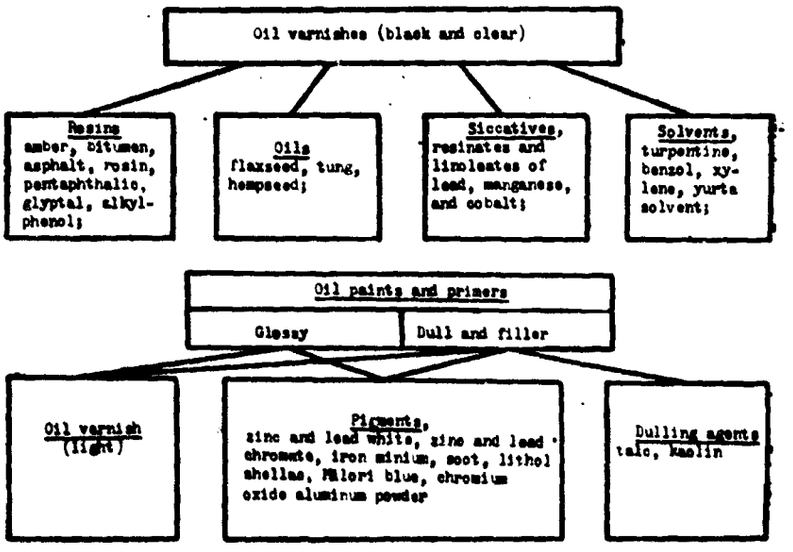


Fig. 27.2. Diagram of composition of oil varnish and paint materials.

Of the oil varnish and paint materials in aviation industry varnishes, enamels, primers, and fillers are applied mainly for coating metallic surfaces.

Components of Oil Varnish and Paint Materials

Oils. Main components of oil varnish and paint materials are specially treated vegetable oils. Upon contact with air they combine with oxygen. Here

there occurs a chemical process, as a result of which the mass is turned into a dense elastic film.

Of greatest value in production of high-quality oil varnish and paint materials are the drying vegetable oils linseed and tung, obtained by pressing seeds of flax or tung tree.

Raw oils dry very slowly (5-7 days). For acceleration of their drying they are specially processed, boiled and purified with fuller's earth. In the process of boiling to oil are added siccatives, accelerating drying. As a result of such processing of vegetable oil, drying oil (olifa) is obtained, which at room temperature dries in twenty-four hours. Olifa prepared from drying vegetable oils is called natural oil.

Siccatives constitute substance promoting oxidation of oils by atmospheric oxygen and therefore accelerating the process of drying. As siccatives we apply oxides or salts of lead, manganese, and cobalt soluble in oils.

Introduction of siccatives in large quantities is not recommended, since this, although leading to fast drying of oil, accelerates aging of films – their destruction with time.

Resins are introduced into varnish and paint materials for production of harder waterproof films and also for achievement of best cohesion of them with painted surface.

Into oils varnish and paint materials we introduce most frequently ester gum or glyptal resin. Ester gum constitutes product of treatment of natural resin of rosin with glycerine at a temperature of 280-290°C. Externally it somewhat resembles rosin but differs by higher melting point. Synthetic glyptal resin is superior in properties to ester gum.

Solvents. All oil varnish and paint materials (besides natural drying oil) contain organic solvents, which are necessary for giving solutions working viscosity. As solvents for ester gum materials we apply turpentine and for glyptals we use benzol (white spirit).

Turpentine is obtained by distillation of sap of coniferous trees. Benzol is a product of distillation of oil.

Pigments. For production of needed color of paint, into composition of varnish and paint materials we introduce pigments.

Oil Varnish and Paint Products

Oil varnishes constitute solutions of drying oil and resin in organic solvents.

We distinguish clear and black (bituminous) oil varnishes. Depending upon conditions of drying, oil varnishes are divided into varnishes of cold (air) and hot drying, hardening at temperatures over 60°C.

According to assignment, we distinguish semifinishing and finishing varnishes. Semifinishing varnishes are used for manufacture of primers, fillers, and enamels. Finishing varnishes are used for production of coverings on unpainted and painted surfaces. Examples of finishing oil varnishes are varnish No. 17-a, applied for protection of small steel and aluminum alloy parts, crystal varnish "Moroz" [LM-33] (ЛМ-33) for decorative coverings of external parts of instruments, and black varnish No. 1C2/19 for coating engine parts over primers No. 101/19.

Oil primers are applied directly on metallic surface. Their assignment is to provide reliable protection of metals from corrosion and to strengthen cohesion of paint covering with surface. Oil primers are obtained by mixing of oil varnish of semifinishing type with pigment. Quantity of pigment in primers must not exceed 40% of weight of varnish. Wood primers contain powdered fillers in the form of talc and kaolin.

The most commonly used varnish primers in aircraft construction are: ester gum primers [ALG-1] (АЛГ-1), ALG-5, and glyptal primers ALG-7, ALG-8, and No. 138a. Primer ALG-1 is used for protection of aluminum and steel parts; primer ALG-5 is used for protection of aluminum parts; primers ALG-7 and ALG-8 are for aluminum and magnesium alloys before being colored with perchlorvinyl enamels. Primer No. 138a is used for metallic surfaces before they are colored with nitrocellulose or perchlorvinyl enamels.

Oil fillers are designed for levelling of primed metallic surfaces. Fillers differ from primer by larger quantity of pigment (to 80%) and smaller quantity of solvent.

The essential deficiency of oil fillers, considerably limiting their application in airplane building, is drying time, which especially sharply is revealed in those cases when it is necessary to apply a comparatively thick layer of filler.

In the airplane industry is applied red filler varnish AM for levelling of parts of cast aluminum preliminarily primed with ALG-1.

Covering oil enamels are applied to surface, forming basic protective layer of varnish and paint covering. Films of oil enamels usually contain 30-60% pigment. If is required that film be dull, into enamel we introduce dulling substances, for instance, talc or kaolin, in quantity of 20-30% of weight of film.

Covering oil enamels are used for painting interior surface of cabins, external sheathing of aircraft, pipes, tanks, parts of instruments, engine accessories, metal propellors, and others. They are released in different colors, depending upon introduced pigments.

According to composition of varnish entering into enamel, we distinguish ester gum and glyptal enamels. These enamels are mutually interchangeable. Enamels are marked with the letter "A" and conditional number designating color. If enamel is prepared on a base of glyptal resin, after the number we place the letter "ф"; glossy enamel is designated by the letter "г" and dull by "м."

For coating interior metallic parts of aircraft are applied the following oil enamels: A-6 (yellow) for coating fuel tanks and fuel lines of aluminum alloys; A-7 (light-green) for coating water tanks and water lines of aluminum alloys; A-8 (brown) for coating oil tanks and oil lines of aluminum alloys; A-9 (blue) for coating units of hydraulic system; A-10 (blue) for coating equipment and lines of oxygen system; A-11 (white) for coating fuel indicators and medicine chests; A-12 (black) for coating air bottles and air lines; A-13 (red) for coating fire-fighting equipment and for identification signs; A-14 (steel color) for coating metallic surfaces preliminarily primed.

Peculiarity of oil varnish and paint materials is their slow drying. Thus, for instance, oil enamels at a temperature of 18-23°C dry in 24-30 h. Deficiency of oil varnish and paint materials is their low resistance to high temperatures and to fuels and lubricants. Oil varnish and paint materials are diluted with turpentine and benzol. Sometimes for this purpose we apply diluent [RI4G] (Р14Г), being a mixture of natural linseed drying oil and benzene. To dilute oil and glyptal primers is possible with diluent Pl, consisting of benzol and pyrobenzol.

§ 3. Cellulose Ester Paint Materials

Cellulose ester paint materials constitute unpigmented or pigmented solutions of cellulose esters in organic solvents. They contain additions of resins,

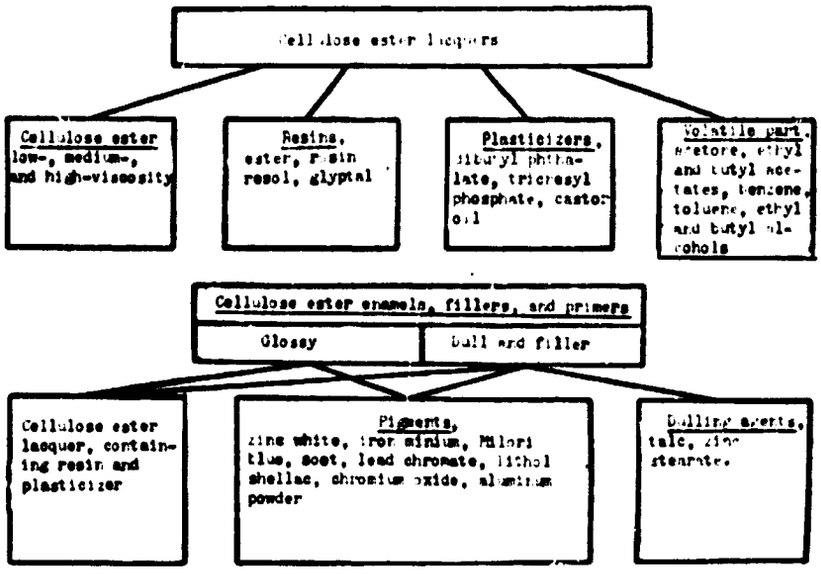


Fig. 27.3. Diagram of composition of cellulose ester paint materials.

plasticizers, dyes, and other components. In distinction from oil varnish and paint materials, the drying process of cellulose ester paint materials is quite fast – in 40-60 min at normal temperature. Drying is reduced to evaporation of solvent. In Fig. 27.3 is given a diagram of composition of cellulose ester paint materials.

Components of Cellulose Ester Paint Materials

Cellulose esters. Cellulose esters are formed as a result of influence of concentrated acids on cellulose. For paint materials of greatest value are nitric acid cellulose ester (nitrocellulose) and acetate (cellulose acetate). Most commonly used are paint materials based on nitrocellulose.

Nitrocellulose is obtained by action on purified cotton down or wood cellulose of a nitrating mixture consisting of nitric and sulfuric acid and water. Nitrocellulose is soluble in acetone, esters, and other organic solvents. After removal of solvent, there forms an amorphous colorless film.

The quite high strength of plasticized nitrocellulose, high surface hardness, plasticity, elasticity, colorlessness, and also good combination with oils and resins are responsible for the wide application of nitrocellulose as film-forming component of protective and decorative paints. Deficiencies of nitrocellulose are its explosiveness, high combustibility, and low light and heat resistance.

Cellulose acetate also is applied as film-forming substance in production of lacquers and films. It is distinguished by lowered combustibility, good light resistance, and considerable thermal resistance.

Nitrocellulose and cellulose acetate have raised hygroscopicity and comparatively low chemical resistance – they are gradually destroyed under action of diluted acids and alkalis.

Resins are introduced into cellulose ester paint materials to increase hardness of film, improve adhesion to coated surface, and to improve water resistance and glossiness. In aviation cellulose ester paint materials of greatest application are synthetic resins ester gum and glyptal.

Plasticizers. Films of cellulose esters during drying from solution are reduced considerably in volume. In certain cases this property is valuable: for instance, in the coating of fabric, since drying film strains fabric with great force. However, in the majority of cases this property is undesirable, since it prevents obtaining smooth covering on metal or wood. This is why to decrease shrinkage into paint materials are introduced plasticizers, which increase elasticity of films. Besides this, plasticizers increase weatherproofness of films. As plasticizer in cellulose ester paint materials we usually introduce tricresyl phosphate, dibutyl phthalate, or castor oil.

Pigments. In cellulose ester paint materials are applied the same pigments used for oil-base paints.

Solvents and diluents. In cellulose ester paint materials are applied other solvents than used in oil-base paints. They consist of active solvents and diluents. Active solvents are acetone, ethyl acetate, butyl acetate, and certain others. As diluents we apply benzol, alcohols, light grades of benzene, and others.

Nitrocellulose Paint Products

Nitrolaki are solutions of nitrocellulose in solvents. In the aircraft industry they find limited application. For lacquering fabric sheathings of aircraft we use airplane dope primer coat [AlN] (AlH). It is used to increase mechanical properties of fabric, to create on it a water- and airtight layer, and to create tension.

A variety of the above is nitrocellulose adhesive AK-20, used for gluing fabrics to wood. For surface covering on layer of nitrocellulose enamels we

frequently apply colorless nitrocellulose [AV-4 d/v] (АЛ-4 Д/В) and [AV-4 d/l] (АВ-4 Д/Л).

Primers based on nitrocellulose are applied rarely in view of their insufficiently good cohesion with coated surface. For coating wood finish applies nitrocellulose primer [DD-113] (ДД-113), film-forming part of which contains, besides nitrocellulose, kaolin, large quantity of ester gum and castor oil. As intermediate layer under nitrocellulose enamels are applied glyptal red primer [illegible].

Nitrocellulose fillers constitute thick mass of nitrocellulose, plasticizers, resins, pigments, fillers, and volatile part. They have to dry fast, adhere well to primer, and after drying form sufficiently durable and elastic film, easily cleaned with sandpaper and pumice.

Nitrocellulose fillers are applied mainly for finishing wood. The most commonly used filler is nitrocellulose yellow [ACh-32] (АЧ-32).

For dilution of cellulose ester paint materials we apply diluent [RDV] (РДВ), in which is contained not less than 30% active solvents. Composition of RDV includes acetone, ethyl acetate, butyl acetate, ethyl alcohol, butyl alcohol, and benzene.

Nitrocellulose enamels constitute mixtures of nitrocellulose with pigments of needed color, which increases their resistance to atmospheric influence. Nitrocellulose enamels are used for coating external surface of wooden sheathing of aircraft, fabric coverings, and internal parts of instruments.

Enamels of different colors intended for coating fabric coverings over airplane dope are released in glossy and dull forms and are called second coat dopes. They are applied by brush or spray. Drying time at normal temperature is 1 h, but when multilayer coatings are applied, for drying of last layer not less than 4-6 h are required. Second coat dopes do not change shrinkage of fabric.

Nitrocellulose enamels are less weatherproof than oil and resin enamels. In designation of nitrocellulose enamels the letter "п" signifies that enamel is intended for spraying and the letter "К" denotes brush application. Most commonly used in the aviation industry are: nitrocellulose enamel AK-1 (К), light-green, dull; AK-4 (п), green, dull; AK-1 (п), blue, dull; [illegible] (п); [illegible], dull, glossy, and certain others.

§ 4. Synthetic Resin Paint Materials

In synthetic resin paint materials plasticizers are synthetic resins, without addition of drying vegetable oils. Into composition of solutions are introduced plasticizers, dyes, etc. Drying of synthetic resin paint materials consists in evaporation of solvent. Diagram of composition of synthetic resin paint materials is shown in Fig. 27.4.

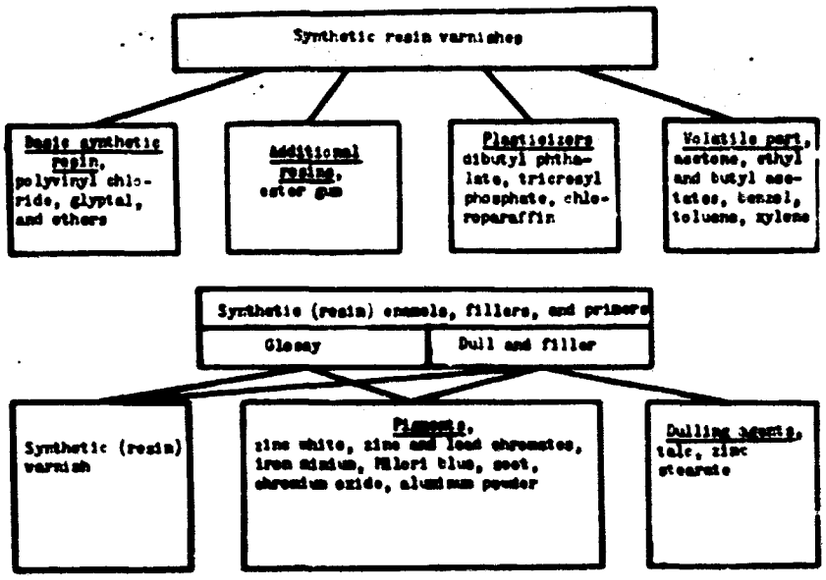


Fig. 27.4. Diagram of Composition of Synthetic Resin Paint Materials.

Synthetic resin paint materials in many respects are superior both to oil and cellulose ester paint materials. Their films are not combustible, are gasoline, oil, water, and weather resistant, where results of aging are almost unnoticeable.

Component of Synthetic Resin Paint Materials

Basic resin. In perchlorvinyl paint materials base is synthetic perchlorvinyl resin. It dissolves well in organic solvents. Coating based on it adhere well to coated surface. Perchlorvinyl resin is dissolved in acetone, ethyl acetate, butyl acetate, and certain other solvents. One of peculiarities of perchlorvinyl resin as a component of paint materials is high chemical resistance. Resin possesses comparatively high brittleness, which can be absolutely eliminated by introduction of plasticizer to it.

In glyptal paint materials base is synthetic glyptal resin. In properties

glyptal materials are somewhat like oil-base materials but differ by considerably greater strength and weatherproofness of coverings.

In pentaphthalic paint materials base is synthetic pentaphthalic resin. Usually it is modified by vegetable oils. Pentaphthalic coatings possess high atmospheric and water resistance and strength, which account for their application for covering of exterior surfaces:

In acrylic paint materials base is synthetic acrylic resin; in polyurethane paint materials base is synthetic polyurethane resin; in polyorganosiloxane (silicone) paint materials base is polyorganosiloxane synthetic resin.

Plasticizers. As plasticizers are applied dibutyl phthalate, tricresyl phosphate, chloroparaffin, and others, introduced in quantity of up to 40% of weight of basic resin. Plasticizers give resin elasticity, which is expressed in ability of films to lengthen during extension.

Auxiliary resins. Perchlorvinyl paint materials, besides basic perchlorvinyl resin, contain other resins, introduction of which is caused by necessity to increase cohesion.

Usually into perchlorvinyl paint materials are introduced synthetic glyceryl phthalate resins modified by vegetable oils or rosin.

Pigments. To impart defined color, corresponding pigments, dyes, are applied.

Solvents and diluents. Volatile part of synthetic resin paint materials consists of active and passive solvents. As active solvents are applied acetone, ethyl acetate, butyl acetate, chlorobenzene, and certain others. Passive solvents include ethyl and butyl alcohols.

Paint Products Based on Synthetic Resins

Synthetic resin paints. Resin paints constitute solutions of corresponding synthetic resins in mixture of organic solvents with addition of plasticizers.

Polybutyl methacrylate paint 9-32 constitutes 6%-solution of polybutyl methacrylate in mixture of butyl acetate, acetone, and toluene. Besides resin, into paint we introduce plasticizers. This paint gives a coating resistant to air but insufficiently resistant to gasoline; we apply it with addition of aluminum powder chiefly for coating sheets of metallic sheathing. It dires at room temperature in 2-3 h or at 65°C in 45 min. Increase of gasoline resistance of

coating is attained by introduction to paint of melamine-formaldehyde resin, promoting conversion of film to solid state in the process of hot drying at 80°C (acrylic 9-32Ф) or addition of nitrocellulose, allowing us to apply air drying (paint 9-32Н).

Polyvinylbutyral lacquer AO constitutes solution of polyvinylbutyral resin with addition of resol, phenol-formaldehyde, and melamine-formaldehyde resins. After drying at 100-120°C for 3 h, lacquer forms film distinguished by great resistance to gasoline, oils, water, weak acids and alkalis. Film is heat-resistant to 250°C.

Synthetic resin primers. Perchlorvinyl primers are prepared from their corresponding base with addition of certain resins, plasticizers, pigments, and volatile part. For priming of wooden parts is applied light-yellow primer [DD-120B] (ДЛ-120Б), containing talc; for priming duralumin parts we use yellow primer [KhVG-1] (ХВГ-1), containing zinc chromate.

Polybutyl methacrylate primers are prepared from acrylic lacquers containing melamine-formaldehyde resin with strontium chromate [AG-10s] (АГ-10с) or with zinc chromate [AG-3a] (АГ-3а). They possess high cohesion with metallic surfaces. Acrylic primer AG-3a dries in 3-4 h at room temperature or in 30 min at 80°C. It is used for protection of parts made from aluminum alloys both as an independent coating and as priming layer under perchlorvinyl enamels. Acrylic primer AG-10s dries in 1-2 h at room temperature. It is applied as priming layer under perchlorvinyl enamels for protection of parts made from steel, aluminum, and magnesium alloys.

Synthetic resin fillers contain the same components as primers but in considerably larger quantities – pigment, and in smaller – volatiles. Perchlorvinyl resin fillers [KhVSh-1] (ХВШ-1) and KhVSh-4 (green) are used for treatment of wooden and metallic surfaces.

Synthetic resin enamels are prepared by addition of pigments to resin base.

Perchlorvinyl enamels are prepared on base of perchlorvinyl resin. Film possesses high weatherproofness, water resistance, chemical resistance, and incombustibility.

In moisture resistance it exceeds by 4-6 times nitrocellulose coatings. Thermal resistance of coating is 100°C.

Perchlorvinyl enamels are designed for coating metallic, wooden, and fabric surfaces. Applied grades of enamels are: [KhVE-1] (XB8-1) (brown), KhVE-4 (green), KhVE-12 (dark-gray), KhVE-13 (red), KhVE-16 (light-gray), KhVE-17 (aluminum), KhVE-19 (aluminum), KhVE-20 (black), and others.

For dilution of perchlorvinyl paint materials are applied diluents P-4 and P-5. They consist of mixture of chlorobenzene, acetone, and dichloroethane.

Polybutylmethacrylate enamel [9-32al] (9-32ал) is obtained by mixing varnish 9-32c 6-8 parts of aluminum powder. It forms protective coating while adding but slight weight. It is used for external coating of duralumin sheathings of aircraft.

Siloxane enamels constitute varnishs based on silicone resins with addition of aluminum powder. They possess high water and gasoline resistance. Coatings sustain heating to 500-550°C. They are used for remaining parts and assemblies as heat-resistant coating.

Acrylic paint materials (lacquer 9-32 and enamel 9-32al) are diluted by special diluent No. 648. It constitutes a mixture of volatile organic solvents: esters, aromatic hydrocarbons, and alcohols.

C H A P T E R XXVIII

GLUING AND SEALING MATERIALS

§ 1. General Information

Glue materials constitute viscous colloidal solutions possessing gluing ability, i.e., the ability to form a hard film which adheres firmly to joined materials.

Recently in aircraft construction application of glues for joining different materials (metals, plastics, rubber, wood, and others) has increased considerably.

Advantages of glued joints as compared to those riveted, welded, bolted, etc. are: possibility of joining heterogeneous materials; more equal distribution of stresses in joints; raised resistance to vibration loads; possibility of manufacture of lightened parts and structures from thin sheets; elimination of operations of drilling holes for mechanical fasteners and, in connection with this, simplification and acceleration of assembly process; higher strength of glued structures than those assembled with mechanical fasteners; lowering of weight of articles; obtaining of glued articles with even and smooth external surfaces; elimination of weakening of connected elements by holes; airtightness of joints; obtaining corrosion-resistant joints; obtaining three-ply constructions with fillers of suitable strength and weight; economy of glued joints in connection with their relatively lower cost.

Basic deficiency of glued joints is their limited thermal resistance, caused by organic nature of glues. Besides this, glued joints possess low strength during nonuniform break away.

Strength of glued joint essentially depends on quality of preparation of

glued surfaces and conditions of gluing.

For reduction of industrial cycle and for obtaining required indices of mechanical strength, thermal resistance, etc., during gluing it is necessary in most cases to heat glues to 60-150°C.

Contemporary glues in most cases constitute compositions of high-polymer substances, in consequence of which glues inherently undergo irreversible changes of their properties with time, especially when used under atmospheric conditions.

Classification of gluing materials. Depending upon application, we distinguish glues of structural and nonstructural assignment. Structural glues are designed for joints bearing loads. Nonstructural glues are used for joining unloaded materials and parts.

Depending upon nature of binder, we divide glues into albumin (casein), resin (based on synthetic resins), and rubber types.

Depending upon possibilities of application of glues for joining different materials, we distinguish universal (for wood, metals, plastics, ceramics, glass, etc.) and special glues (for rubbers only; for wood only; for materials only, etc.).

In composition glues can be either solution of gluing substance in a defined solvent or a mixture of liquid components without solvents.

Glues on resin basis can be thermoplastic (reversible) and thermosetting (irreversible).

In delivery state glues can be liquid, powdered (with preliminary dissolution before use), and film (in the form of impregnated films of fabric, paper, etc.). Most widely used are the liquid glues.

Basic properties of gluing materials. Basic properties of glues are viscosity, shrinkage of glue film, working viability, water resistance, thermal resistance, and strength of cohesion.

Viscosity of glue is determined on viscosimeter [VZ-1] (B3-1) (see Fig. 30.1) (Engler) and is characterized by time required, in seconds for 50 μm^3 (50 cm^3) of glue solution at a temperature of 60°C to flow through nozzle of defined diameter. Engler viscosity degrees is characterized by ratio of outflow velocity of glue solution to outflow velocity of the same volume of solvent.

Shrinkage of glue film. In the process of hardening of film shrinkage occurs. Intense drying may cause considerable shrinkage and breaking of film.

Working viability of glue is duration of preservation of normal viscosity and normal strength of compound. It depends on composition of glue and on conditions of its storage (temperature, humidity, etc.).

Water resistance is determined by change of ultimate strength of glued seam after being in water for 24 h at a temperature of 20°C.

Thermal resistance is characterized by temperature at which sharp fall of ultimate strength of glue compound is observed.

Strength of cohesion (binding ability of glue). Glued joints work well under shear, worse under breaking away and tearing forces. Testing is reduced to determination of ultimate strength during static shear (Table 75). Strength of glued joints can exceed strength of materials glued.

Table 75. Ultimate Shear Strength in MN/m^2 of Glued Joints of Metals with Bilateral Overlap at Different Test Temperatures

Glued metals		Brand of glue	Temperature in °C			
center plates	cover plates		−60	+20	+60	+100
Д16АТ	Д16АТ	ПУ-2	5,5	5,5	5,5	3,0
		ВФ-2	3,0	5,5	5,5	3,0
1Х18Н9 (ЭЯ1)	Д16АТ	ПУ-2	7,5	7,5	6,5	4,5
		ВФ-2	6,0	7,5	6,5	4,5
30ХГСА	Д16АТ	ПУ-2	11,0	11,0	7,0	4,5
		ВФ-2	7,0	10,5	8,5	4,5
30ХГСА	30ХГСА	ПУ-2	15,0	11,0	7,0	5,5
		ВФ-2	6,0	15,5	11,5	8,0

Besides this, there is determined strength during break away (uniform and nonuniform) and also strength during prolonged constant and variable vibration loads. For joints of rubber and textile materials we determine resistance to exfoliation and stratification.

§ 2. Gluing Materials

Glues for Joining Metals and Also Metals With Nonmetallic Materials

For these purposes are applied glues based on different synthetic resins.

Glues of [BF] (ВФ) type constitute alcohol solutions of a mixture phenol-formaldehyde resin and thermoplastic butvar resin. Glues BF-2 and BF-4 are supplied in ready-to-use form. They are liquids (glue BF-4 can be in film form). Viability

of glue is 6 months. Working viscosity is 30-60° Engler at 20°C. Expenditure of glue is 0.15-0.2 kg/m^2 (150-200 g/m^2) of glued surface for every layer.

For bonding the following exposed aging times are required: not less than 15 min at 16-30°C and for nonhygroscopic materials not less than 30 min at 16-30°C and 15 min at 50-60°C. Specific pressure should be 0.5-2 MN/m^2 (5-20 kgf/cm^2).

During the bonding of metals clamping time is 25-60 min at 140-160°C in glue layer. For bonding nonmetallic materials among themselves and with metals aging must be 20 to 60 min at temperature of from 120 to 140°C. Upon the expiration of aging with preheating parts are held under pressure until they cool to 40°C. Shear strength of such glued joint will be not less than 10-150 MN/m^2 (100-1500 kgf/cm^2). Sharp lowering of strength occurs during heating to 60-70°C. Glues of BF type are water-, fungus-, fuel-, and oil-resistant. They do not cause corrosion of duralumin and are practically nontoxic.

Glues BF-2 and BF-4 are used for gluing metals, plastics, wood materials, ceramics, glass, and several other materials among themselves and in their different combinations. Glues are recommended chiefly for joints working in interval of temperatures from -60 to +60°C. Period of storage of glues is 6 months in hermetically sealed packing.

Polyurethane glue [PU-2] (ПР-2) is a combination of two components which at room temperature are in liquid state.

Preparation of glue is carried out by mixing of components. Viability of mixture is not less than 2 h. Gluing may be carried out without preheating or with preheating. During gluing open and closed aging are required at room temperature for 10-30 min. Pressure during gluing is 0.05-0.3 MN/m^2 (0.5-3 kgf/cm^2). Holding under pressure for gluing without preheating is 24-28 h and that at temperature of 105 ± 5°C is 4 h. Strength of joints glued without preheating is 1.5 MN/m^2 (15 kgf/cm^2). Strength of hot-glued joints is considerably higher. It is not inferior to strength of joint obtained by gluing with glue of BF type.

Glue PU-2 is thick and permits gluing parts with badly fitted surfaces. It does not cause corrosion of metals. Joints made with glue PU-2 have comparatively high indices of strength during vibration and prolonged static loads and resist aviation fuels and oils. Their thermal resistance is 100-120°C, which is somewhat

higher than that of joints made with BF. Deficiency of glue PU-2 is lowering of strength of glued joints when moistened. Besides this, the glue is toxic, which it is necessary to consider when working with it.

Glue PU-2 is used for gluing metals and for gluing nonmetallic materials to them (foam plastics, fiberglass laminate, wood, and others) and for gluing plastics among themselves. Period of storage of glue is not less than 6 months.

Epoxy glues consist of epoxy resin and solidifier. Peculiarity of epoxy glues consists in that they do not emanate volatile material during hardening, shrink little, and do not require high pressure during hardening. Gluing is possible both at room temperature and with preheating. Gluing at room temperature lowers strength of glued joint. They are able to form very strong joints both between metallic parts and in combination of metal with different plastics.

Ultimate strength for glued joint of steel with steel can reach 35 MN/m^2 (350 kgf/cm^2). Epoxy glue compounds possess high long-term strength and can be used in separate cases for work at temperatures to 300°C.

Glues for Joining Textile Materials

Glue AMK constitutes liquid composition of glyptal resins, organic solvent, and siccative. It comes in ready-to-use form. Viability of glue (period of storage) is 1 yr. Gluing is produced at room temperature and with preheating to 70-100°C. Viscosity of glue is 15-25° Engler. Expenditure is 0.17-0.2 kg/m^2 (170-200 g/m^2). Drying time of glue at 15-35°C is 26 h; with preheating to 70-100°C it is 6-8 h. Tear strength of glued joint is not less than 750 N/m (75 kg/m).

Glue AMK is fungus-, water-, fuel-, and oil-resistant; does not cause corrosion metals, and is toxic. Glue AMK is used for gluing wool, glass, and cotton thermal insulation to metallic surfaces in articles working at temperatures no higher than 150°C.

Glue AK-20 constitutes liquid composition of nitrocellulose, ester of gum, and solvent [RDV] (РДВ). It comes in ready-to-use form. Viability of glue is 1 yr. Gluing is produced at room temperature. Viscosity of glue is 60-80° Engler. Expenditure is 0.6-0.7 kg/m^2 (600-700 g/m^2). Drying time is 8 h at 18-23°C. Tear strength of glued joint is not less than 600 N/m (60 kg/m). Glue is fungus-, water-, gasoline-, and oil-resistant. Period of storage is 1 yr. Glue AK-20 is

used for gluing different fabrics to wood and plywood. Operating temperature is 60-70°C.

Glues for Joining Foam Plastics and Wood Materials

For these purposes are applied resin and albumin glues.

Widely applied for gluing foam plastics and wood materials are glues based on phenol-formaldehyde resins of grades [VIAM-B3] (ВИАМ-Б3) and [KB-3] (КБ-3).

Glues VIAM-B3 and KB-3 constitute liquid compositions. Glue VIAM-B3 consists of resin VIAM-B, solvent (acetone or alcohol), and solidifier (kerosene catalyst). Glue KB-3 consists of resin Б and solidifier (kerosene catalyst). Glues are prepared by mixing components at room temperature. Their viability at 16-20°C is 3-4 h and at 20-25°C is 2-3 h. Viscosity of glue is 30-120° Engler. Expenditure is 0.1-0.2 kg/m^2 (100-200 g/m^2). Gluing is produced at room temperature and with preheating, here with slight aging. Specific pressure during pressing is 0.05-0.5 MN/m^2 (0.5-5.0 kgf/cm^2). Holding under pressure without heating is 3-16 h and with preheating to 50-60°C is 40-60 min, with cooling to 15-30°C for 30-60 min. Unclamped holding is 6-24 h for parts glued without preheating and 1-2 h for parts glued with preheating.

Glue compound possesses ultimate shear strength of not less than 13 MN/m^2 (130 kgf/cm^2).

Glues VIAM-B3 and KB-3 are highly water-resistant, fungus-, fuel-, and oil-resistant. Glued joints of wood materials age and their strength can drop after 1.5-3 yr by 30-40%. Glue KB-3 is less harmful than glue VIAM-B3 but contains more water.

Glues VIAM-B3 and KB-3 are used for gluing wood, plywood, veneer, delta-wood, textolite, foam plastic, and certain other nonmetallic materials, and also for gluing metals with the above materials with obligatory preliminary application on metal of underlayer of glue BF-2.

Albumin glues are designed for gluing wood, fiber, and cardboard; of the albumin glues most frequently applied is casein glue.

Casein glue is obtained from milk casein. It is easily dissolved in weak alkalis, giving viscous solutions possessing gluing properties. With lime casein forms a compound difficulty solutle in water.

For preparation of glue casein is mixed with alkali salts, lime, blue vitriol, and a small quantity of kerosene. Sodium fluoride gives aqueous solutions, which are the best solvents for casein; sodium fluoride increases viability of glue solutions; excess of sodium fluoride lowers waterproofness of glued seam. Slaked lime gives glued seam waterproofness; excess of it lowers viability of glue solutions and increases brittleness of glued seam. Blue vitriol increases waterproofness of glued seam without affecting viability of glue solution. Kerosene protects glue powder from becoming damp and formation of lumps in it during storage and transport. To moldproof glue we introduce antiseptin-ethylmercurie phosphate.

Casein glues are supplied in the form of dry, light, finely crushed powder. Glue solution from casein glue B-107 is prepared by stirring powder (40-50 min) in pure water (at 10-25°C) until a uniform mixture is obtained. Viability of glue solution is 2-4 h at temperatures below 20°C. Viscosity is 120-500° Engler. Expenditure of glue is 0.175-0.350 kg/m^2 of glued surface. Aging after application of glue is 2-17 min. Specific pressure during pressing is 0.05-0.5 MN/m^2 (0.5-5.0 kgf/cm^2). Holding under pressure without preheating is 3-8 h and 6-48 h without pressure; under pressure with preheating it is 60-80 min at temperature of 50-60°C and cooling to 15-30°C for 40-70 min; unclamped holding is 2-3 h. Ultimate shear strength of glued joint should be not less than 10 MN/m^2 (100 kgf/cm^2). Casein glue B-107 insufficiently water-resistant but is fuel- and oil-resistant. It is applied for bonding wood, plywood, veneer, and delta-wood in combination with wood and plywood, and also fiber. Period of storage of glue at temperatures to 30°C is 5 months.

Glues for Joining Plastic Articles

Gluing of articles of laminar and fibrous plastics or molding powders based on thermosetting resins is produced mainly with resin glue VIAM-B3, based on phenol-formaldehyde resin. For acceleration of gluing aging of glued parts is produced under heat. Conditions of gluing do not differ from conditions of gluing wood with the same glue.

Gluing among themselves of parts made from thermoplastic materials is done basically with glues of special assignment. Very frequently gluing is carried out with help of solvent, which causes swelling of surface of plastic, giving it

Rubber Glues

These are designed for gluing rubbers among themselves and to metal. Rubber glue is a viscous solution, obtained as a result of interaction of rubber or rubber mixture with solvent. At defined temperatures or as a result of chemical transformations, glue forms a hard film, which holds combined surfaces firmly.

For gluing raw or vulcanized rubbers not possessing fuel- and oil-resistance rubber glues of grades 4508 and K-4508 are applied.

Glues of grades 4508 and K-4508 constitute mixtures based on natural rubber with benzine "Kalosha" in the form of a viscous liquid solution of light gray color ("4508") or without benzine in the form of dry sheets of unvulcanized rubber of light gray color (K-4508) with thickness of 4-6 mm.

Preparation of glue 4508 consists in cutting liquid glue with benzine "Kalosha" to concentration of 1:10.

Dry glue mixture K-4508 is rolled on cold rollers, cut into small pieces, placed in glue mixer or cans, and flooded with a double (or triple) quantity of benzine "Kalosha" for 24 hr for swelling. After swelling, the mass is stirred while benzine is added to a concentration of 1:10.

Temperature of gluing with these glues should be not lower than 18°C. Drying time after smearing is 20-30 min at 31-45°C. Holding after gluing is 8 h at normal temperature for parts with subsequent vulcanization and 16 h for parts without subsequent vulcanization. Vulcanization is carried out after rubber parts have been glued. Interlaminar strength of gluing is not less than 30 N (3 kgf). Vulcanized glue film is nonresistant to oils and fuels (kerosene and gasoline).

It is used for gluing unvulcanized rubbers based on natural and sodium-butadiene caoutchouc with subsequent vulcanization and also rubbers in vulcanized form without subsequent vulcanization.

For gluing fuel- and oil-resistant rubbers we use rubber glues of grades [NS-30] (HC-30) and [NSs-15] (HCc-15).

Glue NS-30 is a viscous solution of a mixture of nitrile rubber [SKN-40] (SKN-40) and resin [FKF] (FKF), dissolved in dichloroethane with acetone (or benzol with acetone). Glue of grade NSs-15k constitutes viscous solution of a mixture of nitrile and Sivang rubbers and resin FKF dissolved in dichloroethane with acetone.

Temperature of gluing should be not lower than 23°C. Drying time after smearing is 10-20 min at 30-45%. Holding after gluing is for 6 h at normal temperature. Vulcanization is conducted on glued rubber articles. Interlaminar strength of gluing is not less than 25 N (2.5 kgf). Vulcanized glue film resists oils and kerosene and is sufficiently resistant to gasoline.

Rubber glues NS-30 and NSs-15k are used for gluing unvulcanized rubbers and rubberized fabric materials based on oil- and gasoline-resistant rubbers with subsequent vulcanization.

Glue 4H constitutes viscous solution of nitrile rubber in benzol. Usually it is supplied in the form of thick solution, and therefore it is diluted in benzine to about 15% of content of dry substance. This glue does not require vulcanization and is used for bonding different vulcanized and unvulcanized rubbers. Glue seam possesses great strength, resists oil, but swells in gasoline.

For gluing rubbers not possessing fuel- and oil-resistance we apply rubber glues of thermoprene type (with subsequent vulcanization) and of grade 88 (without subsequent vulcanization).

Thermoprene glue is heat-treated mixture of natural rubber and "paraffin salfonon" acid in the form of sheets of dark-brown color with thickness to 6 mm. For preparation of glue, sheets of thermoprene are cut into small pieces and flooded with double (or triple) quantity of benzine "Kalosha" for 24 h for swelling. After that, the mass is stirred while benzine is added to concentration of 1:10. Temperature of gluing should be not less than 18°C. Drying time after smearing is 2 h 25 min at 31-45°C. Holding after gluing is for 8 h at normal temperature. Vulcanization is conducted on glued rubber parts. Vulcanized film is not resistant to oils and fuels (kerosene and gasoline). Glue provides strength of bond equal to 0.5 MN/m^2 (5 kgf/cm^2). Thermoprene glue is used for fastening to metal of unvulcanized rubbers made from natural, nitrile, Sivang, and sodium-butadiene rubbers with subsequent vulcanization.

Glues 88 and 88N constitute viscous solutions in the form of Sivang (H88) or nitrile (88H) composition with butylphenol-formadehyde resin "101" in mixture of ethyl acetate and benzine "Kalosha" in a 2:1 ratio. It is supplied in ready-to-use form.

Temperature of gluing should be not lower than 12°C. Drying time after

smearing is 10-20 min at 18-45°C. Holding after bonding is for twenty-four h under pressure of not less than 0.02 MN/m^2 (0.2 kgf/cm^2), or without pressure. Vulcanization is not produced. Glue film is not resistant to oils and fuels (kerosene and gasoline). Strength of bonding is very great, 1.3 MN/m^2 (13 kgf/cm^2). Glue does not cause corrosion of metals. Glues 88 and 88H are used for fastening vulcanized rubber on any base to metals, glass, and other surfaces, without subsequent vulcanization.

For gluing rubbers possessing fuel- and oil-resistance to metal, with subsequent vulcanization, we apply rubber glue of leuconate type and Б-10.

Leuconate glue is a liquid solution of triisonate of triphenglmethane in dichloroethane. It is supplied ready for use.

Temperature of gluing must be 18-30°C.

Drying after smearing takes 20-60 min at 30-45°C. Holding after gluing is not necessary. Vulcanization is carried out in a press after parts have been glued. Joints made with leuconate are distinguished by strength and thermal resistance. Tear propagation strength is 4 MN/m^2 (40 kgf/cm^2). Vulcanized glue film resists to oil and fuel.

Leuconate glue is used for fastening to metals of unvulcanized rubbers made from nitrile, Sivang, nitrile, and natural rubber, with subsequent vulcanization.

Glue Б-10 constitutes a black viscous solution of a mixture based on nitrile rubber, benzene-acetone solution of resin FKF, and benzol. Temperature of gluing should be not lower than 18°C. Drying time after smearing is 90 min. Holding after gluing is not required. Vulcanization is conducted in press on glued rubber articles. Vulcanized glue is resistant to oil, fuel (kerosene and gasoline), and possesses high strength of 4 MN/m^2 (40 kgf/cm^2).

Glue Б-10 is used for gluing unvulcanized nitrile, Sivang, and chloroprene rubbers to metals, with subsequent vulcanization.

§ 3. Hermetic Sealing Materials

Development of aviation materiel, creation of high-speed aircraft of able to accomplish high-altitude flights, requires hermetic sealing of structures. Hermetic sealing should ensure normal pressure inside cabin. Prolonged vibrations must not disturb hermetic sealing. Increase of distance and duration of flights makes necessary storage of considerable reserve of transported fuel and this

requires, in turn, creation of hermetically isolated containers for fuel in sections of wing and fuselage set aside for this purpose.

This is why, especially in recent years, in aviation industry wide application has been found for various hermetic sealing materials. Hermetically sealed are riveted, bolted, and welded (spot welding) joints of structures made of duralumin, stainless steel, magnesium, or titanium alloys. Seals have to possess high adhesional properties (adherence) to the materials cited, must be elastic, oil-fuel- and moisture-resistant, must withstand temperatures from -60 to +300-350°C, and must also be simple to manufacture and apply. They must not noticeably weight the structure.

Depending upon assignment and operating conditions, we distinguish: atmosphere- and water-resistant and also oil- and fuel-resistant seals.

According to the character of application in joints, we distinguish surface and intrajoint hermetic sealing materials. Surface seals are applied in the form of pastes or viscous solutions and are applied as packing between combined surfaces of parts (structures). Intrajoint seals are applied in the form of tapes, braids, pastes, or viscous liquids which readily fill gaps in welded or bolted joints.

According to degree of adherence (adhesion) to sealed surfaces, all seals are divided into those directly applied to surface (seals with high degree of adhesion) and those applied over a sublayer of glue films (seals with low degree of adhesion).

Hardening or vulcanization of seals occurs after they are applied to sealed surfaces.

Depending upon composition, we distinguish seals hardened or vulcanized at ordinary temperature and seals hardened or vulcanized at raised temperature.

Depending upon kind of basic component, we distinguish resinous and rubber hermetic sealing materials.

Resinous seals possess good adherence to metal and therefore can be applied without glue underlayer. They are applied in the form of pastes, tapes, and films.

Resinous hermetic sealing materials can be based on thermoplastic (so-called reversible seals - for instance, seal of grade У-20) and thermosetting resins (so-called irreversible seals). Irreversible resinous seals can be cold- (for instance, seal [VI32-3] (ВИ32-3)) and hot-hardening (for instance, tape [NIAT-1] (НИАТ-1)).

Putty sealer [U-20A] (У-20А) constitutes thermoplastic composition of polyisobutylene with powder filler in the form of nondrying plastic putty of grayish-green color. It gives airtightness to riveted seams in temperature interval from -50 to +70°C.

Method of application of seal is the following: inside rivet seam are placed braids of putty U-20A, obtained by method of pressing, and sealing tape made from capron fabric with bilateral coating of glue based on polyurethane resin U-20A. Additional hermetic sealing is carried out by coating surface of seams (on the pressure side) with putty U-20A, with application of primer [ALG-8] (АЛГ-8) and rubber glue No. 88. Putty does not harden, does not cause corrosion of magnesium and aluminum alloys, does not dry, and does not change its physico-mechanical properties. It is not toxic. Sealing putty U-20A jointly with sealing tape U-20A is used for intraseam hermetic sealing of magnesium aircraft alloys working in air.

Hot-hardening tape NIAT-1 is prepared on base of phenol-formaldehyde resin and butvar. Thickness of tape is about 0.3 mm. Tape NIAT-1 is applied for hermetic sealing of rivet joints. For this it is placed at joint of two metallic surfaces, after which riveting is produced. For gluing film to metallic surface and its solidification it is necessary to produce heating to defined temperature.

Fuel-resistant seal of grade VI-32-3 constitutes a cold-hardening polyurethane composition consisting of film varnished cloth (capron fabric with covering of glue [PU-S] (ПУ-С)), paste-like masses of glue PU-S, and primer [PG-11] (ПГ-11).

Seal ensures airtightness over temperature interval from -60 to +110°C in medium of air during repeated static and vibration loads and in medium of kerosene in interval from -60 to +70°C. Viability of glue and primer is 3-6 hr. Method of application of sealer VI32-3 consists of the following: varnished cloth is placed on surface inside riveted seam, with application of glue PU-S as underlayer. After that, the riveting operation is carried out. Primer PG-11 is used as additional surface covering and is applied only to locking heads of rivets. Solidification of material occurs at room temperature in 6 days. Hardening time can be reduced by application of preheating to 60-100°C. In view of toxicity of this sealer, precautionary measures are necessary.

Seal VI32-3 does not cause corrosion of nonferrous or ferrous metals. It is used for hermetic sealing of fuel containers working in medium of kerosene at a

temperature of 70°C and air tanks with operating temperatures to 110°C.

Rubber seals possess high hermetic sealing properties. They can be based on thiocol and polyorganosiloxane rubbers.

Thiocol seals possess high water-, gasoline-, and oil-resistance. They can be vulcanized at low temperature. All this ensures their wide application as seals for riveted and other structures working in air and fuel media. Thiocol seals are applied in the form of solutions, tapes, braids, and pastes. Thiocol seals include packing thiocol putty, seals of type У-30 and [U-30m] (У-30М), and also seal [VTUR] (ВТУР).

Polyorganosiloxane seals, possessing greater thermal resistance than thiocol seals, are used for hermetic sealing of structures working at high temperatures in medium of air. They are produced in the form of pastes, braids, and tapes.

Putty thiocol sealer constitutes composition of thiocol rubber mixture in the form of nondrying plastic putty of grayish-green color. It ensures airtightness of riveted seams working in temperature interval from -50 to +50°C.

Method of application of putty is the following: in the form of extruded braids in combination with sealing tape based on cotton fabric with a layer of putty on both sides it is placed inside rivet seams. Gaps and holes are filled. Holding after application of putty is 15-120 min. Putty possesses unpleasant odor. It does not cause corrosion of ferrous metals and aluminum alloys but causes corrosion of magnesium alloys.

In combination with sealing tape putty is used for hermetic sealing of cabins, windows, and for packing gaps and holes of pipelines on aircraft.

Self-vulcanized sealers of grades [U-30s] (У-30с) and U-30m, constituting thiocol compositions, consisting of hermetic sealing paste У-30, vulcanizer, and accelerator, in the form of paste-like masses of black color, are transformed after self-vulcanization into rubber-like products. Mixtures are hermetically sealed in the cold in 10-15 days. These sealers ensure airtightness under conditions of vibration and repeated temperature loads.

Seals U-30s and U-30m do not possess ability to adhere directly to metal; therefore we apply an underlayer in the form of glue No. 88 (for air medium) or glue К-50 (for fuel medium). Viability of mixtures is 2-15 hr.

Seals U-30s and U-30m are used for surface and intraseam hermetic sealing of

cabins, windows, and fuel sections of aircraft working in temperature interval from -60 to +130°C. Seal U-30s is toxic.

Self-vulcanized sealer of VTUR constitutes thiocol composition with special additions in the form of isocyanate and other products for increase of cohesion with metal. In appearance this is a low viscosity solution of black color, forming rubber-like film after drying. It ensures airtightness under conditions of repeated vibrations and loads in temperature interval from -30 to +100°C.

Viability of composition is 6-8 hr at 18-20°C. Seal is applied by brush or spray. Drying between layers requires not less than 4 h. Vulcanization occurs in cold state. Period of hardening of film is 20-30 h. Full vulcanization is attained after 8-10 days at 18-20°C.

VTUR is resistant to heat aging to a temperature of 130°C and also to the action of light and ozone. It does not cause corrosion of aluminum alloys, protected magnesium alloys, or parkerized and cadmium-plated steel.

VTUR is used for hermetic sealing of fuel sections of aircraft as an independent material and also in combination with U-30s as underlayer or additional film covering. In view of its toxicity, it is necessary to observe precautionary measures.

Heat-resistant sealer [TG-18] (TT-18) constitutes a polyorganosiloxane rubber composition in the form of plastic putty of white color. It ensures airtightness during repeated static loads to temperatures of 250°C (prolonged) and to 300-320°C (briefly).

For intraseam hermetic sealing of riveted seams the sealer is applied in the form of braids in combination with sealing fabric - gasoline resistant protective film VI32-4.

For intraseam hermetic sealing of welded seams putty is applied by spatula or is sprayed on. For surface hermetic sealing of welded and riveted seams material is applied in the form of benzine solutions of different concentration and is applied by brush, sprayer, or spatula.

Conditions of vulcanization are the following: articles to be sealed are placed in a heat chamber for 20-25°C. Temperature gradually (1 h) is raised to 150°C and article is held at 150°C for 30 min. Then temperature is gradually (1 h) increased to 200°C and article is held there for 3 h, after which

temperature is slowly (1 h) raised to 250°C and held there for 6 h. Upon completion of heat treatment article is slowly (1.5-2 h) cooled to 20°C.

Sealer is not toxic, is water-resistant, and does not cause corrosion nonferrous or ferrous metals. Fuel resistance is very limited.

Sealer TG-18 is used for hermetic sealing of air tanks working under conditions of raised temperatures: prolonged at 200-250°C and briefly at 300-320°C. Period of storage is 6 months.

As sheet asbestos sealing materials based on rubber-like binder and different fillers are applied paronite and ferronite.

Paronite [UV-10] (UB-10) a vulcanized composition of asbestos, rubber and fillers.

Paronite is used as packing in aircraft building for joints of parts working in medium of gasoline, kerosene, or oil to temperature of 150°C and briefly to temperature 200°C. It is supplied in sheets of different dimensions.

Ferronite constitutes composition of asbestos, rubber, and fillers with an inner sheet of reinforced metal mesh.

It is applied in the form of linings in aircraft engine building for packing joints of parts working in media of gasoline, kerosene, mineral oil, and in products of their combustion. It is supplied in the form of sheets.

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* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.