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Material Science and Technology of Structural Materials

Text-book

ZNTU, Dike Pole

2008

Ministry of Education and Science of Ukraine
Zaporizhzhya National Technical University

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УДК 621.7+621.9(075.8)
ББК

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Approved by the Science Council of Zaporizhzhya National Technical University. Record №8 from 10/04/2007. I.P. Volchok, S.B. Belikov, V.V. Gazha. Material Science and Technology of Structural Materials: The textbook is intented for students of a speciality 7.03050 «Translation» and also for students of other specialities studying technical disciplines in English / Under editor-ship of I.P. Volchok, Professor, D.Sc. (Engineering) – Zaporizhzhya: ZNTU; Dike Pole, 2008. - 172 p.

In the book the information about engineering materials properties is given. Metallurgical processes of ferrous and non-ferrous metals production are briefly considered. The main foundry processes, forming operation technologies, welding, cutting operations are described.

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CONTENTS

PREFACE

This book covers the theoretical aspects of producing metals and non-metals. It will also help you to learn the principles of physico-chemical treatment of materials to manufacture various parts and products. An old adage in materials science says: "materials are like people; it is the defects that make them interesting". The number and the quality of structural or engineering materials, their technology of production and machine tools used determine how much products a country produces and how well its people live.

Perhaps you already know that people have inhabited this planet for about 2.5 million year. Here we mean so-called skillful people who used tools such as wooden sticks and pieces of stone. Let us assume that this period equals 24 hours, which will help us to consider the progress of humanity.

For many years people were food gatherers, eating only berries, eggs and meat left by other animals. Only 250,000 years ago people learned how to make fire. According to our scale it happened 2h 24 min ago. About 20,000 years ago (11.5 min ago) the first complex tool (which had more than one part), supposedly appear for hunting, was evolved. The main part of the fundamental mechanics - the wheel - was invented about 5,500 years ago (that is about 6 minutes ago).

The metallic tools, such as an anvil, an ax, a chisel, a saw with the set of teeth, shears and proportional divider were developed several thousands years ago (that is several minutes ago). Although people had tools, all work was done by either the physical power of men or beasts, and sometimes by waterwheel. The first real machine appeared in 1776. This machine was the steam engine, invented by James Watt (7.5 seconds ago).

The first motor-car, electric lamp, telephone, airplane, photography, etc. were discovered about 100 years ago (3 sec).

Production of Ti and Mg (industrial method), semiconductors, synthetic rubber, TV sets started about 50 years (1.5 sec) ago.

Modern microelectronics, space laboratory and stations, melting and welding in the space the amorphous alloys appeared practically during your life (15 to 20 years) ago (less than 1 sec). You are living in a very interesting period of time - the time of technical revolution. So you have got a chance to do as much as you can for humanity.

Of course, first of all, you must know modern engineering materials and machine tools, which are the basis of the modern mechanized society. You must know the composition of material, its mechanical, physical and chemical properties to select a structural material for manufacturing the machine elements.

The course consists of 6 parts:

1. structural materials
2. metallurgy
3. foundry practice
4. metal forming
5. welding
6. metal cutting operations.

Materials science is an interdisciplinary field involving the properties of matter and its applications to various areas of science and engineering. It includes elements of applied physics and chemistry, as well as chemical, mechanical, civil and electrical engineering. With significant media attention to nanoscience and nanotechnology in the recent years, materials science has been propelled to the forefront at many universities, sometimes controversially.

Material science is very important for you because it gives an overview of the main technical notions and principals that are very important for the future specialists of your major. The main challenge you will face is technical English. This book will help you to learn more than 2000 technical terms. The dictionary in the end of the book summarizes all these words for you with translation into Russian and Ukrainian.

A word of warning and encouragement: Don't worry if you don't understand this book completely on the first reading. We didn't understand it all on the first writing! Remember that this isn't a book to read once and put on a shelf. We hope you'll find yourself referring to it again and again for useful information and for inspiration.

1 STRUCTURAL MATERIALS

1.1. Classification and General Properties of Structural Materials

Structural or engineering materials are materials used to manufacture parts of structures, machines and devices. *Structures* are the objects without moving parts erected by engineers, such as a concrete dam, a steel melting furnace, a suspension bridge and an oil refinery tower. *Machines* include lathes, steam and gas turbines, engines, electric motors and generators. *Devices* are the most recent addition to engineering materials and refer to such innovations as a transistor, a photoelectric cell, piezoelectric pressure gauges, ceramic magnets, lasers, transformers, voltmeters, etc.

All structural materials fall into two large classes: metals and non-metals. In their turn metallic materials are divided into two groups: ferrous and non-ferrous metals or alloys. The examples of *ferrous metals* are iron, manganese and chrome. F*errous alloys* are the combination of more than one metal, or metals and non-metals. Ferrous metals and alloys are divided into steels and cast irons (Fig. 1.1). The rest of metals (copper, aluminium, titanium, nickel, silver, gold, etc.) are referred to as *non-ferrous* ones and used both in pure state and as alloys. *Non-metallic materials* fall in two groups: organic (wood, leather, plastic, rubber, etc.) and non-organic (ceramics, glass, concrete, graphite, etc.) ones. Organic materials are *polymers* whose molecules consist of many repeating links.

Another way of classifying the engineering materials is based on their nature:

- metals and alloys;
- ceramics and glasses;
- organic polymers.

Metals and alloys possess characteristic appearance. In addition to their capability of changing permanently their shape, metals and alloys have good thermal and electrical conductivity. Ceramics and glasses are nonmetallic inorganic substances, which are brittle and have good thermal and electrical insulating properties. Organic polymers are relatively inert and light and generally have a high degree of plasticity. Fig. 1.2 lists typical examples from each of these three groups of materials. In addition, a number of examples of materials, which are composites, made up of two groups also shown.

To manufacture any machine, device, or part of a machine an engineer must know properties of structural materials. There are several kinds of properties of structural materials such as physical, chemical, mechanical, technological and service ones.

The physical properties include mass density, melting point, heat and electric conductivity, thermal expansion, magnetic saturation and permeability, etc.

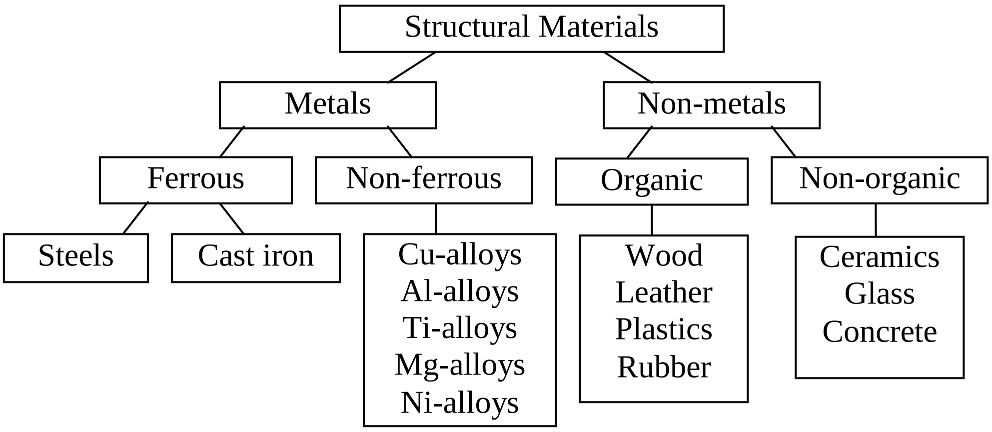


Fig. 1.1. Classification of structural materials

The chemical properties of materials determine their ability to resist moist air, acids and other aggressive media. Hence, corrosion and oxidation resistance are one the main chemical properties.

Structural materials must possess sufficiently high technological properties such as machinability, malleability, weldability, foundry properties (fluidity, shrinkage, etc.) Thus, the technological properties indicate how much labor, machine time, tools and materials are needed to produce a machine part.

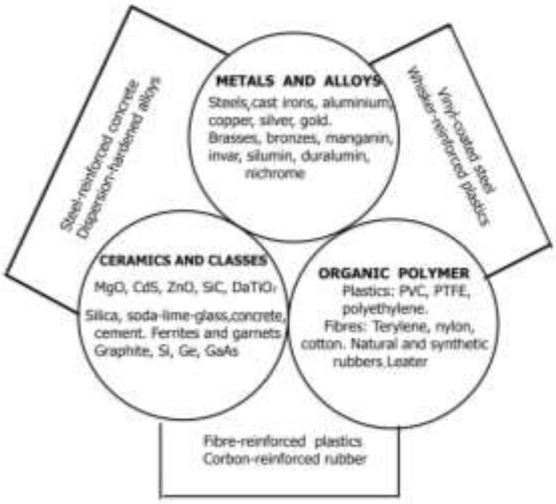


Fig. 1.2. The major groups of engineering materials

The service properties characterize the behavior of the materials in exploitation. They are service life, reliability (safety), cold and heat resistance, etc.

1.2. Mechanical Properties

1.2.1. Stress and Strain

The mechanical properties are of special importance for engineering materials. Knowledge of the mechanical properties allows design and process engineers to determine the limiting loads which a machine part can be exposed to under certain work conditions (load and media) without damage and failure.

The mechanical properties are usually characterized by the following quantities:

- *strength*, which is a resistance of a material to deformation and failure;
- *plasticity,* i.e. the ability to withstand permanent deformation, remaining after removal of the deforming forces without failure; low plasticity or its deficiency is called *brittleness*;
- *hardness*, which is the capability of external layers of a material to resist plastic deformation upon penetration from side of a harder body with definite shape;
- *impact strength*, which is the work, required to fracture the specimen by the impact load;
- *fatigue strength*, which is the resistance to failure under repeating loads a few millions of times.

Deformation, or strain, is the change in size and shape of a solid body due to the influence of applied forces. The Fig. 1.3 illustrates the simplest case of an axial tension for cylindrical body by forces P.

The stress σ developed in the body:

$$\sigma = P/F,\ \text{MPa} \tag{1.1}$$

where F is the area of body's section which is perpendicular to the forces P.

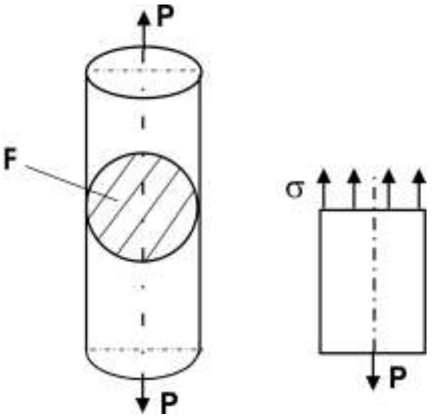


Fig. 1.3. Axial tension of cylindrical body

Strain (deformation) may be either *elastic* or *plastic*. Elastic deformation (Fig. 1.4b) disappears completely when the external force causing it is removed. Elastic strain does not lead to any appreciable changes in the structure and properties of material; the applied load causes only a slight relative displacement of the atoms. Plastic deformation (Fig. 1.4 d) leads to the slip of crystal parts relatively one another and to change of specimen's shape. When the load is removed, the shape, structure and properties of the body are not restored, the body acquires residual deformation.

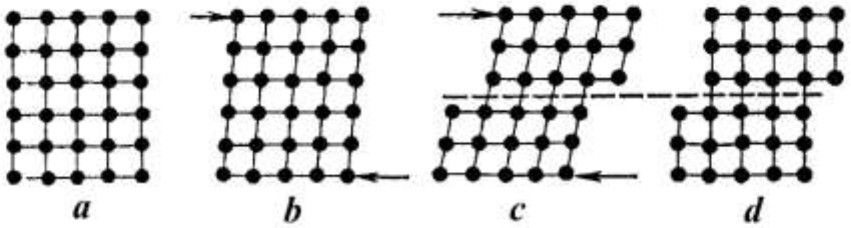


Fig. 1.4. Elastic and permanent strain in shear:
a - unstressed crystal; b - elastic strain; c - elastic and plastic strain; d - plastic (residual) strain

The main purpose of mechanical tests is to get knowledge about machine parts' workability under the certain conditions of work. Due to this reason mechanical properties are determined in static and dynamic tests, at variable loads, low and elevated temperatures, in vacuum and chemically active media. *Static tests* include *tension, compression, bending, shear, torsional* and *hardness ones* (Fig 1.5). These tests are carried out by slowly increasing load P and are referred to as static tests.

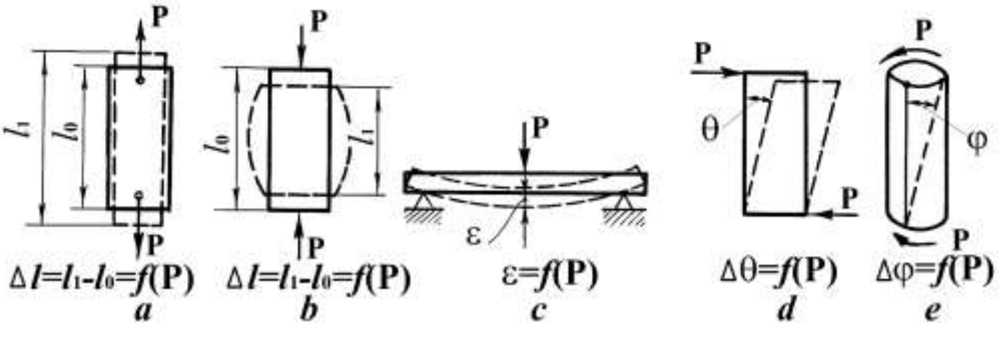


Fig. 1.5. Schemes of tests: a - tensile, b - compressive, c - bending, d - shear and e - torsional tests

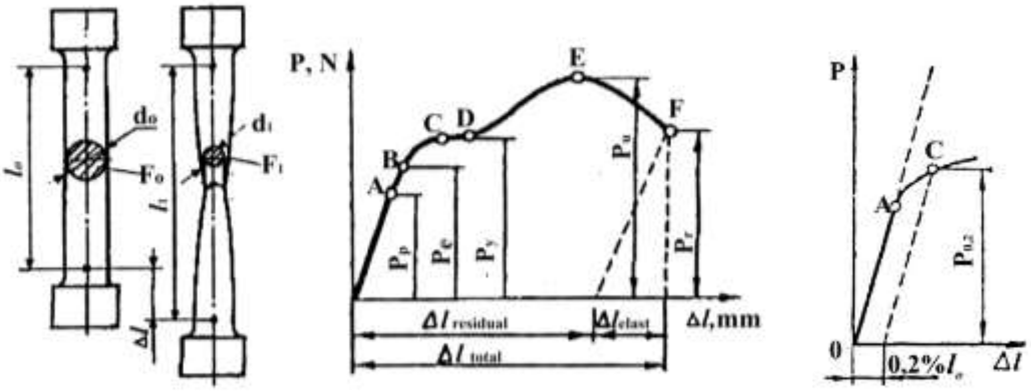
1.2.2. Tension Tests

This type of tests is widely used for structural steels, cast irons, nonferrous metals, their alloys as well as nonmetallic materials.

Tension tests are conducted on standard specimens (mainly of round or square cross section). Testing machine has an instrument that records *the stress - strain diagram*. The applied load *P* is plotted against the elongation Δ*l* of the specimen.

Fig 1.6 illustrates the specimen before and after the tests as well as stress-strain diagram. After the tests the length of the specimen increases, and its cross section decreases. The local reduction of cross section is formed on the specimen. It is referred to as *necking*. The diameter d_1 is measured at this spot, and then the cross-sectional area F_1 is calculated.

The diagram has typical points A, B, C, D, E, F, which allow us to specify the characteristics of metal resistance to deformation. These characteristics are known as stresses, expressed in megapaskals (MPa).



a b c

Fig. 1.6. (a) The Specimen for tests, (b) stress-strain diagram obtained after tension test of a ductile metal; (c) principle of a conventional yield point determination

We can see, that the relationship between the stress and strain remains linear up to the point A, or up to load P_p. According to *Hooke's law* of proportionality, stress σ and relative strain $\varepsilon = \Delta l / l_0$ may be written as the relationship:

$$\sigma = E\varepsilon, \text{MPa} \tag{1.2}$$

where E is the constant of proportionality, or *modulus of elasticity*, or *Young's modulus*, MPa.

The modulus of elasticity equals the tangent of the angle that line OA makes with the axis of abscissas. For the most typical metals the magnitude of this modulus ranges between $4.5 \cdot 10^4$ MPa for magnesium and $40.7 \cdot 10^4$ MPa for tungsten. The modulus of elasticity depends only slightly on the structure of the metal and is determined by the forces of the interatomic bonds.

Taking into consideration the magnitude of the load P_p, the *limit of proportionality* is defined as:

$$\sigma_p = P_p / F_0, \text{ MPa} \tag{1.3}$$

At the beginning of the test up the to point B or load P_e deformation is only elastic one. It means that deformation disappears completely when load P is removed. The stress calculated for the load P_e is called *elastic limit*:

$$\sigma_e = P_e / F_0, \text{MPa} \tag{1.4}$$

The elastic limit is frequently defined as the stress at which residual strain reaches a certain value (from 0.005 to 0.05 % of the initial gauge length of the specimen). Hence, the elastic limits are denoted by $\sigma_{0.005}$, $\sigma_{0.01}$, $\sigma_{0.05}$.

At an increase in load above P_p the relationship between the load and the elongation deviates and can no longer be linear. The straight line on the stress-strain diagram becomes a curve and, a horizontal step CD is sometimes observed at a certain load P_y. This step indicates that the metal is elongated (yields) without any increase in the load. The stress corresponding to the load P_y is called the *yield limit* or *yield point*:

$$\sigma_y = P_y / F_o, \mathrm{MPa} \qquad (1.5)$$

Yield step CD is observed only in testing of high plastic metals. For brittle materials the *conventional yield limit* is defined as the stress at which the specimen receives permanent elongation equaled to 0.2 percent of the initial gauge length lo (Fig. 1.6 c). It is denoted by $\sigma_{0.2}$.

The quantifies σ_P**,** σ_e**,** $\sigma_{0.05}$ and $\sigma_y(\sigma_{0.2})$ characterize the resistance of a material to small plastic deformation. A further increase in load leads to more essential deformation of the whole volume of the metal. The stress corresponding to the maximum load preceding failure of the specimen is called the *ultimate strength* or *tensile strength* (the point E):

$$\sigma_u = P_u / F_0, \mathrm{MPa} \qquad (1.6)$$

In ductile metals, deformation is concentrated at one part of the cross-section starting with the stress σ_u. A localized reduction of the cross-sectional area, called *necking*, appears on the specimen, the load drops and, at a certain moment, failure occurs.

In determining σ_p, σ_y and σ_u the corresponding loads P_p, P_y and P_u were considered to be applied to the initial cross-sectional area F_0 of the specimen. Hence, we don't take into consideration the substantial reduction in cross-sectional area of the specimen in testing, thus σ_P, σ_y and σ_U are *conditional values*. The *true, instantaneous, stress* S_f is found by dividing the load P at the failure instant by the cross-sectional area of the specimen F_1 at the same instant. A true stress-strain diagram is shown in Fig. 1.7.

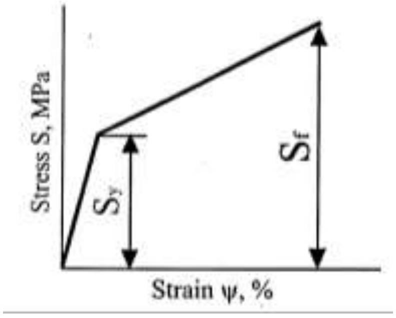


Fig. 1.7. True stress-strain diagram

The *failure stress (true stress):*

$$S_f = P_f / F_1, \mathrm{MPa} \qquad (1.7)$$

Tension tests are also used to determine ductility indices: the *relative elongation,* in percents and *the reduction in area*. The relative elongation δ is defined as the ratio of the increase in the gauge length of the specimen after fracture to its initial gauge length l_0, expressed in percent:

$$\delta = \frac{l_1 - l_0}{l_0} 100\% \qquad (1.8)$$

The reduction in the area φ is defined as the ratio of the reduction in area of the fractured specimen's necked portion to the initial cross-sectional area, also expressed in percent:

$$\varphi = \frac{F_0 - F_1}{F_0} 100\% = \frac{d_0^2 - d_1^2}{d_0^2} 100\% \qquad (1.9)$$

1.2.3. Hardness of Metals

Hardness is the property of materials to resist plastic deformation (less frequently, brittle fracture) upon penetration. Due to the rapidity and simplicity of the tests as well as the possibility of assessing the properties of metal without destroying it, hardness measurement has found exceptionally wide application in the quality control of metals and alloys. There are various methods of testing metals for hardness. The most popular of them are briefly described below.

Brinell Hardness Tests. This method is based on forcing a hardened steel ball 2.5, 5.0 or 10.0 mm in diameter, at constant load P into flat surface of metal on the Brinell press (Fig. 1.8 a). When the load is removed, an *impression (indentation)* remains on the surface of the metal (Fig. 1.8. b).

The Brinell hardness number BHn, or Brinell hardness HB, is the ratio of the load P, applied to the ball in the test to the area of the impression obtained F:

$$HB = P/F = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})},\ \text{MPa} \tag{1.10}$$

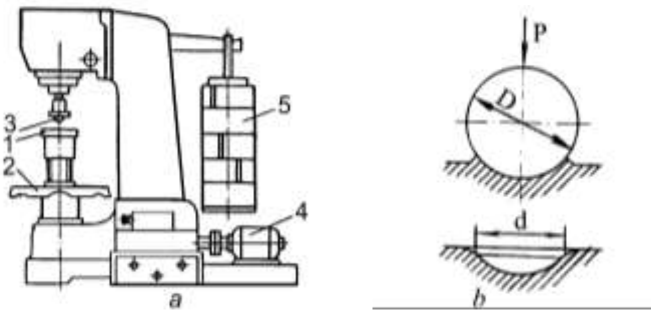


Fig. 1.8. Principle of Brinell hardness test:
a – Brinell press; b – principle of testing; 1 – table for specimen; 2 – fly-wheel; 3 – ball (indentor); 4 – electrical motor; 5 – weight

The ball diameter D and the constant load P are selected to suit the composition of the metal, its hardness and thickness of the test specimen. The load $P=300D^2$ is taken for steel and cast iron;

$P=100D^2$ for copper and its alloys;

$P=25D^2$ for very soft metals (aluminium, babbitts), where P is taken in N, D in mm.

So maximum one is $P=300\cdot100=30000$ N (=3000 kgf=3t). Minimum one is $P=25\cdot6{,}25=$ $=156$ N (=15,6 kgf=0,0156t)

In practice the diameter of impression is measured and used to find the Brinell hardness directly from specially compiled tables. When hardness number is calculated by formula 1.9 (in kgf/mm^2) it is denoted HB250, HB320; when calculations are made in MPa it is denoted HB2500MPa, HB3200MPa.

Disadvantages of the Brinell tests are:

- the ball may be deformed, when the hardness of testified material exceeds HB 4500 MPa, or HB450;
- significant size of the impression;
- the test may be used only for specimens with comparatively high thickness (t>2...6 mm). But now very hard balls from WC (tungsten carbide) may be used and scale of Brinell Hardness may be prolongeted.

Rockwell Hardness Tests. In Rockwell tests the hardness is determined by the *depth of the indentation,* without taking into consideration its diameter.

The indenter, or *penetrator*, is a *diamond cone (brale)* with an apex angle of 120°, or hardened *steel ball* 1.5875 mm in diameter. The diamond cone is used for testing hard metals, and the steel ball is used for softer ones. The cone or ball is indented by two consecutive loads (Fig. 1.9): the minor P_0 equal to 100 N and additional load P_1 equal to:

- 900 N for ball (B scale) - soft-materials;
- 1400 N for cone (C scale) - middle hardness ones;
- 500 N for cone (A scale) - very hard materials.

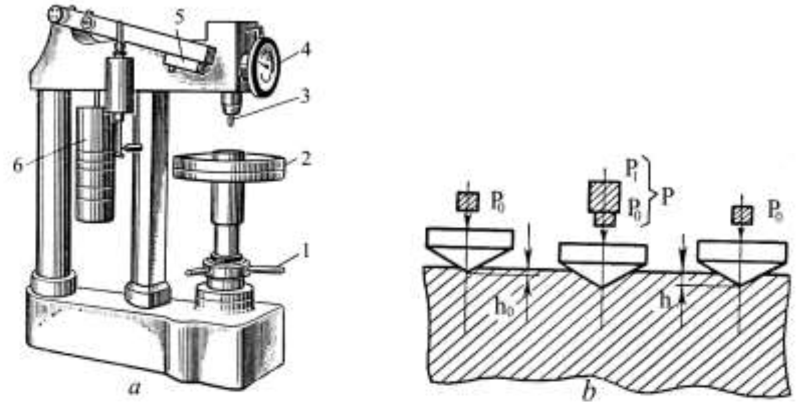


Fig. 1.9. Principle of Rockwell hardness test:
a- Rockwell hardness machine; b – principle of testing; 1 – fly wheel; 2 – table for specimen;
3 – indenter; 4 – scale; 5 – level; 6 – weight

Rockwell hardness is measured in *conventional units*. The hardness number is read directly on the dial of the instrument. Rockwell hardness is indicated: HRA40, HRC35, HRB70. The Rockwell hardness number is conventionally calculated by the formulas:

$$HRC(HRA) = 100 - e, \tag{1.11}$$

$$HRB = 130 - e, \tag{1.12}$$

where e is found by the formula:

$$e = (h_1 - h_0)/0.002, \tag{1.13}$$

where h_0 is depth of penetration of the indenter when preliminary load P_0 is applied;
h_1 is depth of penetration of the indenter due to the total load P.

Rockwell method doesn't have the disadvantages typical for Brinell method: soft and hard metals may by tested; the impression size is small; finished parts may be tested without destruction.

Vickers Hardness Tests (diamond pyramid tests). This method is used for measuring hardness of thin components (t=0.25…3.0 mm) or of thin and hard surface layers as well as of very soft metals and alloys.

It consists in forcing a *square-based diamond pyramid* (with angle of 136° between opposite faces) into the ground, or even polished surface being tested. A square indentation is obtained (Fig. 1.10).

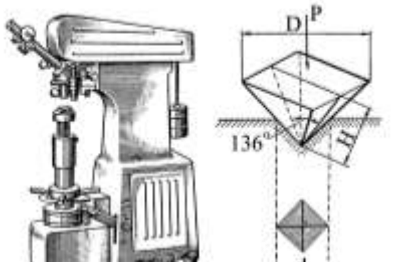


Fig. 1.10. Vickers hardness machine (a) and principle of testing (b)

The Vickers hardness number HV is the ratio of the load P applied to the diamond pyramid to the permanent indentation:

$$HV = \frac{2P\sin\alpha/2}{d^2} = 18.544\,P/d^2,\ MPa \tag{1.14}$$

where P is the load applied (50, 100, 200, 300, 500, 1000, 1200 N),
α is angle between opposite faces of the pyramid indenter (α=136°),

d is arithmetic average of the two diagonals of the indentation in mm, measured after the load is removed with a micrometer microscope.

The thinner the specimen, the less the load required in the Vickers hardness tests.

Vickers and Brinell hardness numbers have the same dimensions (MN/m^2, MPa) and coincide for materials with hardness up to about 4500 MPa (Fig 1.11).

The minimum thickness of specimen for hardness testing:

- by Brinell method is 2...6 mm;
- by Rockwell method is 0,4...2 mm;
- by Vickers method is 0,25...3 mm.

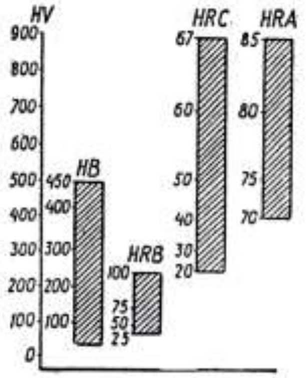


Fig. 1.11. Comparison of several hardness scales

Hardness tests are performed more frequently than any other mechanical test for several reasons:

- they are simple and inexpensive - usually no special specimen need to be prepared;
- the test is nondestructive - the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation;
- other mechanical properties may often be estimated from hardness data, such as tensile strength (Fig. 1.12).

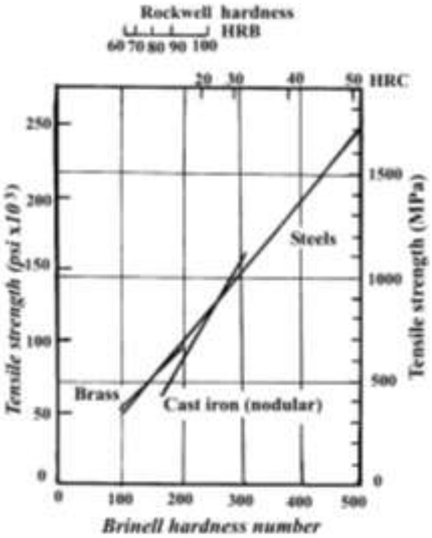


Fig. 1.12. The relationship between hardness and tensile strength for steel, brass, and cast iron

1.2.4. Mechanical Properties Determined in Dynamic Tests

Many parts and structures in normal operational conditions undergo impact loading which promotes brittle fracture. Susceptibility to brittle fracture is enhanced by increase in grain size of metal structure, loading rate, decrease in temperature and presence of notches. Chemical content also influences on impact strength: it is reduced by increase of carbon content as well as detrimental impurities, such as sulphur, phosphorus, hydrogen, nitrogen and oxygen. Static tests do not reveal the resistance of materials to brittle fracture. Therefore the dynamic tests are used.

The dynamic impact bending tests (GOST 9454-78) have gained the widest application. They are of the most severe type and promote brittle fracture. Notched-bar test specimens are commonly used in these tests. The *impact strength* KC is determined as a ratio of the work required to fracture the specimen to its cross-sectional area and, hence, represents the specific work required to fracture. The area is gauged at the notched section before fracture (specimens of brittle materials do not require notches). The impact strength is normally denoted (signed) in accordance with the form of the notch (U-notched specimen with the notch radius of 1 mm, V-notched with the radius of 0.25 mm (Charpy) and crack-notched) as KCU, KCV and KCT correspondently. The work required to get the fracture decreases with the decrease in notch radius.

The pendulum-type machine is used for impact testing (Fig. 1.13). The specimen is placed on two supports of the machine so that the blow of the striker is opposite to the notch. The pendulum of mass G is then raised to height H, from where it is released to fracture the specimen and rise again to height h. The work required to fracture the specimen is:

$$W = mg\,(H - h) = mgl\,(\cos\alpha_2 - \cos\alpha_1),\ \mathrm{MJ}, \qquad (1.15)$$

where g is intensity of gravity, or free-fall acceleration;

m is the mass of the pendulum;

t is the length of the pendulum rising;

H, h are the heights of the pendulum rising;

α_1, α_2 are the angles of the pendulum rising.

Impact strength can be found by the formula:

$$KC = W/F,\ \mathrm{MJ/m^2}, \qquad (1.16)$$

where F is the cross-sectional area of the specimen at the notch before fracture.

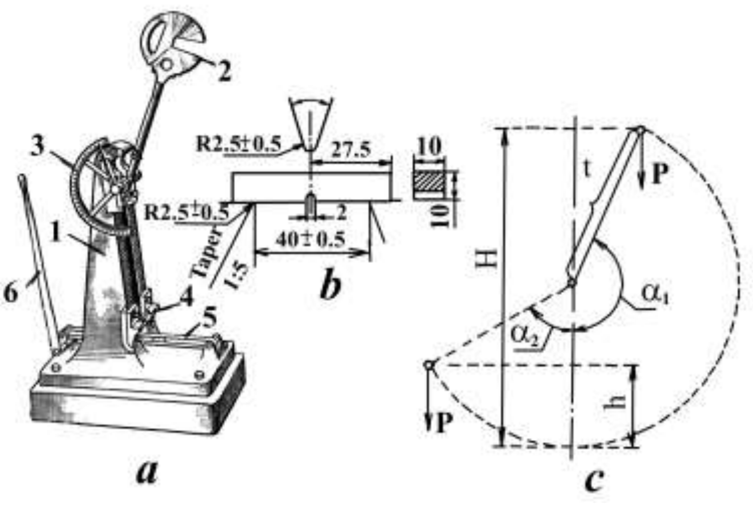


Fig. 1.13. Pendulum-type impact testing machine (a), notched-bar test specimen (b); principle of the impact test (c): 1 – base; 2 – pendulum (striker); 3 – scale; 4 – specimen; 5 – belt of the brake; 6 – handle of the brake.

1.2.5. Fatigue

Fatigue is a kind of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft and machine components). Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load. The term “fatigue” is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cyclings. Fatigue strength is important property, because fatique practure is a cause of failure in metals, estimated to comprise approximately 90% of all metallic failures. Polymers and ceramics (except for glasses) are also susceptible to this type of failure.

Fatigue failure is brittlelike in nature even in normally ductile metals, in which there is very little (if any) gross plastic deformation associated with failure. The process occurs by the initiation and propagation of cracks. Usually the fracture surface is perpendicular to the direction of an applied tensile stress.

In a fatigue failure the fracture consists of two distinct zones (Fig. 1.14). The first zone (1) has a smooth, rubbed-over surface and is called the *fatigue zone*. This zone is gradually formed. At first a microcrack (fatigue crack) is initiated. It then develops into a macrocrack due to the repeated action of the forces on the metal. When the fatigue crack occupies a considerable part of the cross-section, failure occurs in the other part. The second, *after-fracture zone* (2) has a coarse-crystalline surface on brittle metals and a fibrous surface on ductile metals.

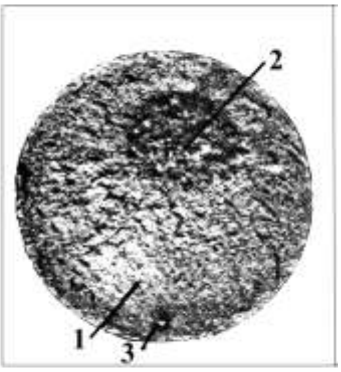


Fig. 1.14. Fracture obtained in failure: 1 – fatigue zone; 2 – after-fracture zone;
3 – point of initiation of a crack

The crack is most often formed at the surface of the first zone The resistance of a metal to failure from cyclic loading is characterized by its *endurance limit,* i.e. the maximum stress that the metal can withstand without failure when subject to a great number N of cycles (N is stipulated by the specification and may range from 10^5 to 10^8 or even higher).

The endurance limit is commonly determined by subjecting a rotating specimen (plain or notched) to flexural loads which develop reversing stresses (tension-compression) in a symmetrical cycle where $|\sigma_{\max}| = |\sigma_{\min}|$.

At least ten specimens are tested to find the endurance limit. The first specimen is tested at the stress σ_1(σ_1=0.6σ_t for steel), determining the number of cycles N when failure occurs. The stresses σ_2, σ_3, etc. for the second and subsequent specimens are increased or reduced each time by 20 or 40MPa, depending upon the number of cycles which caused the failure of the first specimen.

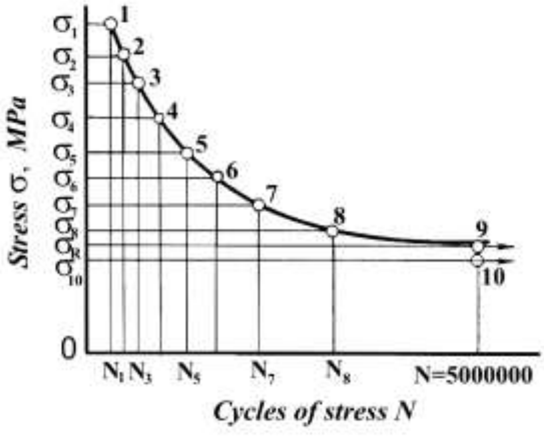


Fig. 1.15. Fatigue curve

The results of the tests are plotted on a diagram with the coordinates stress σ vs number of cycles N in either rectilinear or logarithmic scales (Fig. 1.15). The horizontal portion is the maximum stress at which failure will not occur even at an infinite number of loading cycles. It corresponds to the endurance limit. Endurance limits are expressed in terms of the nominal stresses and denoted by σ_{-1}, MPa.

1.3. Atomic-Crystal Structure of Metals

1.3.1. General Features of Metals

Among 106 elements known today, 76 are metals. Such elements as Si (silicon), Ge (germanium), As (arsenic), Se (selenium) and Te (tellurium) are considered to be intermediate between metals and nonmetals. In the solid state metals possess a number of typical properties:

- high *thermal* and *electrical conductivity*;
- positive temperature coefficient *of electrical resistivity* (the electrical resistance of pure metals increases with the temperature; about 30 metals display *superconductivity,* their electrical resistance drops abruptly to practically zero at temperature near absolute zero);
- *thermionic emission*, i. e. capacity to emit electrons when heated;
- good reflection of light; metals are opaque and have a specific metallic luster;
- they lend themselves well to plastic deformation.

All metals and alloys are crystalline bodies. Their atoms are arranged in a regular order repeated periodically in three directions. This distinguishes them from amorphous bodies, whose atoms are arranged in random disorder.

All typical properties of metals can be explained by the fact that they contain highly mobile *collective conduction electrons*. The bonds between the outer electrons and atoms' nuclei are weak, so metals have so-called “collective” electrons, which move freely between the positively charged and periodically located *ions.* Therefore metals have high electric and heat conductivity as well as electron emission capacity. By regular atoms arrangement metals possess *high light reflection* and high plastic properties.

1.3.2. Concept of Crystal Lattice

The atomic-crystal structure is the mutual positions of the atoms existing in a crystal. A crystal consists of the atoms arranged in a definite order, periodically repeated in three coordinate directions.

The concept of a *space lattice*, or *crystal lattice* describes the atomic-crystal structure of substances. Fig. 1.16 illustrates an example of such a crystal lattice. Heavy lines indicate the smallest parallelepiped (crystal lattice), which could be repeated consecutively along its three axes to build up the whole crystal.

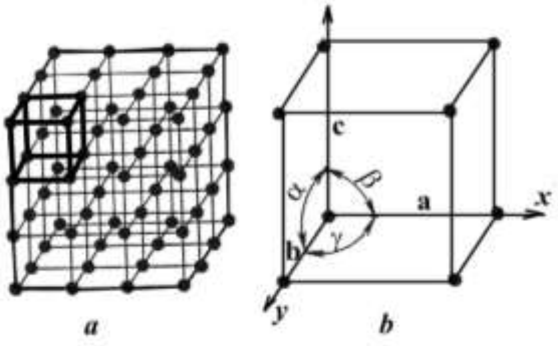


Fig. 1.16. Schematic representation of a crystal lattice

The metals and alloys have various types of crystal lattices. But the great majority of commercially important metals have one of the following highly symmetrical compound lattices with close-packed atoms: *body-centered cubic (bcc)* (Fig. 1.17a); *face-centered cubic (fcc)* (Fig. 1.17b); *hexagonal close-packed (hcp)* (Fig. 1.17c).

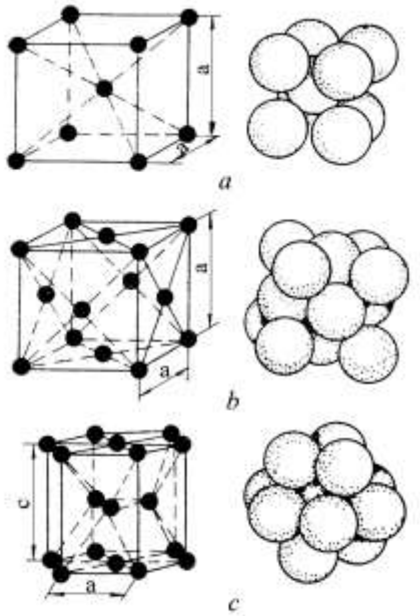


Fig. 1.17. Types of crystal lattices of metals: a – body-centered cybic, b – face-centered cybic, c – hegagonal-close-packed

1.3.3. Allotropic (Polymorphic) Transformations

At different temperatures many metals exist in different crystalline forms. These forms are sometimes called allotropic (polymorphic) modifications. As a result of polymorphic transformation, atoms of a crystalline body with a lattice of one type are rearranged to form a crystal lattice of another type.

The curve of cooling the pure iron is represented in Fig. 1.18. Iron exists in the α-Fe and γ-Fe allotropic forms. α-Fe exists at temperatures below 911 and above 1392°C (sometimes it is named δ-Fe (see Fig. 1.18)). In the temperature range from 911 to 1392°C iron is in gamma form. The crystal lattice of α-Fe is the body-centered cubic type. Up to 768°C iron is magnetic, above this temperature it is nonmagnetic. The crystal lattice of γ-Fe is face-centered cubic type.

Polymorphic transformations are known for metals: Fe, Co, Ti, Mn, Sn, Li, Ca, Sr, Zr, rare-earth metals, etc.

1.3.4. Anisotropy of Metals Properties

Different densities of their atoms in various planes and directions cause that many properties of metal crystals (chemical, physical, mechanical) depend on the direction, they are measured in. This inequality in the properties of a monocrystal in various crystallographic directions is called *anisotropy.*

All crystals are anisotropic bodies. They differ from *amorphous* solids (glass, plastics, etc.), which display the same properties in any direction.

Engineering metals are *polycrystals.* Their *crystallites* have a statistically disordered mutual orientation. Consequently, the general properties of a polycrystalline body are more or less the same in all directions, i.e. engineering metals are isotropic materials.

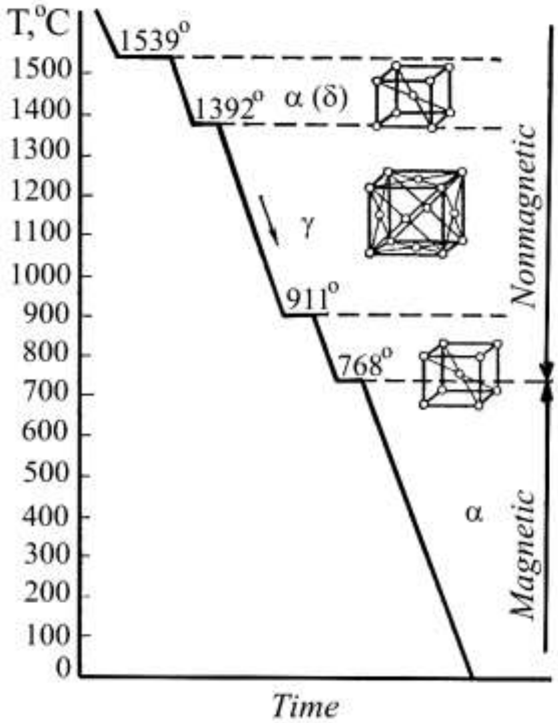


Fig. 1.18. Cooling curve of pure iron

1.3.5. Defects in Crystal Lattices of Metals

A real crystal always has defects in its structure. These defects are classified by their geometric features into:

- *point (zero-dimensional)*
- *linear (one-dimensional)*
- *plane (two dimensional)*

defects

Point defects are the small ones along all three dimensions. Their size does not exceed several atomic diameters. Point defects include (Fig. 1.19)

- *vacancies* (Schottky defects), i.e. lattice points where atoms are absent;
- *interstitial* atoms (Frenkel defects), i.e. additional atoms in crystal lattice;
- *substitutional* atoms, i.e. foreign atoms in lattice nodes of the basic metal.

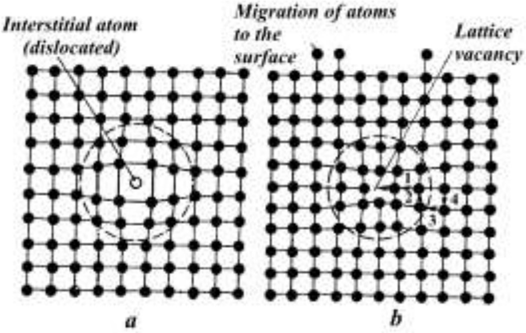


Fig. 1.19. Point imperfections in a crystal lattice

Vacancies are most frequently formed by atoms leaving their regular position at the lattice points, jumping to the surface of the crystal and evaporating from the surface of a crystal. Less frequently, vacancies may be formed by atoms jumping into an interstitial position.

The vacancy concentration increases with the temperature growth. The number of vacancies at temperatures near the melting point may reach one per cent of the total number of atoms in the crystal. At a given temperature not only single vacancies are formed in crystal, but double, triple and even larger ones as well.

Vacancies are formed not only by heating but also in the process of plastic deformation and in bombardment of a metal with high-energy atoms or particles (irradiation in a nuclear reactor).

Interstitial atoms are formed by jumping of an atom to interstitial position, which leaves a vacant site. A vacancy positions itself at the lattice point that was previously occupied by the atom. In the closely packed lattice, typical for the most metals, the energy required to form interstitial atoms is several times greater than that required to form thermal vacancies. For this reason, interstitial atoms are rare in metals, and thermal vacancies are the main point defects in this kind of crystals.

Point defects cause local distortion of the crystal lattice and influence certain physical properties of metals (electrical conductivity, magnetic properties, as well as the phase transformations in metals and alloys).

Linear defects are very small in two dimensions and of great extent along the third dimension. They are called *dislocations.* A crystal lattice with *edge dislocation* is shown schematically in Fig. 1.20. The edge dislocation is a localized distortion of the crystal lattice due to the presence of an “extra” atomic halfplane or *extraplane* B.

In addition to edge dislocations there are also *screw dislocations.* The screw dislocations are formed by incomplete shear of crystal in vertical plane (Fig. 1.21.)

Dislocation density ρ is defined as the total length of the dislocations l in cm per unit volume V of the crystal in cm^3. The technical metals have dislocation density $10^4 \dots 10^{13}$ cm^{-2}, i.e. up to one hundred million km in cm^3.

Plane defects or surface imperfections are small only in one dimension and constitute the interfaces between the separate crystallines (grains) or their blocks in polycrystalline. By different orientation of the neighboring grains, the atoms are arranged much less regularly at the boundary between grains than within the volume of the grains (Fig. 1.22.)

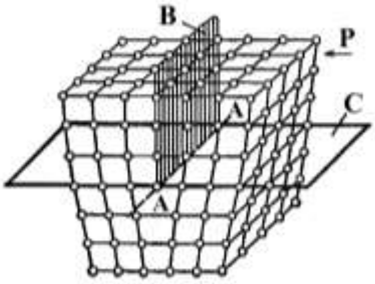


Fig. 1.20. Edge dislocation in a crystal lattice

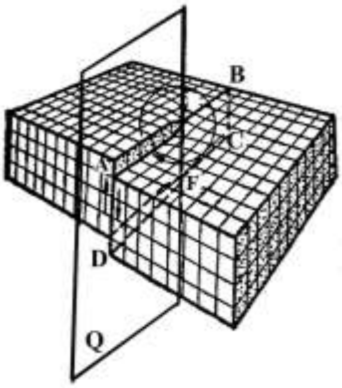


Fig. 1.21. Scheme of a screw dislocation

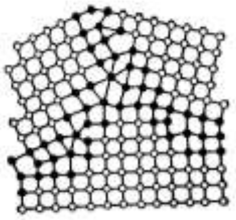


Fig. 1.22. Polycrystalline structure of metal

The grains of metal are usually oriented with respect to one another by angles ranging from several to dozens of degrees (high-angle boundaries). The atoms are arranged much less regularly at the grains boundary than within the volumes of the grains.

1.3.6. Theoretical and Engineering Strength of Metals

Based on the crystalline structure and interatomic forces we can theoretically estimate the force or the stress, required to cause slip or fracture in perfect crystal. To shear the crystal, two rows of atoms must be simultaneously displaced with respect to one another by shear stress (see Fig. 1.4.)

The theoretical shear stress is:

$$\tau_{theor} \approx G/2\pi,$$

where G is the shear modulus (analogous to tensile modulus E). But the *theoretical strength*, calculated by this formula, is from 100 to 1000 times as much as the real strength of engineering materials, or *engineering strength*.

There is no a mistake in theoretical calculations. The matter is that there is no simultaneous displacement of atoms in technical metals during their deformation and fracture. Dislocations are present in structure of real metals promoting the processes of slipping (sliding) and transference of atoms.

This way plastic deformation corresponds to the motion of large numbers of dislocations. An edge dislocation moves in response to a shear stress applied in a direction perpendicular to its line; the mechanics of dislocation motion is represented in Fig. 1.23.

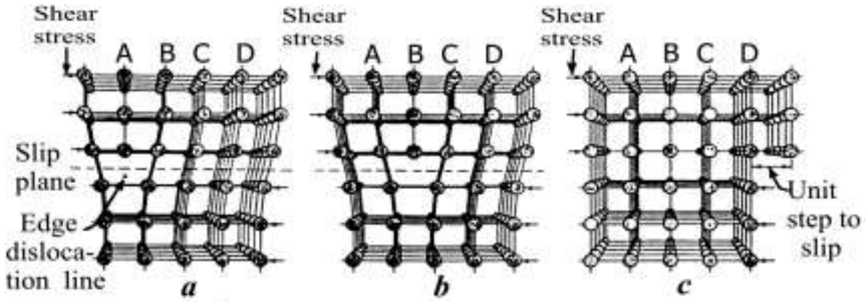


Fig. 1.23. Movement of an edge dislocation in shear

Let the initial extra half-plane of atoms be plane A. When the shear stress is applied as indicated (Fig. 1.23a), plane A is forced to the right; this in turn pushes the top halves of planes B, C, D, and so on, in the same direction. If the applied shear stress is of sufficient magnitude, the interatomic bonds of plane B are severed along the shear plane, and the upper half of plane B becomes the extra half-plane as plane A links up with the bottom half of plane B (Fig. 1.23b).

This process is subsequently repeated for the other planes, so that an extra half-plane moves from left to the right with discrete steps by successive and repeated breaking of bonds and shifting by interatomic distances of upper half-planes. Before and after the movement of a dislocation through some particular area of the crystal, the atomic arrangement is ordered and perfect; it is only during the passage of the extra half-plane that the lattice structure is disrupted. Ultimately this extra half-plane may emerge from the right surface of the crystal, forming an edge that is one atomic distance wide, which is shown in Figure 1.23c.

The process of plastic deformation by dislocation motion is called a *slip*. A plane along which the dislocation line traverses is termed a *slip plane* (Fig. 1.23c). Macroscopic plastic deformation simply corresponds to permanent deformation caused by the movement of dislocations, or slip in response to an applied shear stress.

The theoretical strength is strength of a perfect crystal (without dislocations). Due to this the theoretical strength is much higher than the engineering strength. The strength of metals is not a linear function of the dislocation density. As we can see at the diagram (Fig. 1.24), there are two main methods of increasing the strength:

- by producing metals and alloys of defectless structure;
- by increasing the density of defects, including dislocations, as well as structural barriers impeding the movement of dislocations.

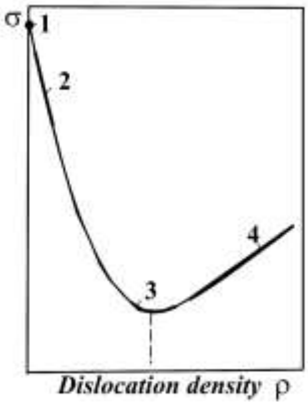


Fig. 1.24 Dependence of the resistance to deformation on the number of defects (dislocation density) in metal: 1 - theoretical strength; 2 - strength of “whiskers”; 3 - pure unhardened metals; 4 - alloys strengthened by alloying, strain hardening, heat and thermomechanical treatment

The curve shows that the minimum strength corresponds to a certain critical dislocation density, equal approximately to 10^6… 10^8 cm^{-2}. This value refers to annealed metals. As the number of defect reduces the resistance to deformation and the strength increase and rapidly approach the theoretical value. Crystals practically without dislocations may be produced. These filament-like crystals are small in size, from 2 to 10 mm long and 0.5 to 2 μm (micrometers) thick, and are called “whiskers”. Their strength approaches the theoretical value. For example, the tensile strengths of such filament crystals of iron, copper and zinc are 13000; 3000 and 2250 MPa; their corresponding engineering strengths are 300; 260 and 180 MPa.

Any increase in size of the whiskers sharply reduces their strength. The whiskers are used for producing of fibrous (composite) materials. High strength and plasticity are obtained in this case by reinforcing a soft metallic matrix (copper, aluminum, silver, nichrome, etc.) or plastics (polymers) by defectless, filament-like crystal of metals or fibres of nonmetals (α -$A1_2O_3$, carbon fibres, carbides B_4C, SiC, etc.). The tensile strength of filament-like crystals amounts to 20000 MPa for $A1_2O_3$, 7000 MPa for B_4C 11000 MPa for SiC and 21000 MPa for carbon filaments.

If the number of defects (dislocations, point and surface defects, etc.) of the crystal structure exceeds 10^6...10^8 cm^{-2}, its strength continues to raise. The relationship between the yield point σ_y and the dislocation density p is:

$$\sigma_y = \sigma_0 + \alpha G b \sqrt{\rho}, \qquad (1.17)$$

where σ_0 is shear stress before deformation (after annealing);
b is Burgers vector;
α is strain hardening factor; depends upon the type of lattice and composition of the alloy.

This equation is the basis for all practical engineering methods of strengthening metals and alloys.

The dislocation density should not exceed 10^{12} or 10^{13} cm^{-2}. At higher density the metal becomes brittle; and cracks are formed in it.

1.3.7. Diffusion

Many of the fundamental processes occurring in metals and alloys (crystallization, phase transformations, recrystallization, surface impregnation, etc.) are of diffusive nature. Diffusion refers to the displacement of atoms within a crystalline body over distances exceeding interatomic for the given substance.

In metals diffusion takes place predominantly by the substitutiuonal mechanism. Here, as it is shown at the Fig. 1.19 b, atom 1 has higher energy and can move into a vacancy. Thus, a new vacancy has been left at the previous location of this atom, which can be occupied by atom 2, etc.

Diffusion of the elements with a small atomic radius (C, N, H) in a metal takes place according to the interstitial mechanism.

The rate of diffusion is defined as the quantity of matter that diffuses through unit area of the interface in unit time. The higher concentration of diffusing element and temperature is, the higher the rate of diffusion.

1.4. Solidification and Metal Structure

1.4.1. Primary Crystallization of Metals in Solidification

The transformation of metals from the liquid to the solid (crystalline) state is called *solidification*, or *crystallization*. The process of solidification begins when temperature becomes lower than melting point, that is, the process begins in the conditions of *supercooling* of metals (Fig. 1.25).

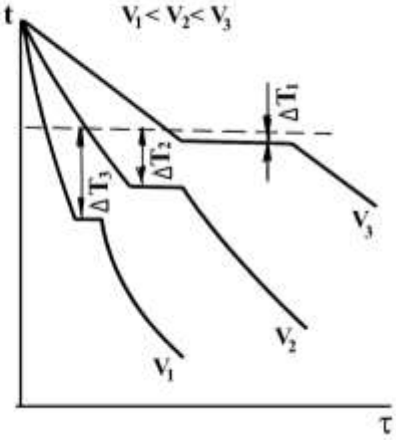


Fig. 1.25. Cooling curves for a pure metal

At very low rates, the degree of supercooling is small and solidification proceeds at a temperature near to the equilibrium one (curve v_3). The horizontal portion found on the cooling curves at the solidification temperature (representing a stop in the fall of temperature) is due to the evolution of the *latent heat of solidification*, even when heat is dissipated in cooling. The degree of supercooling increases with the cooling rate and the solidification process proceeds at temperatures below the equilibrium temperature of solidification.

The rate of solidification and the structure of the solidified metal depend on the *rate of nucleation* RN (number of crystals appearing in unit time and in unit volume) and on the *rate of growth RG of the nuclei*, i.e. on the linear rate of crystal growth. The higher the rate of nucleation and growth of the nuclei is, the more rapid the process of solidification will be. It is usually assumed that with an increase in the degree of supercooling, the rate of nucleation and, consequently, the number of nuclei, increases faster than the rate of crystal growth. The greater the rate of nucleation and the lower the rate of crystal growth, the smaller the crystals (grains) finally will be, and the finer the grain structure of metal will be obtained. The size of obtained grains S is related to the number of nuclei (nucleation rate) RN and to the rate of crystal growth RG by the equation:

$$S = 1.1\,(RG/RN)^{3/4} \tag{1.18}$$

The grain size of metal strongly affects its mechanical properties. These properties, especially, ductility and plasticity, are higher for fine-grained metal.

Nucleation in a liquid metal by the described mechanism is considered to be spontaneous. Spontaneous nucleation, i.e. the formation of nuclei, based on phase and energy fluctuations may take place only in highly pure liquid metals. Commercial, or engineering, metals always contain a large amount of impurities of various kinds (oxides, sulphides, nitrides, etc.), which under definite conditions facilitate the formation of nuclei. These conditions are:

- the impurity should have a higher melting point than the base metal;
- the crystal lattice of the impurity and crystal lattice of base metal should differ only to the minimum extend (principle of structural and dimensional conformity).

Inoculation is the use of impurities, or admixtures, called inoculants, which are added to the liquid metal to obtain fine grain according to the mechanism described above. These inoculants are added in such small amounts (0.001...0.15%) that practically they do not change the chemical composition of the metal. But they enable a fine grain to be obtained and thereby improve the mechanical properties of the metal.

1.4.2. Macro- and Microstructure of Metals and Alloys

In their ordinary structural state pure metals are of low strength and do not possess, in many cases, the required physicochemical, mechanical and technological properties. Consequently, they are comparatively seldom used in engineering practice. The majority of metals employed are *alloys.* Alloys are produced by melting or sintering of two or more metals, or metals and nonmetals, together. The chemical elements that make up an alloy are called its *components.*

The conceptions of *phase* and *structure*, widely used in physical metallurgy, have been introduced to deal with the constitution, transformations and properties of metals and alloys.

A *phase* is a homogeneous portion of an alloy, having the same composition and the same state of aggregation throughout its volume, and separated from the other portions of system by interfaces. For instance, a homogeneous pure metal or alloy is a single-phase system. A state in which a liquid alloy or metal coexists with its crystal is a two-phase system. Alloy may have two and more phases in solid state, for instance, aluminum and silicon in Al-Si alloy (Fig. 1.26).

As the result of various physicochemical interactions of the components the following phases can be formed in alloys:

- *liquid solutions*;
- *solid solutions*;
- *chemical compounds*;
- *phase, or mechanical mixtures*.

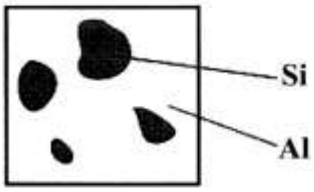


Fig. 1.26. Double-phase structure of Al-Si alloy

As a rule, in liquid state components of alloys are unlimitedly dissolved each in other forming liquid solutions.

Solid solutions are phases in which one component of the alloy retains its crystal lattice, and atoms of the other component (or components) are located in the lattice of the first one, called the solvent, changing its size (lattice constant). Distinction is made between substitutional and interstitial_*solid solutions* (Fig. 1.27). In forming a substitutional solid solution, the atoms of the dissolved component (called *solute atoms*) substitute for a part of the atoms of the solvent (called *matrix atom*) in its crystal lattice. In forming an interstitial solid solution, the solute atoms are accommodated in the interstices (interatomic spaces) of the crystal lattice of the solvent.

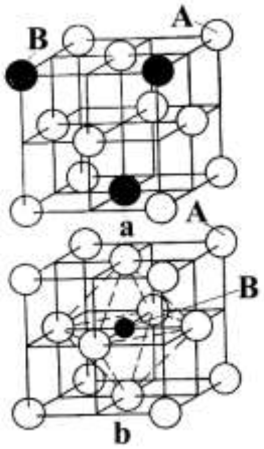


Fig. 1.27. Substitutional (a) and interstitial (b) solid solutions

All metals are mutually soluble to some degree in solid state. For instance, up to 5,5 % Cu can be dissolved in aluminium and up to 39 % Zn in copper without changing the type of their crystal lattice. *A continuous series of solid solutions* may be formed in cases when the components can substitute each other in the crystal lattice in any quantitative ratio.

Chemical compounds are formed according to the law of normal valence. They have typical features that distinguish them from solid solutions:

- they have a crystal lattice that differs from those of the components forming the compound;
- there is a simple multiple relation of the atoms of elements: this enables their composition to be specified by a simple formula A_nB_m, where A and B are elements, n and m are small whole numbers;
- the properties of the compound differ greatly from these of its components;
- the compound has a constant melting point;
- the formation of the chemical compound is accompanied by a substantial *thermal affect.*

Mechanical (phase) mixtures are formed during crystallization of double alloys: Fe-C, Pb - Sn, Al-Cu and so on. They are combinations of two pure metals, or metal and solid solution or solid solution and chemical compound. Mechanical mixtures have constant chemical composition, for example, 0,8%C and 99,2% Fe, 13% Pb and 87% Sb and constant temperature of crystallization or recrystallization.

The industrial alloys consist of many components (two, five, ten and more), therefore they have numerous phases and complex structure composition. The structure refers to the shape, size or mutual arrangement of the corresponding phases in metals and alloys. The structure defines properties of metals and alloys.

There are some methods to control the structure of metals and alloys. They distinguish concept of macrostructure and microstructure.

Macrostructure is constitution of a metal or alloy investigated by the naked eye or by low-power magnification (not more than x50).

Microstructure is constitution of metal or alloy observed by means of optical metallurgical microscope with magnification ranges from x50 to x2000.

Macrostructure can be examined either on a fracture or on specially prepared macrosection (Fig. 1.28). A study of a fracture is the simplest way to reveal the crystalline structure of metals. A fracture reveals grain size and shape, special features in smelting and casting of the metal, heat treatment used and, consequently, certain properties of the metal. *Fractures may be: brittle, plastic, combine (intermediate), fatigue.*

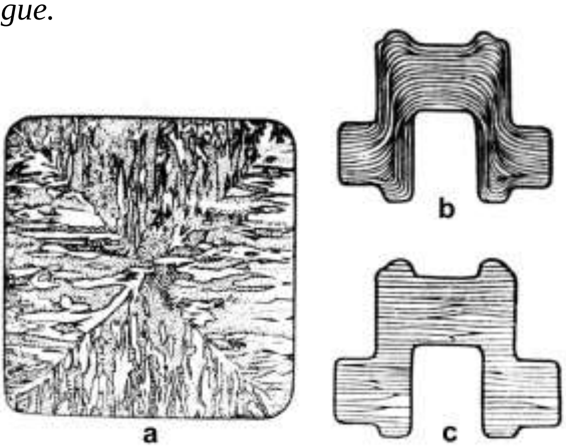
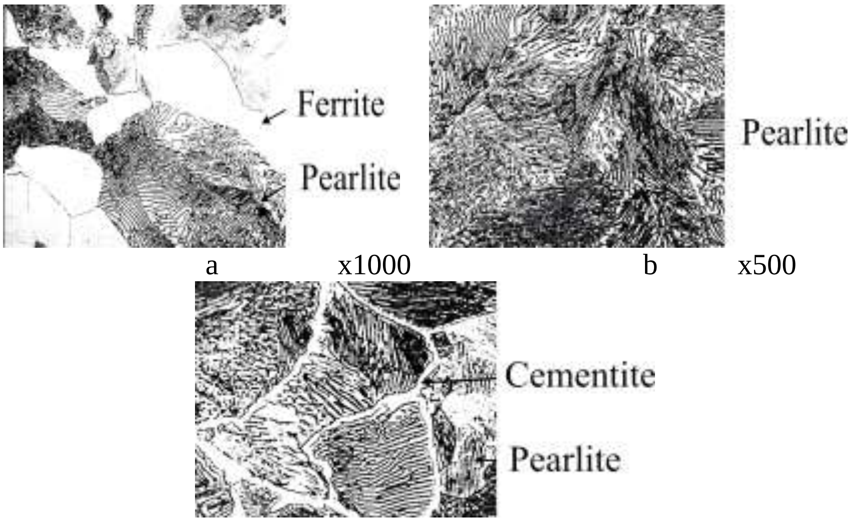


Fig. 1.28. Macrostructure of steel: (a) - “as cast”; (b) - forged; (c) - rolled

If the macrostructure is studied on special macrosection, the specimens are cut out of large billets (ingots, forgings, etc.) or machine parts and are then ground, polished and etched with special reagents called *etchants*. An examination of a macrosection can disclose the shape and arrangement of the grains in cast metals; directions of grain flow lines (of the deformed crystallites) in smith and closed-die forgings; defects impairing the continuity of the metal (shrinkage porosity, gas holes, cracks, etc.); chemical non-homogeneity of an alloy, caused by the crystallization process or resulting from heat -treatment or chemical heat-treatment (carbonizing, nitriding, etc.).

The microstructural analysis reveals the mutual arrangement of the phases, their shapes and sizes. Microstructure is studied on a microsection made of the metal to be analyzed. This is a small specimen, prepared by careful surface grinding, polishing and etching by special reagent. The microstructure of metals is observed by means of an optical or an electron microscope. The useful magnification of an optical microscope does not exceed x2000. This enables details of the structure to be observed if they are larger than 2000 $\overset{0}{A}$ or $2.0 \cdot 10^{-7}$m (Fig. 1.29).



a x1000 b x500

c x1000

Fig. 1.29. Microstructure of hipoeutectoid steel with 0.4%C (a),
eutectoid steel with 0.8%C (b) and hypereutectoid steel with 1,1%C

Today the electron microscope is extensively used to study the structure of metals. Its effective magnification may reach x5000000. The use the electron beams of exceptionally short wave-length (0.04 to 0.12×10^{-8}m) enables details of the object to be distinguished that are near $1\ \overset{0}{A}$ (10^{-10} m) in size (subgrains, dislocations and separate atoms).

1.5. Phase Diagrams and Structure of Alloys. System of Iron-Carbon Alloys

1.5.1. Essence and Plotting of Phase Diagrams

The *solidification (crystallization)* of metallic alloys and many laws concerning their structure can be described by means of the *equilibrium diagrams* discussed below. These diagrams, also called *constitutional and phase diagrams*, are convenient graphical representations of the phase content and structure of an alloy at any temperature and composition. Equilibrium or phase diagrams as their name implies are plotted for equilibrium conditions or for conditions sufficiently close to equilibrium.

The method of thermal analysis is the most frequently used for the phase diagrams plotting. The idea of method is the plotting the cooling curves of different alloys by special device and a thermocouple (Fig. 1.30).

Plotting of lead-antimony (Pb-Sb) diagram is frequently discussed as an example.

The group of Pb-Sb alloys is taken, where Sb content increases from 0 to 100 %: (table 1.1).

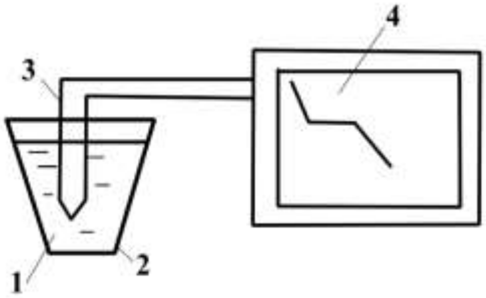


Fig. 1.30. Method of thermal analysis in plotting of phase diagrams: 1-alloy; 2-crucible; 3-thermocouple; 4-device, recording the change of the temperature in the time

Table 1.1 - Group of Pb-Sb alloys for the thermal analysis method

No of alloys	1	2	3	4	5	6	...	11	12
Pb, %	100	95	90	87	80	70	...	10	0
Sb, %	0	5	10	13	20	30	...	90	100

Every alloy is melted in the crucible; and the cooling curve is plotted by the device (Fig. 1.31).

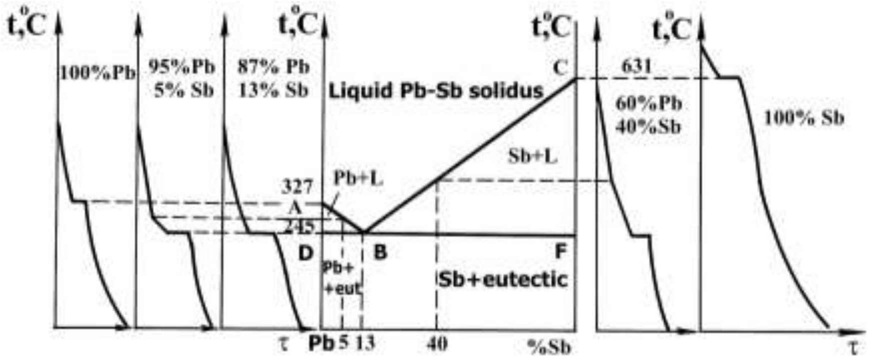


Fig. 1.31. Plotting of Pb-Sb phase diagram

Upon cooling the temperature of pure lead (Pb) drops uniformly to temperature 327°C or melting point, at which lead solidifies. A horizontal step appears on the curve because the *latent heat* of solidification evaluate. When lead has completely solidified, the temperature again drops uniformly. Antimony (Sb) solidifies in a similar manner (alloy №12).

Other alloys, except № 4 (table 1.1), solidify in interval of temperatures, i.e. they have temperatures of solidification beginning and temperatures of solidification finish. For example, when alloy № 2 is cooled, the temperature drops uniformly to the temperature of 285ºC. At this temperature solidification begins and an inflection (*critical point*) is observed on the cooling curve. This inflection is due to a reduction in the cooling rate as a result of the evolution of the latent heat of solidification. Solidification of the alloys begins at the temperatures lying on the *liquidus line* ABC. Crystallization ends at the temperatures lying on the *solidus line* DBF.

Liquid lead-antimony solution exits at temperatures above the liquidus line. Two phases: liquid alloy and solid Pb exist between the lines AB and DB; and liquid alloy and solid Sb exist between lines BC and BF. Alloy № 4 differs from other alloys because it solidifies at constant temperature, like pure metals. Similar structure consisting of definite combinations of two (or more) solid phases, simultaneously freezing out of the liquid alloy, is called a *eutectic*. The eutectic is a mechanical mixture with a definite composition (in our case 13 %Sb+87%Pb).

During solidification the liquid solution of all Pb-Sn alloys is converted into eutectic at temperature 245°C (*solidus line* DBF).

1.5.2. Components and Phases of the Iron-Carbon System

The iron alloys are the most extensively used in industry. The most widely used ones are *steel* and *cast iron*, which are alloys of iron with carbon. Various alloying elements are added to obtain steel and cast iron with the required properties.

Iron is a metal of silvery-whitish color. Its atomic number is 26, the atomic mass is 55.85, and the atomic radius is 1,27 $\overset{0}{A}$. The melting point is 1539 °C. The density of α-iron at room temperature is 7,68 g/cm. Iron is polymorphic, the crystal lattice of α-Fe is of the body-centered cubic type with a lattice constant of 2.8606 $\overset{0}{A}$.

The γ-iron exits at temperatures above 911°C to 1392°C. It has face-centered cubic lattice with constant of 3,645 $\overset{0}{A}$ at the temperature 911°C. The density of γ-Fe is from 8.0 to 8.1 g/cm^3.

Carbon is nonmetallic element. Its atomic number is 6, the density is 2.5g/cm^3, the atomic mass is 12.011, the melting point is 3500°C, and atomic radius is 0,77 $\overset{0}{A}$. Carbon is also polymorphic. It is brittle, and has low mechanical properties, when it has the graphite allotropic form. But carbon also occurs in the metastable diamond form.

The following phases and structural components are distinguished in the Fe-C system of alloys: liquid alloy, solid solutions (ferrite and austenite), the compound (cementite), mechanical mixtures (pearlite and ledeburite) and free graphite.

Ferrite (Fig.1.32a) is solid solution of carbon and other constituents in α-iron. Depending upon temperature, the carbon content in ferrite ranges from 0.006% at 20°C to 0.02 % at 727°C. Under a microscope ferrite is seen as homogeneous polyhedral grains. It has the following approximate mechanical properties:

$$\sigma_u = 250\,\text{MPa},\ \sigma_y = 120\,\text{MPa},\ \delta = 50\%, \varphi = 80\%,\ \text{HB} = 700...800\,\text{MPa}.$$

Austenite (Fig.1.32 b) is the solid solution of carbon and other constituents in γ-iron. The maximum solubility of carbon in γ-iron is 2.14 %. The microstructure is made up of polyhedral grains. Austenite possesses the following approximate mechanical properties:

$$\sigma_u = 400\,\text{MPa},\ \sigma_y = 200\,\text{MPa},\ \delta = 25\%,\ \varphi = 20\%,\ \text{HB} = 1800...2200\,\text{MPa}$$

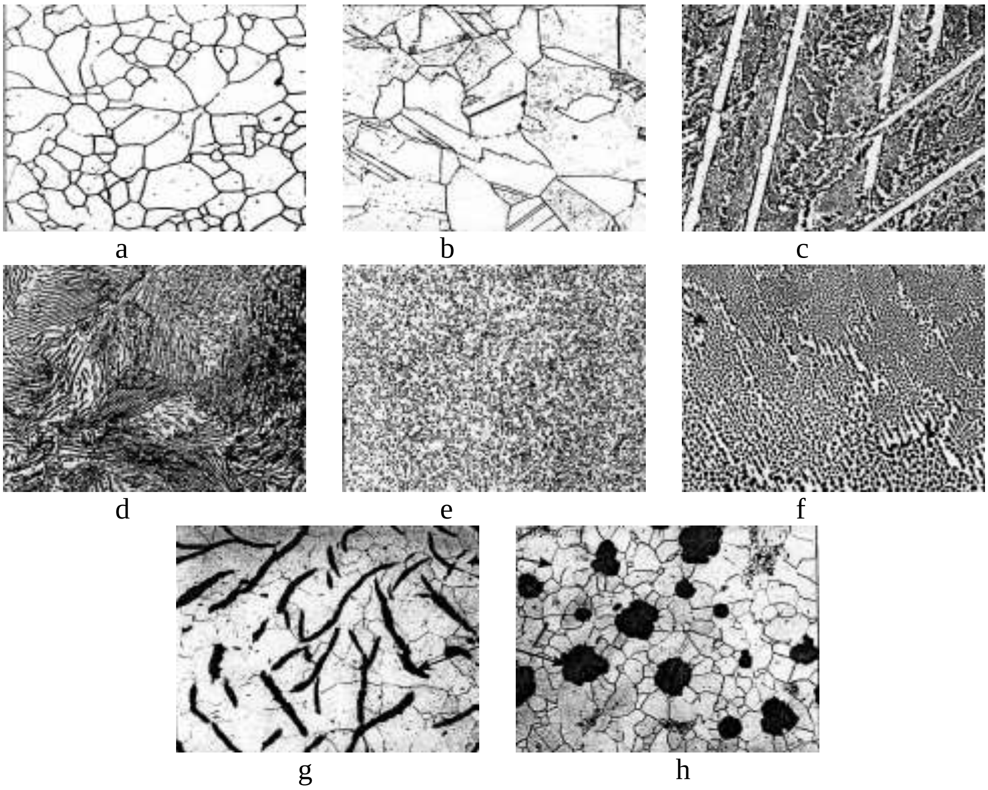


Fig. 1.32. Phases in steel: a – ferrite; b – austenite; c – cementite (white); d – lamellar pearlite; e – globular pearlite; f – ledeburite; g – lamellar graphite; h – spheroidal (globular) graphite. x100

Cementite (Fig.1.32 c) is a chemical compound of iron and carbon, iron carbide Fe_3C. It has a carbon content of 6.67%. Owing to the ability of its decomposition at high temperature the melting point of cementite has not been precisely determined, but is taken equal to about 1250°C. It has high hardness, about 10000 MPa, and low, near zero, ductility. Cementite is a metastable phase. Under equilibrium conditions (holding at high temperature) cementite disintegrates into iron and carbon: $Fe_3C \rightarrow 3Fe + C$ with formation of graphite.

Pearlite (Fig 1.32 d, e) is the mechanical mixture of ferrite and cementite with constant carbon content equal to 0.8 %. Pearlite is a structural component, which may be considered as two phases: ferrite and cementite. Pearlite has the following approximate mechanical properties: $\sigma_u = 700\,\mathrm{MPa}, \sigma_y = 500\,\mathrm{MPa}, \delta = 10\%, \varphi = 15\%, \mathrm{HB} = 2500...2800\,\mathrm{MPa}$. It is named *eutectoid.*

Ledeburite, or *eutectic* (Fig. 1.32 f) is the mechanical mixture of pearlite and cementite at $t \leq 727$°C or austenite and cementite at $t > 727$°C. It has carbon content equal to 4.3 % C. The ledeburite has low strength and ductility, but high hardness, near 6500 MPa.

Graphite (Fig. 1.32 g, h) is soft, and has low strength. Its hardness is HB 100MPa. But carbon graphite fibers of high strength can be obtained in the decomposition of certain organic compounds (natural gas). They are used e.g. for reinforcing of aluminium alloys.

1.5.3. Iron-Cementite Equilibrium Diagram (Metastable Equilibrium)

The iron-cementite diagram shows the phase composition and structure of alloys in the carbon content range from pure iron to cementite (6.67 %C) (Fig. 1.33). The Fe-Fe_3C system is metastable. The formation of cementite in place of graphite takes place in case of rapid cooling of alloys.

Point A (1539°C) on the Fe-Fe_3C diagram is the melting point of pure iron. Point G (911°C) corresponds to the allotropic transformations $\alpha \leftrightarrow \gamma$.

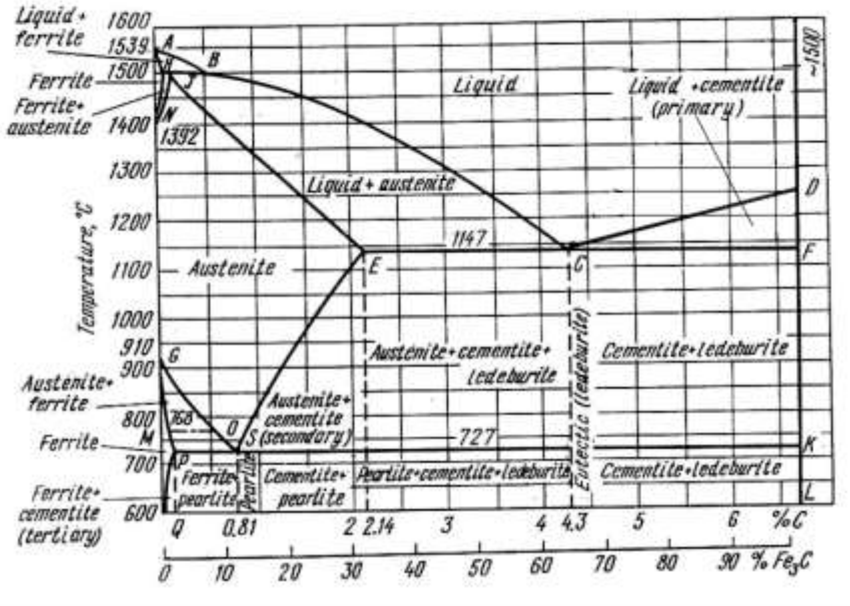


Fig. 1.33. The iron-cementite equilibrium diagram

The carbon content (by mass) for the characteristic points of the diagram is as follows:

- point E (2.14 %C) is the *maximum carbon content in austenite at the eutectic melting temperature* 1147°C;
- point S (0.8 %C) is *the point of eutectoid formation*;
- point C (4.3 %C) is *the point of eutectic formation*;
- point P (0.02 %C) is the *maximum carbon content in ferrite at the eutectoid temperature* 727°C.

Line ABC indicates the temperatures at which austenite (or ferrite 5) begins to freeze out of the liquid alloy, it is the *liquidus line*; line CD (liquidus line) - the temperature at which *primary cementite* (Fe_3C) begins to precipitate out of the liquid alloy.

Line AHJECF indicates the temperatures at which the solidification of alloys is finished. It is *solidus line.* Line ECF corresponds to the crystallization of the eutectic, which is called ledeburite. Thus:

$$\text{Liquid} \rightarrow \text{Austenite} + \text{Fe}_3\text{C}_\text{I} \tag{1.19}$$

Phase and structural changes in Fe-Fe_3C alloys following solidification are due to the allotropy of iron and the change in solubility of carbon in austenite and in ferrite as the temperature is lowered.

In cooling line SE (the maximum solubility of carbon in austenite) is Acm. It represents the temperatures at which *secondary cementite* starts separating out of the austenite:

$$\text{Austenite}_\text{E} \rightarrow \text{Austenite}_\text{S} + \text{Fe}_3\text{C}_\text{II} \tag{1.20}$$

The horizontal line PSK at the *eutectoid temperature 727°C,* conventionally labeled A_1 (in cooling Ar_1, in heating Ac_1), is termed the *lower critical temperature*, below which, under equilibrium conditions, all austenite will have transformed into ferrite and cementite phases:

$$\text{Austenite} \rightarrow \underbrace{\text{Ferrite} + \text{Fe}_3\text{C}}_{\text{Pearlite}} \tag{1.21}$$

The phase boundaries denoted by A_3 (line GS, in cooling Ar_3, in heating Ac_3) and by A_{cm} (line SE, in cooling and in heating is denoted by the same A_{cm}) represent the *upper critical temperature lines*, for hypoeutectoid and hypereutectoid steels, respectively.

The critical point of the $\gamma \leftrightarrow \alpha$ transformation at 1392ºC is denoted by Ac_4 (in heating) and by Ar_4 (in cooling).

Variation of the solubility of carbon in ferrite with the temperature corresponds to line PQ. In cooling under equilibrium conditions, this line corresponds to the temperatures at which *tertiary cementite* begins to precipitate out of the solid alloy; in heating it is completely dissolved at these temperatures. When the temperature drops to 727°C the austenite containing 0.8 %C (point S), is transformed into pearlite. Line PSK is named *the austenite-pearlite transformation line.*

Alloys, containing 0,02 %C or less are called *ingot irons* or simply *irons.*

Alloys, containing from 0,02 to 0,8 %C are called *hypoeutectoid steels*; steel with 0.8 %C is *eutectoid steel*; alloys, containing from 0.8 to 2.14% C are called *hypereutectoid steels*.

Alloys, containing from 2.14 to 6.67 %C are called *cast irons*: they are *hypoeutectic* (C=2.14…4.3 %), *eutectic* (4.3 %C) and *hypereutectic* (from 4.3 to 6.67 %C) alloys.

1.5.4. Effect of Carbon and Minor Constituents on the Properties of Steel

Steel is a multiple-component alloy containing carbon, alloying elements (Mn, Si, Ni, Cr, W, etc.), a number of constant (Mn, Si, Cr, Cu, etc.) and unavoidable impurities (S, P, O, N, H and others), which influence its properties. The presence of these impurities is due to the difficulty of removing them in smelting of the steel (S, P, O, N, H), or their transfer to steel in deoxidation (Mn, Si, Al), or from the charge of scrap metal (Cr, Ni, Cu, etc.)

Effect of Carbon. The more carbon is in steel the more cementite and less ferrite is in it (Fig 1.34). Hard and brittle particles of cementite impede the motion of dislocations, thereby increasing the resistance to deformation and also reduce the ductility and toughness. Consequently, an increase in carbon content in steel increases its hardness, tensile strength and yield point, and reduces the percent elongation, reduction in area and impact strength. The carbon content in excess of 1.0 or 1.2 % increases the hardness of steel in the annealed state, but reduces its tensile strength (Fig. 1.35). The latter is due to the precipitation of secondary cementite along the boundaries of grains, forming a continuous network.

Effect of Silicon and Manganese. The silicon content in carbon steel as an impurity does not usually exceed 0.35 or 0.4 %. The manganese content ranges from 0.5 to 0.8 %.

Silicon and manganese are introduced in the deoxidization period in steelmaking. Silicon and manganese deoxide liquid steel, i.e. they combine with the oxygen of the ferrous oxide (FeO) and go over into the slag in the form of oxides SiO_2 and MnO. Deoxidation improves the properties of steel.

The silicon that remains after *deoxidation* in the solid solution (in the ferrite) greatly increases the yield point σ_y. This, in turn, reduces the *drawing capacity* of the steel and, especially, its capacity to be efficiently *cold-headed*. Therefore, the silicon content must be kept low in steels intended for *cold press working* and *cold heading*.

Manganese appreciably raises the strength of steel without practically reducing its ductility. It sharply reduces the *read-shortness*, i.e. brittleness at high temperatures due to the effect of sulphur.

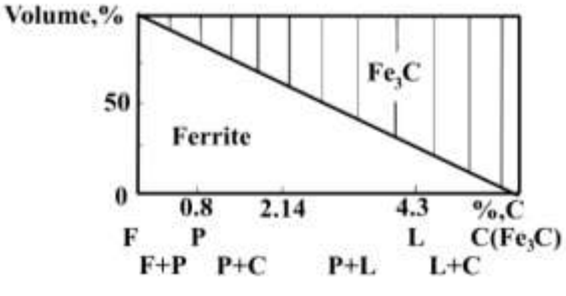


Fig. 1.34. Percent change in ferrite and cementite volumetric content in steel and cast iron

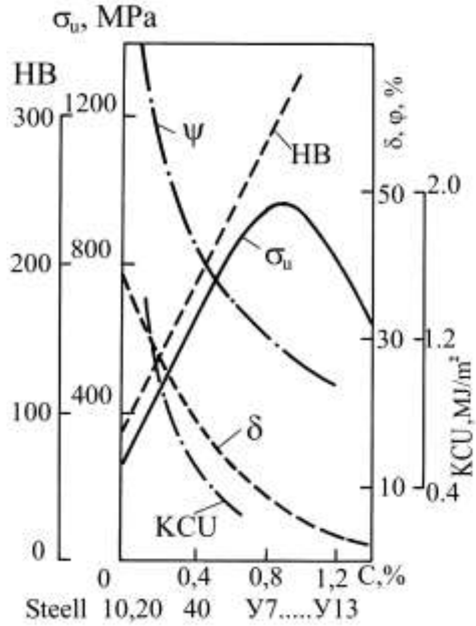


Fig. 1.35. Effect of carbon on the mechanical properties of steel

Effect of Sulphur. Sulphur is a harmful impurity in steel. It forms the chemical compound FeS with iron, which is practically insoluble in iron in the solid state, but is soluble in the liquid metal. This compound forms a eutectic with the iron with the low melting point (988°C). The eutectic is formed even with slight sulphur content, separating out of the liquid at the very end of solidification, and locates mainly along the grain boundaries. When the steel is heated to the rolling or fording temperature (1000° to 1200°C) the eutectic melts violating the bonds between the metal grains. As a result, tears and cracks are developed when the metal is hot-worked. This phenomenon is known as *hot-shortness*, or *red-shortness*. The presence of manganese in steel, which has a greater affinity to sulphur than iron and forms the high-melting compound MnS, practically excludes red-shortness.

Sulphur inclusions unfavorably affect the mechanical properties: impact strength (KCU), ductility and *cold resistance*. For these reasons, the sulphur content in steel is strictly limited. Depending upon the quality of the steel, the maximum permissible content ranges from 0.015 to 0.055 %S.

Effect of Phosphorus. Phosphorus dissolves in both α-Fe and γ-Fe. When it dissolves in ferrite, phosphorus distorts the crystal lattice and increases tensile strength and yield point, but greatly reduces ductility, toughness and cold-resistance. The maximum phosphorus content may range from 0.015 to 0.060 %.

Effect of Nitrogen, Oxygen and Hydrogen. Nitrogen and oxygen are present in steel in the form of brittle nonmetallic inclusions (oxides SiO_2, MnO, Al_2O_3, nitrides Fe_4N, TiN, VN etc.). They reduce ductility, toughness, impact strength and cold resistance.

The hydrogen absorbed in smelting steel not only embrittles steel, but also promotes the formation of flakes (cavities) in rolled stock and large forgings.

Vacuum smelting and blowing by inert gases processes, widely used in steelmaking in recent years, considerably reduce the gas content in steel.

1.6. Heat-Treatment of Steel

1.6.1. Phase Transformations in Iron Alloys

The *heat-treatment* of steel is based on:
- polymorphism of iron;

- different solubility of carbon in α-Fe and γ-Fe;
- ability of cementite Fe_3C to decompose by the reaction $Fe_3C \Leftrightarrow Fe+3C$;
- high diffusion ability of carbon.

Let us consider the transformation of a ferrite - cementite mixture (pearlite) into austenite, using eutectoid steel (0.8 %C) as an example. According to the diagram Fe-Fe_3C, when the steel is heated above line PSK (or point S), pearlite transforms in austenite:

$$\begin{array}{l} Fe_\alpha \quad + \quad Fe_3C \rightarrow Fe_\gamma(C) \\ \underbrace{0.02\%C \quad 6.67\%C}_{\text{pearlite}} \quad \underbrace{0.8\%C}_{\text{auctenite}} \end{array} \qquad (1.22)$$

As we can see the polymorphic transformation $Fe_\alpha \rightarrow Fe_\gamma$ and carbon diffusion take place. According to scientific investigations, process of pearlite-to-austenite transformation consists of some steps (Fig. 1.36):

- beginning of austenite formation at temperature higher than 727°C (point 1);
- end of ferrite-to-austenite transformation (point 2);
- complete dissolution of the carbides and receipt of non-homogeneous austenite (point 3);
- homogenization of austenite (point 4).

When steel with an austenite structure, obtained by heating to temperature above the line GSE, is supercooled to temperatures below the line PSK (A_1), the austenite is in a metastable state and undergoes the transformation.

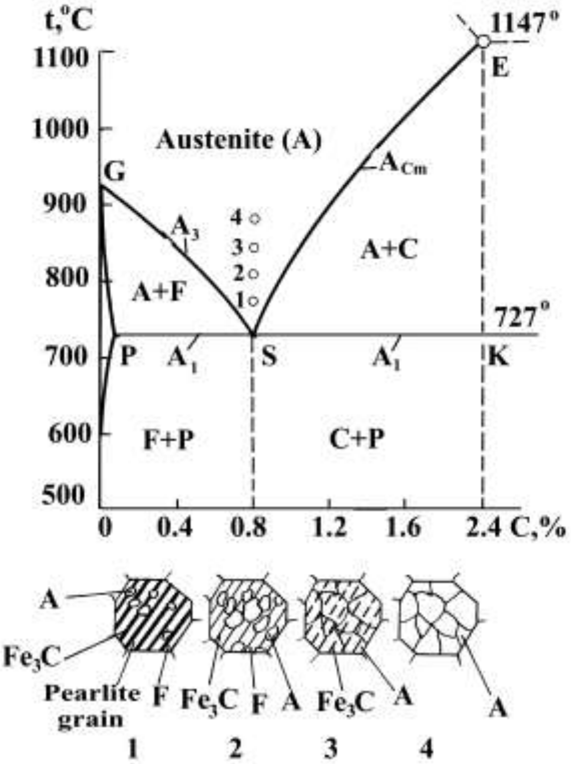


Fig. 1.36. Pearlite-to-austenite transformation in heating

The kinetics of supercooled austenite transformations may be comprehensively described by means of an experimentally plotted *time-temperature-decomposition diagram*, or isothermal (constant-temperature) austenite transformation diagram (more commonly called *TTT diagrams*, because they relate the transformations of austenite to the pertinent time and temperature conditions). Such diagrams are also called *S-curves* and *C-curves* because of their shapes (Fig. 1.37). Curve 1 of diagram represents the beginning of austenite decomposition and curve 2 indicates the time required for complete decomposition. The area to the left of the curve 1 showing the start of austenite decomposition determines the length of the *incubation period*. In the temperature and time ranges, specified by this area, *supercooled austenite* exists in which no appreciable decomposition has yet occurred.

If austenite is cooled with low speed (V_1), decomposition of the austenite occurs with the formation of a lamellar structure of ferrite and cementite (*pearlite*). This process is diffusive. This follows from the fact that austenite, which is practically homogeneous in its carbon concentration, decomposes with the formation of ferrite (almost pure iron) and cementite containing 6.67 % C, i.e. into two phases with greatly differing carbon content.

The transformation Austenite→Pearlite has the same steps as transformation Pearlite→Austenite, but the process goes in reverse order. At low degrees of supercooling (V_1) a clearly differentiated ferrite-cementite aggregate (pearlite) is formed. At a higher degree of supercooling (V_2) a finer mixture called *sorbite* is obtained. At still greater supercooling of the austenite (V_3) an even more dispersed mixture, called *troostite*, is obtained. Pearlite, sorbite and troostite are ferrite-cementite mixtures differing from each other by dispersion only.

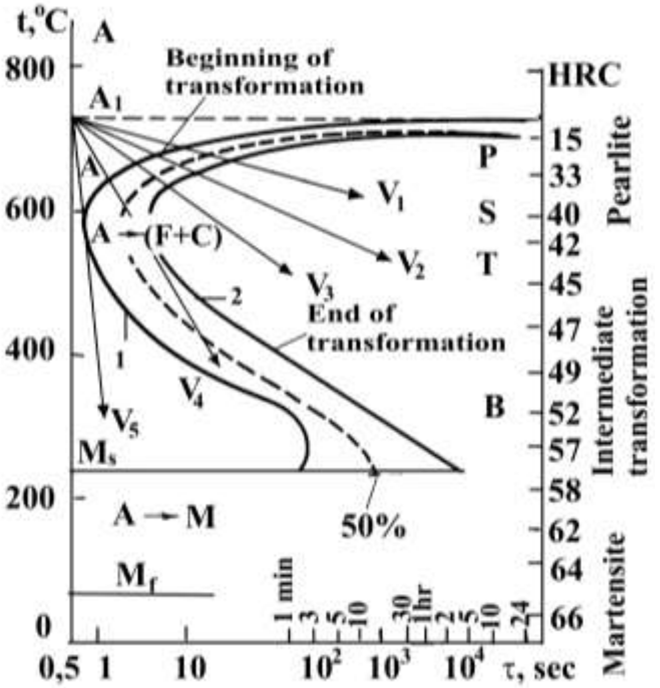


Fig. 1.37. TTT diagram for carbon steel

If austenite is supercooled with high speed (V_5), diffusion is completely suppressed and the formation of phase consisting of ferrite and cementite becomes impossible. This leads to the *diffusionless transformation* of austenite into the structure of hardened steel, called *martensite, which is a supersaturated interstitial solid solution of carbon in α-iron*. For this reason, the carbon content in the martensite in the general case is the same as in the supercooled austenite (ferrite contains no more than 0.02 %C).

An intermediate transformation takes place with intermediate cooling speed (V_4). This transformation has many features inherent in both the pearlite (diffusion) and the martensite (diffusionless) transformations. As a result of this supercooled austenite transformation, a structure is formed which consists of the a-phase (ferrite), oversaturated with carbon and particles of cementite of a typical needlelike shape. This kind of structure is called *bainite.*

1.6.2. Practice of Heat-Treatment of Steel

The term *heat-treatment* means a change in the structure and, consequently, in the properties of an alloy, accomplished by heating it to a definite temperature, holding at this temperature and subsequent cooling at a special rate.

There are several kinds of heat-treatment used in practice (*annealing, normalizing, hardening and tempering*) which differently affect the structure and properties of steel, and which are assigned to meet the requirements to the semifabricated materials (castings, forgings, rolled stock etc.) and finished articles.

The scheme of main kinds of heat-treatment is given below (Fig. 1.38).

First type annealing includes *homogenization*, *recrystallization* and *residual stress-relief annealing* (Fig. 1.39). A distinctive feature of this kind of annealing is that mentioned processes are performed regardless of whether or not phase transformations take place in the alloys during the treatment.

Homogenization (Diffusion Annealing) is applied to alloy steel ingots to reduce *dendrite* and *intracrystalline segregation*, which increase the susceptibility of steel to brittle failure, *anisotropy* of properties, etc. Dendritic segregation reduces the ductility and toughness of steel. Steel should be heated to a high temperature, equal to (0.8…0.9). T melting, K, or 1000…1200°C, in diffusion annealing because the diffusion processes required to equalize the composition throughout the steel are more fully completed at these temperatures.

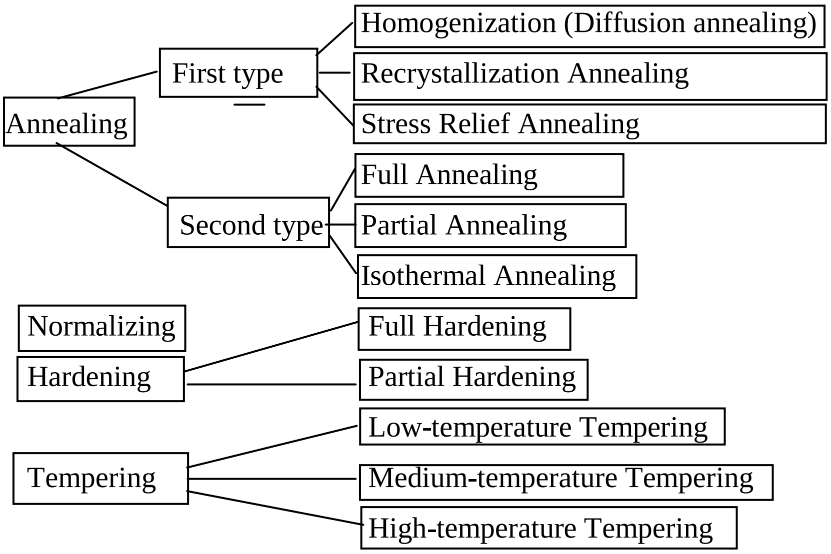


Fig. 1.38. Scheme of main kinds of heat-treatment

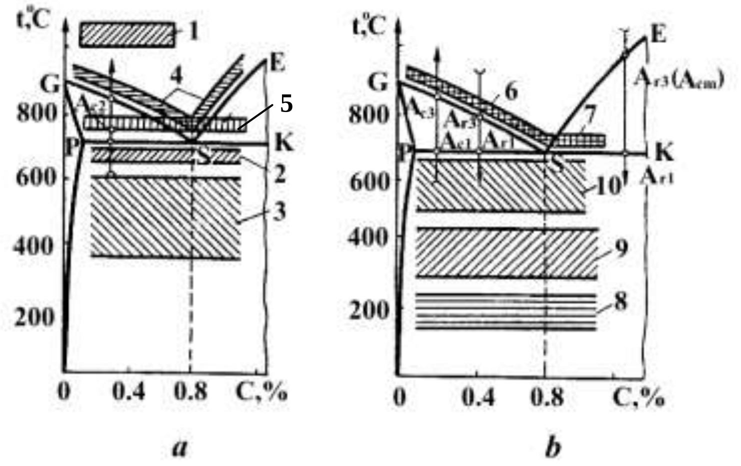


Fig. 1.39. Temperature regions for heating of steel for heat-treatments:
1- diffusion annealing; 2- recrystallization annealing; 3- stress-relief annealing; 4- full annealing;
5-partial annealing; 6 – full quenching; 7 – partial quenching; 8 – low – temperature tempering;
9 – medium - temperature tempering; 10 – high - temperature tempering

The total time required for diffusion annealing may reach from 50 to 100 hours and even more. A coarse grain is produced by diffusion annealing. After homogenization metal undergoes full annealing or normalizing to refine the grain and improve the properties.

Recrystallization annealing consists of heating of cold-worked steel to a temperature above that of recrystallization (0.4…0.6) $T_{melt.}$, K, holding at this temperature and subsequent cooling. The temperature of recrystallization annealing depends upon the composition of the steel and is usually in the range from 650 to 750°C. The heating time is from 0.5 to 1.5 hours. Recrystallization annealing removes (eliminates) *strain hardening*, decreases strength and increases plastic properties.

Stress Relief Annealing is applied to castings, weldments and work pieces, following machining and other operations, in which residual stresses have developed in previous processing as a result of non-uniform cooling, non-uniform plastic deformation, etc. The annealing temperature is usually from 350 to 600°C, the holding time is several hours. Residual stresses are also relieved in performing other kinds of heat-treatment, for example, recrystallization annealing, annealing with phase recrystallization (second type), tempering hardened steel, etc.

Second-type annealing (Phase recrystallization). Annealing of this type consists in heating steel to temperatures above point Ac_3 or Ac_1 (Fig. 1.39), holding at these temperatures and slow cooling. As a result of the phase transformations in the annealing process a state of practically equilibrium structure is reached.

Full annealing is the heating of steel to temperatures above point Ac_3 or Ac_m (line GSE) (Fig. 1.40).

Partial annealing is the heating of steel to temperatures above point Ac_1 (line PSK).

In isothermal annealing alloy steel is heated as for ordinary annealing and then is cooled relatively rapidly (by putting the steel into another furnace) to a temperature lower than Ac_1 (usually by 50 to 100°C) (Fig. 1.33). The steel is hold isothermally at this temperature during a certain time sufficient for complete austenite decomposition. This is followed by comparatively rapid cooling in air. The main advantage of isothermal annealing is that it reduces the time, required for the process, especially for alloy steel, which must be cooled very slowly to obtain the required reduction in hardness.

Normalizing of steel. Normalizing consists in heating hypoeutectoid steel to a temperature exceeding Ac_3 (lines GS) and hypereutectoid steel to one exceeding Acm (lines SE) by 50 or 60°C, holding and then cooling in air.

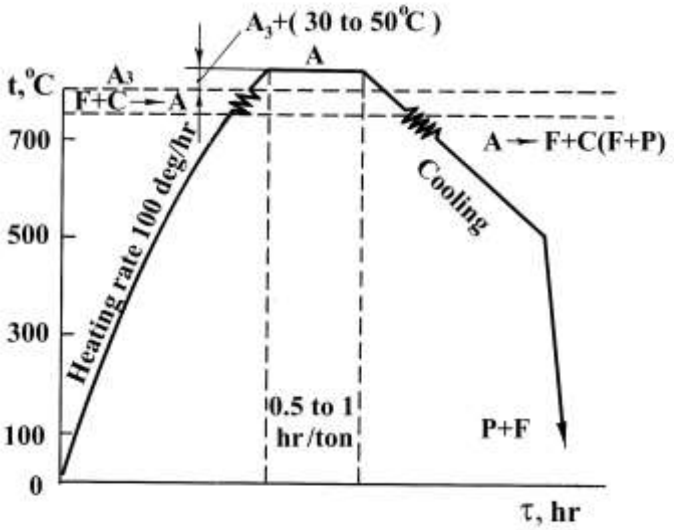


Fig. 40. Diagram of the full annealing of hypoeutectoid alloy steel

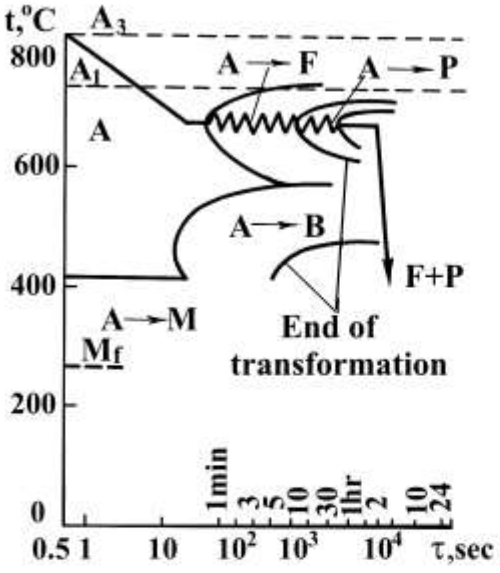


Fig. 1.41. TTT curve for the isothermal annealing of alloy steel

Normalizing causes recrystallization of the steel and, consequently, refines the coarse-grained structure obtained in casting or rolling.

More rapid cooling (in air), used in normalizing, causes the austenite to decompose at lower temperatures. This increases the dispersity of the ferrite-cementite aggregate and improves the mechanical properties of steel.

Hardening of steel. Hardening (quenching) consists in heating to a temperature from 30 to 70°C above point Ac_3 (line GS), or above point A_{cm} (line SK), holding until the phase transformations are completed and then cooling at a rate above the critical (Fig. 1.34). Such cooling is called *quenching* (carbon steels are usually quenched in water, alloy steels in oil or other media). The austenite is transformed into martensite during quenching.

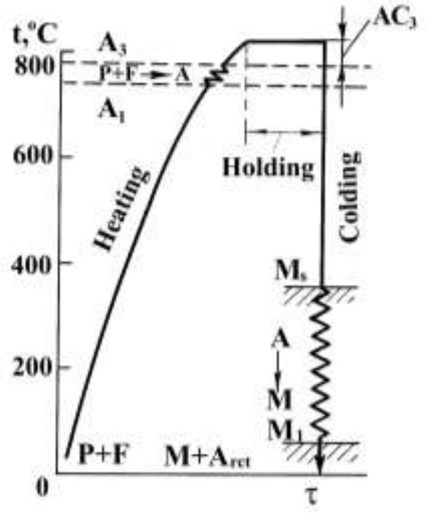


Fig. 1.42. Diagram of hardening of hypoeutectoid alloy steel

Hardening or quenching is not final heat-treatment. It is followed by tempering to reduce brittleness and stresses due to hardening and to obtain the required mechanical properties.

Tool steels are hardened and tempered mainly to increase their hardness, wear resistance and strength; structural steel, to increase its strength (σ_u, σ_y) and hardness and to obtain a sufficiently high ductility (δ and φ) and impact strength (KCU).

Tempering of Steel. Tempering consists in heating hardened steel to a temperature not above Ac_1, holding at given temperature (from 1.0 to 2.5 hours) and subsequent cooling at specified rate. Tempering is a final operation in heat-treatment. Steel acquires the required mechanical properties (Fig. 1.43) as a result of tempering. Besides, tempering completely or partly relieves the internal stresses developed in quenching. The higher the tempering temperature the more completely are the stresses relieved.

Low-temperature tempering is performed by heating to temperatures from 150 to 250°C. It decreases the internal stresses and transformers martensite, produced by quenching, into *tempered martensite.* Mechanical properties retain without any appreciable changes.

Medium-temperature tempering at 350 to 500°C provides improvement of elastic limit and toughness and some decrease in strength and hardness. The tempered steel has structure containing *temper troostite*.

High-temperature tempering is performed in the range from 500 to 680°C. The steel has a structure consisting of *temper sorbite*. This heat-treatment almost completely relieves internal stresses, increases the plasticity and toughness and reduces the strength and hardness.

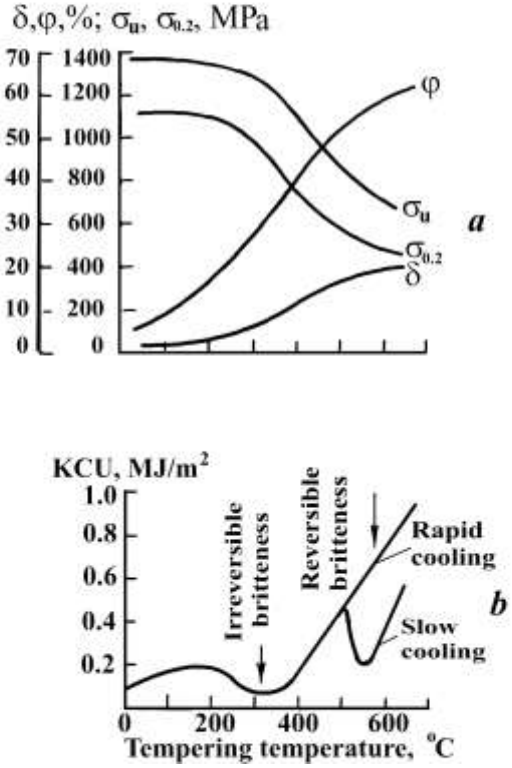


Fig. 1.43. Effect of tempering temperature on mechanical properties of steel containing 0.4 % C (a) and 0.4 % C, 1.5 % Cr and 3.0 % Ni (b)

1.7. Chemical Heat-Treatment (Casehardening) of Steel

Chemical heat-treatment, or *casehardening* as it is called in most cases, consists in adding some elements (for instance, carbon, nitrogen, aluminum, chromium and other) to the surface of steel by diffusion of this element from surrounding media at a high temperature.

Carburizing is the process of adding carbon to the surface layer of steel. Distinction is made between two main procedures: (1) *pack carburizing* and (2) *gas carburizing.*

In pack carburizing the saturating medium is a solid *carburizer,* usually activated *charcoal*, *semicoke* or *peat coke*. A widely used carburizer consists of 20 to 25 % $BaCO_3$, 3.5 % $CaCO_3$ and charcoal. Work pieces and carburizer are placed in metallic boxes, closed and heated to temperature from 910 to 930°C. Under such conditions:

$$BaCO_3 + C \rightarrow BaO + 2CO, \qquad (1.23)$$

$$2CO \rightarrow 2CO_2 + C_{at} \qquad (1.24)$$

The carbon C_{at} evolved in this reaction is in the atomic state. It diffuses into the austenite.

Gas carburizing is accomplished by heating the work in a medium of gases containing carbon:

$$CH_4 \rightarrow 2H_2 + C_{at}, \qquad (1.25)$$

Gas carburizing time ranges from 6 to 12 hours to obtain a case from 0.7 to 1.5 mm in thickness.

The final properties of carburized works are obtained as a result of hardening and low-temperature tempering. Idea of carburizing is to obtain surface layer, which has high strength, hardness and wear resistance.

Nitriding is the process of adding nitrogen to the surface of steel by heating it in ammonia gas at 480…700°C:

$$2NH_3 \rightarrow 6H + 2N_{at}, \qquad (1.26)$$

The atomic nitrogen thus formed diffuses into iron and forms solid solution with α-phase and chemical compounds (Fe_4N, Fe_2N, CrN, MoN, A1N) and therefore increases hardness, strength, wear resistance and resistance to corrosion.

Cyaniding and Carbonitriding of steel are processes in which both carbon and nitrogen are added to the surface layer of steel. *Cyaniding* consists in heating the steel in a liquid medium; if the process is performed in gaseous atmosphere, it is called *carbonitriding.*

Diffusion coating. The impregnation of the surface of steel with Al, Cr, Si, B and other elements is called *diffusion coating*, or *metallic cementation*. Components whose surface is coated in this manner acquire various valuable properties, such as high heat resistance, corrosion resistance, increased wear resistance and hardness.

The diffusion coating of steel with various metals and silicon can be done at 900…1050°C by:

- embedding the components in the corresponding mixtures (usually ferroalloys and 0.5 to 5 % NH_4Cl);
- immersing them in the molten metal if the diffusing element has a low melting point (zinc, aluminum);
- impregnation from a gaseous medium ($A1C1_3$, $CrCl_2$, $SiCl_4$, etc.).

1.8. Classification and Identification of Iron-Carbon Alloys

1.8.1. Steels

All the elements, with the exception of carbon, nitrogen, hydrogen and, to some extent, boron form substitutional solid solution with iron. Dissolving in the iron, they change the temperature intervals in which α- and γ-iron exits. With respect to their effects on the temperature intervals in which the allotropic forms of iron exit, alloying elements can be classified into two groups.

Elements of the first group include nickel and manganese. They lower point A_3 and raise point A_4. As a result the range of the a-phase is narrowed. As shown in Fig. 1.44a, alloys, having an alloying element (Ni or Mn) exceeding certain limit, undergo no phase transformations (α↔γ) when cooled down to room temperature. Their structure at room temperature consists of γ-phase and they are called *austenitic alloys*.

Alloys which partly undergo an α↔γ transformation are called *semiaustenitic alloys*.

Elements of the second group (Cr, W, Mo, V, Si, Al, etc.) narrow and completely enclose in a loop the γ-phase region (Fig. 1.44b). By this at certain alloying element content the alloys consist at all temperatures of the solid solution of the alloying element in the α-iron. These are called *ferritic alloys,* and alloys with only a partial α→γ transformation are said to be *semiferritic*.

With respect to their relation to carbon, all alloying elements can be classified into three groups:

- *graphitizing elements*: silicon, nickel, copper and aluminum (these elements are in the solid solution);
- *neutral elements*: e.g. cobalt, which neither forms carbides nor causes graphitization;
- *carbide-forming elements,* which can be arranged in the following order of their increasing affinity for carbon and the stability of their carbide phases:

$$\mathrm{Fe} \rightarrow \mathrm{Mn} \rightarrow \mathrm{Cr} \rightarrow \mathrm{Mo} \rightarrow \mathrm{W} \rightarrow \mathrm{Nb} \rightarrow \mathrm{V} \rightarrow \mathrm{Zr} \rightarrow \mathrm{Ti}$$

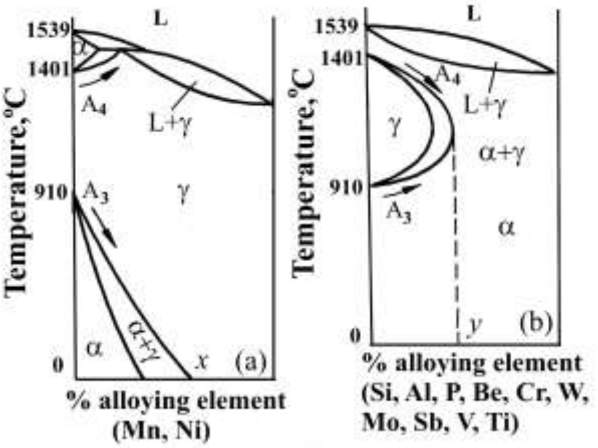


Fig. 1.44. Schematic binary equilibrium diagrams of iron-alloying element (Ni, Mn) (a) and iron-alloying element (Cr, W, Mo, V) (b) systems

If the Mn, Cr, W and V content is small in steel, they dissolve in cementite, in which they substitute iron atoms. The composition of the cementite can be represented in this case by the formula $(Fe, M)_3 C$, where M denotes the alloying element.

Special carbides $(Fe, Cr)_7 C_3$, $(Cr, Fe)_{23}C_6$, $Fe_2 Mo_2C$, $Fe_2 W_2C$ are formed in the steel when alloying element content is sufficient.

All steels can be classified according to:

- their structure;
- their purpose;
- their quality;
- their deoxidization and etc.

According to their structure under equilibrium conditions, steel can be classified as (Fig. 1.45):

- *hypoeutectoid* (F+P);
- *eutectoid* (P);
- *hypereutectoid* (P + Carbides);
- *ferritic* (F);
- *semiferritic* (F + P);
- *austenitic* (A);
- *semiaustenitic* (A+F);
- *ledeburitic* (P+C).

According to their purpose steels can be classified as:

- *machine (constructional) steels;*
- *boiler steels*;
- *die steels*;
- *high speed (rapid-tool, red-hard) steels;*
- *electrical steels*;
- *heat-resistance steels*;
- *stainless (rustless, corrosion-resistant) steels;*
- *welding steels*, etc.

According to their deoxidation steels can be classified as:

- *rimming steel*s (deoxidized by Mn only);
- *semikilled steels* (deoxidized by Mn and Si);
- *killed steel* (deoxidized by Mn, Si and Al).

According to their quality, or method of production steels can be classified (in the former USSR) as:

- *ordinary quality steels* (S≤0.05 %, P≤0.06 %);
- *quality steels* (S≤0.035 % P≤0.035 %);
- *high-quality steels* (S≤0.025 %; P≤0.025 %);
- *super-grade steels* (S≤ 0.015 %; P≤0.015 %).

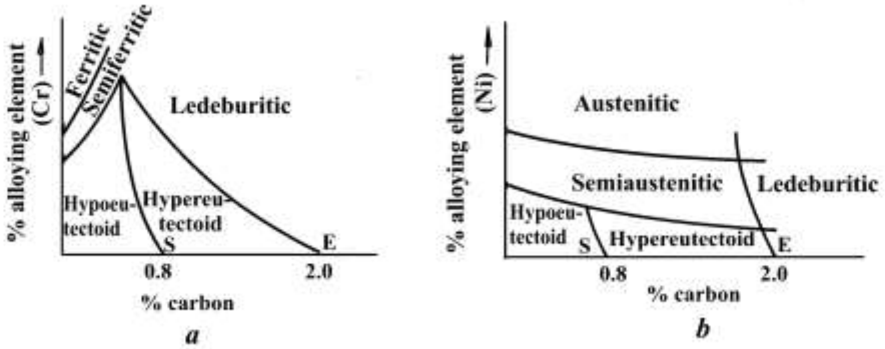


Fig. 1.45. Structural class diagrams of steel

Identification of Steels in Ukraine and Community of Independent States. *Ordinary quality steels* (common steels), according of their purpose and guaranteed properties, are classified into three groups: А, Б and В.

Group A: Ст0, Ст1кп, Ст1пс, Ст1сп, Ст2...Ст6сп,

where Ст is means steel;

0...6 is conventional steel grade number;

кп is riming, пс is semikilled, сп is killed steel.

Group A consists of steels that are supplied with their mechanical properties guaranteed, but not their chemical composition. The higher the number, the more the carbon content, the higher the strength and the lower the ductility.

The group Б comprises steels which are supplied with their chemical composition guarantied: Б Ст0, Б Ст 1кп...Б Ст6.

The group В consists of steels of improved quality which are supplied with their mechanical properties and chemical composition guarantied. The available grades are В Ст2, В Ст3, В Ст4, В Ст 5.

Quality engineering carbon steels are identified by the numbers 08, 10, 15, 20... 85, which indicate the average content of the carbon in hundredths of one per cent. But У7, У8...У13 denote tool carbon steels, where the numbers stand for the average carbon content in tenths of 1 %.

Alloy steels are to be identified by numbers, letters (conventional symbols of the chemical elements) and certain letters at the end, for example, 15Х, 45ХА, 12ХН3А, 20Х2Н14А, etc. The two-digit number at the beginning of the designation indicates average carbon content in hundredths of one per cent; the chemical symbols indicate the alloying elements. The number following each alloying element symbol indicates the approximate content of the element in whole percent. The absence of the number following the symbol indicates that the content of the particular element is about one percent. The letter at the end of designation indicates the quality of steel:

- the absence of a letter -quality steel;
- letter А - high-quality steel;
- letter Ш - super-quality steel;

For example: 12ХН3А is high quality steel, containing 0.12 %C; 1 %Cr, 3 %Ni, 06Х18Н9-Ш is super-quality steel, containing 0.06 %, 18 %Cr, 9 %Ni.

In Ukrainian and Russian standards the alloying elements are indicated by single capital Russian letters, representing the following elements:

A-nitrogen (in the middle of the designation), E-niobium, B-tungsten, Г-manganese, D-copper, E-selenium, K-cobalt, H-nickel, M-molybdenum, П-phosphorus, P- boron, T-titanium, Ф-vanadium, X-chromium, Ц-zirconium, Ч- rare earths, Ю-aluminum.

1.8.2. Cast Irons

Alloys of iron and carbon in which the carbon content exceeds 2.14 % are called cast irons. Carbon in cast iron may be in the form of either cementite (according to the metastable diagram Fe-Fe_3C), or graphite (according to the stable diagram Fe-C), or in both forms.

Cast iron in which all carbon is in the form of cementite (Fe_3C) is called *white cast iron*.

Cast iron in which part of the carbon (more than 0,8 %) is in the form of cementite is called *mottled cast iron*.

Cast iron in which not more than 0.8 %C is combined in Fe_3C is called *graphited cast iron*.

Graphited cast iron may be *pearlitic*, *pearlitic-ferritic* and *ferritic*.

The degree of graphitization depends on cast iron composition and the rate of crystallization and cooling (Fig. 1.46). Carbon and silicon promote the graphitization; Mn, Cr, Ti, V, Nb and other combine with carbon in carbides and prevent the graphitization.

With respect to the graphite form cast irons can be classified into the following groups:

- *grey cast iron* which has lamellar graphite inclusions (see Fig.1.32 g);
- *high-strength cast iron* with graphite as a spheroidal inclusions (see Fig. 1.32 h);
- *malleable cast iron*, which has flaky nodules of graphite (temper carbon). Grey cast iron normally has composition: 2.2…3.8 %C, 1.0…3.0%Si, 0.5…0.8 %Mn, up to 0.2 %P, up to 0.15 %S.

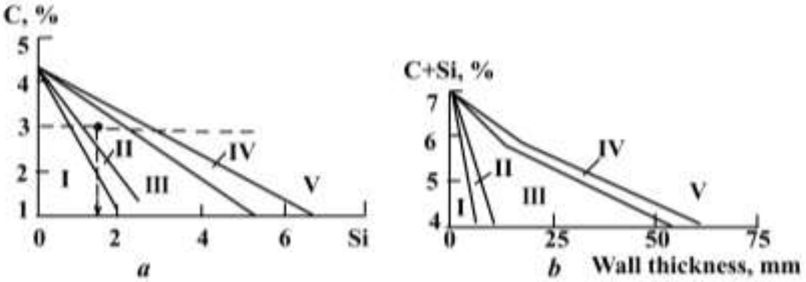


Fig. 1.46. Structural diagram of cast iron with a wall thickness of about 50 mm and various carbon and silicon content (a) and at different wall thickness (b): I-white cast iron; II- mottled cast iron; III-pearlitic grey cast iron; IV-ferritic-pearlitic grey cast iron; V-ferritic grey cast iron

Average mechanical properties of grey cast irons:

pearlitic cast iron	*ferritic cast iron*
$\sigma_u = 300 MPa$	$\sigma_u = 100 MPa$
$HB = 2300...2900\, MPa$	$HB = 1200...2050\, MPa$
δ and $\varphi \approx 0$	δ and $\varphi \approx 0.5\%$

The less amount of C and Si and the more Mn content the higher strength and hardness of cast iron.

Grey cast irons are graded as:

$$\underbrace{\text{СЧ10}, \text{СЧ15}}_{\substack{\text{ferritic and}\\ \text{ferritic-pearliric}}}, \underbrace{\underbrace{\text{СЧ18}, \text{СЧ20}, \text{СЧ25}, \text{СЧ30}, \text{СЧ35}, \text{СЧ40}}_{\text{pearlitic}}, \text{СЧ45}}_{\text{inoculated}}$$

The grade means: СЧ grey-cast iron: (10…45) - σ_u=100…450 MPa.

Grey cast iron is produced by melting and pouring the metals of specified composition into moulds. During solidification the lamellar graphite precipitates.

Inoculated cast iron (СЧ30...СЧ45) is obtained by special additions, called *inoculants* (*ferro-silicon* with 75 % Si, *calcium-silicon,* etc), in amount from 0.3 to 0.8 percent to the liquid cast iron just before pouring the moulds. Inoculation is resorted to obtain iron castings of various wall thicknesses with pearlite metallic matrix and the graphite lamellar of small sizes.

White and chilled cast iron, owing to the presence of cementite, are extremely hard (HB 4000…5000 MPa), brittle and practically unmachinable. The high hardness of the casting surface provides good resistance against wear, especially abrasive wear. Thus, chilled cast iron is used to make rolls of sheet mills, wheels, balls of ball mills, etc. For such components, cast iron with low silicon content, lending itself well to chilling, is used. Its approximate composition is from 2.8 to 3.6 %C, 0.5…0.8 %Si, 0.4…0.6 %Mn.

The alloyed with Cr, Mn, Ti, etc white cast irons are also used. Their identification is similar to alloy steel: 300X, 250X2, 300X28H2, etc.

High-strength cast iron is obtained by making small ladle additions of certain alkali or alkali-earth metals (Mg, Ce, Y, Ca) to the liquid metal. In the most cases, the residual magnesium content amounts to 0.03…0.07 %. With respect to other constituents, high-strength cast iron does not differ from ordinary grey iron. Magnesium and other elements cause the graphite to precipitate in the process of solidification of the cast iron as spheroidal inclusions instead of lamellar. Spheroidal graphite, having minimum surface for a given volume, weakens the metallic matrix to a lesser extent than lamellar graphite. These cast irons have higher mechanical properties than ordinary grades of grey cast iron: σ_u=(400…1000) MPa, $\delta \approx$(1.5…10) %, HB=(1800…2200)MPa.

High-strength cast irons can be identified by the letters ВЧ followed by a number. The number indicates the average tensile strength in MPa$\cdot 10^{-1}$: ВЧ 60, ВЧ 70, ВЧ 100.

Malleable cast iron is obtained by prolonged heating of white-iron castings at high temperatures (annealing).This leads to the formation of rounded graphite nodules. Compared with the lamellars, such nodules, called *temper carbon*, reduce the strength and ductility of the metallic matrix in the cast iron structure considerably less. The metallic matrix of malleable iron is commonly ferrite (*ferritic malleable cast iron*), or less frequently pearlite (*pearlitic malleable iron*). Ferritic malleable iron has the higher ductility and employed in the engineering industries.

The thickness of the cross sections of the casting should not exceed 50 mm to obtain white iron and to prevent the precipitation of lamellar graphite during crystallization.

The malleablizing procedure to obtain pearlitic and ferritic malleable irons is illustrated in Fig. 1.47.

Malleable iron can be identified by letters КЧ followed by two numbers. The first number indicates the tensile strength in MPa-10^{-1} and the second is the percent elongation: КЧ 35-10, КЧ 60-3, КЧ 35-10, КЧ 60-3, etc.

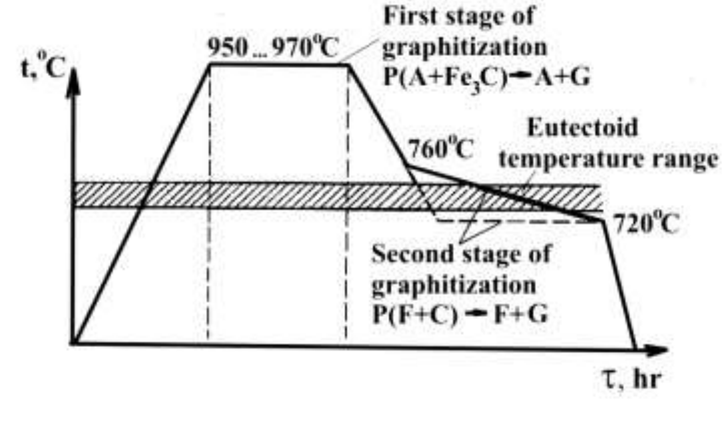


Fig. 1.47. Temperature vs time diagram of the malleablization procedure to obtain malleable cast iron

1.9. Non-ferrous Metals

1.9.1. Aluminum and Its Alloys

Typical features of aluminum are its low density (2.7 g/cm^3), low melting point (660°C) and high electrical and thermal conductivity, high corrosion resistance due to the film Al_2O_3 on its surface.

On the basis of its purity, distinctions are made between aluminum of extra-high purity grade A999 (99.999 % Al), high purity: grades A995, A99, A97, A95 (99.95 %A1) and commercial purity: grades A85, A8, A7, A6, A5, AO (99.0 % Al).

The mechanical properties of high-purity annealed aluminum are: σ_t=50 MPa, $\sigma_{0.2}$ =15MPa, $\delta\approx$50%.

Commercial Al is used for the elements of structures and for components not subjected to loads, under conditions when high ductility, good weldability, corrosion resistance and high thermal and electrical conductivity are required. Aluminum is used for wires in electrical lines and equipment (its electrical conductivity is 65 % of the electrical conductivity of copper), for cables, electrical conductors, for various pipelines, milk tanks, doors, panels, etc.

Al-Cu, Al-Si, Al-Mg, Al-Cu-Mg, Al-Cu-Mg-Si, Al-Mg-Si and Al-Zn-Mg-Cu are most extensively used alloys.

All alloys of aluminum can be divided into 3 groups:

- *wrought alloys*, intended for the manufacture of sheets, plates, pipes, bars, rolled shapes, etc.;
- *casting alloys*, intended for foundry castings;
- *alloys*, obtained by *powder metallurgy techniques*: SAP-sintered aluminum powders ($Al+Al_2O_3$) and SAA- sintered aluminum alloys.

Typical wrought alloys are *duralumins* Д1 and Д16 (4…5 % Cu, 1…1.5 % Mg, ~ 0.5% Mn) which have σ_t=400…500 MPa, $\sigma_{0.2}$=250…380 MPa, δ=10…15% and are widely used for manufacture of sheets for airplanes, rockets, etc.

Besides duralumins, high-strength (σ_t=500…520 MPa), forging and heat-resistance (for components operating at 250…350°C) aluminum alloys are used.

Aluminum casting alloys are intended for foundry castings. The best known are the Al-Si alloys, called *silumins*, eutectic alloys containing from 10 to 13 % Si. Due to eutectic these alloys have good foundry properties: low melting point (~600°C), high fluidity, small shrinkage, etc.

Cast alloys are identified: АЛ1, АЛ2...АЛ21, where, A-aluminum Л-cast, 1...21-number of grades.

Alloys based on $Al-Al_2O_3$ composition have the designation SAP (sintered aluminum powder) and consist of aluminum and disperse flakes of $A1_2O_3$ (6…22%). Compared with other Al alloys the SAP materials have high corrosion resistance and heat resistance when heated for a long time up to 500°C, or when subjected to a short-term load at 1000°C.

Sintered aluminum alloys (SAA) contain a great number of alloying elements (in powder) and have special properties (low coefficient of linear expansion, etc.)

SAP and SAA are obtained by *cold briquetting* of powder mixtures, *vacuum degassing* and *sintering* under pressure.

1.9.2. Copper and Copper-base Alloys

Copper is a red metal with a rose-colored fracture. The melting point is 1083°C, the density is 8.94 g/cm^3. It has the highest electrical and thermal conductivity among all metals, except silver and gold.

With respect to purity copper is available in the following grades: MOO (99.99% Cu), MO (99.95% Cu), Ml (99.9% Cu), M2 (99.7% Cu), M3 (99.5% Cu), M4 (99.0% Cu). Impurities found in copper have a strong effect on its properties.

Copper has good resistance to corrosion under ordinary atmospheric conditions in fresh and sea water and aggressive media, but can't withstand sulphurous gases and ammonia. Mechanical properties of copper are given in table 1.2.

Table 1.2 - Mechanical Properties of Copper.

Condition	σ_t, MPa	$\sigma_{0.2}$ MPa	δ,%
as-cast	160	35	25
hot-worked	240	95	45
cold-worked	450	250	3

Copper is used in electrical, electronics and electrovacuum engineering (mainly for conductors).

Distinction is made between two main grades of copper alloys: (1) *brasses*, alloys of copper with zinc and (2) *bronzes*, alloys of copper with other elements, among which there may be zinc, but only in a combination with other elements. Copper alloys have high mechanical and processing properties and good resistance to wear and corrosion.

The alloys are identified by the letters: Л for brass and Бр for bronze. This symbols, Л or Бр, are followed by the symbols of other components. The numbers following the symbols are separated by hyphens, in the same order as the components are given. In the grade symbols for brasses the first number is copper content and, the remainder points to zinc content. In those for bronzes, copper content is not given, but it is remainder.

Thus, for example, grade Л Ж Мц 59-1-1 is the brass, containing 59 % Cu, 1 % Fe, 1 % Mn, and the remainder is zinc. Grade Бр ОС 6.5-0.15 is the bzonze containing 6.5 % Sn, 0.15 % Pb and the remainder is copper.

In the Ukrainian and Russian Standards the alloying elements are denoted by the letters which represent: O-tin, Ц-zinc, Мц-manganese, Ж-iron, Ф-phosphorus, Б-beryllium, X-chromium, H-nickel, C-lead, Al-aluminum, K-silicon.

Distinction is made between *wrought* and *casting* brasses and bronzes.

1.9.3. Magnesium and Its Alloys

Magnesium is light-grey metal; its characteristic features are low density (1,74 g/cm^3) and melting point (651°C). Magnesium has adequate corrosion resistance in the atmosphere, but only poor resistance in fresh and sea water. Magnesium is combustible in air. Pure magnesium is used in pyrotechnics and the chemical industry.

The most widely used alloys are those with Al (up to 10 %), Zn (up to 6 %), Mn (up to 2.5 %) and with Zr (up to 1.5 %).

Magnesium casting alloys МЛ1...МЛ12 and wrought alloys (MA1...MA14) owing to their high strength to density ratio (σ_t/γ) have found wide application in aircraft construction, in rocket engineering, in electrical and radio engineering, in automobile, textile industry, etc.

1.9.4. Titanium and Titanium-base Alloys

Titanium is a silvery-white metal. Its melting point is 1665±5°C, density is 4.5 g/cm^3. Three grades of commercial titanium are available (in Ukraine): BT1-00 (99.53 % Ti), BT 1-0 (99.48) and BT 1 (99.44 % Ti). Pure Ti has σ_t=250 MPa, δ=70 %.

A stable oxide film readily forms on the surface of Ti. As a result, it has high corrosion resistance in fresh and sea water and in certain acids. It is also stable against cavitation corrosion and corrosion under voltage.

Ti is alloyed with Al, Mo, V, Mn, Cr, Sn, Fe, Zr, Nb, Si. Titanium alloys have a high strength-to-density ratio (σ_t/γ), higher than that of steel. They are widely used in aviation and rocket engineering, in equipment engineering, in shipbuilding, etc. Ti-alloys have high ductility at low temperatures. This makes them suitable for cryogenics engineering.

1.9.5. Babbits

Babbits are antifriction alloys based on either tin or lead (table 1.3). These alloys are used for lining (babbiting) sleeve bearings. Distinguishing features of babbits are their low melting point (350…450°C), capacity for running-in and the absence of a tendency to seize with steel. An alloy with high antifriction properties has heterogeneous structure consisting of a soft and ductile matrix (Sn or Pb) with hard inclusions.

Table 1.3 - Chemical Compositions of Babbits

Grades	Composition, %			
	Sn	Cu	Sb	Pb
B89	89	3.5	Rest	-
B83	83	6.5	Rest	-
B16	16	2.5	16	Rest

The soft matrix of babbits B83 and B89 is the solid solution of antimony and copper in tin. The hard particles in the structure are crystals SnSb, Cu_6Sn_5, Cu_3Sn.

2 METALLURGY

2.1. Materials Used in Metallurgy

Metallurgy is a science and engineering which studies the methods used to obtain metals in free condition from compounds that occur in nature.

Only some metals are mined in the native state. Among these are gold, silver, platinum, mercury, tin and, partly, copper. Most of the metals, however, are found in the earth in the form of oxides, silicates, sulphides, carbonates, etc. Native metals and metal compounds are associated with considerable amount of foreign materials, such as rock, gravel, sand, clay and other impurities that require removal.

Metal ore is its chemical compounds plus foreign impurities. Ore may be rich or poor. In the last case it must be *dressed (concentrated)* to remove undesirable impurities. When ore may be mined and converted in metal with commercial profit it is called *pay or able ore.* Ores of different metals are put through various dressing processes to obtain them with small quantity of impurities, i.e. to obtain almost pure metal compound and then to obtain metal in the free condition.

To convert ore in metal the high temperature is usually required. To obtain high temperature we use fuel, which may be:

- *gaseous* (native gas, blast-furnace gas);
- *liquid* (black mineral oil, or mazut);
- *solid* (anthracite, coke, charcoal).

Electric energy is also used in metallurgy to receive heat.

Some impurities, in the main oxides, find their way into a furnace together with ores. As a rule, oxides have high melting point: $A1_2O_3$-2040°C, CaO-2570°C, MgO-2800°C, etc. Besides that, an *ash* is formed on account of fuel burning.

To remove these impurities and ashes from the furnace *fluxes* are used. Fluxes render the impurities fusible at operating temperatures, combine with them and carry them off into *slag*.

All metallurgical processes are accompanied by slag formation, representing oxides, suphides, nitrides, and other chemical compounds. Slags are formed on the account of added fluxes as well as damage of furnace lining. The slag importance in metallurgy is very high: such important reactions as oxidation and deoxidation are possible because of slags, sulphur and phosphorous are assimilated and carried away with slag. Slags protect metal against gas saturation, facilitate heat accumulation in metal. The principal components of ferrous metallurgy slags are: CaO, SiO_2, P_2O_5, Al_2O_3, FeO, MnO, CaS, MnS, etc. The main slag characteric is its *basicity* mostly determined as CaO/SiO_2.

Metallurgical furnaces are operated at high temperatures. To prevent damage their walls are covered with *refractory* or *fireproof* materials. Refractory are materials that can stand at high temperatures from 1580 to 2400°C and more without considerable mechanical damage and withstand chemical attack of molten metal and slag.

According to chemical composition refractories are divided into:

acid materials:

$$\mathrm{CaO/SiO_2}\langle 1 \begin{cases} \textit{dinas brick } (93...95\%\ \mathrm{SiO_2}, \text{max. working temperature } 1700^\circ\mathrm{C}\textit{)}, \\ \textit{silica sand } (95...98\%\ \mathrm{SiO_2}, \sim 1700^\circ\mathrm{C}) \end{cases}$$

basic materials:

$$\mathrm{CaO/SiO_2}\rangle 1 \begin{cases} \textit{magnesite } (90...95\ \%\ \mathrm{MgO}, 2000 - 2400^\circ\mathrm{C}) \\ \textit{dolomite } (\mathrm{MgOCaO}, 1800...1900^\circ\mathrm{C}) \\ \textit{chromomagnesite } (\mathrm{MgO} + \mathrm{Cr_2O_3}, \sim 2000^\circ\mathrm{C}) \end{cases}$$

inert refractory:

$$CaO/SiO_2 \approx 1 \begin{cases} \textit{chamotte}\ \text{(brick made of fireproof clay : 55 \%}SiO_2, \\ \sim 45\ \%\ A1_2O_3,)1580...1758°C \\ \textit{graphite}\ \text{(powder and bricks) (}\sim 90\ \%C, 1750...2000°C), \\ \textit{carbon fireproof materials}\ \text{(graphite + fire - clay,} > 2000°C) \end{cases}$$

Correspondingly, slags may be acid, neutral or basic. Only acid slag may be built up in a furnace with acid lining and, on the contrary, in the basic furnace basic slag must be formed, because of acid slag reaction with basic lining, or basic slag reaction with acid lining with formation of easy fusible compound: $SiO_2+CaO=CaSiO_3$ and with destruction of lining.

2.2. Blast-Furnace Process

Blast-furnace process is used in ferrous metallurgy for cast iron production. The main product of ferrous metallurgy is steel, but two-stage process of steel production is now predominantly used in the metallurgy: Fe-ore→cast iron→steel.

Cast iron (iron) is a general term applied to iron-carbon alloys, containing more than 2.14 %C.

So iron is obtained in blast furnace by reducing from ores by carbon. The following raw materials, named *charge*, are commonly used in the blast furnace process: iron ore, fuel, flux.

Four chief types of iron ore are used:

- *hematite* Fe_2O_3;
- *limonite* $2Fe_2O_3 \cdot 3H_2O$;
- *magnetite* Fe_3O_4;
- *siderite* $FeCO_3$;

After mining the iron ore is crushed to powder, dressed from impurities and sintered in pieces. Such sintered ore is called *agglomerate*. During agglomeration main part of sulphur is removed from the ore and limestone $CaCO_3$ is added to the ore. Hence, we receive and use in blast furnace so-called *fluxed ore*.

The main fuel in blast furnace is *coke*, which is produced of coking coal by preheating it at temperature ~ 1000°C without air during 14…16 hours. Coke has the chemical composition: 80…88 %C, 8…12 % ash, 2…5 % moisture, 0.5…1.8%S, 0.02…0.2 %P. Part of coke may be replaced by *natural gas* (CH_4), or *black mineral oil*, or *powder coal*, or blast furnace gas.

Limestone $CaCO_3$ is used as a flux in the blast furnace.

The modern blast furnace constitutes the largest and most complicated type of metallurgical plant. Such a plant is capable to produce more than ten thousand tons of iron a day and night (24 hours). It works continuously from 7 to 10 years.

The blast furnace is like a vertical pipe, lining by refractory inside, in which fluxed ore and coke, named a charge, are charged from the top and preheated air (1100°C) is blown into the furnace below. Iron and slag are tapped from the furnace periodically through a *tap hole* and a *slag hole*.

The blast furnace derived its name from the fact that air to support combustion must be blown into it under pressure, because of the resistance offered by the column of material within the shaft to passage of the combustion gases. A typical blast furnace is shown in Fig. 2.1.

Chemical reactions between carbon, oxygen, iron and its oxides occur within the blast-furnace by combustion of coke and temperature equal from 1500 to 2000°C.

Nearby tuyeres carbon of coke combines with oxygen of air with evolution of heat:

$$2C + O_2 \rightarrow 2CO + Q \qquad (2.1)$$

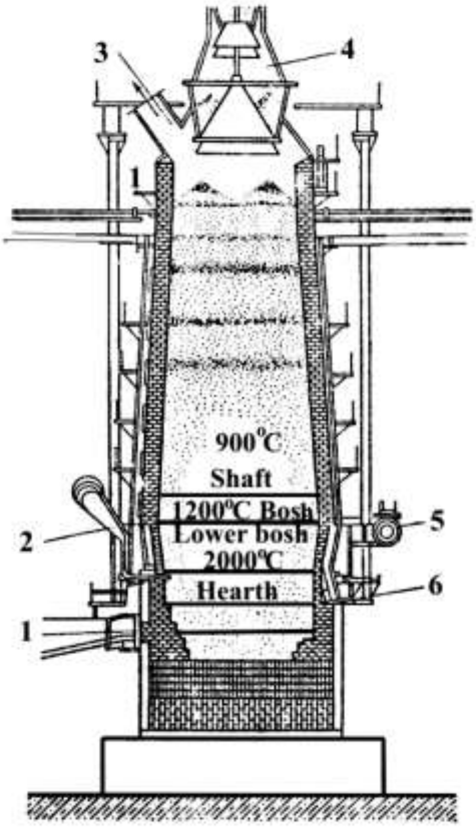


Fig. 2.1. Blast furnace: 1 – iron taphole; 2 – tuyeres; 3 – exhaust pipes; 4 – top; 5 – air blast pipe; 6 – slag hole

Reduction of iron is performed in the first turn by CO in succession from higher to lower oxydes and to pure iron ($Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$):

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2 \qquad (2.2)$$

$$Fe_3O_4 + CO \rightarrow 3FeO + CO_2 \qquad (2.3)$$

$$FeO + CO \rightarrow Fe + CO_2 \qquad (2.4)$$

Reduction by CO is called *indirect* one, reduction by C and H_2 is called *direct* one:

$$3Fe_2O_3 + C \rightarrow 2Fe_3O_4 + CO\text{...and so on} \qquad (2.5)$$

$$3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O\text{...and so on} \qquad (2.6)$$

At temperature above 1000°C the *carburizing of iron* takes place:

$$3Fe + 2CO = Fe_3C + CO_2 \qquad (2.7)$$

$$3Fe + C = Fe_3C \qquad (2.8)$$

Hence, because of the carburizing we have cast iron with approximately 4 % of carbon instead of pure iron.

The reduction of Mn, Si, P also takes place, and S from coke dissolves in molten cast iron. As a result, cast iron has the following chemical composition: 4.0…4.4 %C, 0.6…3.0 %Si, 0.3…1.0 %Mn, 0.15…0.30 %P, 0.03…0.07 %S.

The blast-furnace produces:

- *conversion iron*, or *steelmaking pig iron*, or *pig iron* used for steel-making practice (contains ~l %Si);
- *foundry iron*, poured in pigs and used for remelting in foundry shops (contains ~3 %Si);

- *ferromanganese* - alloys used for deoxidation and for alloying of steel. FeMn has average chemical composition: 7 % C, 70 % Mn, the rest-Fe;
- *ferrosilicon* - alloy used for deoxidation and alloying of steel: 2%C, 13%Si, the rest-Fe;
- *slag* (CaO, MgO, $A1_2O_3$, SiO_2, FeO, MnO, etc.) used in building industry;
- *blast-furnace gas* (14…18 % CO_2, 22…28 % CO, 2…6 %H_2, 50…55% N_2) has low calorific value (3350…4000 kJ/m^3).

2.3. Steel production

Steel contains lower amount of carbon and impurities than steelmaking pig iron (table 2.1).

Table 2.1 - Chemical Compositions of Steel and Cast Iron

Alloy	C,%	Mn,%	Si, %	S,%	P,%
Steel	0.05…1.3	0.4…0.8	0.2…0.4	to 0.05	to 0.05
Pig iron	4…4.2	0.75…1.25	0.75…1.75	to 0.3	to 0.07

To produce steel, utilizing pig iron, it is necessary to decrease content of carbon, other elements and impurities.

There are three main steel production methods in metallurgy: (l)oxygen-converter process, (2) open-hearth process and (3) electric-furnace melting.

2.3.1. Oxygen-Converter Process

Oxygen converter is pear-like tank made of steel sheets and having a *refractory lining* inside (Fig. 2.2).

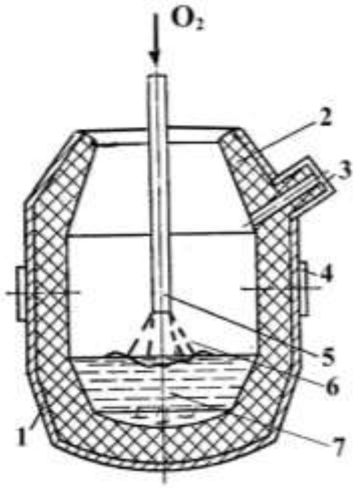


Fig. 2.2. Oxygen converter: 1-steel construction; 2-refractory lining; 3-hole for steel tapping; 4-tilting device; 5-water-cooled copper lance; 6 – oxygen jet; 7 – liquid metal

The liquid pig iron (conversion iron) is poured into converter and by water-cooled *lance* oxygen less than 10…12 atmospheres pressure is given on metal surface. When the blowing is started, the slagforming components (*lime* CaO, iron ore Fe_2O_3, etc.) are introduced into the converter.

Oxygen penetrates into liquid metal and oxidizes iron according to the law of mass:

$$[Fe]+\{1/2O_2\}=[FeO], \qquad (2.9)$$

where component is: in metal [], in slag (), in gas atmosphere {}.

Iron protoxide reacts with C, Si, Mn, oxidizes them and their oxides pass from metal into slag and atmosphere:

$$\text{Indirect oxidation}\begin{cases}[FeO]+[C]\rightarrow[Fe]+\{CO\}; & (2.10)\\ [FeO]+[Si]\rightarrow[Fe]+(SiO_2); & (2.11)\\ [FeO]+[Mn]\rightarrow[Fe]+(MnO); & (2.12)\end{cases}$$

Direct oxidation by O_2 also proceeds:

$$[Si]+\{O_2\}\rightarrow(SiO_2) \quad (2.13)$$

$$2[Mn]+\{O_2\}\rightarrow2(MnO) \quad (2.14)$$

$$2[C]+\{0_2\}\rightarrow2(CO) \quad (2.15)$$

Due to high-basic slag formation, reactions of desulphurization and dephosphorization take place:

$$[FeS]+(CaO)\rightarrow(CaS)+(FeO) \quad (2.16)$$

$$2[P]+5(FeO)+4(CaO)\rightarrow(4CaO\cdot P_2O_5)+5[Fe] \quad (2.17)$$

By oxidation of alloying elements and impurities (Fig. 2.3), accompanied with great amount of heat evolved, metal is overheated to high temperature t. To cool metal coolers in form of steel scrap are added during melting.

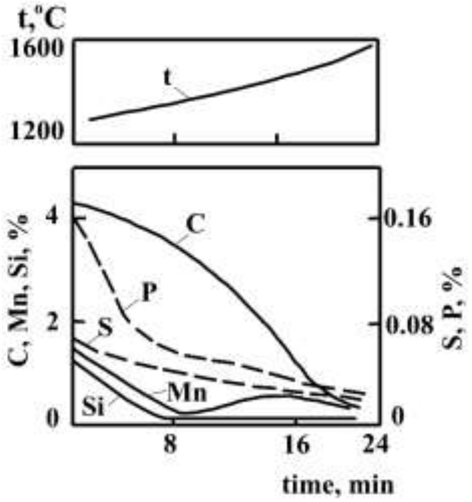


Fig. 2.3. Variation of temperature t and chemical content of steel vs time in oxygen converter process

Any fuel is not needed for oxygen-converter process. It is carried out very rapidly, during from 25 to 40 min. High production rate creates some problems with control and getting required chemical composition of steel.

When the carbon content is dropped to required level the blowing is stopped and alloying is accomplished. So far as steel is saturated with oxygen the operation of *deoxidation* must be performed.

The FeMn and FeSi are added into the converter and Al is placed into the ladle, where the steel is poured from the converter. When steel mixes with deoxidizers the deoxidizing reaction occurs by the formula:

$$[FeO]+[Mn,Si,\ Al]\rightarrow(MnO,SiO_2,Al_2O_3)+[Fe] \quad (2.18)$$

The capacity of oxygen converters ranges from 50 to 400 tons, the tap-to-tap time is 25...45 minutes, providing thereby the highest productivity.

2.3.2. Open - Hearth Process

The main parts of modern open-hearth furnace (Fig. 2.4) is a *reaction chamber* 7 formed by bottom 6 below, *roof* at the top and side walls, all made of refractory materials. The front wall has doors 5 through which scrap is charged into the reaction chamber, samples of steel are taken, and the process of melting is inspected. The back wall has an opening (taphole) closed with refractory mass during melting and opened when the metal in the furnace is ready for tapping. Ports 3, 4 and 8, 9 connect the reaction chamber with *regenerators* 1, 2 and 10, 11 which are brick-lined chambers filled with a checkerwork of refractory brick. The regenerators serve to utilize waste heat of the combustion product leaving the furnace, so that the temperature during melting can be increased from 1400°C (in a furnace without regenerators) to 1800°C.

Ports 8 and 9 are conduits for supplying the gaseous fuel and air that form the flame in the furnace and for removing the combustion products.

Reverse valves 12 and 14 are used to reverse periodically, every 10 or 20 minutes, the direction of the air and gas flow from one end of the furnace to the other. The valves are connected to a flue for directing combustion products to the stack 13 after they have given up most of their heat to the checkers. During the furnace operation, the waste gases from the furnace are conveyed through downtakes 3 and 4 (left in Fig. 2.4) into regenerators 1, 2. After heating the checkers the gases are taken by flues 17 and 18 to the stack 13.

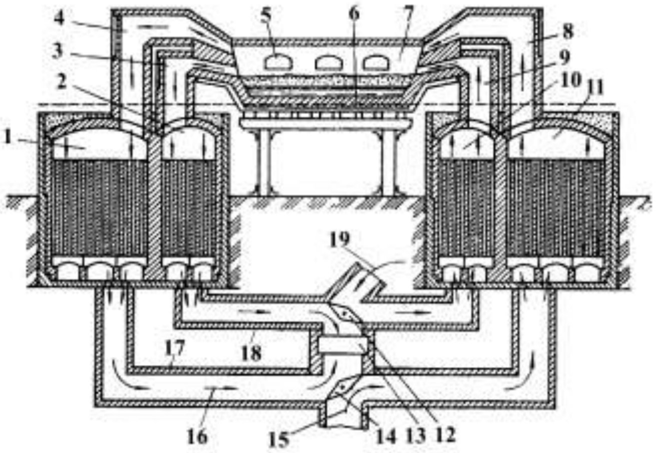


Fig. 2.4. Open-hearth furnace: 1, 2, 10, 11 – regenerators; 3, 4, 8, 9 ports; 5 – door; 6 – bottom; 7 – reaction chamber; 12, 14 – reverse values; 13 – stack; 15 – air; 16 – combustion products; 17, 18 – flues; 19 – gas

At the same time, cold gas 19 and air 15 pass through right flues, regenerators 10 and 11 and uptakes 8 and 9 and enter the reaction chamber 7 at a temperature of 1.000...1.200°C to heat and melt the metal and slag. When one part of regenerators is substantially cooled and the other heated, the direction of gas and air flow is reversed, so that the temperature in the reaction chamber is always near stable.

According to the charging materials used for melting in an open-hearth furnace, a distinction is made between *ore*, *pig-and-ore* and *pig-and-scrap processes.*

The ore process uses molten pig iron with addition of iron ore to oxidize the impurities in the iron.

The pig-and-iron process employs a charge consisting mainly of molten pig iron with the addition of scrap and iron ore.

In the pig-and-scrap process the charge is solid. It consists mainly of steel scrap and solid pig iron.

The reactions of metal oxidizing by FeO (iron ore) in open-hearth furnace are the same as in an oxygen converter.

After oxidation steel is deoxidized, alloyed and then tapped.

Open-hearth furnaces have capacity from 20 to 900 tons, the tap-to-tap time is 5…10 hours. The steel quality is the same for oxygen converter and for open hearth furnace. But the open-hearth process considerably lost in productivity.

The open-hearth process is a dying process; it is not used in the United States, Germany, and Japan. But the main amount of common and quality steel in Ukraine is still produced in the open-hearth furnaces.

2.3.3. Electric Steel Making

Electrometallurgy is a branch of engineering concerned with the reduction of metals from their oxides and manufacture of various steels and alloys with electric energy being used as the source of heat.

Electric furnaces have a number of substantial advantages over other types of melting plants: some types of high-quality steel, such as high-alloy tool steel, stainless, refractory and heat-resistance steels and many structural steels can be smelted only in electric furnaces. It is easy to form an oxidizing, reducing or neutral atmosphere in the electric furnace. Steels with lower content of sulphur and phosphorus, deoxidized and poorly contaminated by nonmetallic inclusions may be easily produced in such furnaces.

All metal-melting electric furnaces can be divided into three groups according to the methods by which electric energy is transformed into heat:

- *electric-arc furnaces*;
- *induction furnaces*;
- *resistance furnaces*.

The method of heating may be used to classify all electric-arc furnaces into direct-arc, indirect-arc and plasma furnaces. In direct-arc furnace electric arc is drawn between electrodes and metal being heated. In indirect-arc furnace the arc strikes between electrodes (as a rule, 2 electrodes) and metal is heated by radiation from the arc. A plasma furnace is similar direct-arc furnace, if plasmatrons are used instead electrodes.

Figure 2.5 shows a direct-arc furnace. The furnace has a steel shell 4 in the form of a tapered cylinder with a spherical bottom 12. The shell has a refractory lining 5 inside. The reaction chamber of the furnace is covered from above by removable roof 6 made of refractory bricks. The furnace has a charging window 10 with a door, and taphole 2 with a tapping spout. The furnace is fed with three-phase alternating current and has three electrodes 9 fastened in electrode clamps 8. Current is supplied via water-cooled flexible cables 7. Arcs are formed between electrodes and metal. The metal is covered by slag. The furnace has rollers 11 to turn it for tapping or for charging.

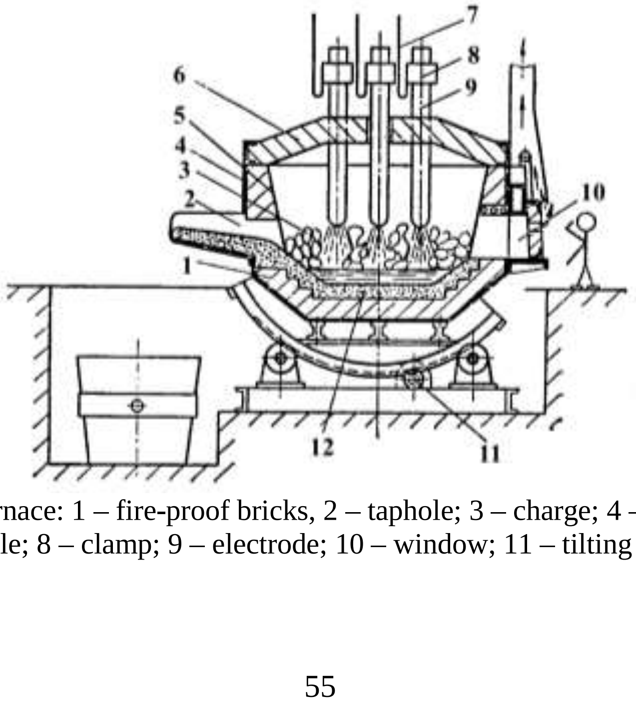


Fig. 2.5. Direct-arc furnace: 1 – fire-proof bricks, 2 – taphole; 3 – charge; 4 – steel shell; 5 – lining; 6 – roof; 7 – flexible cable; 8 – clamp; 9 – electrode; 10 – window; 11 – tilting mechanism; 12 – bottom

The furnace charge consists of steel and cast iron scrap, foundry iron, ferroalloys, oxidizers, deoxidizers and slag forming materials (*limestone* $CaCO_3$, lime CaO, *fluorspar* CaF_2, *sand* SiO_2, *broken chamotte* $Al_2O_3+SiO_2$); from 10 to 20 % of liquid conversion (pig) iron is added sometimes.

The furnace is charged from the top by means of a *drop-bottom_bucket.* To open the reaction chamber for charging, the *furnace roof* (together with electrodes) is raised and moved to the side. The door 10 is used for small additions during heat.

The lining of walls 5 and bottom 12 may be acid or basic. By this melting process in the electric furnace can be carried out by one of the following main methods:

- in the basic furnace, oxidizing the admixtures with iron ore;
- in the basic furnace without oxidizing the admixtures (remelting process or fusion of steel scrap);
- in the acid furnace with oxidizing;
- in the acid furnace without oxidizing.

Only the electric arc with basic lining allows removing S and P, because lime CaO is needed for dephosphorization and for desulphurization. In acid furnace lime reacts with acid lining and destroys it:

$$\underset{\boxed{\text{slag}}}{\mathrm{CaO}} \quad + \quad \underset{\boxed{\text{lining}}}{\mathrm{SiO_2}} \rightarrow \mathrm{CaSiO_3} \tag{2.19}$$

The melting process in the basic arc furnace may be divided into stages as follows:

- *fettling* of the furnace, i.e. small repair by powder fireproof materials (refractories);
- *charging* of the main charge (steel scrap iron, iron ore, lime);
- *melting* of the main charge and dephosphorization:

$$2[P]+5(FeO)+4(CaO)=(4CaO\cdot P_2 0_5)+5[Fe]+Q \tag{2.20}$$

- *bath boil* and heating of the metal to required temperature; ferrous ore or oxygen is given info furnace and the process of oxidizing of carbon, silicon, manganese is started:

$$(FeO)+[C+Si+Mn]\rightarrow[Fe]+\{CO_2\}+(SiO_2)+(MnO) \tag{2.21}$$

$$\{O_2\}+[C+Si+Mn]\rightarrow\{CO_2\}+(SiO_2)+(MnO) \tag{2.22}$$

The bubbles of CO_2 are formed in metal, which are named "metal boils".

- *skimming of the oxidized slag* to remove phosphorus;
- *formation of the reducing* slag by adding CaO, CaF_2, FeSi, coal (C) and others;
- *deoxidation* of metal by reducing slag and desulphurization:

$$[FeS]+(CaO)=(CaS)+(FeO)-Q \qquad (2.23);$$

- *final deoxidation* of metal by Mn, Si, Al, Ca, Ce, e.g.:

$$[FeO]+[Al]\rightarrow(Al_2O_3)+[Fe] \tag{2.24}$$

- *tapping of metal.*

As we can see (reaction 2.20), the amount of phosphorus passing to slag is proportional to the concentration of ferrous oxide FeO and lime CaO in the slag. The reaction is preceded with heat uptake. By this reason, the degree of dephosphorization is higher at low temperature. In electric steelmaking, the temperature of the metal increases gradually and it is therefore essential that the greatest part of the phosphorus had time to pass to slag at a low temperature, i.e. during melting of charge and in the initial 10...15 minutes of the oxidizing stage. To remove phosphorus the part of slag is skimmed off from the furnace.

For desulphurization low concentracion of FeO, high concentration of CaO (high basity of slag) and high temperature are required (reaction 2.23).

The basic lining is more expensive and has smaller life as compared with acid one. That is why it is mainly used in electric arc furnaces for production of quality and high-quality steels.

2.3.4. Tapping and Teeming

The *spout* of the furnace is lined with fireclay bricks. During melting time the spout should be cleaned from scrap and slag, well dried and blown with compressed air.

Steel is tapped from the furnace into a *teeming ladle*, whose construction may be seen from the Figure 2.6.

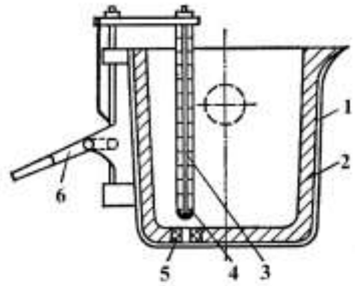


Fig. 2.6. Teeming ladle: 1-steel construction; 2-fireclay brick lining; 3-stopper; 4-stopper end; 5-nozzle; 6-stopper moving mechanism

The teeming ladle is used for pouring or teeming of steel. There are three methods of pouring steel in metallurgy:

- *top (direct) pouring*;
- *uphill teeming*;
- *continuous and semicontinuous casting*.

According to the first and the second methods (Fig. 2.7) the cast iron moulds, named *ingot moulds*, are used. In the first case one ingot mould is filled with metal. In the second case from 2 to 32 ingot moulds are simultaneously filled with steel by using gating system.

In the first case we use all metal for ingot, but because of metal splashing the surface of ingot may have some defects. In the second case we have smooth filling of the mould and good quality of ingot surface, but metal is partly wasted on gating system.

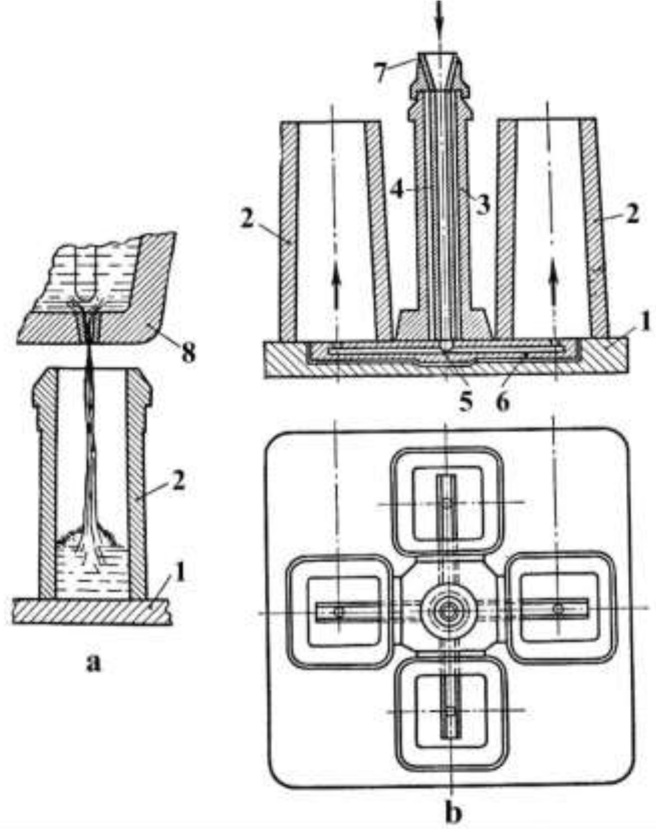


Fig. 2.7. Top (a) and uphill (b) teeming: 1 - bottom plate; 2 – mould; 3 – metallic shell of central downgate; 4, 6 – chamotte tube; 5 – central brick; 7 – funnel; 8 - teeming ladle

Nevertheless, labor productivity is higher in the second case.

But in both cases the ingot has non-uniform structure (Fig. 2.8): *shrinkage cavity* (pipe)-4, heterogeneous crystal structure (*fine* crystals 1, fringe crystals 2, *coarse* crystals 3).

Shrinkage cavity forms in the *riser*, because it freezes last. The riser and *bottom ends* are cut off and undergo remelting.

The ingot has droplet *(dendritic) and zone segregation*. For example, a content of C, S, P in top part of the ingot is in several times much as their content in lower part (zone segregation).

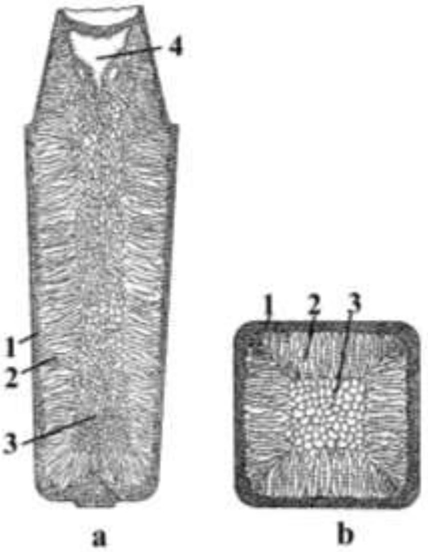


Fig. 2.8. Steel ingot structure: 1 – fine crystals; 2 – fringe crystals; 3 – coarse crystals; 4 – shrinkage cavity

The continuous casting (pouring) was advanced in order to get rid of disadvantages. The schemes of two types of machines for producing of continuous billets (blanks) are shown in Fig. 2.9 a) vertical continuous caster and b) curved type continuous caster. The molten metal from a ladle 1 is poured into a cooper water-cooled mould 3 through intermediate ladle 2. By cooling action water 4 liquid metal starts to solidity in mould 3 and solidifies finally in cooling zone 5. A steel billet 7 is drawn from the mould by rollers 6 and then is cut by a cutting mechanism 8 into measured sections.

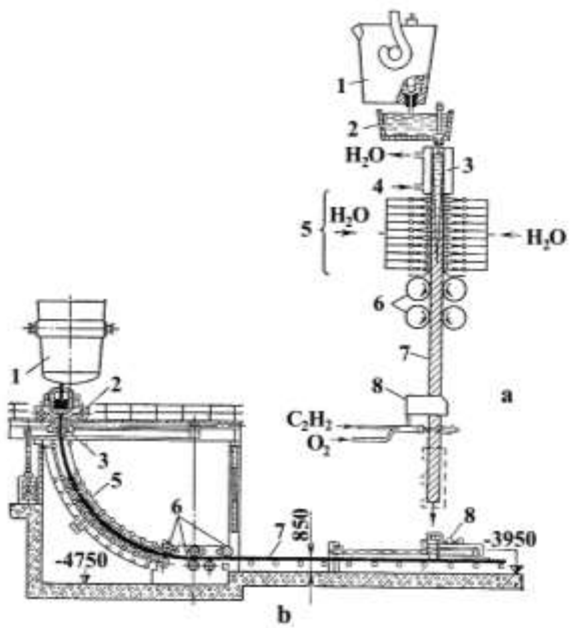


Fig. 2.9. Continuous casting: 1 – stopper ladle; 2 – intermediate ladle (tundish); 3 – water-cooled mould; 4 – water; 5 – zone of secondary cooling; 6 – drawing rollers; 7 – billet; 8 – cutting mechanism

The positive aspects of continuous casting are follows. The losses of metal owing to shrinkage pipe (cavity) in common ingots amounts to 10…16 per cent and 4 per cent are lost as cropping of the bottom end of ingots. With continuous casting the total loss is only 4...5 per cent. Owing to accelerated solidification billets have no segregation and are more homogeneous in structure, which improves metal quality. The method requires less labor and can readily be controlled automatically.

2.3.5. Production of High-Quality and Super-High Quality Steels

Many branches of modern engineering require metals of the highest quality, which cannot be produced in electric furnaces. As a rule, high-quality steels contain small amounts of non-metallic inclusion and gases. They also have fine and dense (lack of pipes) structure without segregation.

There are two main directions of improving of steel quality in metallurgy:

- by treatment of liquid steel melted in ordinary furnaces;
- by remelting of steel in special furnaces (this branch is named special electrical metallurgy).

The first direction is connected with: *vacuum degassing* of molten steel (a) and treatment of molten steel by *synthetic slag* (b).

There are numerous methods of vacuum degassing of steel in metallurgy. The main is degassing in the ladle (Fig. 2.10).

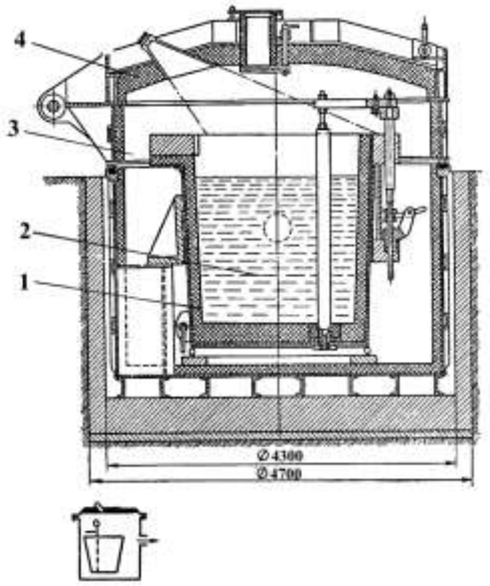


Fig. 2.10. Scheme and draught of chamber for vacuum degassing in the ladle:
1 – ladle; 2 – steel; 3 – chamber; 4 – cover of chamber

The ladle 1 with molten steel 2 is positioned in vacuum chamber 3, closed by the cover 4. Then the air is exhausted from the chamber by a vacuum pump and gases (O_2, H_2, N_2) in consequence are extracted from steel. The disadvantage is that only gases are removed.

Synthetic slag (40 % Al_2O_3, 55 % CaO, rest-SiO_2, MgO, and others) 1 is melted in electric furnace and then is poured into a ladle 2 (Fig. 2.11). Then steel 3 is poured into the ladle from the height 5...8 m. Large contact surface is formed during mixing of steel with slag. Thus, slag absorbes impurities from steel (sulphur, oxygen, phosphorus). The disadvantage is that special furnace is necessary for slag melting.

Main special electrometallurgical processes are (1) *vacuum arc remitting* (Fig. 2.12); (2) *electroslag remelting* (Fig. 2.13); (3) *plasma arc remelting* (Fig. 2.14, 2.15).

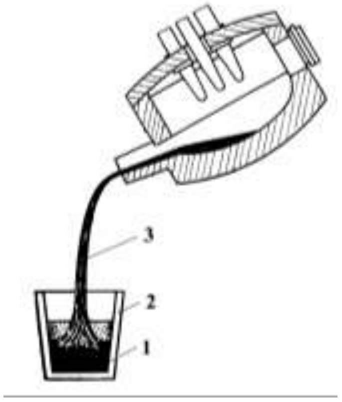


Fig. 2.11. Treatment of molten steel by synthetic slag: 1 – slag; 2 – ladle; 3 – steel

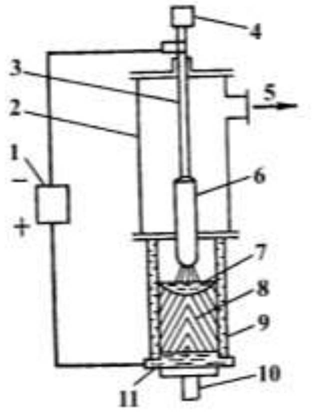


Fig 2.12. Vacuum arc remelting: 1 – d.c. generator, 2 – vacuum chamber; 3 – electrode holder; 4 – electrode-moving gear; 5 – exhaust of air; 6 – comsumable electrode; 7 – liquid metal; 8 – ingot; 9 – mould; 10 – carriage for moving the ingot down; 11 – bottom of the mould

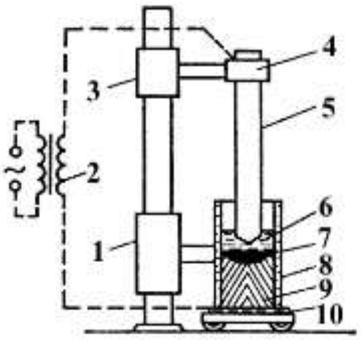


Fig 2.13 Elecrtoslag remelting: 1 – mould lifting carriage; 2 – transformer; 3 – electrode replacing mechanism; 4 – holder; 5 – comcumable electrode; 6 – liquid slag; 7 – liquid metal; 8 – mould; 9 – ingot; 10 – bottom

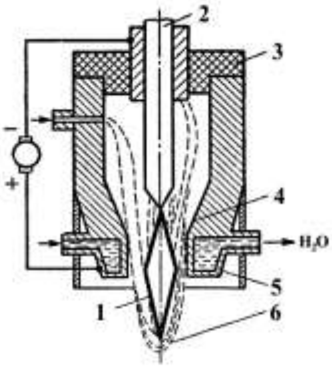


Fig. 2.14. Plasmatron construction: 1 – electric arc; 2 – tungsten electrode; 3 – insulator; 4 – body; 5 – water-cooled nozzle; 6 – plasma jet

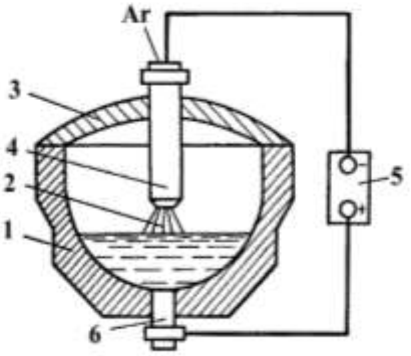


Fig. 2.15. Plasma-arc furnace: 1 - lining; 2 - plasma arc; 3 - roof; 4 - plasmatron;
5 - power supply; 6 - bottom electrode

A consumable electrode 6 is remelted in vacuum chamber 2 by electric arc (Fig. 2.12). Drops of steel are degassed in vacuum and steel solidifies in water-cooled metallic mold 9, forming the ingot 8. Ingot has a good structure (fine grain, high density) and low content of gases and non-metallic inclusions. A main disadvantage of the process is the complexity of vacuum installation.

A simple method, electroslag remelting for improving the quality of metal, has been developed at the E.G. Paton Institute of Electric Welding. In this process (Fig. 2.13), metal droplets, formed during the melting of a consumable electrode 5, pass through a layer of specially prepared slag 6 and solidify into an ingot 9 in a mold 8. Slag refines metal from sulphur, phosphorus, oxygen, nitrogen and hydrogen.

A new branch of metallurgy-metal melting by means of *electric plasma*-has been developed in recent years. It employs both *plasma arc furnaces* of original design and *plasma heaters* used in conventional type furnaces. *Plasma* is an ionized gas with total charge equal to zero. A distinction is made between hot plasma with temperature up to a few hundred thousand degrees K and cold plasma, in which temperature reaches 30,000 K and its degree of ionization is around 1 percent. The latter is used in metallurgy. Let us consider the construction of the simplest plasmatron (Fig.2.14). It has an internal rod electrode 2 and a concentric water-cooled annular external electrode 5 in the form of a nozzle. If direct current is applied from d. c. generator, the internal electrode is the cathode and the external one is the anode. The dielectric part 3 joins parts 2, 4 and 5. A flow of gas supplied in chamber of the plasmatron blows out the electric arc, that burns between cathode and anode through the nozzle to the outside. The electric arc 1 is transformed into a plasma jet 6, as a result of squeezing, which is directed on the object to be heated.

The melting in plasma-arc furnaces offers the following advantages as compared with the melding in electric arc furnaces:

- it avoids contamination of the metal with carbon of the electrodes and with hydrogen from the furnace atmosphere;
- the plasma jet may be composed of any mixture of gases which also may be used for metal alloying (such as nitrogen);
- the rate of melting is rather high due to the high concentration of energy.

Figure 2.15 shows schematically a plasma arc furnace with refractory crucible 1. The furnace is hermetically sealed. The plasmatron 4 is fed with direct current. The shape of the furnace resembles that of a steelmaking arc furnace.

2.4. Production of Non-Ferrous Metals

The most common non-ferrous metals are copper, aluminium, magnesium, titanium, tin, lead and nickel. These metals have valuable properties and find wide application, despite of their relatively high cost, in engineering, aircraft, radio and electronic industry and in a number of other areas.

Content of various elements (including non-ferrous metals) in the Earth's crust (in mass %) are:

Oxygen-46.6
Silicon-27.7
Aluminium-8.0
Iron-5.0
Magnesium-2.3
Titanium-0.6
Copper-0.01
Nickel-0.01
Tin-0.004
Zink-0.004
Lead-0.0016
Silver-0.00001
Gold-0.0000005
Platinum-0.00000005

So, such metals as aluminium, iron, magnesium and titanium have the highest abundance in the Earth's crust. But copper, having low content in the crust, is used by man during from 8 to 10 thousand years, while the industrial method of aluminium production was suggested only in 1886 independently by American student Ch. Hall and French engineer Poll Eru. Industrial production of magnesium and titanium started about 50 years ago. The point is that copper is present in nature sometimes in metallic state, besides that, it may be received from chemical compounds (copper ore) relatively easily. Aluminium, titanium and magnesium have very high chemical affinity to oxygen and other elements. Consequently, it is very difficult to receive them in metallic state.

2.4.1. Production of Aluminium

Aluminium is one of the lightest of the structural materials. It has a specific gravity of 2.7 g/cm^3 and melting point 660°C. Annealed aluminium exhibits low ultimate strength of 80 to 120 MPa, and reduced hardness of HB 250 MPa, but possesses high ductility with elongation ranging from 35 to 45 %. But due to low specific gravity aluminium alloys have higher specific strength (σ_u/γ) than some kinds of alloy steel. Aluminium has good electrical and heat conductivity, is resistant to attack of corrosion in fresh water and atmosphere. Its alloys are used for production of parts of aircrafts, rockets, cars, ships and other machines and devices. Pure aluminium is used in electrical industry as a conductor. The main aluminium ores are *bauxites*, which consists of aluminium hydroxides $AlO(OH)$ and $Al(OH)_3$ and foreign impurities. The process of aluminium production consists of two stages:

- production of *alumina* Al_2O_3 from *bauxites*;
- production of aluminium from melted alumina by electrolysis process.

After refining process bauxites undergo leaching in autoclaves at temperature 150 to 250°C and pressure 0.5 to 1.0 MPa (5...10 atm).

The following reactions take a place:

$$AlO(OH) + NaOH = NaAlO_2 + H_2O \quad (2.25)$$

$$Al(OH)_3 + NaOH = NaAlO_2 + 2H_2O \quad (2.26)$$

Sodium aluminate $NaAlO_2$ is dissolved in water and all impurities fall out on the bottom of the autoclave.

After filtration, cooling of liquid and decrease in pressure magnitude the reaction proceeds:

$$NaAlO_2 + H_2O = Al(OH)_3 + NaOH \quad (2.27)$$

$A1(OH)_3$ particles have the form of flakes, which come to the surface of liquid. They are removed from the surface of liquid, dried at temperature 1200°C in tube furnace and converted into alumina:

$$2A1(OH)_3 \rightarrow A1_2O_3 + 3H_2O \quad (2.28)$$

Alumina has high melting point, equal to 2050°C. Because of this it is dissolved in *cryolite* Na_3AlF_6, which has low melting point.

The *dissociation* ($Al_2O_3 \rightarrow 2Al + {}^3/_2O_2$) takes place in the bath at the temperature 930 to 950°C (Fig. 2.16). Liquid aluminium falls out on the bottom of the bath. Then it is removed from the bath and subjected to refining.

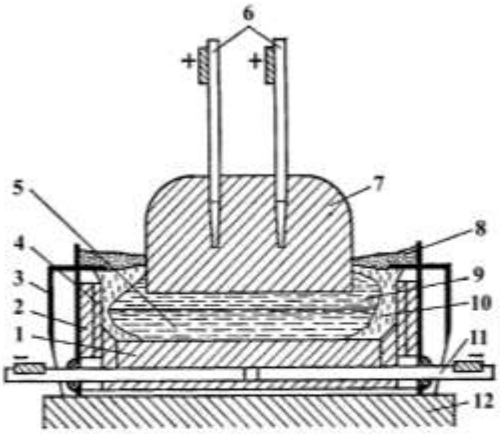


Fig.2.16. Scheme of electrolyzer for aluminium production: 1 - cathode; 2 – fireproof lining; 3 – metallic shell; 4 – graphite lining; 5 - rough aluminium; 6 - current lead; 7 - sintered pitch resin (anode); 9 - electrolite (90 % Na_3AlF_6+10 % $A1_2O_3$); 10 - graphite (carbon) bath; 11 – electrode; 12 – foundation.

2.4.2. Production of Copper

Copper holds one of the leading positions among the non-ferrous metals by its high thermal and electrical conductivity, enhanced ductility and good corrosion resistance. Copper is easy to work in the cold and hot state. It has density of 8.93g/cm^3 and melting point 1083°C. Annealed copper has an ultimate strength of 250 MPa, relative elongation of 45 to 60 %, and Brinell hardness of 600 MPa. Because of its high conductivity, copper has wide application in electrical engineering for production of conductors, connecting wire, magnet wire and current-conducting parts of devices. But application of pure copper as a structural material is limited. Industry widely employs the copper base alloys namely, *brass* and *bronze*.

Copper ores, named *copper pyrite* and *copper glance*, usually contain small amount of copper, from 0.5 to 6 %, and require concentration (dressing). Main compounds of copper ores are: Cu_2S, CuS, Cu_2O, $CuCO_4$, $Cu(OH)_2$, FeS, SiO_2, Al_2O_3, CaO, MgO and others.

Copper production process consists of several operations:

- *concentration* of ore to increase copper content from 0.5…6 to 35 %:
- *oxidizing roasting* of copper concentrate at 750...800°C to reduce sulphur content;
- *melting* of concentrate and preheating it to temperature of 1250 to 1300°C to separate the slag, which consists of oxides of iron, silicon and other impurities and *primary matte*, which consists of sulphides of copper and iron;
- *convertation of matte* by air blasting through it in converter to remove sulphur and iron and receive *rough copper* which is 98.4 to 99.4 % pure.
- *fire and electrolytic refining* to remove impurities and receive copper from grade MOO that is 99.99 % pure to grade M4 having a purity of 99 %.

2.4.3. Production of Magnesium

Magnesium is the lightest structural metal produced in commercial amounts. The density is 1,74 g/cm^3, melting point is 651°C, tensile strength in the as-cast state ranges from 100 to 120 MPa and elongation is 8…12%. Like aluminium, magnesium has high specific strength and is used in form of alloys with aluminium, manganese, zinc and other metallic elements as a structural material for production of parts of rockets, aircrafts, cars, ships and so on. Magnesium alloys has σ_u=200...400 MPa and high resistance to corrosion.

Magnesium is obtained from *carnallite* $MgCl_2 \cdot KC1 \cdot 6H_2O$, *magnesite* MgCOs and from *dolomite* MgCOs·CaCOs. It is largely produced by the electrolysis of molten salts mixture (Fig. 2.17), which has composition: 10% $MgCl_2$, 45% $CaCl_2$, 30% NaCl, 14% KC1 and 1% ($NaF+CaF_2$). This composition is needed to decrease melting point of electrolyte, which ranges from 710 to 730°C. At this temperature and voltage of 2.7...2.8 V the reaction of dissociation only $MgCl_2$ takes a place:

$$MgCl_2 \rightarrow Mg + Cl_2 \qquad (2.29)$$

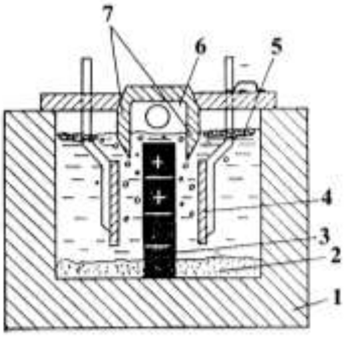


Fig. 2.17. Scheme of the unit for magnesium production by electrolysis: 1 – bath; 2 – slime; 3 – anode; 4 – cathode; 5 – magnesium; 6 – chlorine; 7 – collector with pipe for removing of chlorine

Liquid magnesium evolves on cathodes 4 and comes to the surface of electrolite. Gas chlorine evolves on a graphite anode 3 and comes into chorine collector 7. $MgCl_2$ periodically is added into a bath 1.

Crude magnesium produced by this method contains from 2 to 5 % harmful impurities. The crude metal is refined by melting it in an electric furnace under refining slags to obtain magnesium of 99.82 % to 99.92 % purity.

2.4.4. Production of Titanium

Titanium has density of 4.5 g/cm^3 and melting point 1670°C. Commercially pure titanium contains no more than 0.1 % impurities, has a tensile strength from 300 to 500 MPa and relative elongation from 20 to 30 %. The alloying elements added to titanium make it stronger, but less ductile.

Titanium and its alloys possess the advantages of high mechanical properties and low density combined with the resistance to attack against corrosive environments, such as nitric, hydrochloric, and hydrofluoric acids. Titanium alloys of required mechanical properties are produced by alloying titanium with chromium, aluminium, vanadium, molybdenum, tin and other metals. These alloys are rather heat-resistant and can withstand temperatures up to 600...700°C.

Ilmenite ($TiO_2 \cdot FeO$) and *rutile* (TiO_2) are the major titanium ores. The process of titanium production consists of two stages:

- the conversion of rutile in titanium tetrachloride $TiCl_4$;
- the reduction of titanium by liquid (molten) Mg.

In electric resistant furnace, at presence of carbon-containing material (coke, oil coke) and at temperature 600°C rutile is converted in tetrachloride by Cl:

$$TiO_2 + 2Cl_2 + 2C = TiCl_4 + 2CO \qquad (2.29)$$

$TiCl_4$ has melting point of 23°C and boiling temperature equal to 136°C. It is poured in steel retort and is reduced by liquid Mg in atmosphere of argon at temperature 750...800°C:

$$TiCl_4 + 2Mg = Ti + 2MgCl_2 \qquad (2.30)$$

The *sponge* of composition: 55...60 % Ti; 25...30 % Mg, 10...15 % $MgCl_2$ is formed on the walls of the retort. $MgCl_2$, which is in liquid state, goes into electrolytic bath for producing of magnesium. The sponge undergoes vacuum distillation at temperature 900...950°C. During this operation part of impurities is evaporated, part is removed in liquid state. After that a consumable electrode is made of titanium sponge. The electrode is remelted in vacuum arc furnace to refine titanium to 99.6...99.7 % purity.

Melting and pouring of titanium and its alloys are conducted in vacuum because of high chemical activity of titanium.

2.5. Powder metallurgy

There are three types of metals and alloys (according to technological features):

- *cast*, that are castings and ingots;
- *wrought* alloys, i.e. alloys after metal forming;
- *sintered* alloys, that are alloys produced by methods of powder metallurgy.

Powder metallurgy uses metal and non-metal elements and their chemical compounds for manufacture of products. The powder metallurgy techniques comprises following stages:

- *powders production*;
- *preparation of mixture* of powders and technological additions;
- *forming of an article* by pressing process (compressing a briquette or green compact);
- *sintering* that renders the article proper strength.

This technique is more complex and expensive than casting or plastic working methods. But the powder metallurgy techniques attracts more and more attention since they offer ample scope for production of materials and parts with high heat and wear resistance, which display stable magnetic properties or specific physicochemical properties. Main advantage of these techniques is that mentioned properties are impossible to be obtained by casting or plastic working methods.

Powders are produced by mechanical and physicochemical methods. Mechanical methods do not change the chemical composition of material and prepare powder by two ways:

- *grinding* solids in ball mills, vortex chambers and vibratory mills;
- *granulating* the melt, that is spraying the liquid metal.

Mechanical methods are applicable only for hard and brittle materials, which are the base material of all cermets. These are the powdered carbides of such metals as tungsten titanium and tantalum the hardness of which is close to that of diamond.

Physicochemical methods enable to reduce crushed oxides (ores) or carbides to metal powders. Sizes of metal powders range from 0.005 to 0.5 mm.

Ball mills or vibratory mixers may be used to blend ingredients in required proportions.

Moulding the blend into various shapes is the process of single-action or double-action compaction (pressing) in dies by mechanical or hydraulic presses at a pressure of 150 to 800 MPa (Fig. 2.18).

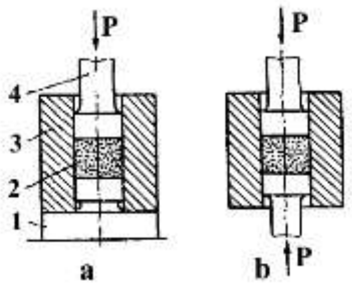


Fig. 2.18. Single-action (a) and double-action (b) pressing of powders: 1-bottom; 2-powder; 3-container; 4-plunger

Another method of powder moulding is compaction of metal powder into *strip*, including *bimetallic strip*.

Sintering is the process of heating green compacts in vacuum furnace or in furnace with shielding gases (argon, nitrogen, hydrogen) at a temperature from 60 to 80 % of the melting temperature of the base metal and holding time from 1 to 2 hours.

To impart the parts the final shapes and desired properties, the sintered articles can be put through additional processing: heat treatment, diffusion heat treatment, and coining or sizing.

Powder metallurgy techniques are used for manufacture of:

- *filters*, because of porosity of articles (porosity ranges from 10 % to 50 % of volume; it is determined by moulding pressure);
- *frictional materials*, produced by additions of asbestos, oxides and carbides to metallic powders;
- *antifrictional materials*, produced by additions of graphite and plastics to metallic powders;
- *cutting tools* by sintering carbides of tungsten, titanium and tantalum with cobalt powder;
- *fireproof materials* by sintering oxides and carbides, which have high melting point;
- *pseudoalloys*, components of which can't form solution in liquid state (e.g. iron and lead).

3 FOUNDRY PRACTICE

3.1. Theoretical Fundamentals of Foundry

Foundry practice is a branch of science and engineering, which deals with the methods used to obtain cast half-finished parts named *castings*. Foundry production is a branch of machine industry. The principle of casting consists of pouring the molten metal into *sand* or *metal_mould* whose cavity conforms to the shape of the required casting. The casting forms when metal cools and solidifies.

Main advantages of foundry processes are:

- possibility of production of parts from tenths of gram (zipper element) to a few hundred tons (machine tool bases, turbine parts, monuments) in mass;
- parts of intricate shapes may be produced;
- in many cases, casting process proves to be the only method to manufacture the required parts (large and heavy parts, intricate castings and the parts where the alloy used is not enable to machine tool operations, or to metal forming);
- foundry technology provides low production cost of half-finished parts.

But foundry processes are connected with procedures of metal melting, its pouring and solidification during which such foundry defects as *thermal stresses, cracks, segregation, shrinkage pipes* and *porosity* appear in castings.

The quality of castings depends on foundry properties of alloys, such as:

- *fluidity;*
- *linear* and *volumetric shrinkage*;
- formation of *shrinkage cavity* and *porosity*;
- *crack formation*, etc.

The fluidity is an ability of an alloy to fill the mould cavity and reproduce exactly its configuration. Foundrymen use fluidity tests to gain an idea of the alloy's ability to flow through long passage of definite shape and cross - section sizes (Fig. 3.1). During movement in channel the metal cools and freezes. The length of the passage l in cm filled by the metal is considered to be the index of fluidity.

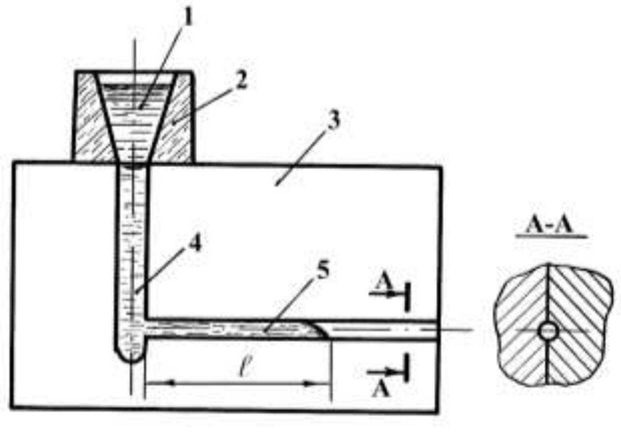


Fig. 3.1. Fluidity test: 1 – liquid metal; 2 – pouring basin; 3 – half of the mould; 4 – downgate; 5 – channel (passage)

The fluidity depends on:

- the chemical composition of the alloy and its solidification nature;
- the temperature of the alloy;
- the temperature of the mould.

A number of defects may be developed in cast alloys. Most of the defects are caused by volumetric shrinkage or contraction during solidification. Let us consider the solidification of a casting (Fig. 3.2a).

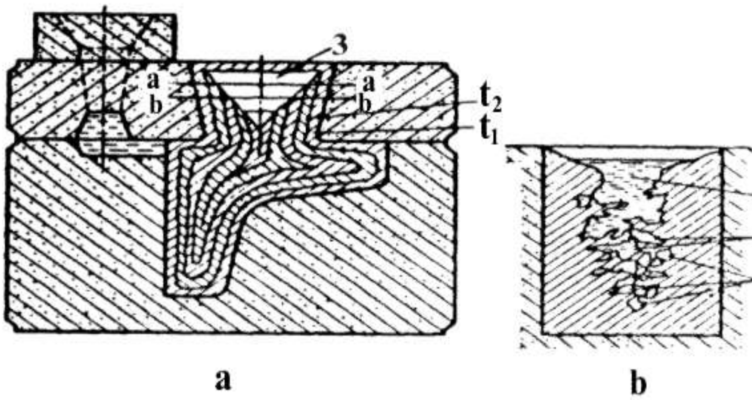


Fig. 3.2. Formation of a pipe (a) and porosity (b) during:
1 – porosity; 2 – separated volumes of liquid metal; 3 – shrinkage cavity

At time 0 all metal is in liquid state. At time 1 a solid shell t_1 is formed on the surface of the casting and due to contraction of liquid metal its level drops to the line a-a. At time 2 a next solid shell t_2 is formed and level of metal further drops to the line b-b and so on.

Because of contraction of liquid metal the shrinkage cavity 3 and porosity 1, 2 are formed inside the casting (Fig. 3.2b). Because of contraction in solid state the decrease in sizes clearly exhibits.

So, shrinkage is usually understood as a percentage change in volume (*volume shrinkage* ε_v) or in length (*linear shrinkage* ε_l):

$$\varepsilon_v = \frac{V_0 - V_1}{V_0} \cdot 100\% ; \tag{3.1}$$

$$\varepsilon_1 = \frac{l_0 - l_1}{l_0} \cdot 100\% ; \tag{3.2}$$

where V_0, V_1 is initial and final volume;
l_0, l_1 is initial and final length;
A free linear shrinkage of steel is from 2 to 2.8 %,
of cast irons is 0.8...1.2 %,
of non-ferrous alloys is 1…2 %.

The volumetric shrinkage is three times as large as the linear shrinkage So, volumetric shrinkage amounts to 8.5 % for steel and the volume of the shrinkage cavity amounts to 6...8 % of the casting's volume.

To have sound (dense, defectless) castings foundrymen use the principle of directional solidification in process of design of foundry technology. It allows them to take out a shrinkage cavity from casting's body (Fig.3.3 a) into a riser (Fig. 3.3 b). It is necessary to avoid *hot spots* within casting. When metal has a low shrinkage, for instance, cast iron, the principle of simultaneous solidification is used (Fig. 3.3 c).

During cooling the part A of the casting (Fig. 3.3 d) is contracted and parts B and C move one to other. But the mould prevents the displacement and, as a result, hot or cold cracks may appear.

Cast stresses, cracks, dendritic and zone segregation develop in castings, especially, in heavy castings and those having intricate shape.

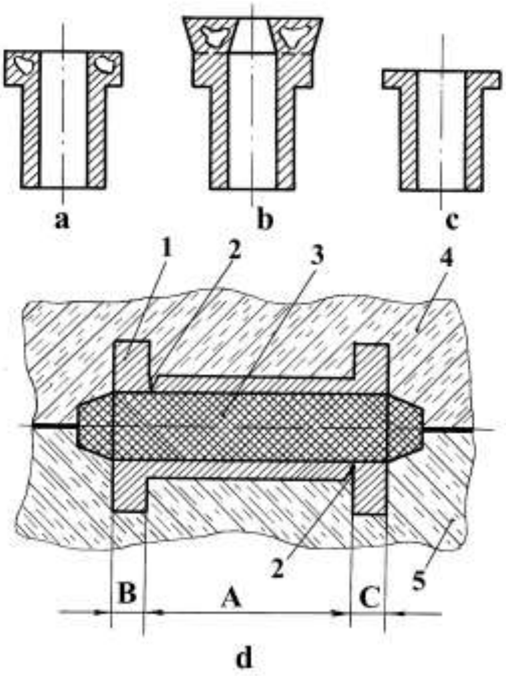


Fig. 3.3. Defects in castings and principles of their design: a – formation of shrinkage cavity in casting; b-installation of a riser; c-principle of simultaneous solidification; d-formation of cracks: 1-casting; 2-crack; 3-core; 4-upper half-mould; 5-lower half-mould

3.2. Manufacture of Castings in Sand Moulds

This is a main foundry method. About 70 % of castings are produced in sand moulds. There are main technical operations involved in making castings in sand moulds:

- development of *casting's drawing*, using a drawing of the part (article) and working out of technological process;
- *patternmaking*, including *core boxes*, *gating system patterns*, *moulding boxes* (*flasks*) and other auxiliary equipment;
- preparation of *moulding* and *core sands*;
- *moulding* (manufacture of mould and cores);
- *melting an alloy* and pouring it into the mould;
- *cooling* of moulds and *shaking out* of castings;
- *cleaning of castings* to remove moulding and core sands;
- *cutting off the gating system, risers and fins*;
- *preliminary inspection* of the casting to reveal defects and assess general quality;
- *heat-treatment*;
- *fettling* of castings to remove scale (rust);
- *final inspection* (structure, mechanical properties, etc);
- *finishing operations* (painting, oiling, branding, etc);
- *shipment.*

Development of casting's drawing (elaboration of technological process) consists of several steps.

First step is examination of the drawing of a part to be cast (Fig. 3.4 a):

- surfaces A, B and C must be machined;
- D is a hole with screw, which can't be produced by a foundry process;
- ring flute B must be done by machine tool;
- lower part of the article C has higher surface quality than upper one;
- internal surface E does not undergo to machining.

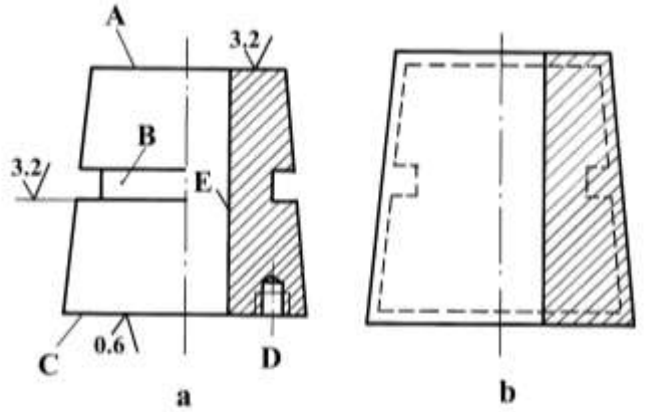


Fig. 3.4. Drawing of a part to be cast (a) and casting (b)

Next step is to select the position of the casting in the mould so as to ensure directional solidification from the casting towards the riser located above the feed end.

We can choose two possible positions of the casting in the mould (Fig. 3.5): with vertical (a) and horizontal (b) axis.

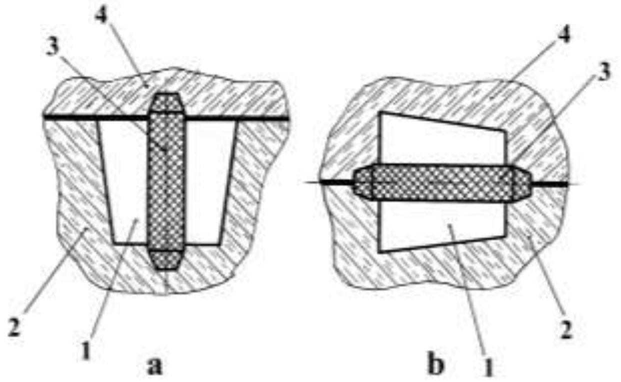


Fig. 3.5. Possible location of the casting in the mould: vertical (a) and horizontal (b) positions;
1 – mould cavity (casting); 2 – lower half-mould; 3 – core; 4 – upper half-mould

Let us admit that our alloy possesses small linear shrinkage, so we should not use a riser and, hence, opt for the second position which provides equal distribution of metal in half-moulds.

The next step: we see that surfaces A, B, C, D have to undergo machine tool operations. Proceeding from this we ought to specify reference book indices: machining allowance; overlaps (flute B and holes D are not available to be produced as-cast, they are formed by turning and drilling); foundry slopes to ensure the pattern to be removed from the mould (slopes are normally equal to 1...3°).

Then, using reference book, we have to calculate sizes of *gating system*, i.e. set of channels, to feed molten metal into the mould cavity (Fig. 3.6): a *pouring basin (cup)* 1, a *downgate* 2, a *dirt trap (crossgate)* 3, *ingates* 4.

Patternmaking. A *pattern* serves for receiving of hole (cavity) of definite shape in the mould i.e. to make an imprint in the mould that conforms to the shape of the casting to be made. Thus, the shape of a pattern supposes to accommodate the casting's shape. Patterns are made of wood in small scale (individual) production and of metal and plastics in mass production of castings.

According to the selected technology we have to manufacture the pattern consisted of two parts or *split pattern* (Fig. 3.7). Pattern's dimensions are in excess of casting's ones by shrinkage value. *Gating system* patterns are needed to make in the mould cast channels for feeding mould cavity by liquid metal. Then *core box* is made (consists) of two parts (in our case). *Flasks* are intended to hold the mould and are also prepared.

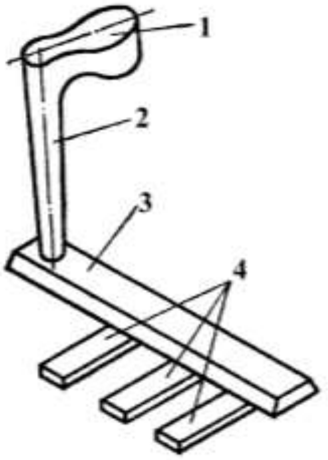


Fig. 3.6. Gating system: 1 – pouring basing; 2 – downgate; 3 – crossgate; 4 – ingates

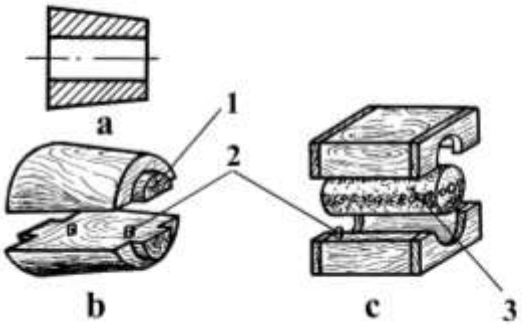


Fig. 3.7. Casting (a), pattern (b) and core box (c): 1-core print; 2-slotted key; 3-core

Preparation of *moulding* and *core sands*. Mould and core sands (mixtures) consist of:

- *fireproof base* (silica sand SiO_2, alumina $A1_2O_3$, chromite Cr_2O_3, powders of magnesite, chromomagnesite and so on);
- *binder*: fireproof clay which is hydrated silicate of alumina: $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ (caolinite) or $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$ (bentonite); water glass $Na_2O \cdot mSiO_2$ or $K_2O \cdot nSiO_2$; dextrine; molasses; vegetable oils; sinthetic resins;
- *technological additions* (water, graphite powder, mineral oils, wood sawdust and others).

Classical, widely used and the cheapest moulding sand consists of: 6...10% fireclay, 4...6% H_2O, SiO_2-rest.

Owing to hindering properties of fireclay (or another binder) the sand grains are connected with each other, thus imparting strength to the mixture. Due to pores (pockets) between grains the mixture possesses *gas permeability* (gases can pass through the sand). The more binder contents the lower gas permeability of the mould mixture.

The following foundry terms are used. *Green sand* is the sand in the green, or undried condition. Casting into green sand or undried moulds is common practice for the majority of small-and medium-sized ferrous and non-ferrous castings.

Dry sand is sand from which all the free, or uncombined moisture has been removed by heating in a drying oven or stove.

Facing sand is used in green state against the face of the pattern and forms the face of the mould. It is of high quality.

Backing or *floor sand* is sand from cast-up moulds, it is used several times to fill the flask over the facing layer.

Facing and backing sands are used in individual production. In mass production, (machine moulding) *unit sand* is used. It has a high quality (similar to the facing sand).

Core sand is used for cores manufacture to produce hollow castings. Core sand is usually used as dry sand because core is surrounded by molten metal. For *compliance* (*deformability*) of cores during solidification and shrinkage of castings the wood powder (sawdust) is used.

Mould and core sands are prepared by special equipment: edge-runner mills, aerators, hoppers, conveyors and others.

Main operation of mould and core sands preparation is mixing of the components.

Moulding. Let us consider the moulding process step by step (Fig. 3.8).

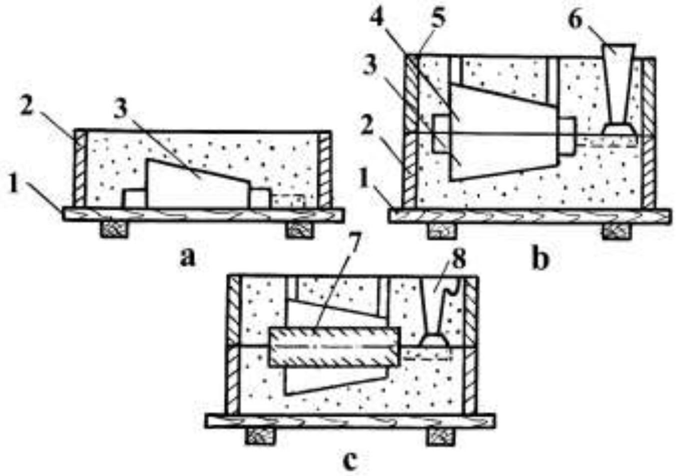


Fig. 3.8. Moulding process: a-drag moulding; b-cope moulding; c-assembled mould:
1 –board; 2, 5 – flasks; 3,4 – parts of a pattern; 6 – gating system pattern; 7 – core; 8 – gating system

A *ramming-up board* 1 is placed on a table, and lower part of a pattern 3 and a flask 2 are placed on the board. Then pattern is covered by facing sand and by backing sand. Facing and baking sands are rammed by hand or pheumatic rammer.

After ramming of sand the superfluous mixture is removed by a ruler, drag is turned over and the second part of the pattern 4, gating system patterns 6 and the next flask 5 are mounted. The flask is filled up by facing and backing sand and rammed.

So the upper part of the mould (cope) is prepared. Then the cope is lifted and parts of the pattern are removed from the half-moulds. The foundry slopes enable to remove patterns without the mould's damage.

Cores are made similar to the mould. The mould assembly consists of installation of core 7, mounting the cope, fastening the half-moulds by clamps or loading them by pouring weight. *Clamps* and *pouring weight* prevent lifting of the cope by liquid metal.

Sand moulds and cores are used one time. After pouring and crystallization of the casting the mould is destroyed by *shaking out* operation. Shaking out of castings is carried out using *pneumatic knock-out* (individual production) or *jolting knock-out grid* (mass production) (Fig. 3.9).

Cutting off the gating systems, risers and fins are carried out by *hammers*, *mechanical saws*, *pneumatic* or *hydraulic presses*. *Fins* are removed by *pneumatic chisels* or by *grinding machines*.

After inspection to reveal defects, chemical analysis and mechanical tests the required *heat-treatment* is conducted. Next operation is *fettling* of castings to remove burning-on scale and oxide films from the casting's surface. This work is carried out by *shot blasting (blast cleaning)*, *hydroblasting* and *tumbling (rumbling).*

Finally inspection (visual, pressure test, X-ray screening, etc.), finishing operations (painting, branding, etc) and *shipment* are performed.

Up to 70...75% of castings are produced in sand moulds. Hence, this is the main casting method. Its advantages were listed in section 3.1.

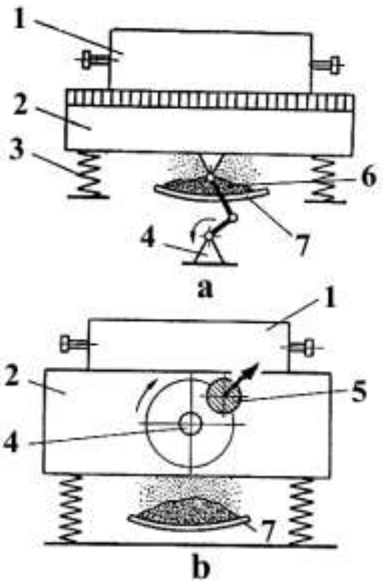


Fig. 3.9. Off centre (a) and inertion (b) jolting knok-out grids:
1-mould; 2-grid; 3-spring; 4-drive; 5-inertion load; 6-sand; 7-sand-trap

The disadvantages of sand mould casting are as follows:

- moulds and cores are used one time;
- still relatively high manual labor consumption and *environment pollution* (dust, evaporations);
- low dimensional accuracy of castings and respectively high machining allowances.

To avoid these disadvantages the special methods of castings have been proposed.

3.3 Shell-Moulding Process

The shell-moulding process (shell-mould casting) was developed in Germany during the second word war (introduced in the USSR in 1950 on Leningrad carburetor plant).

The principal characteristics of the process are:

- production of castings with high standard of surface finish and dimensional accuracy;
- high productivity from a small floor space;
- reduction in mould and core sands consumption up to 10 times.

In conventional sand moulding the sand grains are bonded by clay, whereas, in shell moulding the clay is replaced by a synthetic resin. The shell-moulding mixture consists of 6...7 % of synthetic resin (phenolformaldehyde resin) and fine grain sand as a rest. Low thickness of shell mould (6 to 20 mm) does not prevent gas evacuation and allows to use a fine grain sand (silica, magnesite or zirconium sands).

Figure 3.10 shows the successive steps of shell-making.

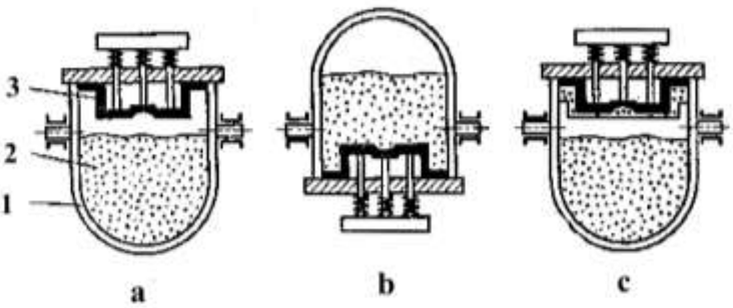


Fig. 3.10. Shell making process: a – initial position; b – shell formation;
c – a shell on the pattern and pattern plate; 1 – box; 2 – sand-resin mixture; 3 – pattern

The metal pattern plate and pattern 3 are preheated to 200...220°C by electric heaters and placed with the pattern facing downward on top of a turning dump box 1 filled with sand-resin mixture 2. The box is turned over and resin-sand mixture covers the pattern by a layer of about 350...400 mm. The hot plate and pattern causes the resin to soften and flow with sand grains producing precise imprint of the pattern. Chemical reactions take place in the heated resin that enables to bond grains of sand. After about 20 seconds changes are only partially completed, but the shell is formed. Next, the dump box is inverted, the shell of sand, bonded by the partly cured resin, adheres to the pattern plate, the remainder of the mixture falls back into container and is available for subsequent use. The pattern is placed in an oven for final solidification (curing). This is carried out at about 400°C and may take up to 2 min. When curing is completed the shell is hard and rigid and can be stripped from the pattern by means of spring-loaded ejector pins.

Two such shells form a complete mould and are mutually fixed by gluing or by clamps before being poured. As a rule shell moulds are surrounded in a box by sand or by cast iron shot before pouring (Fig. 3.11). After hot metal pouring resin burns, shell mould is destroyed and shake out operation is not required.

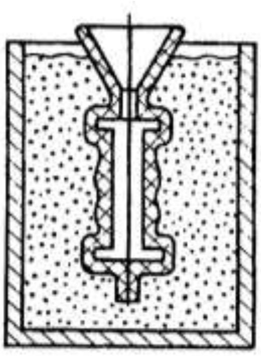


Fig. 3.11. Shell mould

Main disadvantage of the method is high price of phenolformaldehyde resin and pulverbakelite. For this reason mass of castings does not exceed 100kg. Usually, the shell-moulding process is mechanized and automatized.

3.4. Metal Mould Casting

Unlike the ordinary sand mould process, the molten alloy is poured in metal mould, named *permanent mould*, or *gravity die* (Fig. 3.12). About 15% of castings are produced using this method. The pattern is not needed. Both metal and sand cores are used to make cavities in cast pieces.

The metal mould life is equal to: dozens and hundreds of thousand castings produced when Al and Mg alloys are poured; thousands castings produced of Cu-alloys and cast iron; hundreds castings produced of steel.

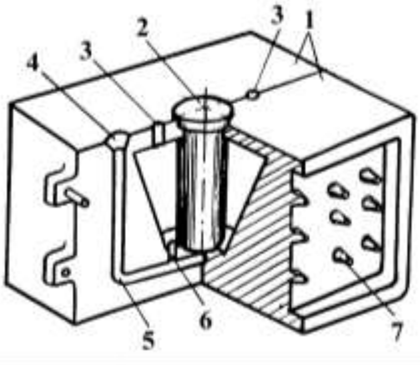


Fig. 3.12. Metal (chill) mould: 1-half-moulds; 2-core; 3-gas relief sprue; 4-pouring basin; 5-downgate; 6-ingate (runner); 7-dowels for high-rate heat removal

The advantages of the method are the following:

- the metal mould is used repeatedly to obtain large number of castings;
- stable sizes of the metal mould provide stable sizes of casting and small machining allowance;
- high heat conductivity of the metal mould provides high rate of crystallization, high density, fine structure and high mechanical and service properties;
- structure segregation is developed rarely;
- sand mixes are not used or used in small quantities;
- high production rate from a small floor space;
- patternless method.

The disadvantages of the method are characterized by the following facts:

- the metal mould does not possess gas permeability that sometimes provokes gas porosity in castings;
- the metal mould is rigid, i.e. is not compliant to shrinkage and may cause casting's cracking;
- cast iron *chilling* appears sometimes as a sequence of high cooling rate.

To prevent cast iron chilling and increase service life the moulds are heated to 150...450°C and painted with refractory paint before pouring. About 45 % of aluminium and magnesium, 30 % of copper, 12 % of cast iron and 6 % of steel castings are produced in metal moulds.

Usually metal mould machines are used. They may be mechanized, semi-automatic and automatic machines.

Metal moulds are normally made of cast iron. Sometimes steel is used. But cast iron has better service properties and lower price.

3.5. Centrifugal Casting (Spinning)

This method is used to manufacture hollow castings, which have a shape of rotating bodies. Two modifications of the method are distinguished: with *vertical* and *horizontal axes of rotation* (Fig. 3.13).

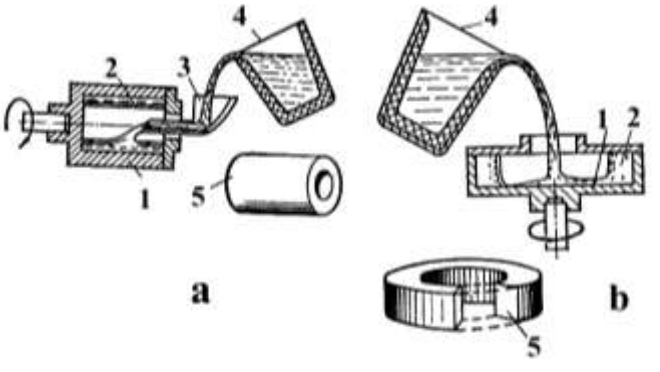


Fig. 3.13. Centrifugal casting with horizontal (a) and vertical(b) axes of rotation:
1 – mould; 2 – liquid metal; 3 – spout; 4 – ladle; 5 – casting

Ingot moulds are made of cast iron. They are heated (150...450°C) and painted by refractory mixture (paint) before pouring of metal.

Method with vertical axis of rotation is used for production of castings small in height, because inner surface of the casting acquires paraboloid shape and lower diameter of hollow is less than upper one.

The second method is used for castings of significant length production, e.g. hydrostatic pressure and overflow pipes. They have length from 3 to 12 meters. Advantages of the methods:

- high density of metal due to the action of centrifugal forces;
- reduced metal consumption, because a gating system is absent;

- inner hollow in castings is received without using of cores;
- a mould is easily filled by molten metal under the action of centrifugal forces;
- a patternless method.

The disadvantages are as follows:
- low dimensional accuracy of inner surface;
- inner surface is contaminated by segregation products and non-metallic inclusions.

3.6. Pressure-Die Casting

Method has the highest output from 200 to 400 castings per hour. Sand mixtures are not applicable for the method. Crystallization of castings is carried out in a metal mould, named press-mould. Essence (main point) of the method is that liquid or both liquid and solid metal is pressed into press-mould under high pressure (30...300 MPa) and with high speed (0.5...140 m/sec). Mass of castings may be from a few grams to several tens kilograms. Alloys of zinc (very often), aluminium (often), magnesium (often), copper (sometimes), iron (very seldom) base are used.

The casting's nomenclature ranges from part of a zipper to automobile block of cylinders.

Automatic or semi-automatic plunger machines with cold and hot pressing chambers are employed (Fig. 3.14).

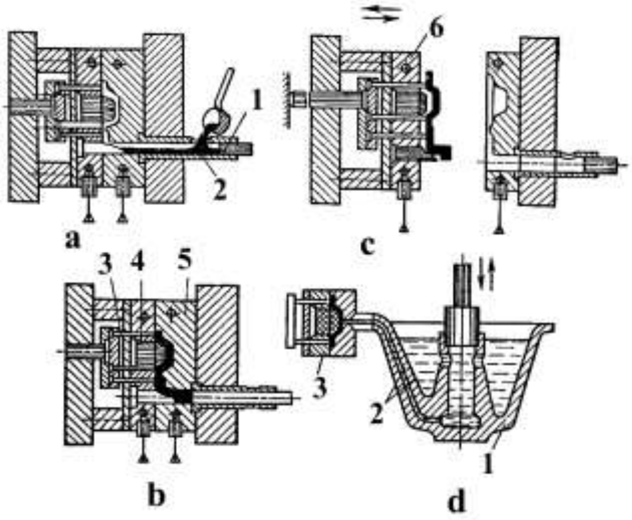


Fig. 3.14. Plunger machines with cold (a, b, c) and hot (d) pressing chambers: a…c: 1- plunger; 2 – pressing chamber; 3 – pusher; 4 – metallic core; 5 – removable half-mould; 6 – irremovable half-mould; d: 1 – heating crucible; 2 – metal-conductor; 3 – press-mould

In the first type machine the metal together with air by a plunger 1 is pressed into mould 2 and solidifies under pressure. Compressed gases dissolve in metal and the casting acquires normal density. But further heat-treatment is not available, because gas holes are formed at high temperature.

In the second type machine the metal is pressed into a mould 3 without any gases, but plunger and chamber work at high temperature, in liquid metal and by this reason they are rapidly damaged.

The advantages of the method:
- very high productivity;
- sand mixture isn't used at all;
- dimensional accuracy is very high (for example, screw thread may be received);
- thickness of casting may be 1 mm and less;
- patternless method.

The disadvantages of pressure die-casting:
- high cost of press-moulds;
- short service life of press-moulds;
- powerful machines are required to produce medium mass castings.

3.7. Investment Casting

This is one of the oldest casting methods. *Expendable (investment) patterns* are mostly prepared of waxlike materials. The essence of the method:

- a pattern is made of easily meltable material;
- the pattern is covered by refractory layer;
- the pattern is removed (melted);
- a *shell mould* is preheated to remove the pattern rest;
- a metal is poured in hot mould.

The method enables to manufacture castings very complicated in shape. That is why it is used, first of all, for casting of monuments. In the prehistoric, ancient and the Middle Ages and later the wax was used as a pattern material. Now oil product, such as *paraffin*, *stearin; pine-tree product*, such as *rosin*, and so on are used.

Investment casting appeared in foundry practice 50 years ago when new binder *ethylsilicate* was found out.

Manufacturing process consists of (Fig. 3.15):

- pattern-making in metallic moulds; the pattern mix, which has melting point about 50°C, is pressed into a mould;
- removing of patterns from the mould after solidification;
- assembly of paraffin-stearin patterns in blocks by soldering method (using a heated knife);
- dipping a *pattern complete* set in *refractory suspension*, which consists of *silica flour and ethysilicate*;
- dipping the pattern complete set in fluidized sand;
- chemical drying of suspension and sand layer;
- manufacturing of new layer (from 5 to 15);
- dipping of the pattern complete set with refractory shell into boiling water to remove the pattern mix;

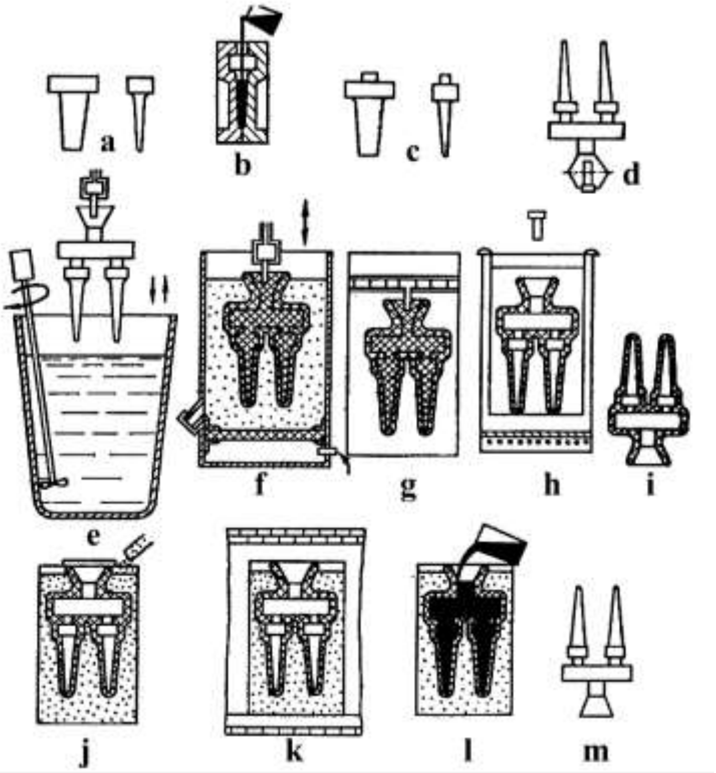


Fig. 3.15. Investment casting process: a – part; b – pattern-making; c – pattern; d-pattern complete; e – dipping in suspension; f – dipping in fluidized sand; h – chemical drying; i – removing the pattern mix; j – setting of the block into steel box; k – heating of box; l – pouring of a metal; m – castings with gating system

- settling of shell moulds into steel box and filling box by sand;
- heating of boxes with the moulds to 800...850°C to remove pattern remains from the moulds;
- pouring of a metal into heated moulds;
- destroying of the moulds and cutting off the gating, inspection, heat treatment and finishing operations.

Investment casting provides high dimensional accuracy (similar to pressure-die casting), but it is the most complicated method of foundry. Hence, using of it is profitable in the mass production, especially in production of castings of alloys with high melting point (steels, Ni-alloys, Mo-alloys).

Mass of castings varies from several grams to a few kilograms.

Advantages:

- high dimensional accuracy and surface quality;
- possibility to produce castings, which have a very complicated shape;
- possibility to mechanize and automatize practically all operations.

Disadvantages:

- very complex process;
- small mass of castings.

3.8. Modern Processes of Metal Production for Castings

The most common foundry metals are cast irons, steels, bronzes, brasses, aluminium, magnesium and titanium alloys. The structure of alloys in our country and abroad is shown in table 3.1

Table 3.1 - Structure of foundry alloys in various countries

Alloys	Ukraine	USA, Germany, Japan
Grey cast iron	64…65	43…52
Nodular (high-strength) cast iron	1.3…1.5	26...38
Malleable cast iron	3	1...3
Steel	23…25	5...10
Non-ferrous alloys	3…5	18...30

Grey cast iron is considered to be the most frequently used cast engineering material. It has high foundry properties, low cost and low mechanical properties. Nodular (high-streagth) cast iron has the same chemical composition as grey cast iron, except small content of modifier (0.03…0.07% magnesium). Owing to this, the costs of these two alloys have small difference. But high-strength cast iron has high mechanical properties and very often is used in machinery instead more expensive steels.

The tendency of using the non-ferrous alloys, especially aluminium ones, instead steels and cast irons had development in many countries last years. The aluminium alloys have small mass density γ=2.7 g/cm^3 (steels have γ=7.8 g/cm^3) and high specific strength σ_u/γ. The replacement of steels and cast irons by the aluminium alloys gives a chance to machine's mass decrease and improve its quality and efficiency.

As we can see (table 3.1), Ukrainian machinery does not realize the possibility for improvement of its production quality by changing of the foundry alloys structure.

3.8.1. Cast Iron Production for Castings

Iron-carbon alloys where carbon content is higher than solubility in austenite, i.e. greater than 2.14 %, are called *cast irons*. Real cast irons have the composition: 2.2...4.5 % C, 0.5...3.5 % Si, 0.5...1.2 % Mn, 0.01...0.20 % S, 0.03...1.20 % P. The most important indices of quality for non-alloyed cast irons are the carbon state (the amount of combined carbon), shape of graphite inclusions and state of metal matrix.

The following cast irons are distinguished: *white, mottled, chilled, grey, malleable, nodular (or high-strength) ones.*

All carbon is chemically combined in white cast iron. Correspondingly, all carbon is in the form of graphite in ferritic cast iron. Amount of chemically combined carbon in grey pearlitic cast iron is equal to 0.8 %.

Carbon, silicon, aluminium promote graphitization. Chromium, manganese, vanadium, titanium, sulphur prevent this process.

A distinction is made between *ferrite, pearlite* and *ferrite-pearlite structures.*

Up to the recent years the most commonly used furnace to melt grey cast iron is a cupola, where about 70 per cent of this alloy used to manufacture of castings is smelted.

A cupola (Fig. 3.16) is a typical shaft furnace (like a blast furnace): its design comprises a vertical pipe (steel shell) 8 on columns 2. But unlike the blast furnace only metal remelting process takes place in the cupola.

Cupola charge consists of: ~35 % foundry iron (ingots); -30 % cast iron scrap; -15 % steel scrap; -15 % coke (fuel); -5 % limestone $CaCO_3$ (flux).

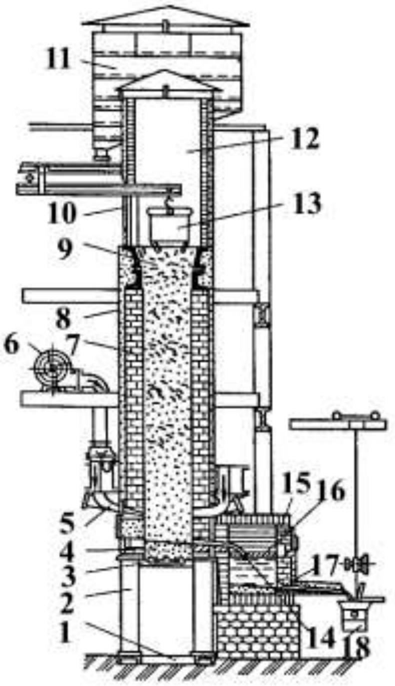


Fig. 3.16. Cupola: 1 – fundament; 2 – column; 3 – folding cover; 4 – bottom; 5 – air tuyere; 6 – ventilator; 7 – refractory lining; 8 – steel shell of shaft; 9 – cast iron plates; 10 – charging window; 11 – spark extinguish; 12 – pipe; 13 – charging bucket; 14 – taphole; 15 – receiver; 16 – slag taphole; 17 – cast iron taphole; 18 – ladle

The cupola has a refractory lining 7 inside and a window 10 for charging a furnace burden. Compressed air is given from compressor 6 through a pipe, wind box and tuyeres 5 into the cupola. Air is necessary for coke burning and high temperature (~1700°C) attainment. Metal charge is melted at high temperature. Besides that metal absorbs carbon and sulphur of coke. This is the main disadvantage of the cupola. From the cupola cast iron drains through an intermediate taphole 14 into a receiver 15, than through taphole 17 it is tapped into a ladle 18. When the cupola is without the receiver, cast iron fills up a hearth (lower part) of the cupola. To tap metal from the receiver, the tap hole is opened by picking up a bott. The slag is removed through the slag hole.

When melting process is finished the locking bar is displaced, bottom plates 3 are turned and rest of charge is withdrawn. Next, repair of the cupola lining is accomplished.

The cupola is a furnace of permanent action but usually its working time ranges from 8 hours to 7 days. It is distinguished by simple design and high efficiency (about 40%). The main disadvantages of the cupola are:

- absorption of carbon by cast iron and difficulties in production of low-carbon cast iron (the less carbon content the higher mechanical properties);
- molten cast iron absorbs sulphur which decreases properties of iron and is a reason of red (hot) shortness;
- it is difficult to control and change chemical composition of cast iron;
- it is difficult to overheat cast iron more than 1420...1430°C;
- high content of CO (9...12 %), SO_2 (1...2 %) and dust (20 g/m^3) in waste gases and consequent ecological problems.

For these reasons electrical furnaces, such as *electric arc and induction units*, are used to melt cast iron. To meet high demands of developed up-to-date technology the electric furnaces are the most satisfactory melting units, because:

- coke, rich in sulphur, isn't consumed, providing therefore cast irons with less carbon and sulphur content and consequently high mechanical properties to be obtained;
- electric furnaces give a possibility to overheat metal up to demanded temperature.

Design and operation of electric-arc furnace were considered in part "Metallurgy".

Figure 3.17 portrays crucible (coreless) induction furnace comprises the following principal units: metallic carcass, inductor 1, rammed crucible 2, axis of furnace tilting mechanism, lip, metal 3, electric generator (high-frequency) or transformer (main-frequency) switch board.

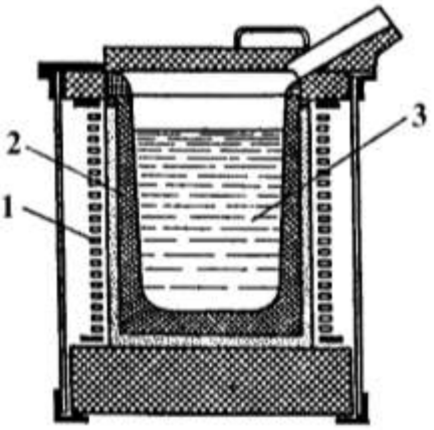


Fig. 3.17. Induction furnace: 1 – inductor; 2 – crucible; 3 – metal (charge)

The induction furnace operates as a transformer without an iron core, the primary winding of which is a multiturn coil-inductor 1 and the secondary winding and the load at the same time is the metal to be melted.

The higher frequency the smaller pieces of charge may be heated and melted. For this reason small capacity furnaces with high frequency generator are used. But induction furnaces of high capacity (1...30 tons) are equipped with transformers and sometimes triple frequency multipliers (150 Hz). Piece of charge, not less than 250 mm in size may be melt in mains-frequency furnace.

Cast iron melted in electric-arc and induction furnaces has higher mechanical and service properties than the one produced in the cupola.

A charge in electric furnaces consists of steel and iron scrap, foundry iron, ferromanganese, ferrosilicon and other ferroalloys. When basic lining is used, sulphur and phosphorus may be removed from metal.

Nodular Cast Iron Production. Nodular, or high-duty, or high-strength cast iron with spheroidal graphite has the same chemical composition as grey cast iron, except sulphur content, which is lower in nodular cast iron (0.8...0.12 % S in grey cast iron and 0.01...0.02 % S in nodular one). Unlike grey cast iron, which has lamellar graphite, nodular cast iron contains spheroidal graphite and, due to this reason, has higher mechanical properties. To convert lamellar graphite in spheroidal foundrymen carry out inoculation procedure, i.e. they add inoculator (magnesium, cerium, lanthanum, yttrium) in liquid cast iron. Inoculator reacts with sulphur in metal:

$$2[\mathrm{Mg}]+3[\mathrm{FeS}]\rightarrow(\mathrm{Mg_2S_3})+3[\mathrm{Fe}] \qquad (3.3)$$

So, low sulphur content ensures obtaining of spheroidal graphite. That is why metal for nodular cast iron is melted in induction or electric-arc furnaces to prevent its saturation with sulphur. Nodular cast iron has ferrite or pearlite, or ferrite-pearlite metal matrix structure and globular graphite inclusions. In case of heat-treatment *martensite, troostite,* or *sorbite structure* may be received.

Malleable cast iron is produced by annealing of white cast iron. The less amount of carbon and silicon in iron, the more easily the white cast iron may be produced. Therefore liquid metal contains 2.2...2.9 % C and 0.8...1.4 % Si. Thickness of casting should not exceed 50...60 mm. It is very difficult to receive low carbon content in cupola cast iron, because coke saturates liquid metal with carbon. Thus, induction and electric-arc furnaces are used to smelt metal in malleable cast iron production. Sometimes *duplex-process* (cupola and electric-arc furnace) is used. Cast iron from the cupola is poured into arc furnace, where it is overheated. The carbon content in it is lowered by steel scrap additions in the furnace. Malleable cast iron possesses intermediate foundry properties between grey cast iron and carbon steel. Castings are normally manufactured with risers.

Sand, metallic, shell and centrifugal moulds may be employed for iron casting.

3.8.2. Steel Castings Production

Cast steels are divided into carbon and alloy steels. The grade of cast steel is marked by the letter Л (cast):

- carbon steels: 40Л, 35Л, 25Л;
- alloy steels: 30Х2НВЛ.

Unlike cast iron steel has worse foundry properties: high melting point (~1500°C), high shrinkage ($\varepsilon_l \approx 1.5...2.5$ %, $\varepsilon_v \approx 5...8$ %). But steel is distinguished by its high mechanical properties: $\sigma_U = 500...2500$ MPa, δ up to 30%, φ up to 50 %. Steel castings are usually supplied with risers. They are intended to produce parts designed for operation in severe service conditions.

The electric-arc furnaces and, sometimes, induction coreless high-frequency furnaces are used to melt steel for castings.

Sulphur and phosphorus may be removed from steel in basic electric-arc furnaces. Induction furnaces are used as remelting units only. Sand, investment, shell and, sometimes, metal moulds may be used.

3.8.3. Melting of Copper-Base Alloys

Two types of copper-base alloys are mainly employed:

- *brasses*, alloys of copper with zinc and other elements (Al, Fe, Mn, Pb, Si);
- *bronzes*, alloys of copper with tin and other elements (Ni, Sn, Pb, Zn, Al, Si, Mn, Be), among which there may be zinc, but only in combination with other elements and in small quantities.

Copper-base alloys have good wear and corrosion resistance in atmosphere, fresh and sea water, and other aggressive media.

Melting point of copper alloys is about 1100°C, pouring temperature is about 1200°C. They have relatively good casting properties: high fluidity, medium shrinkage (ε_l=1.4...1.7 %, up to 2.5 %, only for some alloys).

Furnaces of different types and design are used to melt copper-base alloys. *Flame furnaces* as well as electrical-both *arc and induction furnaces* are most frequently used for this purpose. In small scale foundries *crucible furnaces* are mainly employed.

Many elements, such as Zn, Si, Al and others, are easily oxidized. Some of them even evaporate. What is more, some elements comprising copper-base alloys in liquid state tend to gas absorption from the furnace atmosphere, especially hydrogen.

Thus, melting furnaces should provide the possibility of rapid melting with minimum losses of easy-oxidizing and evaporating components as well as of protecting metal against hydrogen saturation.

To protect metal against oxidizing and hydrogen saturation, melting of copper-base alloys is done under fluxes, comprising charcoal, chlorides, fluorides, soda glass and other components.

Reverberatory furnaces may be stationary or tilting (Fig. 3.18) and are used in those cases when it is necessary to produce a great amount of metal.

This type of furnaces is mostly oil- or gas-fired. In reverberatory furnace metal and slag are melted due to direct contact with gases and heat from the roof and walls radiated downward on the charge. The furnace (in our case the tilting one) is burned by jet 1, which is supplied by oil or gas. Combustion gases pass through a combustion chamber 2, melting chamber 3 and tapping throat 4 into exhaust pipe.

Contact of large metal surface with furnace gases is a major disadvantage of these furnaces, as it facilitates metal saturation with gases and causes high metal losses.

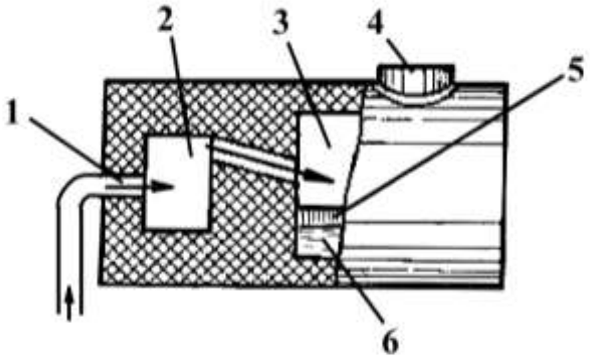


Fig. 3.18. Tilting reverberatory furnace: 1 – yet; 2 – combustion chamber; 3 – melting chamber; 4 – tapping throat; 5 – slag; 6 – metal

Electrical arc furnaces of indirect heating (Fig. 3.19) are the mostly used furnaces to melt copper-base alloys. Electrical arc is formed between two horizontal electrodes 1 and is located at a certain distance from the metal surface. Metal heating takes place on the account of the heat radiation from electrical arc and red-hot lining surface.

Disadvantages of the arc furnaces are noise, caused by the electric arc; high temperature of electric arc (~3000°C), which facilitates metal burning, its evaporating and quick wear of lining.

Induction furnaces are divided into *coreless high and mains-frequency and mains-frequency with steel core.* A furnace with the steel core 1 (Fig. 3.20) represents as if step-down transformer where metal in the furnace is a secondary winding.

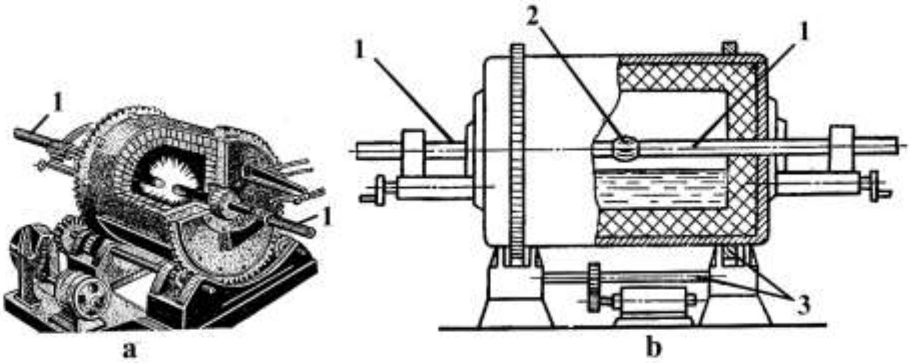


Fig. 3.19. Electric arc furnace of indirect heating a – drawing; b - scheme: 1 – electrode; 2 – electric arc; 3 – tilting mechanism

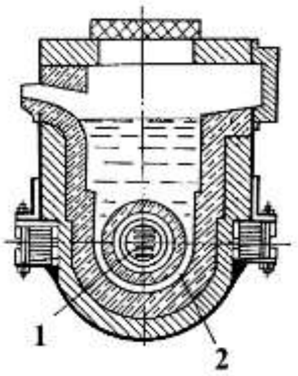


Fig. 3.20. Induction furnace with the steel core: 1 – steel core; 2 – metal channel

Transformation of electrical energy into thermal one in these furnaces is performed in the following way. Mains-frequency current in a primary winding causes a magnetic flux around it closing through a steel core of the transformer and inducing secondary current in the metal present in a ring-like channel 2. Metal in the channel is melted, preheated, moves around core 1 and heats the metal into crucible. So we have metal circulation in the furnace.

Peculiarity of melting in induction furnaces with the steel core lies in the following: liquid metal filling bottom ducts should remain in the furnace after tapping to form a closed electrical circuit during the next heat. Due to this reason it is difficult to pass over from one alloy grade to another.

Crucible furnaces are used for melting small amounts of certain foundry alloys. Crucible furnaces may be either stationary or rotary. They are fired by liquid, gaseous or solid fuel.

Figure 3.21 represents a crucible furnace.

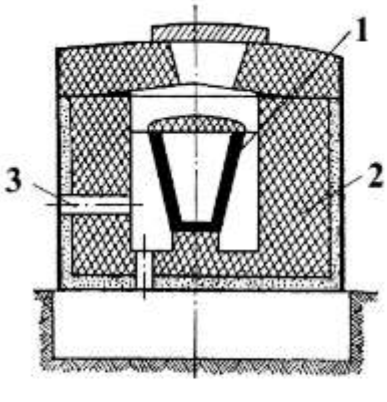


Fig. 3.21. Crucible furnace: 1 – crucible; 2 – furnace; 3 – hole for flame jet

Deoxidation and Refining of Copper -Base Alloys. The charge melting in the furnace reacts with furnace atmosphere, lining and fluxes. As a result, some elements and their compounds transfer to molten metal, slag and gaseous atmosphere.

Presence of soluble and nonsoluble oxides in metal causes decrease in physical and mechanical properties and formation of defects in castings (gas porosity, slag holes, etc.). To improve quality of castings deoxidation of alloys is performed.

Deoxidizers for copper-base alloys are divided into 2 groups:

- surface-active and non-soluble in metal;
- soluble in liquid metal and active inside the alloy.

Surface-active deoxidizers are calcium carbide (CaC_2), magnesium boride (Mg_3B_2), carbon (C) and liquid boric slag. They are milled and given on the surface of metal:

$$5(Cu_2O)+(CaC_2)=(CaO)+2\{CO_2\}+10[Cu] \quad (3.4)$$

$$6(Cu_20)+(Mg_3B_2)=3(MgO)+(B_20_3)+12[Cu] \quad (3.5)$$

$$2(\mathrm{Cu_2O}) + (\mathrm{C}) = \{\mathrm{CO_2}\} + 4[\mathrm{Cu}] \tag{3.6}$$

The most commonly soluble deoxidizer of Cu-base alloys is phosphorous consumed in the form of foundry alloy (~10 % P, 90 % Cu):

$$5(\mathrm{Cu_2 0}) + 2[\mathrm{P}] = \{\mathrm{P_2 0_5}\} + 10[\mathrm{Cu}] \tag{3.7}$$

Refining is a process of cleaning of liquid alloy from hard oxides, slag particles and gases. More efficient refining process is flotation (Fig. 3.22). It consists of blowing neutral gases (N_2, Ar) through the liquid alloy or introducing different substances into it in oredr to obtain as a result products of gaseous or vaporous nature (e. g. P_2O_5). Gas or vapor bubbles floating up to the metal surface carry away non-metallic inclusions and penetrating inside bubbles gases (H_2).

Sand, metal, investment, shell and centrifugal moulds are employed.

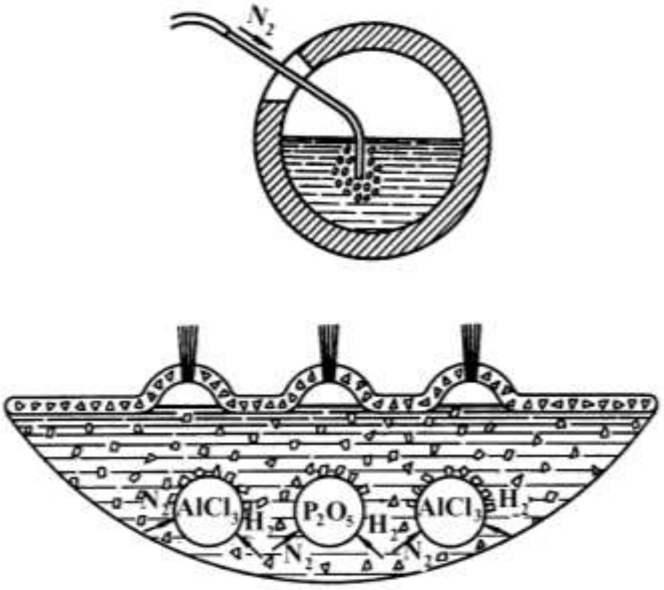


Fig. 3.22. Flotation refining process

3.8.4. Melting of Aluminum-Base Alloys

Aluminum-base alloys possess high fluidity, comparatively low shrinkage ($\varepsilon_1 \approx 1\%$), low tendency to form hot cracks and porosity, and low melting point (~650°C). Al-alloys have good mechanical properties, high corrosion resistance and low density (2.7 g/cm^3). The most widely used alloys are Al-Si (6...22 % Si), Al-Cu (3.6...6.0 % Cu), Al-Mg (9.5...11.5 % Mg), Al-Si-Cu, Al-Si-Cu-Mg and others alloys.

Inoculants, such as Ti, Zr, B and V (0.05...0.15 %) are added to the alloys to refine grains and consequently, to improve mechanical properties.

Different furnaces are used to prepare Al-base alloys. In small-scale foundries they are crucible (stationary and tilting) furnaces with solid, liquid fuels or gas-fired. In large-scale foundries stationary *flame furnaces* as well as *electric resistance* and induction furnaces are used.

Design of furnaces for melting Al-base alloys is the same as for Cu-base alloys. But in crucible and induction furnaces crucibles are made of cast iron or graphite-chamotte mixture. Working surface of cast iron crusibles is painted to prevent dilution (paint: chalk, zinc oxide, water glass, water).

Figure 3.23 represents a reverberatory electrical resistance-tilting furnace for melting Al-alloys.

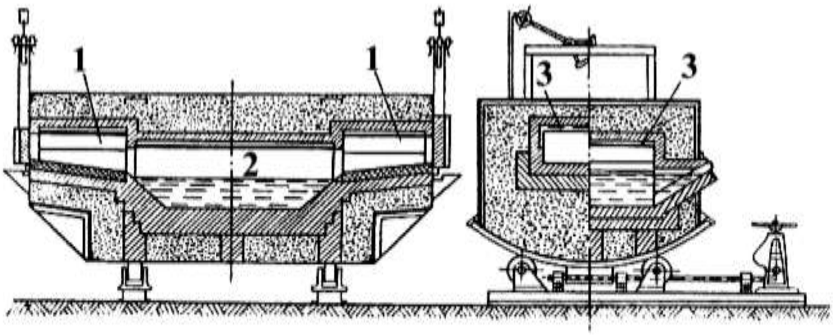


Fig. 3.23. Reverberatory electrical resistance furnace:
1 – charging window; 2 – bath; 3 – heating elements

The following techniques of Al-alloys treatment in addition to special measures for preparation of the furnaces, charge and melt under coating effluxes are applied:

- *degassing* for the purpose of gas removal from the alloy;
- *inoculation* to get fine grain structure with improved mechanical properties. Degassing is carried out by chlorine, which forms aluminum chloride. Bubbles of aluminum chloride carry away the hydrogen, the nitrogen and oxides from metal (Fig. 3.24).

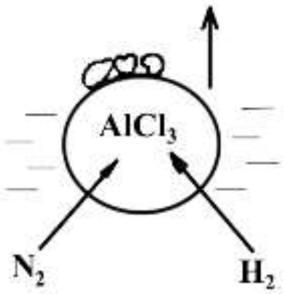


Fig. 3.24. Principle of degassing

After degassing inoculation treatment is carried out by adding inoculants in liquid Al-alloys or by keeping liquid metal under inoculating mixes consisting of fluorides and chlorides (CaF_2, $MnCl_2$, NaCl, $ZnCl_2$, etc.):

$$(\mathrm{NaCl})+[\mathrm{Al}]\rightarrow\{\mathrm{AlCl_3}\}+[\mathrm{Na}] \tag{3.8}$$

where $AlCl_3$ is refining gas, Na is inoculant.

Metallic, sand (intricate castings), pressure-die and centrifugal moulds are used for Al-base alloys pouring.

3.8.5. Melting of Magnesium-Base Alloys

Magnesium is an element of high chemical activity. It reacts with oxygen, in liquid state very easy catches fire and absorbs hydrogen and nitrogen. Magnesium has good foundry properties like high fluidity, small shrinkage (ε_1= 1.1...1.4 %) and low melting point (651°C). Pouring temperature of Mg-base alloys ranges from 650 to 700 °C.

Cast alloys are alloyed with Al, Zn, Mn, Zr and other elements. By low density (1.7 g/cm^3) they are used in automobile engineering, aircrafts, rockets, etc.

Due to high chemical activity magnesium-base alloys are melted in crucible induction and electric resistance furnaces under slag coating, consisting of chlorides of Mg, K and Na.

During pouring magnesium may catch fire. To prevent this, magnesium stream is powdered by sulphur. Sulphur is burned and gas SO_2 prevents the reaction between magnesium and oxygen. Sulphur and boric acid are added in moulding mixes to prevent burning of magnesium within a mould. Metallic, pressure-die and sand moulds are normally used.

3.8.6. Melting of Titanium-base Alloys

Titanium possesses high melting point equal to 1665°C. In liquid state it reacts with O_2, N_2, H_2 very intensively. Melting and pouring of Ti-alloys is carried out in vacuum induction furnaces (Fig. 3.25).

When melting process is completed the chamber is turned and liquid metal is poured into the mould.

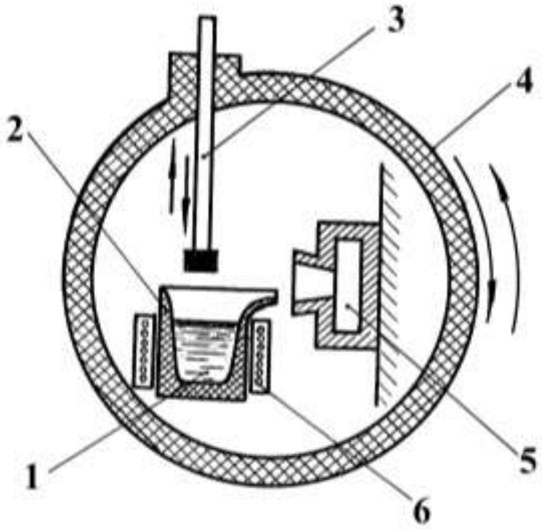


Fig. 3.25. Melting of titanium-base alloys in vacuum: 1 – liquid metal; 2 crucible; 3 – manipulator; 4 - vacuum chamber; 5 - mould; 6 - inductor

4 METAL FORMING

Metal forming, or *plastic metal working,* is based on an ability of metals to get residual plastic deformation by affecting of external forces on a half-finished part. Main advantages of the process are:

- improvement of structure, density, physical and mechanical properties of metals and alloys;
- reducing of metal outlay as compared with cutting (increasing of metal utilization coefficient);
- high labor productivity.

Approximately 90 % of steel and 55 % of non-ferrous metals undergo metal forming operations.

On the base of metal forming new kinds of *heat-mechanical* (*thermomechanical*) *treatment* have been recently found out. These methods are known to be combination of metal forming and heat-treatment and provide regulation of structure, peening (strain hardening) degree and mechanical properties.

4.1. Physical and Mechanical Fundamentals of Metal Forming

The necessary condition for metal forming process is the proper plasticity possessed by material, i.e. ability of material to be deformed under an external load without failure. During forming process elastic and plastic deformations take place.

Elastic strain is a deformation, whose influence on shape, structure and properties of a body completely disappears when external forces causing the deformation are removed. The applied load causes only slight relative and completely reversible displacement of the atoms.

Plastic strain takes place when the shear stresses exceed a certain definite value (elastic limit) and the deformation becomes irreversible (Fig. 4.1). After removement of the load only the elastic component of the deformation is eliminated. The part of the deformation that is called *plastic* or *residua, strain* remains.

During plastic deformation the distances between atoms do not change (practically) and, hence, volume of a deforming body remains constant. This main law of metal forming is used for the definition of a deformation degree. The *deformation degree* represents relative change in cross-sectional area, or dimensions of a half-finished article.

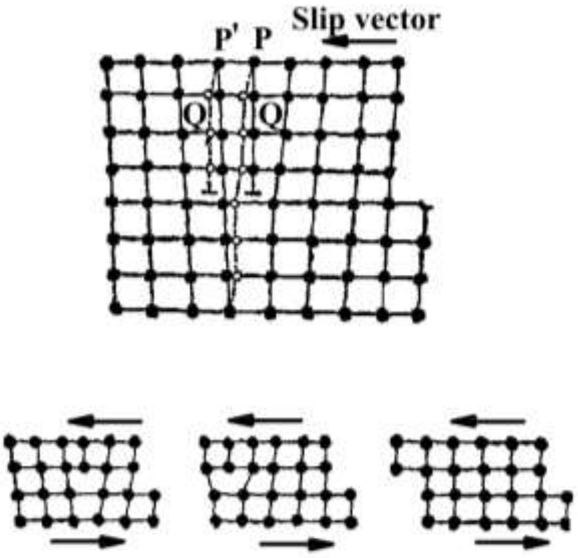


Fig. 4.1. Dislocation mechanism of plastic deformation

Let us assume that we have a prism with 90-degree angles and dimensions before forming A, B, C and after it, correspondingly, a, b, c.

The condition (law) of volume constancy may be expressed as follows:

$$ABC = abc \tag{4.1}$$

Hence, deformation coefficients may be calculated. Coefficient of increase in height (length), or *extension coefficient:*

$$t = b/B = AC/ac = (F_o/F_1) \tag{4.2}$$

Coefficient of *cross section reduction*:

$$\varepsilon = \frac{F_0 - F_1}{F_0} \cdot 100\% = \frac{AB - ab}{AB} \cdot 100\% \tag{4.3}$$

Coefficient of decrease in thickness (in breadth):

$$\mu = C/c = ab/AB \tag{4.4}$$

Changes in the structure of metal in plastic deformation also take place. The shape of metal is changed in plastic working as a result of plastic deformation of each grain. Since the grains are differently oriented, plastic deformation can't occur simultaneously and in the same way throughout the whole volume of the polycrystal.

Owing to slip processes, the grains (crystallites) are changed in shape as a result of considerable deformation (Fig. 4.2). The grains before the deformation are of more or less equiaxed shape (a). As a result of displacement along the slip planes the grains are stretched by deformation in the direction of the acting forces to form a *fibrous* or *banded structure* (b).

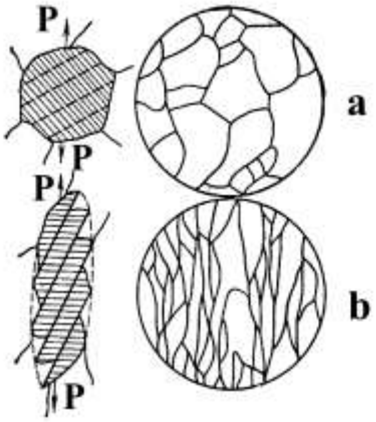


Fig. 4.2. Effect of plastic deformation on microstructure of a metal: a – a grains and structure before deformation; b – the same after deformation

Deformation texture. A high degree of deformation results in preferable crystallographic orientation of the grains. Ordered orientation of the crystallites with respect to the external deforming forces is called *texture (deformation texture).* The formation of the texture promotes *anisotropy* of the mechanical and physical properties. Deformation texture is revealed by etching with special reagents. Orientation of texture must be taken into consideration when parts of machines are produced.

Strain Hardening. With an increase in the degree of deformation (at room temperature), properties, which characterize the resistance of steel to deformation (σ_u, σ_y, HB, etc.), are increased and, on the other hand, the capacity for plastic deformation (percent elongation δ and reduction in area φ) is reduced (Fig. 4.3).

Hardening of metal in the process of plastic deformation takes place due to the increase in the number of defects of crystal structure (dislocations, vacancies and interstitial atoms). All the defects impede motion of the dislocations, thereby increasing resistance to deformation and reducing ductility.

Of prime importance is the increase in dislocation density, which at high degree of deformation may reach extremely high values: 10^{11} to 10^{12} cm^{-2} instead of 10^{6} to 10^{8} cm^{-2} before the deformation.

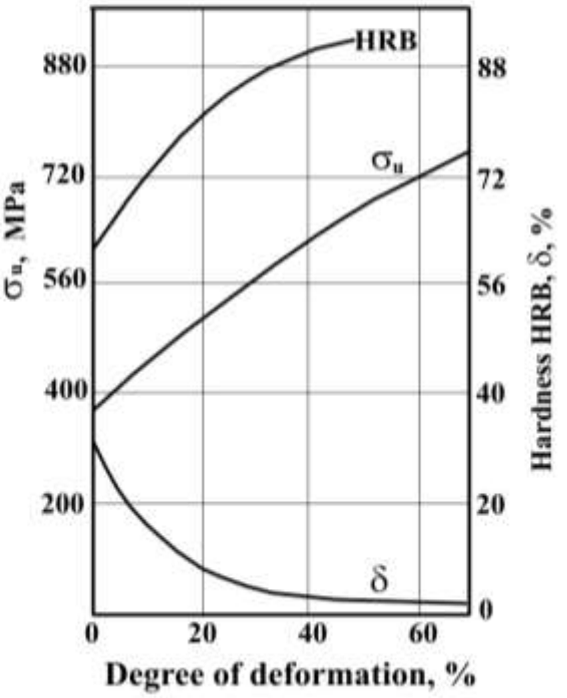


Fig. 4.3. Effect of plastic deformation (cold working) on the mechanical properties of low-carbon steel

4.2 Recovery and Recrystallization

The process of *recovery* occurs, when a strain-hardened metal is heated to comparatively low temperatures, usually below (0.2 or 0.3) T melting point (Tmp). It comprises the relief of *microstresses* and partial elimination of distortion of the crystal lattice as a result of reduction in density of structural defects.

The ordinary set of mechanical properties does not usually exhibit any changes in the recovery process.

A further rise in temperature increases the mobility of the atoms, and when a definite temperature is reached, new equiaxed grains are formed (Fig. 4.4). The formation of new equiaxed grains in place of the oriented fibrous structure is called *recrystallization treatment* or primary recrystallization. As a result of recrystallization the effects of strain hardening are practically completely eliminated; and the properties approach their initial values. As may be seen in Figure 4.4, the tensile strength and especially the yield point drop sharply upon recrystallization, and the ductility (δ and φ) increases. This reduction in strength and hardness can be explained by the elimination of lattice distortion and the drastic reduction in dislocation density (from $10^{10}…10^{12}$ to $10^{6}…10^{8}$ cm^{-2}). The lowest temperature t_{br}, at which recrystallization begins and proceeds and at which metal is softened is called the temperature threshold of recrystallization.

The temperature t_{br} is about 0.4 T_{mp} for commercially pure metals. For pure metals this temperature is reduced to (0.1 to 0.3) T_{mp} and for solid solution alloys it is raised to (0.5 to 0.6) T_{mp}. As the first appoxitation this rule enables the temperature at which primary recrystallization begins to be determined. It is about -33°C for lead, about 270°C for copper and about 450°C for low-carbon steel. These temperatures separate *cold* and *hot metal working.*

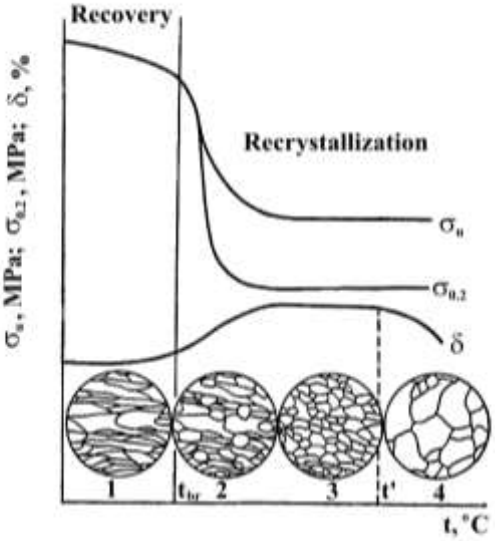


Fig. 4.4. Effect of heating on the mechanical properties and structure of strain-hardened steel

To eliminate the effect of strain hardening metal is heated to higher temperatures than t_{br} to ensure a high rate of recrystallization and completion of the process. Such heat-treatment is called *recrystallization annealing* (it is carried out at temperatures from 650 to 750°C for steel).

Collective recrvstallization. When the process of primary recrystallization has been completed, subsequent heating leads to growth of recrystallized grains. This process is called *collective recrystallization.* In collective recrystallization period the mechanical properties are reduced because of large sizes of grains.

Overheating and Burning. Prolonged heating of steel at temperature above t′ (Fig.4.4) leads to the formation of exceptionally large actual grains, both at these temperatures and after cooling to 20 °C. This effect is called overheating. Overheated steel has a coarse crystalline fracture and low mechanical properties. Overheating can be corrected by repeated heat treatment.

Heating steel to a higher temperature than that causing overheating, especially in an oxidizing atmosphere, leads to *burning.* This is accompanied by the formation of iron oxides along the grain boundaries. Burnt steel has a stony brittle fracture. Burning is an irremediable defect of steel.

4.3. Technological Plasticity

Technological plasticity is the main property required for metal forming processes. The plasticity of metals depends on:

- alloy composition and its structure;
- working temperature;
- scheme of deformation;
- rate of deformation.

Pure metals possess higher plasticity than their alloys. The less carbon contents, the higher is the plasticity of steel. When temperature increases the resistance of metal to deformation decreases, because of decrease in strength and hardness.

In every point of stressed body elementary very small cube may be picked out so, that plane stresses should be perpendicular to its plane surfaces. There are 9 cases of *stressed states* with one, two and three main stresses (Fig. 4.5). An alloy has higher plasticity when it undergoes *compressing stresses* and it has lower plasticity in case of *tensile stresses.*

The degree of deformation at first decreases, then raises with the increase in deformation rate.

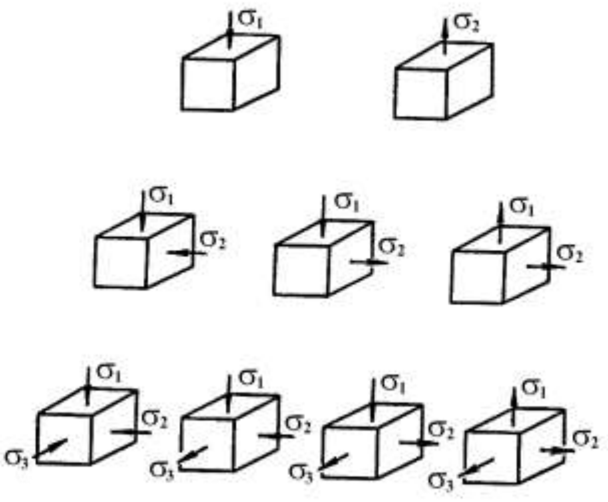


Fig. 4.5. Possible cases of stressed state

4.4. Heating of Metals

There are three types of metal forming with respect to work temperature: *cold forming, thermomechanical treatment* and *hot forming.* The main type is *hot forming,* or *hot plastic metal working.* As we know, cold metal working causes strain hardening (sometimes it's favourable effect), decrease in plasticity and, as a result, cracks in billets appear. During hot plastic working metal has high plasticity, it does not undergo structural changes and strain hardening, capacity of forming machines and deformation forces required are less as compared with cold forming. But hot forming causes a *scale formation*, which leads to metal losses and *dimensional accuracy* decrease.

Heating temperatures for steel are (Fig. 4.6) by 100…200°C below solidus line AE and by 25…50°C above the line GSK, that is hot forming is carried out when steel has homogeneus austenite structure (hypereutectoid steel has structure: austenite + carbides).

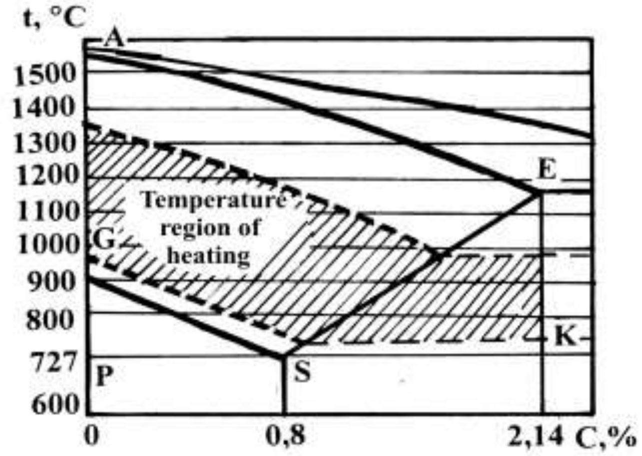


Fig. 4.6. Heating temperatures for hot plastic metal working

According to a source of heat a distinction is made between *flame* (gas or oil) *reverberatory furnaces* and *electrical resistance reverberatory_furnaces*. According to a working principle a distinction is made between *bath* and *continuous furnaces* (Fig. 4.7).

Flame furnaces are used for big ingots, both electrical induction and *contact heating devices* are used for small billets.

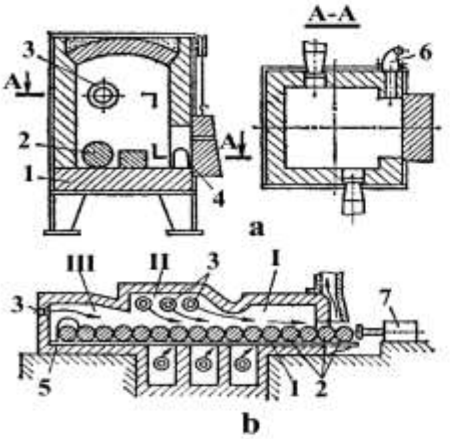


Fig. 4.7. Chamber (bath) (a) and continuous (b) heating furnaces: 1 – bottom; 2 – billet; 3 – gas burner; 4 – lid; 5 – unload hole; 6 – flue; 7 – pusher; I – preheating zone (600…800°C); II – zone of maximum heating (1250…1350°C); III – Standing zone (1200…1300°C)

4.5. Rolling

Rolling is the main method of metal forming. *Bars, pipes, double tees, corners, sheets, balls, wheels* and other products are manufactured using this method. Rolling is a method, in which revolving rolls are used for deformation of material.

A distinction is made between three rolling methods (Fig. 4.8): *lengthwise* (a), *cross* (b) and *helical* (c).

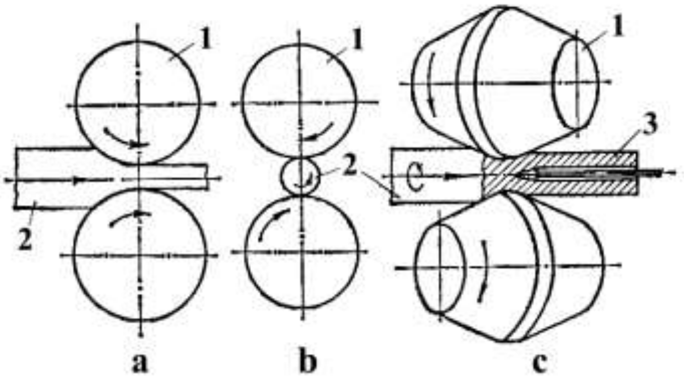


Fig. 4.8. The main methods of rolling: 1-roll; 2-billet; 3-mandrel

Let us consider the lengthwise rolling (Fig. 4.9). Sizes of a billet before rolling: L, B, H; after it 1, b, h, and L<1, B<b, H>h.

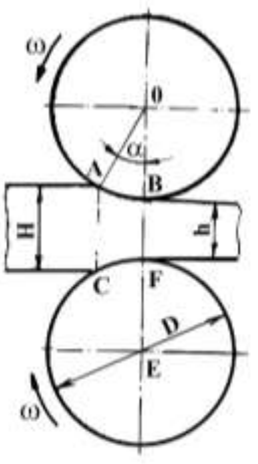


Fig. 4.9. Deformation of a billet in lengthwise rolling

Degree of deformation in general named drawing (extension) coefficient:

$$\lambda = L/l = F_0/F_1 = BH/(bh) = 1.1...1.6 \qquad (4.5)$$

Four main types of the rolled stock (products) are known:
- shape rolled stock;
- sheet rolled stock;
- pipe (tube) rolled stock;
- special rolled stock (periodical, balls, wheels and so on).

Tools and Equipment for Rolling. Metal is deformed between rolls, which may be *plain* (Fig. 4.10a) or *size* (Fig. 4.10 d), i.e. with *grooves* on their surfaces. Two grooves of size rolls form a *roll pass*. The pass may be *open* (fig 4.10 b) or *closed* (Fig. 4.10 c).

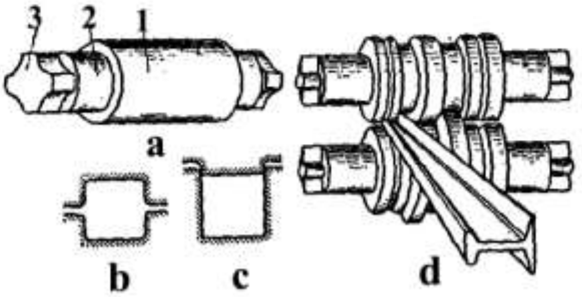


Fig. 4.10. Milling rolls and passes: 1 – barrel; 2 – neck; 3 – capture

Equipment for rolling is named a *mill* (Fig. 4.11).

According to the number and arrangement of roll stands, a distinction is made between: *duo* mill; *three-high* mil; double duo mill, or *four-high* mill; *multiroll* mill; *universal* mill.

Rolling technology. Duo rolling mills, as a rule, are used to manufacture half-finished products: *blooms* and *slabs*. The mill, named *blooming,* is used for squeezing of ingots to obtain blooms with cross section from 150x150 to 450x450 mm. Then blooms are used for production shape rolled stock. The mill named *slabing* is used to produce slabs, which have cross section form 65x1600 to 300x2600 mm and then are used for sheet rolled stock manufacture.

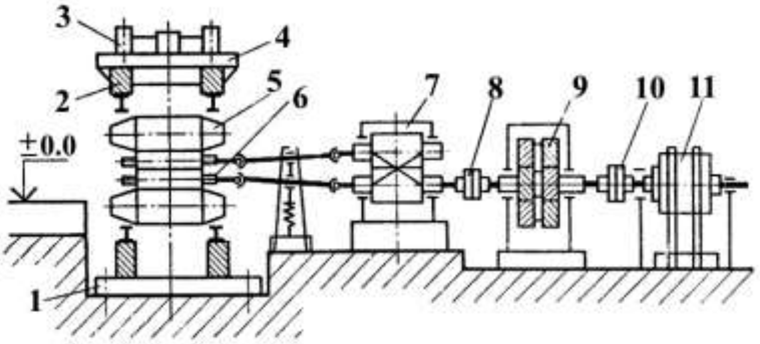


Fig. 4.11. Scheme of a mill: 1-bed of roll stand; 2-4-pressing device; 5,6-support and working rolls; 7-pinion stand; 8,10-clutch; 9-reduction gear; 11- electrical motor

Three-high mill has two passes and works similar to duo mill.

Double duo and multiroll mills provide the use of working rolls with small diameter, and by this to reduce deformation zone volume without bending of the rolls.

To receive a required cross section of rolled product bloom or slab is passed through systems of passes (Fig.4.12).

Welding pipes are produced from *skelp* (Fig. 4.13). Process includes forming of plane half finished article (skelp) in a pipe, welding and finishing operations. Skelp is deformed at temperature 1300…1500°C and thereby furnace welding is mainly employed. Electric arc welding also may be used.

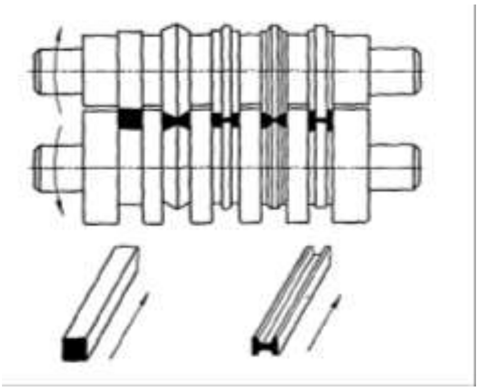


Fig. 4.12. Production of double-tee bar

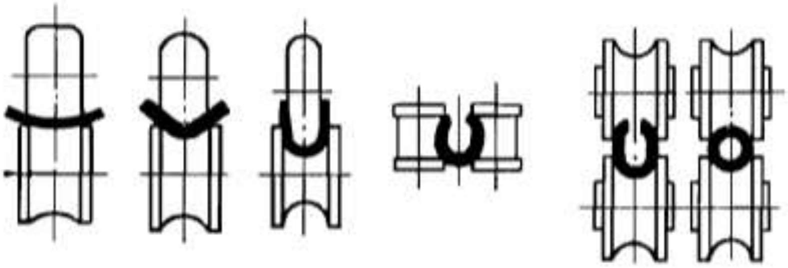


Fig. 4.13. Process of welding pipes production

4.6. Extrusion of Metals

Extrusion is a comparatively new and foremost process among the industrial methods by which metal is wrought into useful forms. Essentially it is a process of converting a block of solid metal into a continuous length of uniform cross-section by forcing it to flow under high pressure through a *die orifice*, which is shaped to impart the required form to the product.

In the majority of cases pressing is a hot working operation, so a billet is heated to provide a suitable degree of softness and plasticity, but sometimes (e.g. for plastic metal) the cold process may be used.

The sketches in figure 4.14 serve to illustrate the essential principle of the process. At the same time, it also explains the distinction between two methods of working, known as *direct* and *inverted* extrusion.

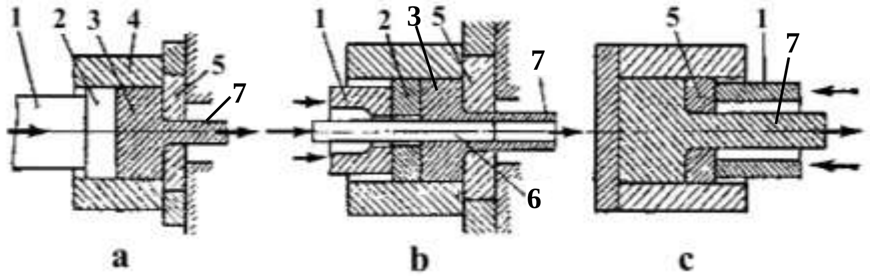


Fig. 4.14 Direct (a, b) and inverted (c) extrusion: 1, 2- ram; 3-billet; 4-container; 5-die; 6-needle (mandrel); 7 - article

The *needle* is used when a hollow product must be produced.

This method is used for manufacturing of steel and non-ferrous alloys:

- bars from 3 to 250 mm in diameter (thickness);
- pipes from 20 to 400 mm in diameter;
- different shapes which can't be produced by rolling.

Degree of deformation (extension) is the highest, with respect to other methods, from 10 to 80, because metal is compressed in three directions. Dimensional accuracy is higher compared to rolling. The extrusion is carried out by means of powerful hydraulic presses.

The advantages of the method are

- intricate shapes may be produced;
- brittle materials may be deformed, because metal is compressed in three directions and plasticity is high;
- high dimensional accuracy of product.

The disadvantages are the following:

- rapid wear of tools;
- large *pressing rest* of metal in container.

4.7. Drawing

This process is used for reducing the cross section of shape rolled stock, wire and pipes by drawing half finished article through special tool, named *reducing die*, or *draw hole*.

Figure 4.15 represents schemes of drawing the bar and pipe. Procedure is usually executed without heating.

Degree of deformation (drawing coefficient) is the smallest, because tensile stresses act within a billet: $\lambda=1/L=1.25\dots1.45$

Cold deformation promotes strain hardening of metal. To prevent an article's fracture the recrystallization annealing is carried out after a few drawing operations.

The drawing is used for production wires, which have diameter from 0.002 to 10 mm, pipes with diameter from 0.2 to 500 mm, bars with diameter from 3 to 150 mm and intricate shapes.

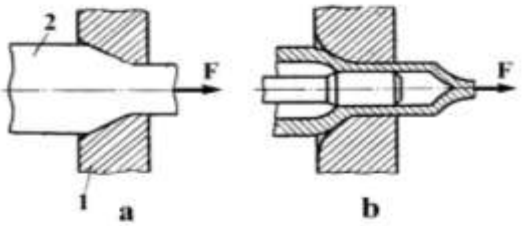


Fig. 4.15. Schemes of drawing of a bar (a) and a pipe (b):
1-reducing die; 2-billet (half-finished article)

The drawing provides a very high dimensional accuracy and surface quality, because the drawing die is polished and deformation is mainly cold.

The drawing die is made of tool steel (large sizes), hard-facing alloys (middle sizes) and technical diamond (small sizes for wire less than 0.2 mm in diameter).

Two types of drawing mills are used (Fig. 4.16):

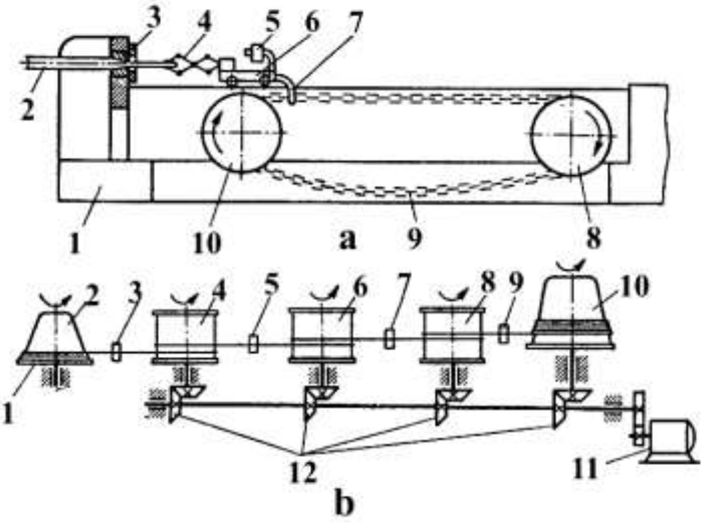


Fig. 4.16. Chain (a) and drum (b) mills; for a: 1 -die-support; 2-billet; 3-reducing die; 4-6-capture device and carriage; 8, 10-sprockets; 9-chain; for b: 1-wire; 2, 4, 6, 8, 10-drums; 3, 5, 7, 9-reducing dies; 1 1-motor; 12-gears

- drum mill for wire production;
- chain mill for rods and pipes production.

4.8. Hammering

Hammering, or *forging* is the method of hot metal forming in which metals are deformed by universal tools, such as hammer, anvils, block heads and others.

There are two types of hammering:

- *hand (smith)* forging;
- *machine* forging.

Only the second type of hammering is used in machine industry. A half-finished product of hammering is named a *forging.* Mass of forgings ranges from a few grams to 250 ton. The main advantages of hammering are:

- simple universal tools are used for manufacturing of different articles;
- heavy forging may be produced only by hammering.

Main Hammering Operations (Fig. 4.17). *Upsetting* is conducted under impact loading P of a billet located an the anvil. As a result the height of a billet is reduced.

Degree of deformation is determined by the following formula:

$$\text{У} = H / h = F_1 / F_0 \qquad (4.6)$$

where F_0 and F_1 are initial and final cross sections correspondingly;

H and h are initial and final heights correspondingly.

Heading (Fig. 4.17d) is local upsetting of the upper part of a billet (e.g. to produce head of a bolt).

Spreading is a process of making the billet wider and correspondingly thinner.

Drawing (Fig. 4.17a) is a forging operation for elongation of the billet or a part of it.

Ring rolling or *paying out* (Fig. 4.17c) means increasing in diameter of a ring, which undergoes hammering by block head and a rotation around cylindrical mandrel.

Piercing (Fig. 4.17e) is making a hole in the billet.

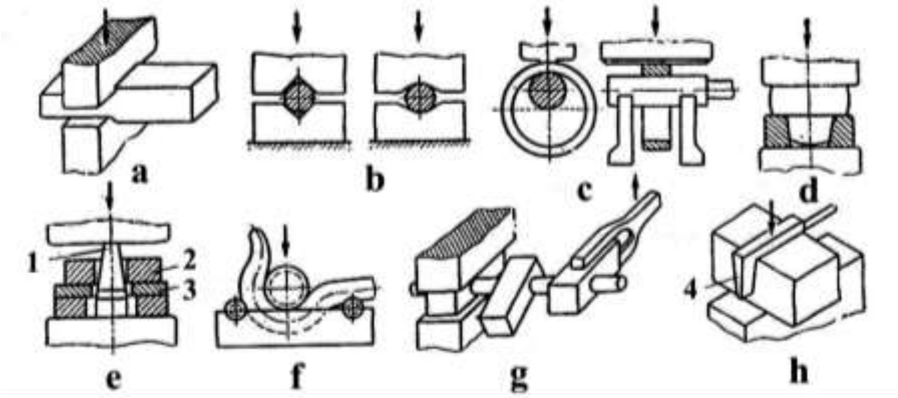


Fig. 4.17. The main hammering operations: a, b – drawing; c – ring rolling; d – heading; e – piercing; f – bending; g – twisting; h – cutting off

Chopping or *cutting off* (Fig. 4.17h) is separating of one part of half-finished article from another one.

Bending and *twisting* operation are shown in Fig. 4.17f and 4.17g correspondingly.

Hammers (smith forging hammers) and hydraulic presses are used in forging process. The forging hammer is a machine of impact action. The impact is produced by mass of falling parts. A compressed air, steam and electrical energy are used in forging hammers.

Let us consider design of a pneumatic forging hammer (Fig 4.18). When compressed air is given through hole 4 a piston 6 moves up in a cylinder 5. The piston lifts a piston rod 8, a slider 10 and a block head 11, which are assembled together.

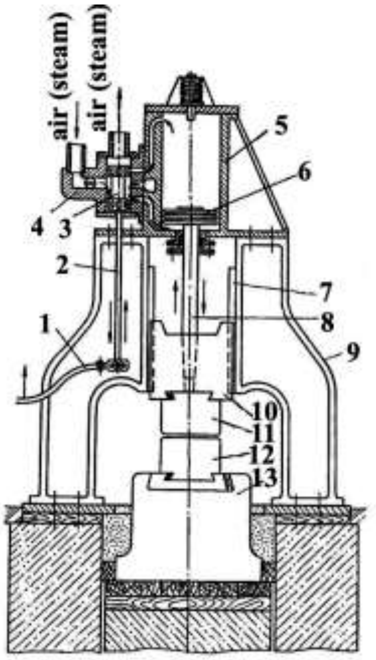


Fig. 4.18. Forging hammer: 1 – handle; 2 – traction; 3 – valve; 4 – hole (pipe); 5 – cylinder; 6 – piston; 7 – sliding surface; 8 – rod; 9 – body; 10 – slider; 11 – block head; 12 – smithy; 13 – anvil block

During the next part of the working cycle compressed air is released away and all moving parts named *falling parts* (the piston, the rod, the slider and the block head) fall down to perform deformation of a workpiece. This workpiece is placed on a *smithy (swage anvil)* 12, which is mounted on anvil block 13, located, in turn, on a basement. In steam-air hammer a bedframe 9 is mounted separately from the anvil.

The higher the mass of the anvil block is, the higher the efficiency of an impact and work of the hammer will be. The capacity of hammers is defined by mass of the falling parts. It ranges from 50 to 1000 kg. Forge hammers are used for producing forgings that have mass up to20kg.

Hydraulic presses (Fig. 4.19) are machines of static action. When oil is given into a main cylinder 10 under pressure from 20 to 30 MPa a plunger 6 with traverse 3 and head block 2 is moved down and the head block deforms a work. The plunger 6 and the head block 2 are raised by cylinders 9 and pistons 5.

Hydraulic presses have deforming force from 5 to 600 MN.

Forging manufacturing process. Process of manufacturing a forging comprises the following operations (steps):

- drawing of the forging is developed on the base of drawing of a finished part;
- the machining allowances, laps and tolerances are point out on the forging’s drawing (Fig.4.20);
- the shape and weight of required billet is determined;
- the necessary equipment is selected;
- the sequence of forging operations should be specified.

Let's assume that the part be done has shape of a lever with a jaw (Fig. 4.21a) and the billet has shape of a cube (Fig. 4.21.b). The sequence of operations to manufacture a part are shown in Fig. 4.21c…i. As a result, the required forging is received.

4.9. Die Forging

The main disadvantages of forging process are:

- low output;
- low dimensional accuracy;
- difficulty in receiving forgings of intricate shapes.

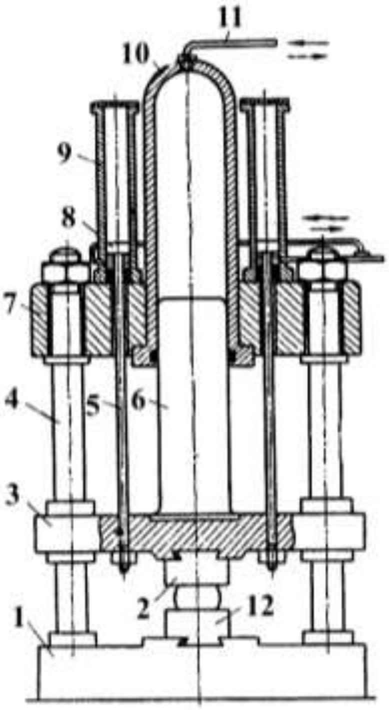
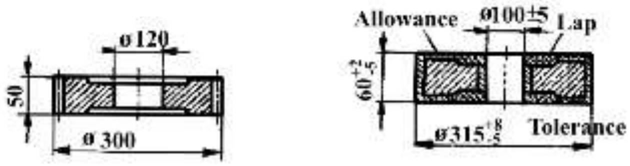
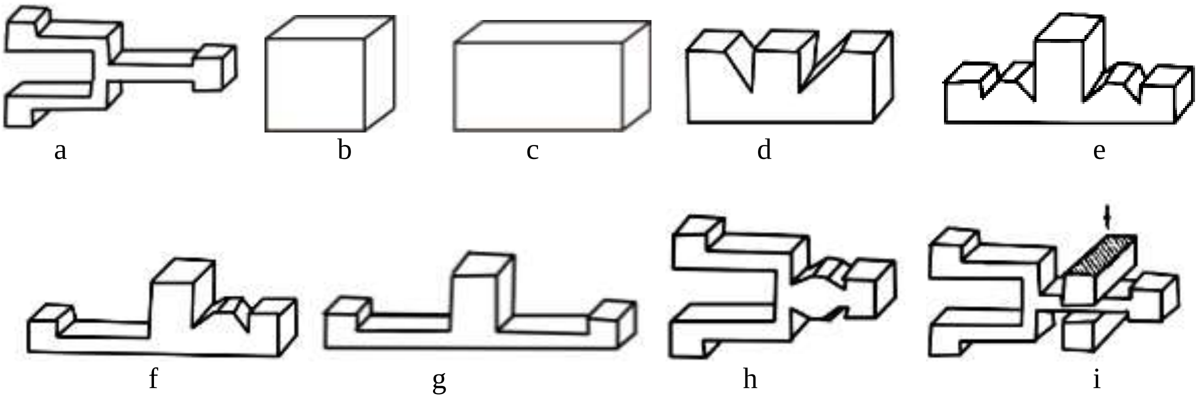


Fig. 4.19. Hydraulic press: 1 – base; 2 – block head; 3 – traverse; 4 – column; 5 – rod; 6 – plunger; 7 – traverse; 8 – piston; 9 – raising cylinder; 10 – main cylinder; 11 - oil feed



a b

Fig. 4.20. Drawings of the gear (a) and the fording (b)



a b c d e

f g h i

Fig. 4.21. Technological process of manufacturing of a lever with a jaw: a – article; b – billet; c, f, g - drawing; d, e, h - necking; i - bending and necking

To settle these problems *die forging* is used. There are two types of die forging: *hot* and *cold* ones. The hot die forging has a wide application in the machine industry. The cold die forging is used, mainly, for manufacturing the forgings of alloys which have high plasticity.

The essence of die forging is that a forging is manufactured by means of a *metal die*, which as a rule consists of two parts. When the parts are moved to meet together by a hammer or a press a billet is transformed into forging. The manufacturing die forging process is similar to a hammering one.

Two methods of hot die forging are distinguished (Fig.4.22):

- with flash (die is "open");
- without flash (die is "closed").

In the first case mass of a billet must be equal or exceed mass of the forging. When the billet will be squeezed-inside the die cavity, named *impression;* the surplusmetal will be squeezed into the *ring flute*, forming a flash. Then it is necessary to remove a *flash* by cutting.

In the second case mass of the billet must be equal to the mass of the forging. So we need to control the mass of the billet very carefully.

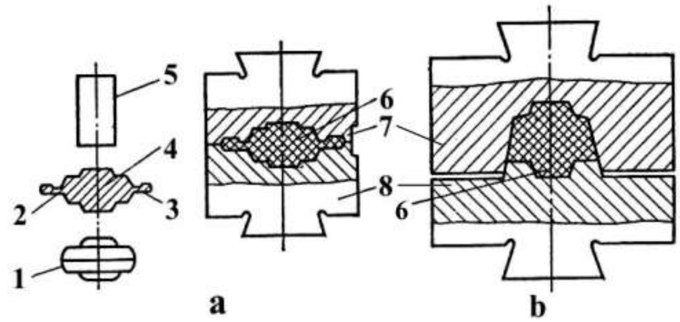


Fig. 4.22. Die forging process in open (a) and closed (b) dies: 1 – forging; 4, 6 – forging with flashes 2 and 3; 5 – billet for forging; 7, 8 – parts of the die; b: 1, 2 – parts of the die

Dies may have one impression for manufacturing the simple forging or several impressions for manufacturing the intricate forging. In the latter case the process consists of a sequence of die forging operations, first, in roughing impressions to draw or bend the billet and then in intermediate and finishing impressions to produce a finished forging (Fig. 4.23).

Finishing operations of die forging are as follows:

- *flash cutting;*
- *film cleaning;*
- *dressing* of forgings (correction of their shape) in hot or cold conditions by presses;
- *heat treatment;*
- *cleaning from scale;*
- *calibration (coining)* to receive more precise dimensions; calibration may be plane or volume one (Fig. 4.24).

Equipment for hot die forging includes hammers, crank presses, horizontal forging machines, hydraulic and screw presses, etc.

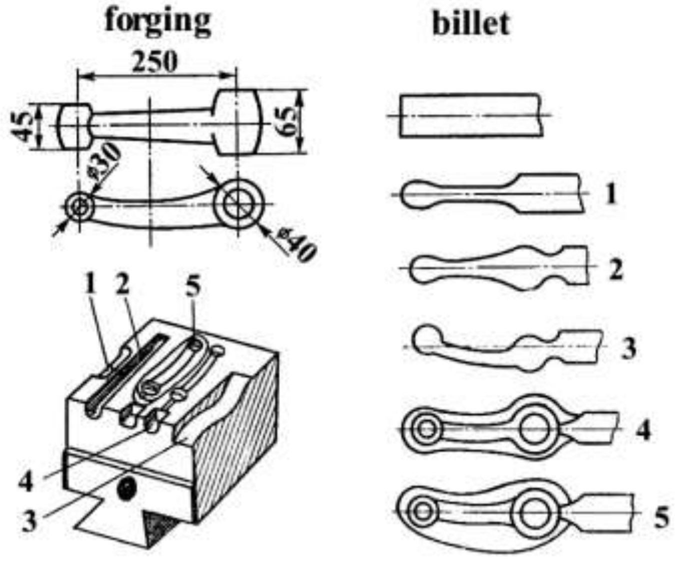


Fig. 4.23. Multi-impression die and operations of forging: 1 – fullering; 2 – drawing (extending); 3 – bending; 4 – blocking; 5 – finish fording

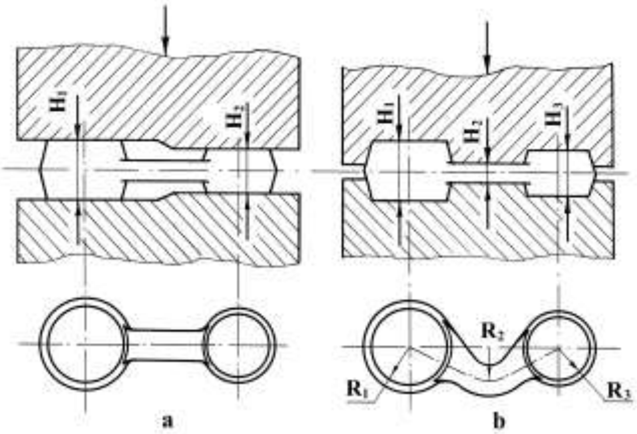


Fig. 4.24. Plane (a) and volume (b) calibration (operation of calibration undergo sizes indicated on the sketches)

Hammers do not allow to obtain high dimensional accuracy of forgings because parts (halves) of dies are not interconnected and their replacement is very high.

The crank press (Fig 4.25) consists of electric motor 1, belt transmission 2-3, gear transmission 5-6, crank 8, plunger 10 and table 9 of variable height. Two parts of the die are fixed to the plunger and the table and slide along guiding columns. This ensures high dimensional accuracy of forgings.

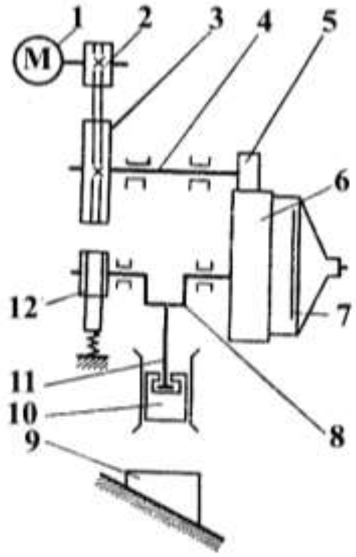


Fig. 4.25. Cinematic scheme of a crank hot-forging press: 1-electric motor; 2 – pulley; 3 – fly-wheel; 4 – shaft; 5, 6 – gears; 7 – friction coupling; 8 – crank; 9 – table; 10 – plunger; 11 – rod; 12 – brake

Advantages of die forging process: high productivity (dozens and hundreds of forgings per hour); high accuracy.

Disadvantages:

- complex and expensive tools, which may be used only for definite articles;
- mass of work (forging), as a rule, are not more than 30 kg; for manufacturing of heavy forgings powerful equipment is required.

Cold die forging is mainly used for manufacturing the forgings of alloys with high plasticity (Al, Mg, Cu, sometimes, low carbon steel). There are three basic types of the process: cold forming, cold extrusion and cold upset forging.

Cold forming process is similar to hot die forging, but it is carried out at a room temperature.

Cold upset forging process is carried out by cold upsetting automatical machines, which are similar to horizontal forging machines, but have higher productivity (from 20 to 400 forgings per minute).

Cold die forging requires higher deforming forces. After it metal acquires strain hardening, but the method offers higher, than hot die forging, dimensional accuracy, surface quality and absence of scale losses.

4.10 Stamping

Stamping or *sheet stamping* is a cold method of the plastic metal working. A strip or a tape may be used as a billet (half-finished article). Such parts as a watch hand, car bodies, rocket shells are manufactured using stamping.

Stamping provides high productivity: sometimes, a part per second. Alloys of high plasticity (Cu, Al, Mg, Ti) low carbon steel, plastic, leather and other materials undergo stamping.

All stamping operations are carried out by special tools and machines (stamps and presses).

Stamping operations may be classified as *forming* and *separating*.

The separating operations are used for cutting of a sheet in tapes and pieces by shears. The shears may be of three main types: straight-blade, guillotine and circle shears (Fig. 4.26).

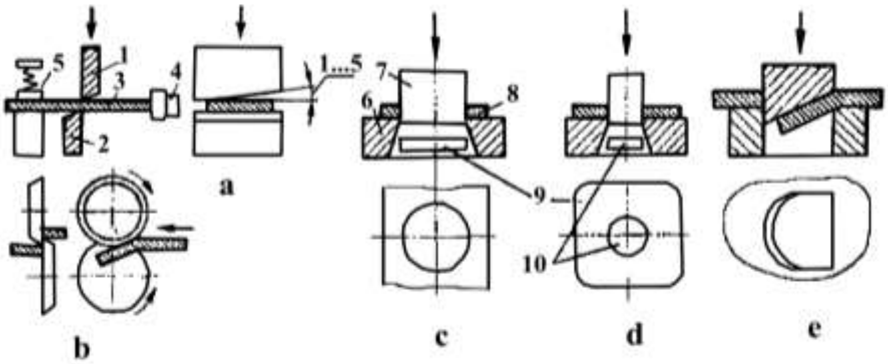


Fig. 4.26. Separating operations of sheet stamping: a-cutting by guillotine shears; b-cutting by circle shears; c-blanking; d-piercing; e-notching; 1 – upper knife; 2 – lower knife; 3, 8 – billet; 4 – size restrict; 5 –fixer; 6 – lower die; 7 – upper die; 9 – part (stamping); 10 – waste

Length of the cutting line for straight-blade and guillotine shears is not in excess than horizontal length of the shears L.

The length of the cutting line (of the tape) is not limited when the circle shears are used. The cutting out (blanking) and piercing are making external and inner contours of a part, correspondingly.

Forming operations are plotted in Fig. 4.27.

All these and other operations are made by dies of complex construction. Stamps consist of upper dies, bed dies, upper and bed plates, columns, bushings, springs and other parts. Upper plate is fastened to plunger of a press, bed plate is fasten to a table of the press.

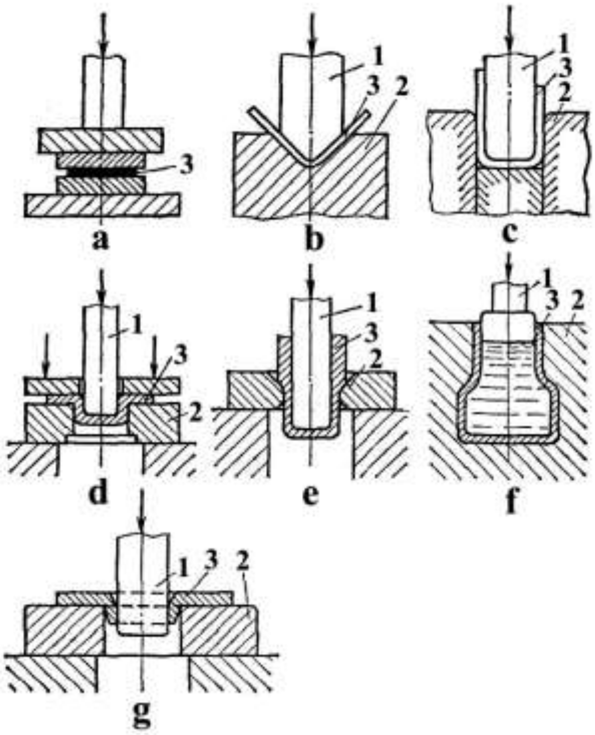


Fig. 4.27. Forming operations of sheet stamping: a-straightening; b-bending; c, d, e-draw-forming, f-spread forming, g-flanging; 1 – upper die (punch); 2 – lower die; 3 – billet.

5 WELDING

Welding is a technological method of manufacturing of *permanent joints* and *facing the surfaces* of parts if required. Parts of various materials may be welded. Welding is carried out in the air or other gases and vapors, under water, in vacuum.

The first welding method was found 4...5 thousand years ago, when man produced iron from iron ore in open fire, using charcoal as a fuel and reducer. During hammering to remove residual charcoal the pieces of iron were joined with each other. This was *blacksmith*, or *forging (hammer) welding*.

Then man noticed that during hammering at room temperature two pieces of gold (it possesses high plasticity) might be joined too. This was a *cold welding*. It happened approximately 3 thousand years ago.

Approximately at this time the *foundry welding* was introduced into practice. It was performed in the following way: liquid metal (brass) was poured between two brass parts and welded them together.

These three methods of welding have been used for long time and only in 1882 Russian engineer M. Benardos suggested arc welding with non-consumable carbon electrode.

In 1888 Russian scientist N. Slavjanov worked out a method of the arc welding with *metallic (consumable) electrode*. In 1902 *gas welding* was suggested in France. So, the application of welding has rapidly expanded in the recent 100 years. About 60 welding methods are employed now.

5.1. The Physical Fundamentals of Welding

The physical essence of welding lies in formation of strong connections between atoms of parts to be welded. The parts should be squeezed together so that surface imperfections are crushed and atomic attractive forces start to act.

For metals which have high plasticity only plastic deformation is sufficient for activation of atoms. For metals of medium plasticity additional heating of parts is needed. Metals of poor plasticity must be heated over melting point. Hence, we can say that physical processes used for welding may be classified as *mechanical, thermomechanical* and *thermal* ones.

According to that all welding methods are divided into two groups:

- *pressure welding;*
- *fusion, or non-pressure, welding.*

The following scheme presents the classification of welding methods (Fig. 5.1).

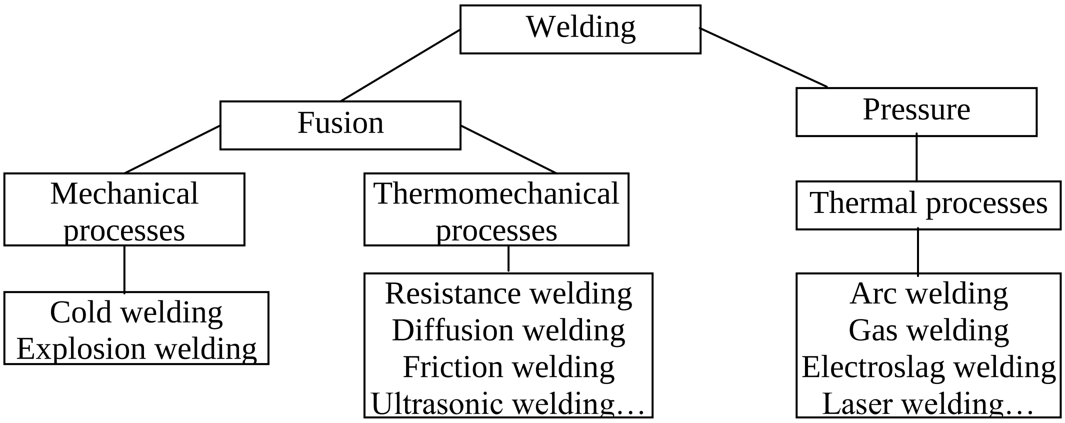


Fig. 5.1. Classification of welding methods

5.2. Arc Welding

The method relies on the thermal effect of an electric arc sustained between the electrode and parts to be joined in order to provide the melting zone. The electric arc is a powerful stable arc discharge in ionized atmosphere of gases and metallic vapors (Fig. 5.2). The process possesses high efficiency (0.6...0.9), i.e. 60...90 % of evolved heat is consumed for melting of electrode and works.

Electric properties of an arc are described by a *static voltage-current characteristic*, representing the dependence between voltage and current intensity at stable arcing distance (3...6 mm). The characteristic consists of three parts (Fig.5.3): dropping-I; stable (rigid)-II; increasing-III.

The stable part is more suitable for welding processes, because the voltage is independent of the amperage and arc burning is stable.

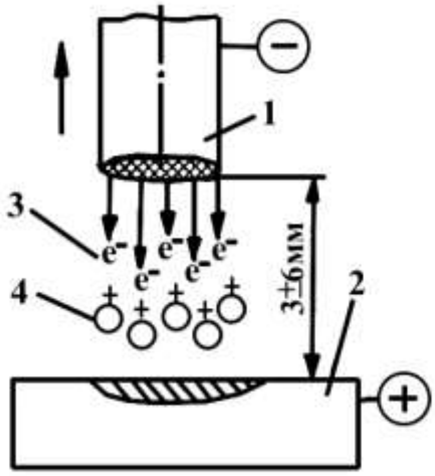


Fig. 5.2. Electric arc: 1-electrode; 2-part; 3-electron; 4-ion

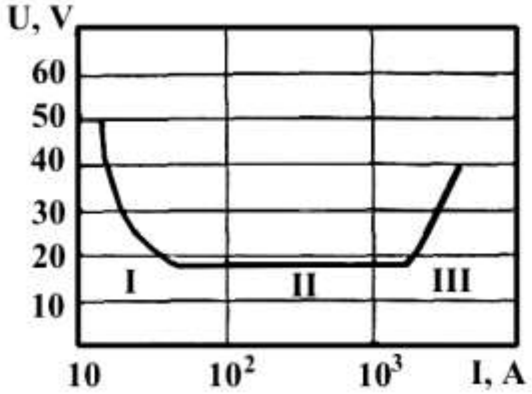


Fig. 5.3. Static voltage-current characteristic of an arc: I – dropping; II – stable; III - increasing

Sources of welding current (power sources or *welders)* have the external characteristic, which is a dependence of voltage on external terminals upon amperage in electric circuit. They may be of four main types (Fig. 5.4): dropping - 1; gradually dropping - 2; rigid - 3; increasing - 4.

The intersection point of arc and power source voltage-current characteristics is supposed to accommodate the stable arcing (welding). Thus, if the process is conducted within rigid part of arc characteristic, the welder with dropping or abruptly dropping external characteristic should be employed (Fig. 5.5).

Power sources of both alternating current (*electrical transformers*) and direct current (*electrical generators and rectifiers*) are used for welding. Transformers are cheap, simple in design and more efficient power sources. But power sources of direct current offer stable welding process and give the possibility to use direct and reverse polarity if necessary.

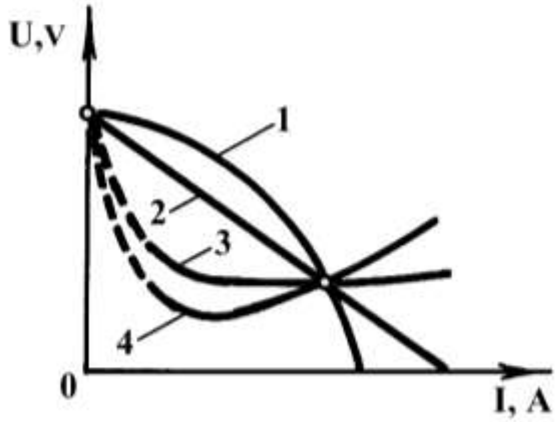


Fig. 5.4. The main types of external characteristic of welding power sources:
1 – dropping; 2 – gradually dropping; 3 – rigid; 4 – increasing

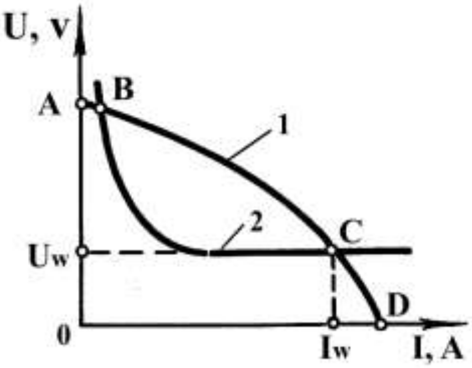


Fig. 5.5. External characteristic of a power source (1) and stable characteristic of the arc (2):
A – point of open-circuit run; B – point of non-stable arcing; C – point of stable arcing;
D - point of short circuit; U - welding voltage; I_w- welding current

Welding current is adjusted by means of supply chokes (a-c welding) or variable resistances (d - c welding) (Fig. 5.6).

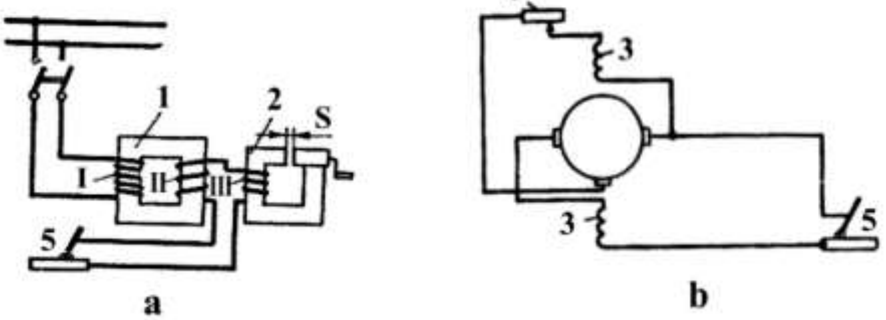


Fig. 5.6. Adjustment of welding current by means of a choke (a) and a variable resistance (b):
1 -transformer; 2-choke; 3 -windings of generator; 4-variable resistance; 5 – welding;
I, II, III – windings of transformer and choke; S- regulated clearance

The arc welding is performed by an arc arcing between electrode and works. It is possible to use either consumable or non-consumable electrodes.

Figure 5.7a represents arc welding scheme when the transformer is used as a power source. Consumable electrode 1 is melted in the electric arc 2 and its drops form liquid bath, which connects works 3 after solidification.

Figure 5.7b represents similar process, but the electrode 1 is non-consumable. It is made of carbon (graphite) or tungsten. A filler metal 4 is used for formation of a weld.

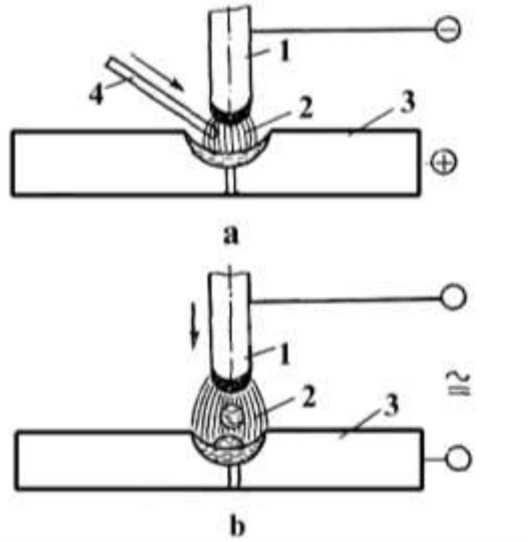


Fig. 5.7. Schemes of the arc welding: a - by N.Benardos; b - by N.Slavjanov;
1 – electrode; 2 – electric arc; 3 – works be welded; 4 – filled metal

Direct and reverse polarity may be used when direct current welding process takes place (Fig. 5.8).

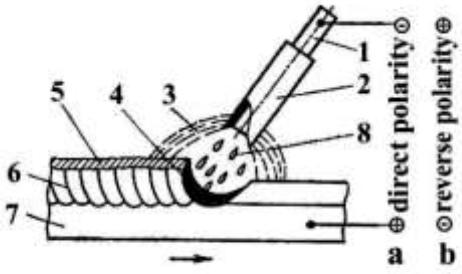


Fig. 5.8. Direct (a) and reverse (b) polarity in welding process: 1 – core of electrode (wire); 2 – luting;
3 – gas protection; 4 – weld bath; 5 – slag crust; 6 – weld; 7 – base metal; 8 – drops of liquid metal

5.2.1. Manual Arc Welding

Manual arc welding is carried out by a welder, who keeps an electrode holder with an electrode and manually regulates the distance between the electrode and works to be welded. The metallurgical processes (oxidation of alloying elements, saturation with gases) take place in the welding bath. To prevent metal oxidation and alloying elements losses, consumable electrodes is covered by luting. The consumable electrodes represent the metallic rods from 1.6 to 12 mm in diameter coated with luting (Fig. 5.8).

The luting may be thin, of medium- thickness, thick and very thick. It consists of following components:

- slag forming (chalk, marble, Mn-ore, SiO_2 sand);
- gas forming (wood powder, starch, etc.);
- deoxidizing (Mn, Si, Al, Ti, etc.);
- alloying (Mn, Si, Cr, Ni, Mo, V, Ti, etc.);
- stabilizing ($CaCO_3$, K_2O, Na_2O, etc).

The thin and medium-thickness lutings are used mainly for stabilization of electric arc. The thick and very thick lutings are used for stabilization of arc, protection of molten metal by slag and gases, deoxidizing and alloying it.

The electrode diameter depends on thickness of works to be welded. The amperage I_w depends on the electrode diameter d_e, mm:

$$I_w = (35\ldots60)d_e,\ \text{A} \tag{5.1}$$

So, welding regime is completely characterized by welding current (I_w) and electrode diameter (d_e). Electrodes with the diameter of 3...6 mm are mainly used in manual arc welding. Voltage ranges from 16 to 30 V and welding current is from 120 to 350 A.

The basic types of welds or joints produced by fusion welding are represented in figure 5.9.

The main advantages of manual arc welding are

- simplicity of the process;
- ability to carry out welding in different space positions (Fig. 5.10).

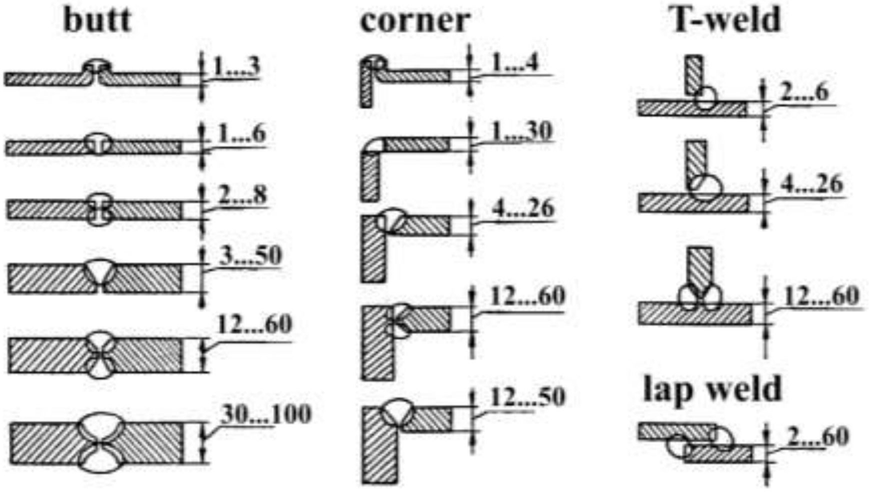


Fig. 5.9. Basic types of welds produced by fusion welding (the figures are thickness of the parts be welded)

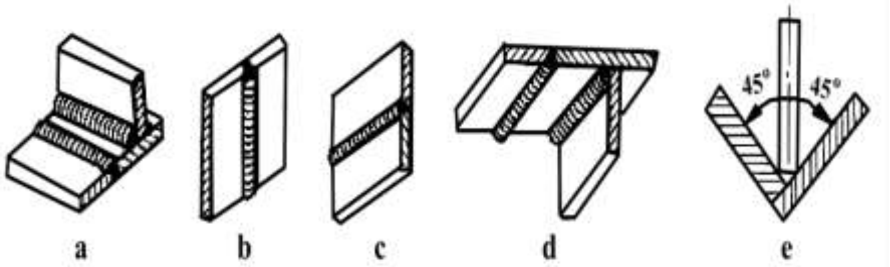


Fig. 5.10. Possible space positions of welding: a-down (flat); b-vertical; c-horizontal; d-inverted (overhead); e-in-corner

The disadvantages of the process are

- manual labor;
- low productivity;
- the welder must have high qualification level (proficiency).
- non - stable quality of the weld.

5.2.2. Automatic Arc Welding

The automatic submerged-arc welding differs from manual arc process by the following peculiarities:

- the process is conducted by bare electrode, that is a wire without luting;
- arc and metal bath are submerged or covered by flux layer;
- all processes, such as electrode wire and flux feed, movement of welding head, are completely automated.

Flux or gases may be used as shielding substances.

Correspondingly, two types of automatic arc welding are distinguished:

- automatic welding under flux shield;
- automatic welding in shielding gases.

In both cases the welding tractor is used. Figure 5.11 illustrates the process of automatic welding.

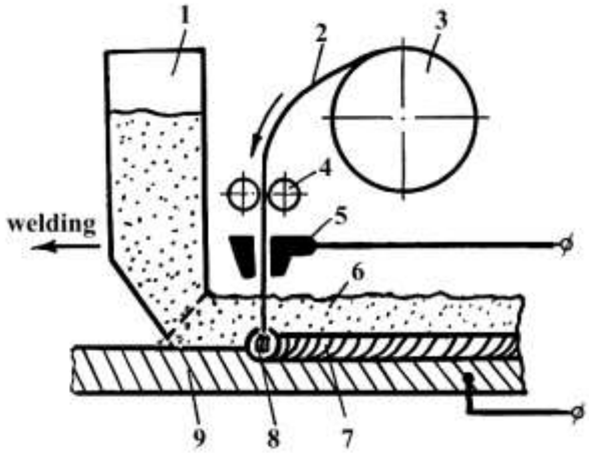


Fig. 5.11. Automatic welding by a welding tractor: 1-tank for a flux; 2-wire; 3-cassete; 4-rolls for wire supply; 5-guide sleeve; 6-flux layer; 7-weld; 8-arc; 9-base metal

The arcing is carried out under flux, which shields metal from oxidation and splashing, providing therefore ability to increase amperage in 15 to 20 times as compared with manual arc welding and correspondingly to raise quantity of overlaying metal and welding productivity.

Main advantages of automatic submerged-arc welding as compared with manual one are:

- high productivity;
- welders of high qualification aren't required;
- high quality and homogeneity of the weld;
- thickness of the weld reaches 20 mm.

Disadvantages of the method:

- only flat welds may be produced;
- the difficulties with producing the welds of small radiuses.

Instead of flux shielding gases, such as carbon dioxide CO_2, nitrogen N_2, hydrogen H_2, argon Ar, helium He are used. The distinction is made between: inert gases (Ar and He) and active gases (CO_2, N_2, H_2).

The automatic electric-gas welding has lower capacity than welding under flux shield, because of metal splashing.

There are several schemes of electric-gas welding: with tungsten or consumable electrode (Fig. 5.12) on direct, reverse polarity and alternating current welding.

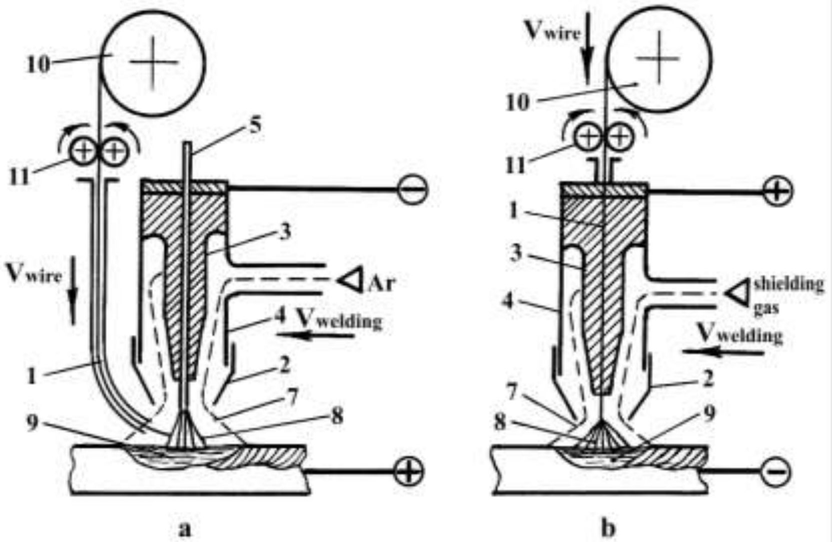


Fig. 5.12. Semi-automatic shielding gas welding with non-consumable (a) and consumable (b) electrode: 1 -wire; 2-nozzle; 3-guide sleeve; 4- torch; 5-W-eletrode; 7-shielding atmosphere; 8-arc; 9-welding bath; 10-cassette; 11 – rollers for moving of wire

Ar and He are expensive gases, but provide high quality of welding.

CO_2, N_2 and H_2 are cheap gases, but CO_2 is decomposed at high temperature and oxidizes metal:

$$CO_2 \rightarrow CO + O \tag{5.2}$$

$$O + Me \rightarrow MeO \tag{5.3}$$

$$CO + Me \rightarrow MeO + C \tag{5.4}$$

Saturation of metal with N_2 and H_2 decreases its mechanical properties. CO_2 -shield is used with alternating current power sources, which decreases arc stability, but allows removing oxides from liquid metal.

Mixtures of different gases are used very often to decrease welding expenses and to raise quality of welding joints.

Flat welds are commonly produced by automatic gas arc welding. But sometimes the welding tractor has a holder and can produce different welds, for example carry out a welding of pipes of great diameter.

Semiautomatic and *manual gas-shielded arc welding* are used, especially for welding in different space positions. In this case a welder holds arc torch, a wire and gas are fed automatically.

When the welder holds arc torch and feeds filler metal the manual gas-shielded arc welding takes place.

5.3. Gas Welding

Gas welding is one of the chemical welding processes in which the required heat energy is produced as a result of combustion of gases. The main materials available for gas welding are known to be acetylene C_2H_2, hydrogen H_2, natural gas C_mH_n, kerosene. Oxygen O_2 is used as an oxidizer.

Acetylene, possessing the highest heat-producing ability, provides in combustion the highest flame temperature (~3200°C) and gain wide application in gas welding. Calcium carbide CaC_2 interacts with water to produce acetylene in the *acetylene generators:*

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2 + Q \tag{5.5}$$

Three types of generators are distinguished:

- contact-type (water recession);
- water-to-carbide;
- carbide-to-water.

Figure 5.13 represents the most widely applied generator of contact type.

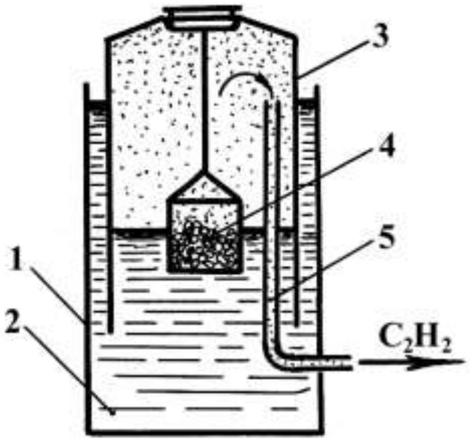


Fig. 5.13. Acetylene generator of contact (water recession) type:
1 – tank; 2 – water; 3 – bell; 4 – calcium carbide; 5 – acetylene

A tank 1 contains water 2. Calcium carbide in net 4 is hang up in the bell 3 and reacts with water producing acetylene. When tap is closed, acetylene pressure increases, water is expelled and its level in the tank drops. The reaction is retarded. When acetylene is consumed, pressure is lowered, water returns to the bell, the reaction surface increases and acetylene yield correspondingly rises.

Hence, acetylene is usually produced in acetylene generators, or is taken from cylinders, charged at special station. Acetylene is explosive gas and requires careful treatment. Cylinders are filled with charcoal powder and acetone under a pressure of 1.6 MPa. Cylinders are white painted.

Oxygen is obtained from the air using a selective evaporation at special shops. Blue cylinder is filled by oxygen under a pressure of 15 MPa.

Equipment necessary for gas welding is as follows: *protective water seals, acetylene and oxygen cylinders, pressure regulators, welding torch.*

Welding torches are used to produce acetylene-oxygen mixture in subsequent combustion of which the welding flame is obtained. Welding torches of injector type are normally employed nowadays (Fig. 5.14). The oxygen pressure before an injector 4 is about 0.3...0.4 MPa. Running out with high speed into mixture chamber 3 it produces significant vacuum, by which acetylene is sucked into the chamber (its pressure within the hoseline may be rather low, from 0.001 to 0.015 MPa). There is replaced tip (head) 2 with calibrated orifice at the end of the gas torch. It serves for regulation of the flame power.

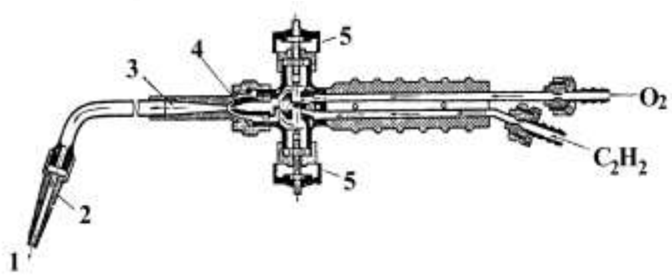


Fig. 5.14. Gas welding torch: 1 – fuel mixture; 2 – tip; 3 – mixture chamber; 4 – injector; 5 – valves

Pressure regulators are employed to reduce the gas pressure within the cylinder to the working value and to maintain the value at a constant level automatically.

The ratio between C_2H_2 and O_2 is adjusted by corresponding valves 5 on the torch.

Three particular zones are differed in welding flame (Fig. 5.15):

- *core* (I)
- *welding zone* (II)
- *tongue, or jet* (III)

The highest temperature is achieved in welding zone (3100...3200°C). Hence, welding process is carried out in this zone.

Three types of flame are distinguished according to the ratio between oxygen and acetylene in the mixture:

- balanced (normal) - $O_2/C_2H_2 \approx 1$
- oxidizing - $O_2/C_2H_2 > 1$
- reducing (carbonizing) - $O_2/C_2H_2 < 1$

Different flame types are employed in welding of various alloys. For instance, in welding the high carbon steel or cast iron reducing flame is needed; in welding the brasses oxidizing one is required. In the majority of cases balanced flame is employed.

Gas or oxy-acetylene welding provides gradual (smooth) and slow (regulated) heating to be achieved. It is the main peculiarity and advantage of the process. That is why gas welding is used for thin steel parts (0.2…0.5 mm in thickness), non-ferrous alloys, cast iron and a number of alloy steels inclined to cracking (crackness).

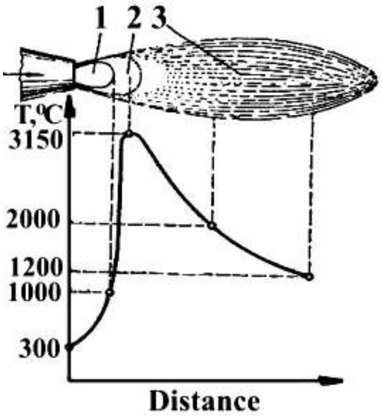


Fig. 5.15. Peculiar zones of welding flame: 1 – core; 2 – welding zone; 3 – tongue (jet)

5.4. Resistance Welding

Resistance welding is a group of pressure welding processes wherein coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in welding circuit and by the application of pressure. There is no any external heat source. Heat is developed in the parts to be welded and pressure is applied by the welding machine through electrodes. No fluxes or filler metals are used.

Current for resistance welding is usually supplied through *welding transformers,* which transform the high-voltage, low-amperage power supply to usable high amperage at low-voltage.

Pressure, or more properly, the electrode force, is supplied either by air or oil pressure through a cylinder, mechanically by cams, manually by foot or hand levers through linkages or some other means.

5.4.1 Heating Fundamentals in Resistance Welding

Any current flow in an electrical conductor creates heat. The amount of heat generated depends on three factors:

- the current intensity;
- the resistance of the conductor;
- the time of current flow;

$$Q = I^2Rt, \tag{5.6}$$

where Q is heat generated in Joules;
I is current in Amps;
R is resistance of the work in Ohms;
t is time of current flow in seconds.

The formula shows that the heat generated is directly proportional to the resistance and square welding current. The total heat generated is partly used to make the weld and partly lost to the surrounding metal, mainly, by thermal conductivity.

Figure 5.16 represents *spot welding.* In making a weld, the current passes from one electrode through the base metal to the other electrode. During this flow it encounters seven separate resistance zones as shown in figure 5.16.

Points 1 and 7. The electrical resistance of the electrode material (copper, or bronze) is of low value.

Points 2and 6 are corresponding to the contact resistance between the electrode and the base metal. The magnitude of this resistance depends on the surface condition of the base metal and electrode, the size and contour of the electrode face and the electrode force P. This is a point of high heat generation, but due to thermal conductivity of the electrode material and the fact, that it is usually water cooled the base metal does not reach the fusion temperature during the current passage.

Points 3 and 5. The total resistance of the base metal itself is low, but it is higher than electrode material resistance.

Point 4. This is a point of highest resistance and therefore of the greatest heat generation. Due to hot spots 2 and 6, the heat generated at this interface is not readily lost to the colder electrodes. That effects formation of the weld interface contact.

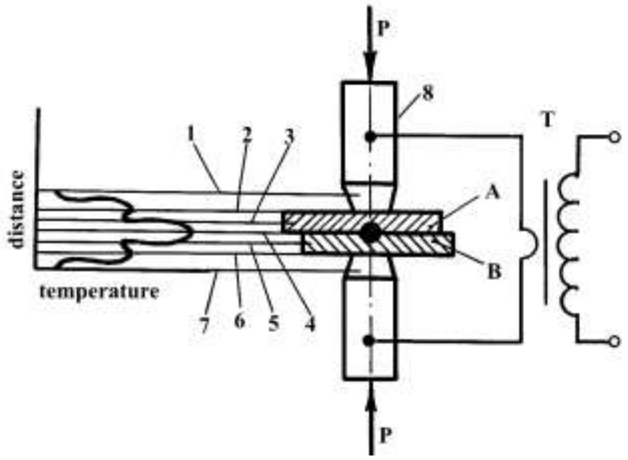


Fig. 5.16. Scheme of spot welding: 1…7 – resistance and temperature zones; 8 – electrode; A, B – parts to be welded; T – electrical transformer; P – compressing forces

The following types of resistance welding are distinguished: *spot, seam, projection, flash, upset* and *percussion welding.*

5.4.2 Spot Welding

Spot welding is a *resistance welding* wherein coalescence is produced by heat obtained from resistance to the flow of electric current through the work parts held together under pressure of electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes. In the simple single spot weld shown in figure 5.17 the passage of current and electrode force application must be through the electrodes 2, the overlapped work pieces 1 and the weld.

The are four definite stages of time in the spot-welding cycle (Fig.5.18):

- squeeze time is the time between the first application of the electrode force P and welding current turn-on;

- weld time is the time, during which welding current flows:

- time, during which the electrode force either is still applied or is increased (for better deformation of weld) after the welding circuit has being deenergized;

- off time is the time when the electrodes are off the work.

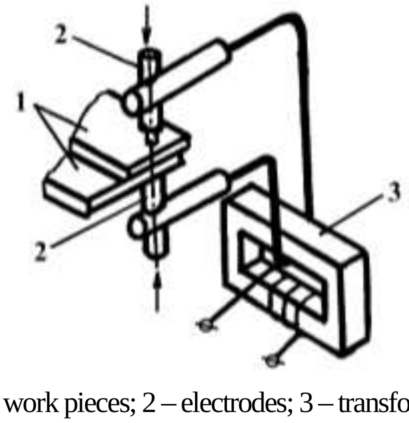


Fig. 5.17. Spot welding: 1 – work pieces; 2 – electrodes; 3 – transformer; P – pressure

The thickness of welding works is from 0.5 to 12 mm. There are two main regimes of welding:

- soft (easy):
  - $j=I/F=80...160$ A/mm^2 (F-area of a weld);
  - $P=15...40$MPa;
  - $t=0.5...3.0$ sec;
- rigid:
  - $j=120...360$ A/mm^2;
  - $P=40...150$MPa;
  - $t=0.001...0.010$ sec.

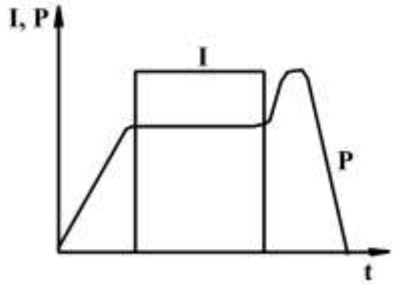


Fig. 5.18. Spot welding cycle: I-current; P-pressure; t-time

5.4.3. Seam Welding

Seam welding (Fig.5.19, 5.20) is a resistance-welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by circular electrodes. The resulting weld in seam welding is series of overlapping spot welds (practically continuous or persistent) made progressively along a joint by rotating circular electrodes with automatic current cut-off.

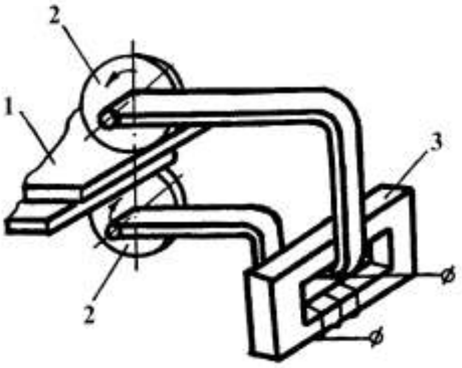


Fig. 5.19. Seam welding process: 1-works; 2-electrodes; 3-transformer

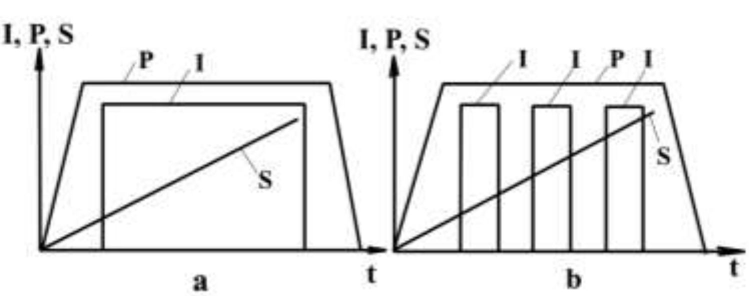


Fig. 5.20. Seam welding cycles: I – current; P – compressing force;
S-distance of works' movement; t – time

Seam welding has much in common with spot welding. Welds may be single or multiple, that is a single seam or more parallel seams may be produced simultaneously. Welds may be direct, or indirect, similar to spot welding.

Seam welding is used usually when persistent leak-free weld is required.

5.4.4. Projection Welding

Projection welding is schematically very similar to spot welding, but has some differences:

- a work undergoes stamping before welding for formation of projections (ledges);
- electrodes have large sizes and welding machine has high capacity; Types of projection welds are shown in figure 5.21.

After welding the upsetting is produced to smooth down the work surface. Main advantage of the process is high productivity. Main disadvantage is high welding machine capacity.

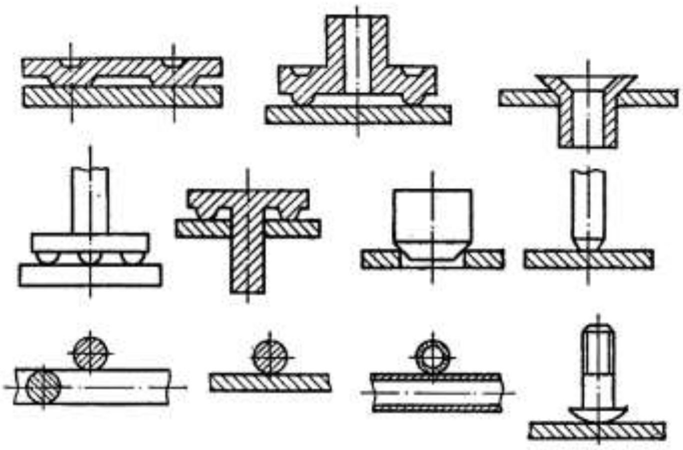


Fig. 5.21. Examples of projection welds

5.4.5 Flash welding

Flash welding (Fig. 5.22) is a resistance-welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces by the heat obtained from resistance to the flow of electric current between the two surfaces, and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint.

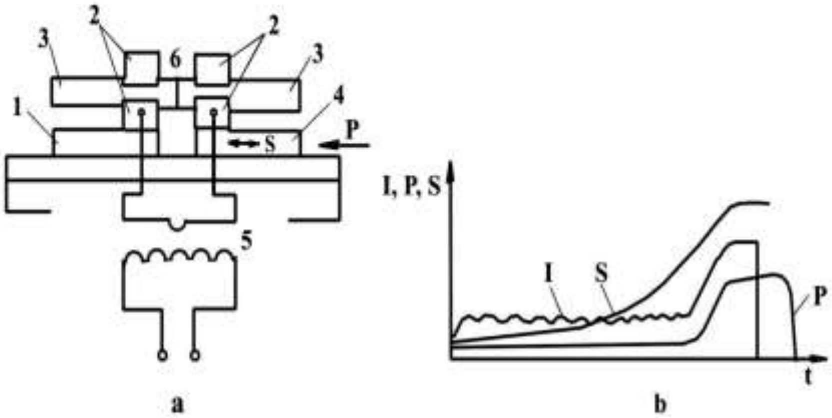


Fig. 5.22. Scheme of flash welding (a) and welding cycle (b):
1 – immovable plate; 2 – clamp (electrode); 3 – work; 4 – movable plate; 5 – transformer;
6 – contact (weld); I – current; S – replacement of movable plate; P – pressure

Flash welding is done by placing one of two work parts in the jaws of the machine. As the parts are brought together into very light contact, a voltage of sufficient magnitude is applied to form a flashing action between the parts. Flashing continues as the parts advance until the work pieces reach a forging temperature (sometimes a melting point). The weld is completed by the application of sufficient forging pressure and the interruption of current.

5.4.6 Upset welding

Upset welding is a resistance-welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces or progressively along a joint by the heat obtained from resistance to the flow of electric current through the area of contact of those surfaces. Pressure is applied before heating is started and maintained throughout the heating period (Fig. 5.23).

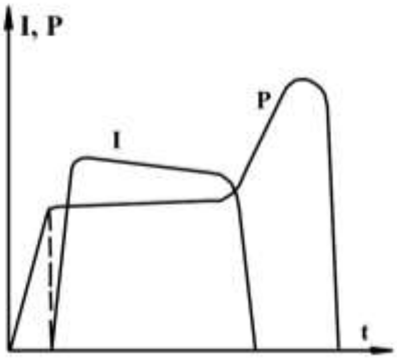


Fig. 5.23. Upset welding cycle

In upset welding the parts are brought into solid contact and current takes the path through the contact area until a sufficiently high temperature is generated to allow the forging of a weld. The heat is generated mainly by the contact resistance between the two pieces. The difference between upset welding and flash welding is that no flashing from the abutting surfaces occurs at any time and the heat is developed slowly by the resistance between the two parts.

5.4.7 Percussion Welding

Percussion welding (capacitor energy-storage, electrostatic percussive welding) is a resistance welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces by the heat obtained from an arc produced by a rapid discharge of stored electrical energy with pressure percussively applied during or immediately following the electrical discharge.

There are two main variations of this process:

- transformer welding (with transformer 5)
- transformerless welding (without transformer 5) (Fig. 5.24).

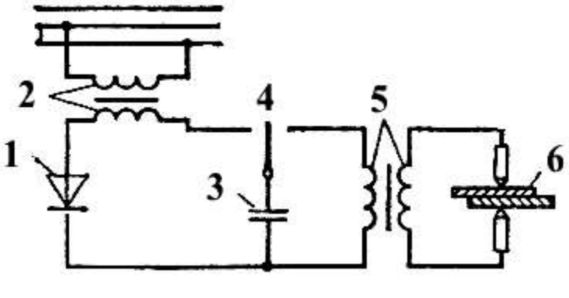


Fig. 5.24. Percussion welding: 1 – rectifier; 2, 5 – transformer; 3 – capacitor;
4 – switch; 6 – parts to be welded

Transformer 2 is the main transformer. It reduces voltage, for instance, from 16 kV to 220V; transformer 5 is reducing welding transformer.

When switch 4 is on the left position the charging of the capacitor 3 takes a place. When the switch is in the right position the discharge of the capacitor 3 and welding of works 6 takes a place.

The method allows:

- to remove overloads in electrical circuit (network), which is peculiar to resistance welding;
- to produce a welding by definite dose of electrical energy and eliminate overheat of welding parts.

5.5. Diffusion Welding

The method was found out in the USSR by N.F. Kozakov. It is one of methods of pressure welding. The works 1 (Fig. 5.25) are replaced into vacuum chamber 3, pressed and heated by heater 2. The welding occurs by the mutual diffusion of atoms in the surface layers of the pieces brought in contact.

The advantages of the method are

- the absence of electrodes and fluxes;
- the absence of weld when the same metals are welded;
- the possibility to weld materials which cannot be welded by other methods, for instance, metal and glass, steel and aluminium, etc.

The disadvantages of this method are the following:

- long time of welding (15…25 min);
- welding in vacuum.

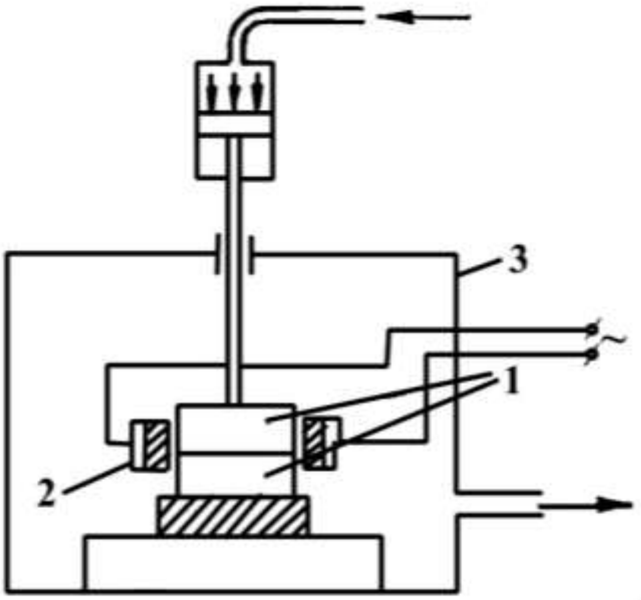


Fig. 5.25. Diffusion welding: 1 – works to be welded; 2 – heater; 3 – vacuum chamber

6 METAL CUTTING OPERATIONS

Quite accurate workpieces and parts may be produced by the advanced methods of casting, metal forming and welding. But their *dimensional accuracy* and *surface finish* are not satisfactory to use them for assembling the machines and devices. Therefore *machining* still remains and will probably be for a long time the main technique of *finishing mechanical treatment.*

We can say that *machine tool* is a mother of all machines, devices and things used by people, because each of them is produced by machine tool. So, machine tool is the basis of human society.

In simple terms a machine tool is a power-driven machine designed to cut or shape metal or other material. From the machine tool flows every object of our industrialized word: automobiles, airplanes, atomic bombs and atomic power plants, washing machines, electric stoves, radio-sets, refrigerators, etc.

6.1. Principles of Cutting and Shaping the Metals

In many cases the desired shape and dimensions of a workpiece are obtained by *detaching chips* from the material by means of cutting tools. Machine tools shape workpiece by cutting operations (Fig. 6.1). During the sequence of operations workpiece and tool perform certain motions relative to each other.

The process of chip removal is affected by the working motions of the machine tool (formative motions), which are transmitted either to the cutting tool, or to the workpiece, or to the both simultaneously. Working motions of the machine tool include a *primary cutting motions* and a *feed motion* (motions). Each of the working motions is specified by its speed or rate.

The primary cutting motion V provides cutting of the chip from the blank at a cutting speed V equal to the velocity with which the chip leaves the work.

The feed motions enable the cutting process to be extended to the whole surface to be machined; it may be longitudinal S_1 or transverse S_t.

In addition to the working motions *auxiliary motions* are needed to prepare the machine, tool and work for carrying out the cutting process. One of them is *setup motion of tool* S_s, which, determines the cross-sectional area of the chip, or the thickness t of removed metal.

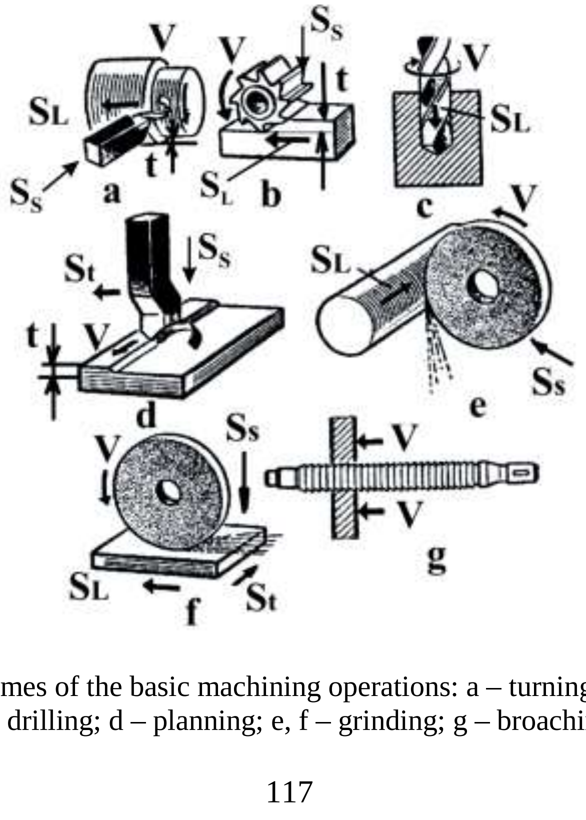


Fig. 6.1. Schemes of the basic machining operations: a – turning; b - milling; c – drilling; d – planning; e, f – grinding; g – broaching

A straight-line reciprocating primary cutting motion V is employed in shapers (Fig.6.1d), planers, slotters, etc. This motion can be transmitted either to the tool, as in shapers and slotters, or to the work, as in planers.

The cutting cycle consists of a working stroke V_w during which the tool cuts a chip, and the idle or return stroke V_r, when the tool or work returns to its initial position.

In turning (Fig. 6.la), drilling (Fig. 6.1c), milling (Fig. 6.1b) and grinding (Fig.6.1e, f) the primary cutting motions are rotary motions of work, or of tool. In broaching (Fig. 6.1g) longitudinal feed is absent.

There is no set-up motion in the drilling, so the width of cut is determined by drill diameter.

6.2 Geometry of a Cutting Tool

The material of the cutting tool must be of higher hardness than the material of the work. The illustrations given above show that the wedge is the basic shape of any cutting tool, whereas the specific shape of the wedge depends on the intended purpose. There are certain angles at a cutting tool, which determine the efficiency of the tool and the value of the applied cutting forces.

The principles underlying cutting-tool angles are the same whether the tool is a turning (lathe) tool, a milling cutter, or a grinding wheel. Since turning tool is the easiest to visualize, it will be discussed in details (Fig. 6.2). It consists of two parts: working (cutting) I and shank II ones. The working operations of turning are carried out by the working part; the shank is intended for fixing of the tool on the lathe.

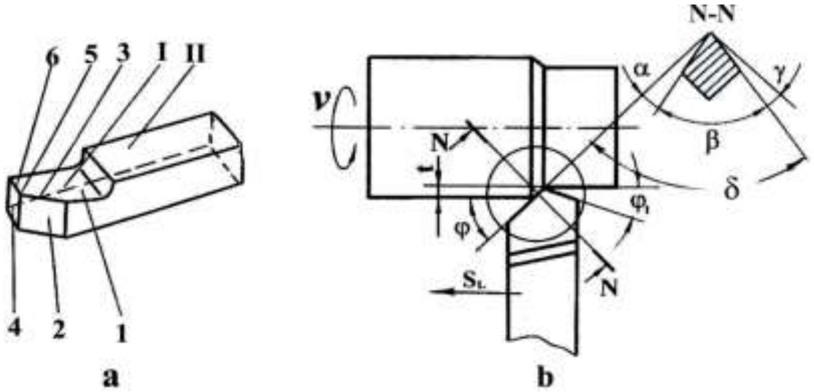


Fig. 6.2. Elements, surfaces and cutting angles of a turning tool: I – working part; II – shank; 1 – top race; 2 – main back rake; 3 – main edge; 4 – auxiliary back rake; 5 – point; 6 – auxiliary edge; α - clearance angle; β - wedge angle; γ - top rake angle; δ - cutting angle

Due to the *clearance angle* α, only the cutting edge of the tool contacts with the surface of the workpiece. Thus, friction is reduced and additional rise in temperature in cutting avoided. This angle is limited by the lower face of the wedge and the surface of the workpiece.

The *wedge angle* β determines the resisting force of the cutting edge. The larger the wedge angle, the longer the tool life (during which a sharpened tool can be used without interruption until it becomes blunt), the higher the cutting force value. The wedge angle is limited by the top of the wedge also known as top (true) rake and the lower face, known as main back rake (flank).

The *top rake angle* γ is formed by the top rake, also known as face, of the wedge and the (imaginary) line running perpendicular to the surface of the workpiece. The value of this angle determines the formation of chip. Large top rake angle allows the chip to peel off easily.

The *cutting angle* δ largely determines the cutting operations. It is formed by the top face of the wedge and the surface of the workpiece. It determines, among other things, shape and size of the chips.

Shape and size of chips, moreover, are determined by plasticity of work.

Continuous chips are received, when metal has high plasticity; and discontinuous chips are formed, when plasticity is low.

6.3. Cutting Speed and Chip Formation

In machining metals the cutting speed is of great importance. It is defined as the speed of the relative motion between the cutting tool and work. In planning and shaping, for example, the tool moves through a straight path over the work, detaching chip. The cutting speed V can be calculated by the following formula:

$$V = \frac{\text{Distance S(m) covered by tool}}{\text{Time t(minutes)}}, \text{m/min} \qquad (6.1)$$

Cutting speed is normally expressed in meters per minute; for high-speed tools, e.g. grinding wheel, the cutting speed is expressed in meters per second.

In the case of rotating tools or workpieses the formula of the cutting speed is as follows:

$$V = \frac{\pi D n}{1000} \text{ m/min, } , \qquad (6.2)$$

where D is diameter of workpieses (turning) or tools (milling, grinding) in mm;
n is revolution speed of workpiece or tool, revolution per minute, or (r.p.m).

When the cutting tool is pressed into the material, chip is produced. The production of chips and their shape are determined by the properties of the material to be tooled, the shape of the tool edge, the cutting edge geometry and the cutting speed. The different types of the chips produced are known as *flowing* (Fig. 6.3a) *shearing* (Fig. 6.3b) and *tearing* chips (Fig. 6.3c).

In the case of flowing chip, which is cut from tough materials (steel 10, 15, 25, 30, Cu, Al, Mg) at high cutting speed, a very smooth surface of the workpiece is produced. When tough materials are tooled at low cutting speeds, or when materials with low toughness are tooled, the shearing chip is produced (steel 50X, 65Г, 60XTC).

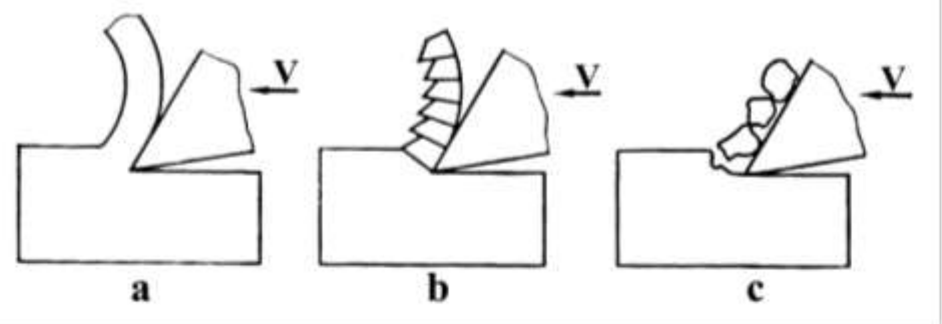


Fig. 6.3. The basic types of chip: a – flowing; b – shearing; c – tearing

In the case of brittle materials (grey cast-iron, hard steels, hard brass) the advancing crack is relatively large. The brittle materials fracture and discontinuous chip is formed. This type is called tearing chip. At low cutting speeds the work surface will be very rough.

6.4. Cutting Materials

The cutting edge of tool is especially stressed by the cutting forces and the heat evolved in cutting because of friction and plastic deformation of machined materials. Thus, the tool is exposed to wear and tempering (softness at high temperature). Frictional heat and wear may be reduced by the use of special coolants or cutting fluids. But at high cutting speed the rise in temperature at the cutting edge may exceed the specified limit so that the tempering and loss of hardness may take place.

So the cutting materials must have a high hardness at room and high temperatures. The last is named *red hardness*. The higher red hardness the higher cutting speed may be taken.

The table 6.1 illustrates the composition and properties of the cutting materials.

Table 6.1. Composition and properties of cutting materials

N	Material	Composition	HRC	Red hardness temperature, °C	Max.cutting speed V, m/min	Notes
1	Carbon tool steels У7,У8…У13	0.7...1.3%C	60...62	200	15	For chisels, axes, saws, files
2	Alloying tool steels 6ХС 9ХВГ, 8Х4В3М3Ф2	0.6...0.9%C+Cr, Si, W, Mo,V	61...65	250...400	20...25	Cutting, surgical, measuring tool
3	High-speed steels Р9, Р12, Р18, Р6М5, Р9Ф5, Р9К10...	~1%C, 4%Cr, 2%V +6…18% W (first figure) + Mo, V, Co	62...64	600...650	up to 100	Cutting tool (unbroken solid or composite)
4 4.1 4.2 4.3	Hard alloys ВК2...ВК25 Т5К10,Т14К18 ТТ7К12	WC+2...25%Co WC+5(14)% TiC+18%Co WC+7 %(TiC+ TaC)+12 %Co	74...86	800...1000	up to 800	Monocarbide alloys, two carbide, three carbide alloys
5	Cermets	$A1_2O_3$ as base + ZnO_2, MgO and etc as a binders	HRA 90	1200	1500 (250 mps)	Cheap, but brittle, is used as insert for finish cutting (without shocks)
6	Super-hard tool materials	Diamonds, elbor BN, silica carbide SiC	HRA 94...96	700...1800	1200 (200 mps)	As cutting tip of tool and indentors for hardness measurement
7	Abrasive grains	$A1_20_3$, SiC, BN, diamond+ +binder	-	1800...2000	900 to 6000 (15...100 mps)	As a component of grinding tools

The selection of the materials to be used for the production of tools depends on the materials, from which works to be machined are made. Another point of view for option is the cutting speed and hardness of tool at elevated temperatures.

Unalloyed or *carbon tool steel,* also known as plain tool steel, having a carbon content from 0.7 to 1.3 % can be used in the lower range of cutting speeds. It has a low elevated temperature (*red temperature*) and hardness (only about 200°C). At higher temperature the tempering process causes hardness decrease.

In addition to 0.6...0.9% of carbon, a*lloy tool steel* contains chromium, silicon and other alloying elements and have a red temperature from 250 to 400°C and maximum cutting speed about 25 m/min. Cr, W, Mo, and V form carbides at elevated temperatures. But to further increase of red temperature special carbides should be formed, such as $M_{23}C_6$, M_6C, MC (M means metal). Therefore, high-speed steels have about 1%C, 4 % Cr, 2 % V, and, in addition to that, 6...18 % W, 0...5 % Mo, 0...10 % Co, up to 5 % V. High-speed steels loose their cutting capability only at 600...650°C. This means that they can be used at high cutting speeds (up to 100 m/min). That is the reason why they are called "high-speed" steels.

Extremely high cutting speeds and a long service life can be achieved with *hard metals* also known as *cutting metals*. Their elevated temperature hardness or red temperature is about 800°C. Cutting metals are made by sintering the carbides of tungsten, titanium, tantalum and, sometimes, other elements with metallic cobalt as a binder in this case. That is why these cutting materials are also known as *cemented carbides*. Carbides are chemical compounds of the mentioned metals and carbon. The melting temperature of these carbides is very high (about 5000°C), but melting point of cobalt is 1494°C. Cemented-carbide products for tools are used in the form of small plates (inserts) to be attached to the tip of tools. Hard metals have a high price.

Newcomers to the cutting-tool field are *cermets*, or *ceramics*, or *cemented oxides*. The principal ingredient of this tool is cheap aluminum oxide (melting point 2050°C), with varying percentages of the other oxides. The material is sintered at very high temperatures (about 2000°C). The material is ceramic, and as a consequence, has high brittleness. The present application seems to be for finishing purposes without shocks. Long service life and the ability to cut the newer materials of high hardness are important ceiling points of this material.

Synthetic diamonds, cubic borous nitride BN, named elbor or belbor and *silica carbide SiC* are produced at high temperature (1700...2500°C) and pressure (10^4...10^5 MPa). In the form of tip of cutting tool diamond and BN may be used for cutting either very hard materials, or very tough (viscous) ones (hard rubber, bakelite, plastics, aluminum, brass, etc.) Like most hard materials they are quite brittle and cannot stand shocks.

Abrasive grains of aluminium oxide, borous nitride, silica carbide and synthetic diamonds in various forms (loose, bonded into wheels and stones, and embedded in papers and coating) find wide usage in industry. They are used for grinding and sharpening of hard materials such as tools, carbides in all forms, and alloys, which have been previously hardened. They are also used when a superior finish is desired on hardened or unhardened materials.

6.5. Machine Tools Classification

At the present time the machine-tool industry produces a large number of metal-cutting machine-tools different in purpose, processing capacities, degree of automatization and size. According to domestic classification, all machine tools are divided into ten main groups depending upon the type of processing operation they perform or tools they employ:

0-reserve group; 1-lathes; 2-drilling and boring machines; 3-grinding and microfinishing machines; 4-combination machine tools; 5-gear-and-thread-cutting machines; 6-milling machines; 7-planers, shapers, slotters and broaching machines; 8-cutting-off machines; 9-miscellaneous.

Each main group, in turn, is further divided into ten subgroups. For example, for lathes we have: 0-special, 1-automatic and semiautomatic single-spindle, 2-automatic and semiautomatic multiple-spindle, 3-turret lathes and so on.

Each subgroup is subdivided into some type, size and modification classes, or sub-subgroups. For example, 1K62 is specified:

1-machine tool of lathe group engine turning, threadcutting and facing lathe;
6-engine and facing lathe (subgroup);
2-maximum radius of work is 200 mm (size class);
K-modification.

But, basic model of the 1K62 engine lathe has the following modifications: model IK62A with tracer control, model 1K62B, which is the same model but of higher accuracy, model 1K62T, which is a high-precision lathe, model lK62ПУ with numeral controls and so on.

6.6. Lathe Works

The lathe is a machine tool that holds work between centers or in a chuck while it is rotated against a fixed tool to form a surface of revolution, e.g. cylindrical, conical and contoured surfaces.

Besides the basic operations of turning, facing, boring, drilling, threading, etc., the lathe can also do milling, shaping, gear cutting, fluting and grinding. Any other machine tool cannot perform such a variety of operations. For continuous or heavy-duty work a specialized machine tool is recommended for these secondary operations.

The Fig. 6.4 represents the simplified scheme of the model 1K62. The principal parts of the lathe machine 1K62 are: bed with two legs 1 and 15, headstock 2, tailstock 14, carriage 7 and chuck 6 on spindel. The speed gearbox 5 is driven through V-belts from electrical motor housed in the left leg 1 of the bed.

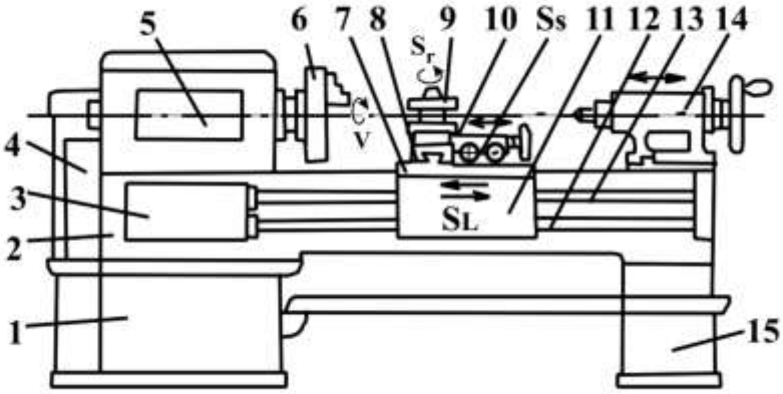


Fig. 6.4. Engine lathe: 1, 15 – legs; 2 – headstock; 3 – teed gear box; 4 – V-belts transmission; 5 – speed gear box; 6 – chuck; 7 – carriage; 8 – sledge; 9 – turning tool-holder; 10 – support; 11 – apron; 12, 13 – screws; 14 – tailstock

Thanks to combination of 26 gears the spindel and chuck 6 with a workpiece have variable rotation speed.

Before starting any work the work piece must be clamped with a chuck 6, when it has small length, or with the chuck and center of tailstock 14, when it is long enough (l>3d). The tool-holder 9 is mounted on support 10, which may perform 4 motions (Fig. 6.4 and 6.5):

- longitudinal S_L together with carriage 7 along slide bars;
- crossing one S_S;
- revolving one S_r;
- inclined to spindel axis S inc (Fig. 6.5k).

The tailstock moves manually on slide bars and its center has longitudinal motion by manual wheel. Instead of center the drill or the reamer may be installed.

In the headstock the feed gear box 3 is placed. It revolves screw 13, which moves carriage and special chisel when thread is cut. Longitudinal and crossing motions of support 10 with chisel may be carried out manually by wheels or by power drive and screw 12.

Figure 6.5 shows workpieces upon which numerous operations have been done. A study of this illustration will give some indications as to why different tools are used for turning (a), facing (b), necking and parting (c), drilling (d), boring (e), threading (f), forming (g), tapering (h, k).

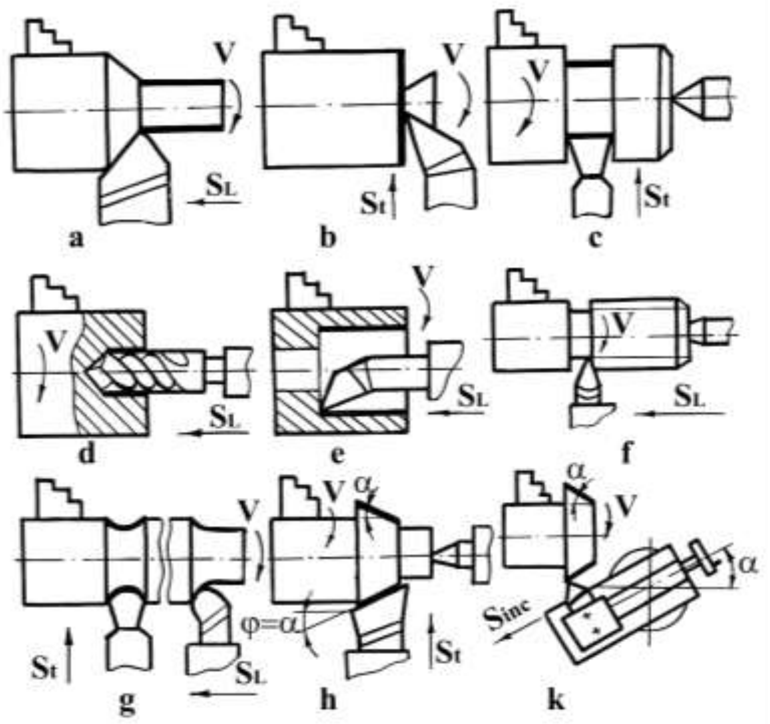


Fig. 6.5. Cutting operation used in lathe work: a – turning; b – facing; c – necking or parting; d – drilling; e – boring; f – threading; g – forming; h, k – tapering

Tools are classified according to their designated purpose (operations), location of the main cutting edge (right - hand and left-hand), shape and material of the blade, etc.

A lathe can be used for drilling and boring. The process is called drilling, when a hole is to be cut in a solid work piece. In the lathe the drill is inserted into the tailstock sleeve.

Drilled holes or integrally cast holes of castings are frequently bored to the finished size (Fig. 6.6).

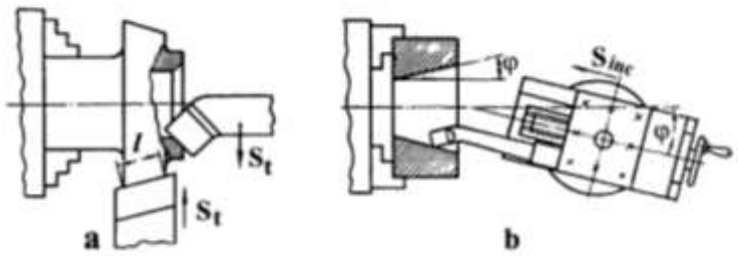


Fig. 6.6. Cutting inside contours: a – a face; b – a conic surface

6.7. Drilling

6.7.1. Main Operations

There are several operations of holes machining that are usually done by a drilling machine.

Drilling is an operation of producing a circular hole by removing solid metal. The cutting tool used is called a *drill*. The drills are most commonly used in the machine shop are twist drills. Figure 6.7 shows such a drill with the main parts identified.

The drill has two (main) cutting edges and one crossing cutting edge. The dimensional accuracy of drilling (Fig. 6.8a) is not high.

Boring is the operation of *enlarging* a hole with a drill (Fig. 6.8b), or by means of a cutting tool with 3 and more cutting edges, named a *bore* (Fig. 6.8c), or by means of an adjustable cutting tool with only one cutting edge (Fig. 6.8d, e). The bore is similar to the drill, but without crossing cutting edge.

Reaming (Fig. 6.8 f) is an operation of sizing and finishing a hole by means of a cutting tool having several cutting edges. This tool is called a *reamer*. Reaming serves to make the hole smoother, straighter and more accurate.

Boring provides higher shape and dimensional accuracy than drilling.

Counterboring (Fig. 6.8 g) is an operation of enlarging the end of a hole cylindrically, as to produce recess for a fillister-head screw.

Countersinking (Fig. 6.8 h) is an operation of making of coneshaped enlargement on the end of a hole, as to make recess for a flathead screw.

Spot-facing (Fig. 6.8 i) is an operation of smoothing and squaring the surface around a hole, as for the seat for a nut or head of a cap screw.

Some bores have guide cylinder for getting an alignment of a drilled hole and cutting hole or surface.

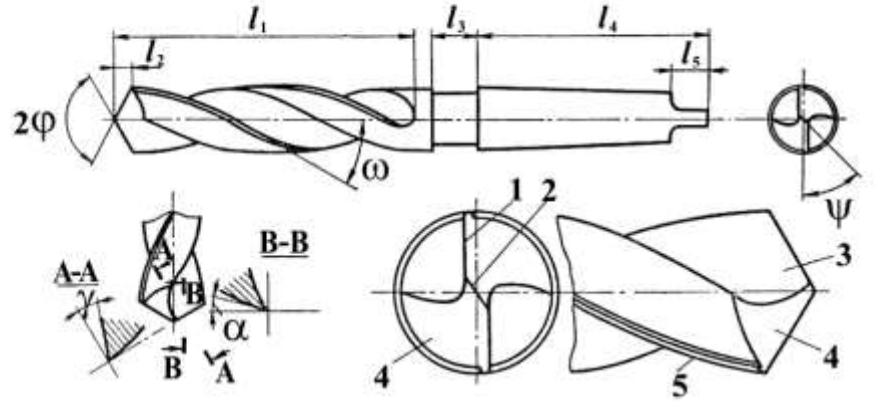


Fig. 6.7. Parts and elements of twist drill: l_1 - body; l_2 - lip; l_3 - neck; l_4-shank; l_5 - tang; 1-main cutting edge; 2-cross cutting edge; 3-top rake; 4-back rake

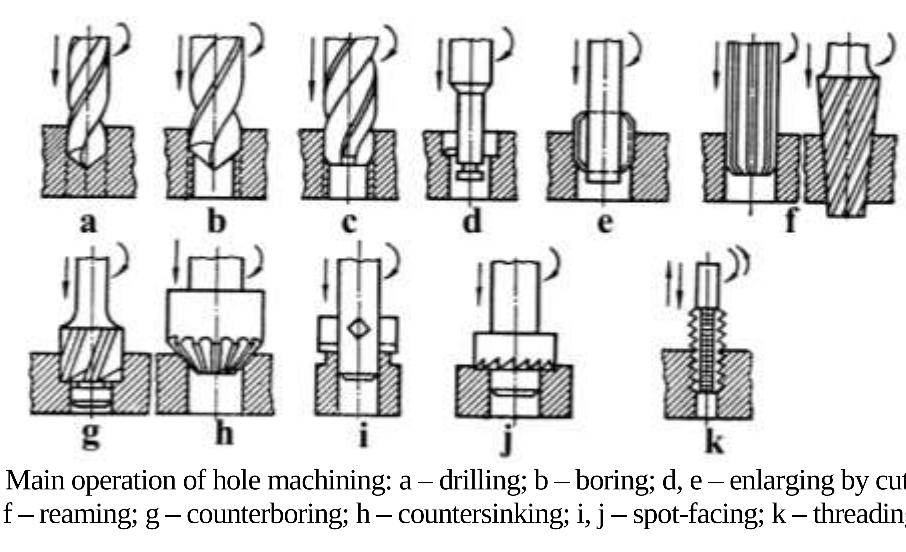


Fig. 6.8. Main operation of hole machining: a – drilling; b – boring; d, e – enlarging by cutting tools; f – reaming; g – counterboring; h – countersinking; i, j – spot-facing; k – threading

Treading (tapping) (Fig. 6.8 k) is an operation of forming internal threads with a tool called a *tap*. To withdraw the tap by power in a drilling machine either a reversible motor or reversing attachment, or tapping attachment are required. To withdraw a tap by hand it is necessary to loosen the chuck or other holding device.

6.7.2. Drilling machines

Drilling is one of the oldest methods of tooling. Most different materials such as wood, metals, and plastics are drilled by means of appropriately shaped tools.

Drilling machines are primarily used for making and treating the cylindrical holes. Drilling and other operations frequently serve to prepare metal parts for riveting, bolting, pinning and other operations.

In metal working the bench-type (Fig.6.9), upright (Fig.6.10), radial (Fig.6.11) drilling machines, boring and fine boring (Fig. 6.12) machines are used.

The drilling spindle 1 of bench type machine can be moved vertically up and down by manual control 2. The cone pulley 3 of the drilling spindle is connected with a cone pulley 4 of an electric motor 5 by a belt. Normally three-step cone pulleys are used. Thus, a range of three speeds is obtained, which are selected by shifting the belt onto the various steps of the cone pulleys. A tool holding device 6 is fitted on the lower end of the drilling spindle. The column 7 is fitted on the cast-iron bed 8.

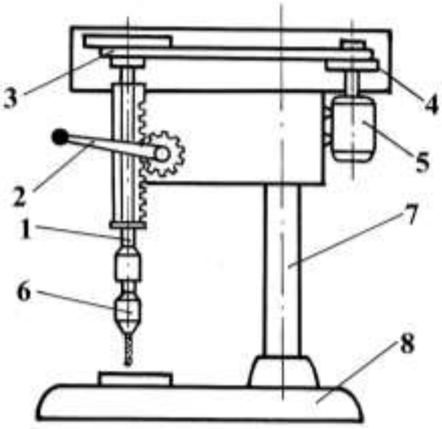


Fig. 6.9. Bench-type drilling machine: 1 – sprindle; 2 – handle; 3, 4 – cone pulleys of V-belt transmission; 5 – electric motor; 6 – chuck with drill; 7 – column; 8 – bed

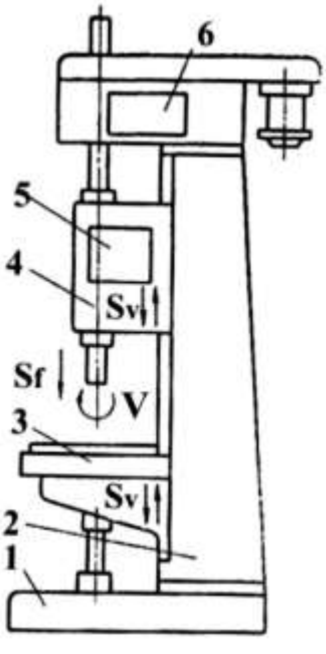


Fig. 6.10. Upright drilling machine: 1 bed; 2 – column; 3 – table; 4 – spindle; 5 – feed gear box; 6 – speed gear box; V – spindle (tool) revolution; S_f – feed motion; S_v – vertical motion of table 3 and feed gear box 5

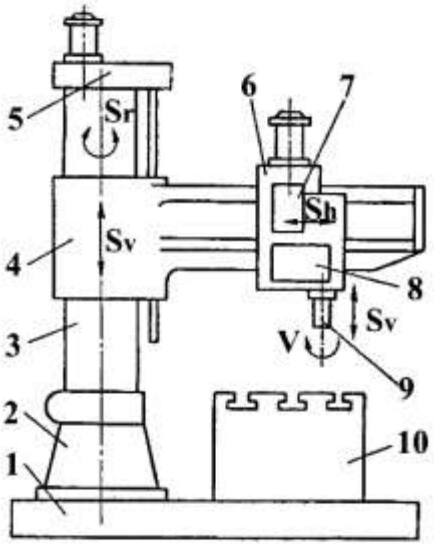


Fig. 6.11. Radial drilling machine: 1 – plate; 2 – bed; 3 – rotating (S_r) column; 4 – rotating together with column and moving up and down (S_v) traverse; 5 – moving mechanism; 6 – spindle head, moving horizontally (S_h); 7 – gear box of springle head; 8 – feed mechanism; 9 – spindle; 10 – table

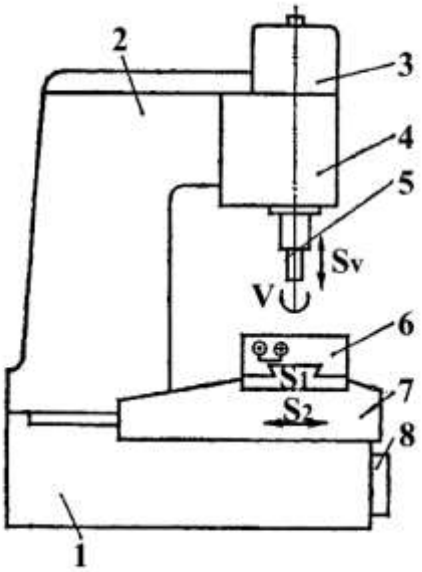


Fig. 6.12. Fine boring machine: 1-bed; 2-frame; 3-drive; 4-boring head; 5-spindle; 6-table; 7-carriage; 8-drive

The design of upright drilling machines (Fig. 6.10) in essence resembles that of a bench type drilling machine. Modern upright drilling machines, however, are not driven by means of a belt drive. The gearcase 6 houses several pairs of gears, which can be engaged by appropriate shifting levers. In this way a wide speed range is ensured (more than 30 speeds).

If material is hard or drills of a large diameter are used, the manual power by means of hand lever will not suffice to perform the feed motion S_f. Therefore, upright drilling machines are equipped with feed-gear mechanism 5 which can be thrown into gear when required. From this follows that there are two possibilities of feeding the drilling spindle 4 (Fig. 6.10). First, the spindle can be fed manually with the feed-gear mechanism disengaged. Secondly, the required feed motion from motor through gearcase 6 and spindle 4 can be effected by means of the feed-gear mechanism 5. The feed-gear mechanism together with spindle, tool and table 3 can move vertically up and down (S_v) along slide bars.

For large workpieces, or workpieces, which require very precise holes, radial drilling machines or jig boring machines are used.

The design of the radial drilling machine (Fig.6.11) in essence resembles that of the upright drilling machine, but its spindle, except vertical S_v, can do two horizontal motions by rotation column 3 S_v and horizontal replacement of spindle head 6 S_h on the traverse 4. The part to be worked up is fixed on the table 10 or on the plate 1.

The fine-boring machine (Fig. 6.12) has spindle 5, which can do two motions: rotating V and vertical S_v ones. The machine has a table, which can do two horizontal motion: S_1 (perpendicular to the drawing plane) and S_2 (parallel to the drawing plane) with very high accuracy (±0.001 mm). The highest accuracy in operation of these machines is achieved by means of

- high accuracy of transference mechanism of table;
- holding constant temperature (20 ± 1 °C);
- sometimes using diamond tools.

Except vertical drilling machines there are horizontal drilling and boring machines of different types.

6.8. Planing, Shaping and Slotting

Planing and shaping machines are used to machine plane surfaces. Shaping and planning machines remove metal in series of straight cuts, in contrast to the rotary cutting action of other machines. The process is accomplished either by reciprocating a cutting tool while the work is fed, as in case of shapers, or by reciprocating the work while the tool is fed, as in planning (Fig. 6.13a, b).

Shaping machines (shapers) (Fig. 6.14) are also used for cutting of recess or grooves in workpieces, for manufacturing of dies, for tool making and similar purposes. Shapers are distinguished by the fact that a single-point cutting tool is reciprocated perpendicular to the longitudinal axis of the workpiece, which is clamped on the table 6. Working motion of the ram 9 is up to 1000 mm.

Slotting and relief-slotting machines have the same working principle as shaping machines but working and free running of tool is vertical. Examples of jobs that can be done by the slotting machines are shown in Fig. 6.15.

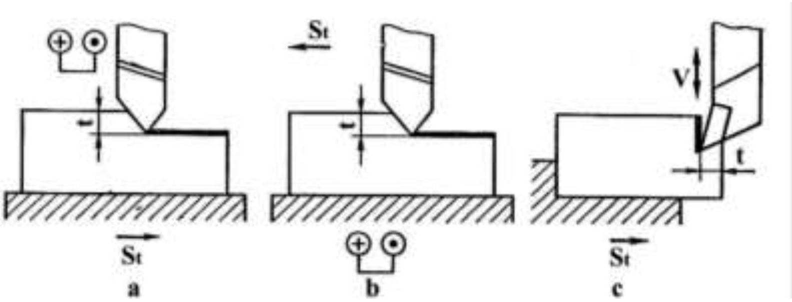


Fig. 6.13. Shaping (a), planing (b) and slotting (c)

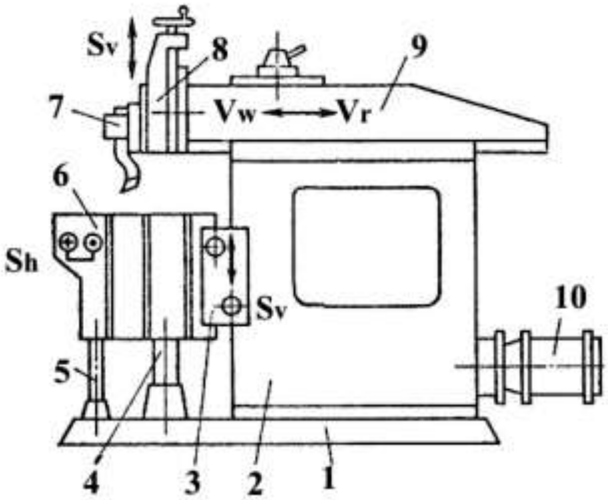


Fig. 6.14. Shaping machine: 1 – foundation plate; 2 - body; 3 – traverse for transference S_h of the table 6 horizontally; 4 – column; 5 – screw for transference S_v of the table 6 vertically; 7 – tool; 8 – support; 9 - ram, doing horizontal motions: V_w – working stroke and V_r – return stroke; 10 – drive

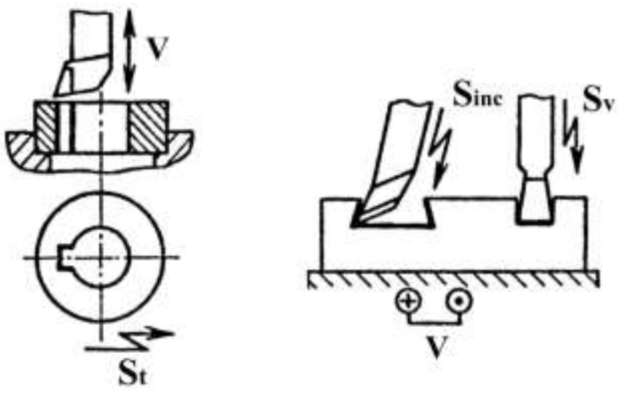


Fig. 6.15. Examples of jobs that can be done by the slotter

The planer is the largest of the reciprocating machine tools (Fig. 6.16). Since it is larger than the shaper and the miller, the planer can take work, which neither of those machines can handle. It is also capable of taking mach heavier cuts than either of those machines. The shaper moves a tool against the workpiece, but the planer moves the work against the tool. The work is mounted on a table, which is supported throughout its entire movement, so a maximum support is obtained. Like the shaper, the planer is intended to produce vertical, horizontal or inclined planes. It can also produce certain warped surfaces if these surfaces are composed of straight-line elements and the work can be indexed or turned. Modern planers have tables of up to 25...30 m in length.

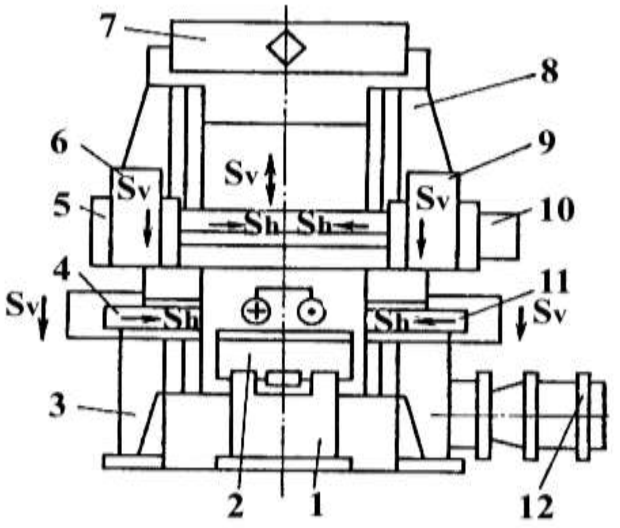


Fig. 6.16. Block diagram of a planer: 1 – body; 2 - table; 3, 8 – colomns; 4, 6, 9,11 - tool-heads;
5, 10 – traverses; 12 – drive

6.9. Milling

Milling is the metal cutting operation, in which chip is detached by series of cutting edges arranged on the circumference of rotary milling cutters. Due to the high number of cutting edges, a large volume of chip can be removed in the single operation. Frequently, the workpieces may be finished in the single operation.

Milling tool is a cutter, which rotates around either horizontal or vertical axis. In accordance with this there are two types of milling (horizontal and vertical one) and three types of milling machines: horizontal, vertical (Fig. 6.17) and universal. The latter machine has the spindle, which can incline. Two methods of horizontal milling are distinguished: cut-up (conventional) and down-cut (climb) milling (Fig. 6.18).

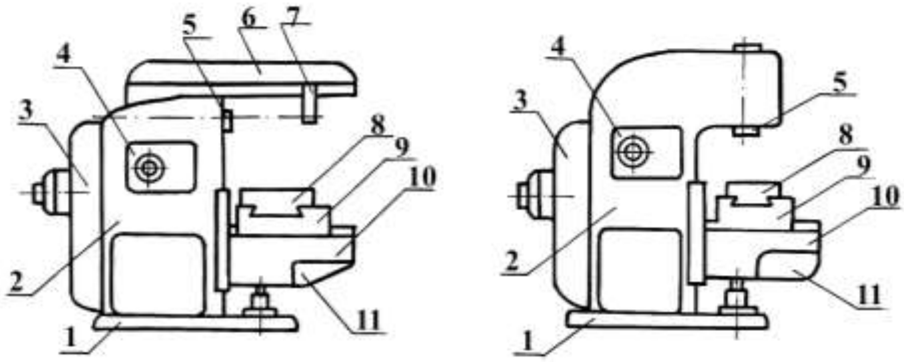


Fig. 6.17. Horizontal (a) and vertical (b) milling machines: 1-base; 2-column; 3-electric motor with belt transmission; 4-spindle speed gear box; 5-horizontal or vertical spindle; 6-overarm; 7-outer arbor support; 8-table; 9-slide; 10-knee; 11-feed gear box

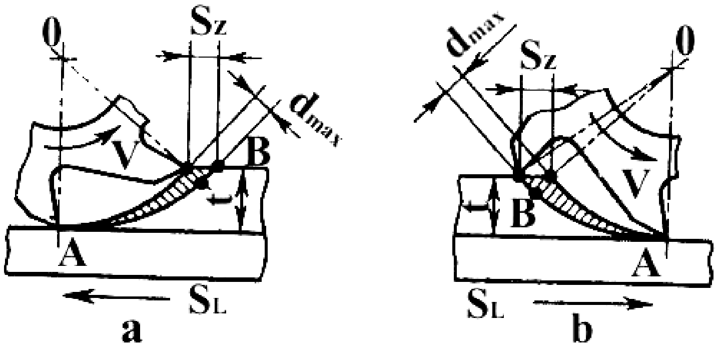


Fig. 6.18. Conventional (up) (a) and climb (down) (b) milling: thick-ness of removed metal; d_{max} – maximum chip thickness; S_z – feed motion on one tooth of cutter

The milling cutters used in horizontal machines are called hobs. The longitudinal axis of the cutter runs in parallel to the surface of the workpiece to be milled. Teeth of the cutter penetrate into the material when cutter is rotated. In cut-up milling process (Fig. 6.18a) the cutter rotates (cutting motion V) against the direction of movement of the work (feed motion S_L). The workpiece runs against the milling cutter. Each tooth or cutting edge of the cutter starts with zero chip thickness (point A) and increases it to maximum d_{max} as tooth leaves the work (point B). So, the load on the tooth increases gradually. But cutting forces aspire to lift the workpiece causing its vibration and deterioration of the machined surface. Nevertheless, cut-up milling method is the ordinary or conventional method used in horizontal milling machine work.

In the down-cut milling method (Fig.6.18b) the cutter revolves in the same direction as the work moves. This results in maximum chip thickness d_{max} at the beginning of the cut tapering off to zero thickness at the end of the cut and in high shocking loads on the teeth. Therefore, this method can be used only with particularly steady milling machines. The workpiece in this method is pressed to a table of the machine that results in high quality of surface finish.

Both in conventional and down-cut milling the cutting tool and machine are loaded not uniformly. This non-uniform stress may be balanced to a considerable extent by a special arrangement of the cutting edges of the cutter, e.g. in spiral teeth milling cutter (Fig. 6.19a).

Milling cutters for horizontal milling machines. Cylindrical milling cutters are primarily used for milling the plane surfaces (Fig.6.19a).

If both plane surfaces and end faces are to be milled at the same time shell-end cutters (Fig. 6.19c) are used (sometimes they are called corner cutters).

If the workpieces are to be slotted circular saw blades of the required width are used (Fig. 6.19q).

Angular cutters (Fig. 6.19i) are used to produce straight-sided shapes. To manufacture contoured surfaces or profiles formed milling cutters (Fig. 6.19k) of the appropriate shapes are used.

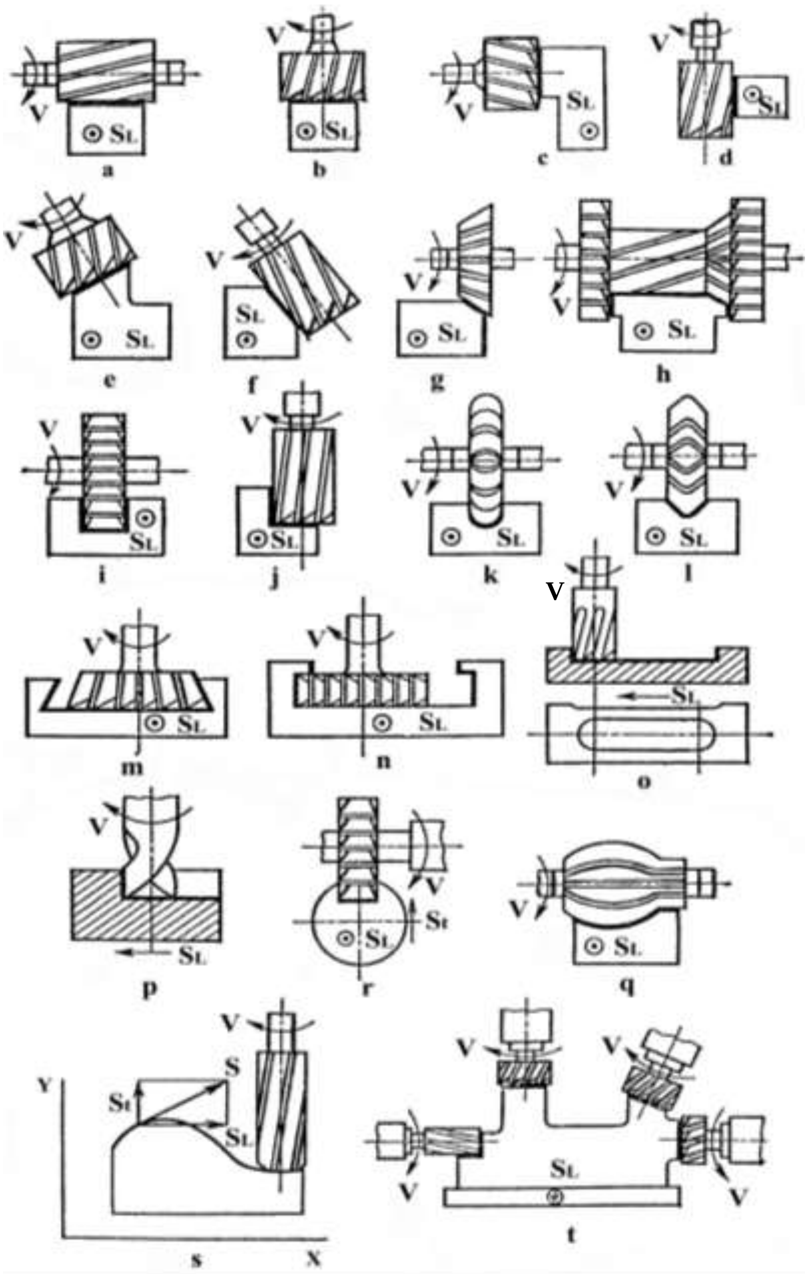


Fig. 6.19. Basic milling operation and tools

If surfaces of different dimensions or certain contours are to be produced on a workpiece, it is possible to use a set of milling cutters (gang cutters) (Fig. 6.19h) with a view to machining the workpiece in one single operation.

Basic operations and tools of vertical milling machines. The cutter, mounted in the work spindle of vertical milling machines, normally operates in a position perpendicular to the surface of the workpiece to be milled. The teeth of the cutter remove a uniformly thick chip. This results in more uniform stress on the milling machine. In vertical milling the cutter performs the cutting action with the teeth on the end face. Therefore, this cutting operation is also known as face milling (Fig. 6.19b). To mill grooves end (Fig. 6.19o) or side milling cutters are used; their width should be equal to that of the groove to be milled. In many cases milling by means of end milling cutters has the advantage over horizontal milling. Vertical milling machines are used to produce flat surfaces and are also employed to cut recesses of various type in work pieces.

6.10. Gear - Cutting Methods

The two principal methods are employed in gears manufacturing: form cutting and generating. In form cutting process cutting tool with cutting edges formed to the shape of the tooth space to be cut is used. Gear-tooth milling cutters of the disk or end-mill type are examples of such tools (Fig. 6.20).

If a single tool is employed, the cutting alternates with indexing, i. e. turning the blank to the next tooth space or 1/z revolution, where z is the number of teeth of the gear. The production capacity of this method is low since each tooth space is machined separately, and time is lost in returning the tool to its initial position and indexing the gear blank.

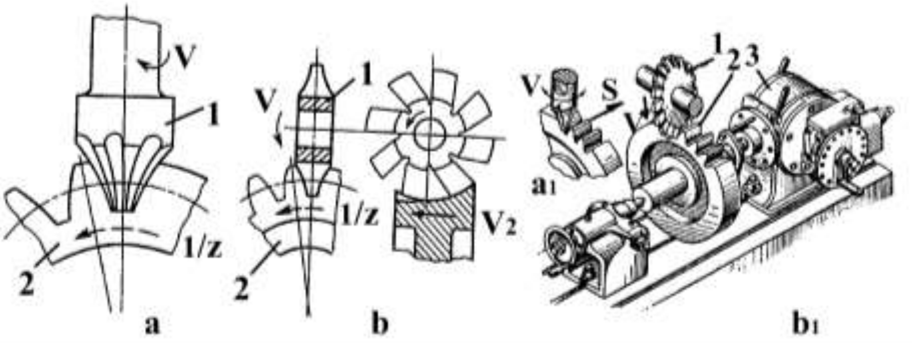


Fig. 6.20. Form gear-cutting: a, b – scheme; a_1, b_1 – drawing; 1 – cutting tool; 2 – billet; 3 – device for periodical turn of the billet on 1/z

In mass production the form cutting principle is applied in the multiple tool slotting cutter head used to cut all the tooth spaces of the gear at the same time (Fig. 6.21). This cutter head has as many radially arranged form tools as the number of teeth spaces (teeth) in the gear to be cut. The profile of the tools is exactly of the same shape as the gear-tooth spaces. During each full stroke V (cutting and return) of gear blank each tool is fed radially towards the blank V_r, by the amount equal to the infeed prior to each cutting stroke. All the tools by motion V_v of keeper 3 down are simultaneously retracted from the work in the return stroke to avoid rubbing of tool clearance surface against the machined surfaces. All the tooth spaces are cut simultaneously, and the gear is finished when the tools reach their full depth of cut.

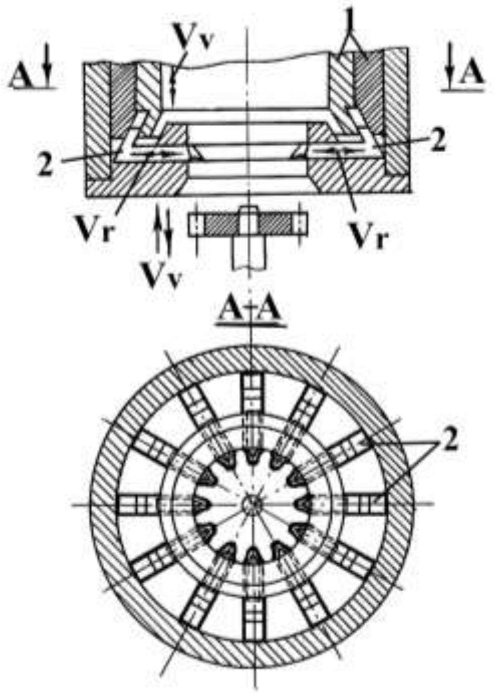


Fig. 6.21. Gear cutting by multiple tool slotting head: 1-gear; 2-radially arranged tools

The production capacity of this gear-cutting method is very high because accuracy of the cut gears depends only upon the accuracy of the cutter head, which may be sufficiently high.

Comparatively complex manufacture of the cutter heads and the necessity to have a separate head for each gear are among the drawbacks of this method.

The generating process is based upon the meshing of the cutter with gear being produced to develop the tooth by the relative rolling motion of the cutter and the work. For this purpose the cutter is shaped like a gear, gear rack or worm, i.e. a part which could mesh with the gear being cut; or the tool is made so that its cutting edges describe in space the surfaces of the tooth profiles of a certain imaginary gear or rack, known as the generating gear or rack.

In this general type of gear-cutting machines the cutting tool resembles either a gear and is called a rotary gear cutter (shaper), or a gear rack, in which case it is called a rack-type cutter.

A gear slotter (operating with the rotary type cutter 1) has the following principal motions (Fig. 6.22):

- straight line primary cutting motion V accomplished by travel of the cutter only in one direction (cutting stroke) and return of the cutter to the initial position (return stroke);
- continuous rotation of the cutter V_c and the gear blank V_b to obtain the circular feed (indexing motion);
- feeding motion (radial infeed) of the cutter S_c is obtained by travel of the cutter 1 axis in a direction towards the blank 2 axis with reciprocation of the blank V_b to avoid friction while return stroke.

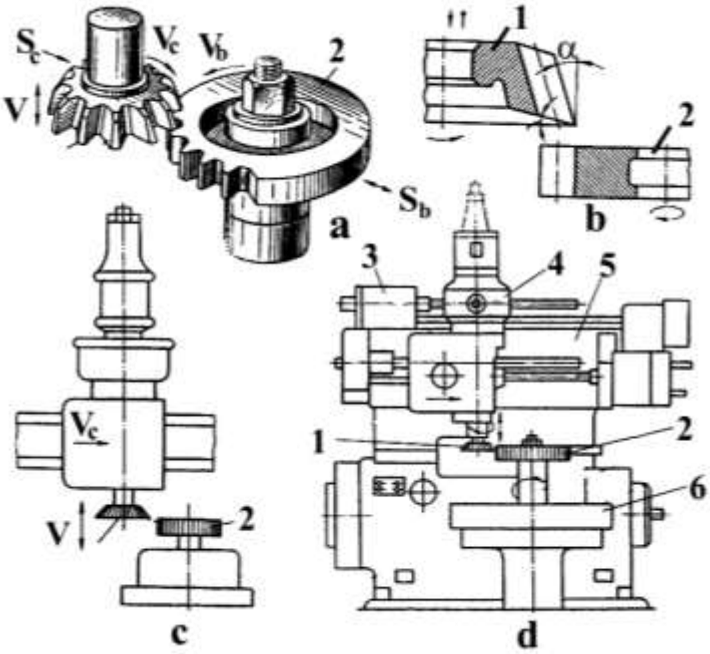


Fig. 6.22. Rotary type gear cutter: a – drawing; b – cutting angles of the cutter; c – work part of gear-cutting machine; d – gear-cutting machine: 1 – cutter; 2 – blank; 3 – driving mechanism; 4 – cutting head; 5 – traverse; 6 – table

6.11. Grinding

Grinding is a metal cutting process carried out with abrasive grains, which are bonded by special materials. Usually grinding tool has a shape of a disk; sometimes it has a shape of a cone, a bar and so on.

The abrasive cutting has peculiarities:

- grains have negative top rake angle γ (Fig. 6.23);
- the cutting speed is very high ($v>30$ m/sec); the rotary speed of wheels is limited by strength of wheel bond;

- the grinding wheel is similar in action to multi-tooth milling cutter; it presents about 300 million cutting edges to a workpiece in 1 minute; grains break off periodically to present new cutting edges; bond wears away faster than grains, it allows to expose new grain for cutting; grinding wheel produces a chip just like any other cutting tool, but it is dust-fine chip, being visible only under a microscope;
- these chips are given in the form of sparks because of their high temperature.

Corundum $A1_2O_3$, silica carbide SiC, boron carbide B_4C and diamond C are used as abrasive materials. According to their sizes the distinction is made between:

- grains, which have sizes from 2.00 to 0.16 mm;
- powders, which have sizes from 0.12 to 0.03 mm;
- micropowders, which have sizes from 0.04 to 0.005 mm.

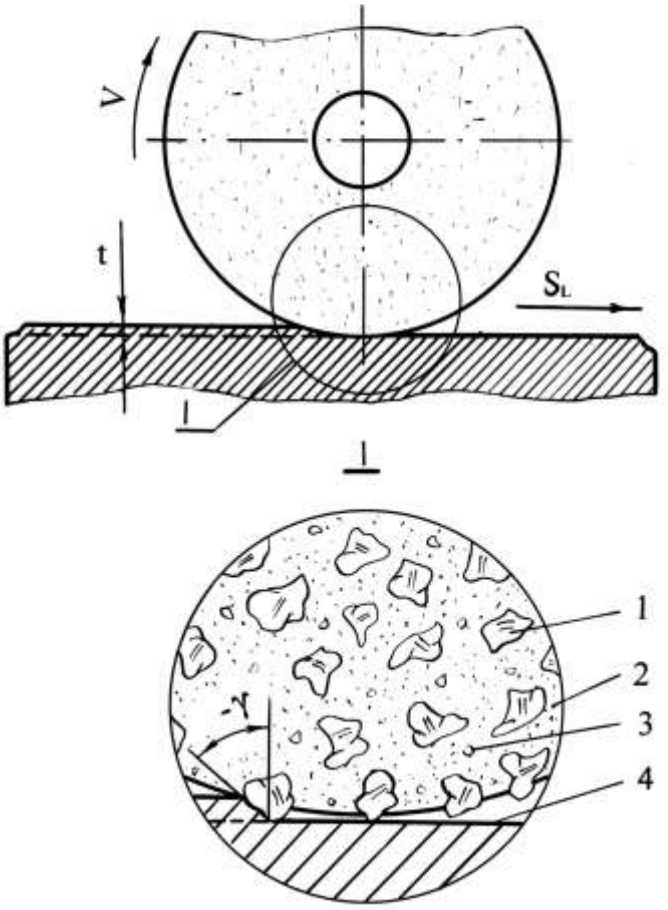


Fig. 6.23. Cutting by grinding tool: 1 – abrasive grain; 2 – bond (matrix); 3 – pore; 4 – blank

Fireclay, water glass, quartzite (non-organic substances) and bakelite, rubber, phenol-formaldehyde resins (organic substances) and other substances are used as a bond.

A distinguishing feature of *grinding machines* is a rotative abrasive tool. This group of machines is employed chiefly in finish machining operations accomplished by removing layers of metal from the work surface with an accuracy that may reach tenths of a micron and producing a very high class of surface finish.

Grinding machines handle workpieces that have been previously machined, in the most cases, in other types of machine tools, leaving a small grinding allowance of magnitude depending upon the required class of accuracy, size of the work and the proceeding machining operations to which it has been subjected.

Operations efficiently performed by grinding machine include:

- roughing and cutting off blanks;
- precise machining of flat surfaces, surfaces of revolution, profiles of gear teeth, thread and other helical surfaces, contoured surfaces, etc.;

- sharpening of all types of cutting tools.

Cylindrical grinding machines (Fig. 6.24 a, b, c) are intended for grinding external cylindrical and tapered surfaces. The primary cutting motion is a grinding wheel rotation V_d. The auxiliary cutting motion is a workpiece rotation V_d. The longitudinal feed motion S_L is a work motion and infeed traverse motion S_t is the periodic crosswise tool motion D is diameter of a workpiece, t is thickness of removed metal.

Internal grinding machines are intended for grinding cylindrical (Fig.6.24d) and tapered holes. The end faces of the workpiece are usually ground in these machines as well.

In addition to the primary cutting motion of the grinding wheel rotation V_w internal grinders of the chucking type have the following working motions:

- work revolution V_p;
- longitudinal motion (the reciprocating motion of the work or grinding wheel) S_L;
- set-up - infeed motion (the periodic crosswise motion of the wheel (wheel head) S_t.

In the *planetary-type internal grinders* (Fig. 6.24e), designed for finishing holes in workpieces of irregular shape, or large heavy workpieces, work rotation is replaced by rotation of the axis of grinding wheel in a circle about the axis of the hole being ground $V_{w.p.}$. The longitudinal motion S_L is obtained by reciprocation of either the grinding wheel or work table, on which the work is clamped.

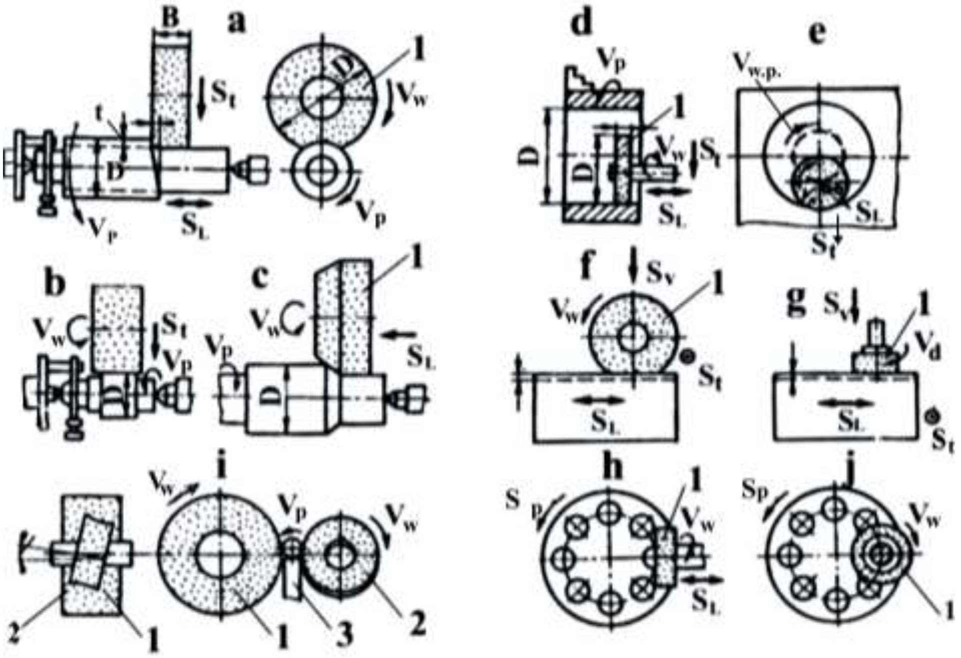


Fig. 6.24. Basic grinding operations: a, b, c, i – grinding of external cylindrical and tapered surfaces; d, e – grinding of internal surfaces; f, g, h, j – grinding of flat surfaces; 1, 2 – abrasive disks; 3 – support (blade)

Today the most widely used types of surface grinders at the present time are the following: *horizontal-spindle reciprocating-table grinders* (Fig. 6.24f); *vertical-spindle reciprocating-table grinders* (Fig. 6.24g); *horizontal-spindle rotary-table grinders* (Fig. 6.24h); *vertical-spindle rotary-table grinders* (Fig. 6.24j).

In respect to the kind of surface they can grind, *centreless grinders* are classified as external (Fig. 6.24i) and internal centreless grinders. Workpiece is supported in the external centreless grinder on work-rest blade 3 and between grinding wheel 1 and regulating wheel 2. The grinding wheel rotates at a peripheral speed of 30 to 40 m per second and removes the grinding allowance from the work-piece. The regulating wheel rotates at a peripheral speed of 10 to 50 m per minute. It imparts both rotation and axial motion to the workpiece.

In the internal centreless grinder a work-piece is rotated between support roll, pressure roll and regulating roll, and is grounded by grinding wheel.

6.12. Finishing and Microfinishing Processes in Machining of Metals

Tolerances. In the metal working industry, especially in large-scale production, the workpieces are machined to specified sizes. The size mentioned in technical instruction, called nominal size, must be obtained.

But when several workpieces are measured their actual sizes will vary from the nominal size by more or less significant differences. For example, it is impossible to make two work-pieces to measure exactly 40 mm (40.000 mm). When exact measurements are taken, one workpiece may have a dimension of 40.070 mm, the other one of 39.999 mm.

The following principle has been adopted by the metalworking industry: the size of a workpiece should not be as precise as possible but as precise as necessary.

The principle of tolerance led to the establishment of certain tolerances also known as permissible variations or limits of dimensions (Fig. 6.25), for workpieces in accordance with their intended use. For example, working parts of an engine must have a higher dimensional accuracy than components of agricultural machines. If a length in technical drawing is 50±0.1 mm, the permissible variation of ±0.1 mm means that a work-pieces having an actual size of 49,9 mm or 50,1mm are still useful. Any actual size between these limits also fits for service.

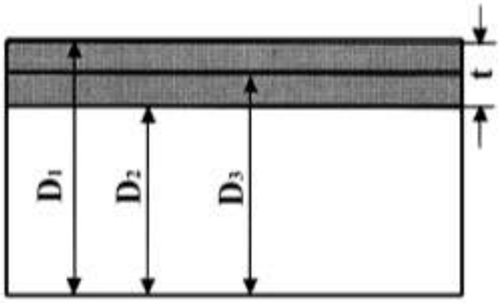


Fig. 6.25. The principle of tolerance: D_1-maximum size; D_2-minimum size; D_3- nominal size; t – tolerance

Surface roughness. On the other hand, any method of machining cannot provide an absolutely smooth surface of a workpiece. Every surface of the workpiece has some departures from the nominal surface. These departures or deviations have a form of peak and valley, named microirregularities, and characterize the degree of surface roughness.

The surface roughness is characterized by the middle average height H of microirregularities within a base length 1 (Fig. 6.26).

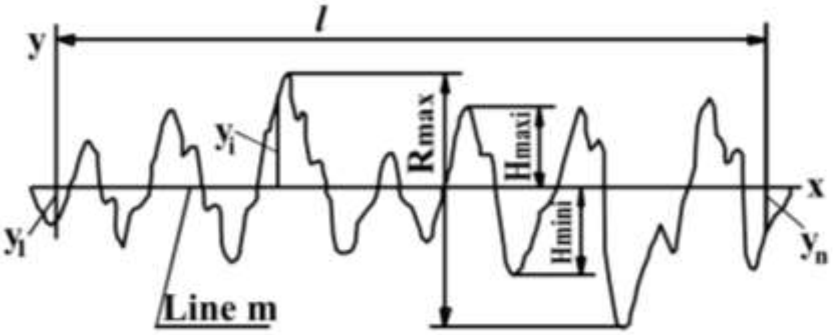


Fig. 6.26. Surface roughness assessment

Surface finish (roughness) has a vital effect on the most important functional properties of machine parts. These include wear resistance, fatigue strength, corrosion resistance and power losses by friction in motion.

Therefore, *finishing and microfinishing processes* are employed in machining the surfaces of many parts to obtain minimum tolerances and minimum roughness of surfaces (Table 6.2). Such processes include *finish cutting, finish grinding, honing, lapping, supper finishing* and other ones.

To obtain the roughness as small as possible tools must have special forms (Fig.6.27) and travel with small feed motion, removing small allowance to decrease cutting forces and workpiece deformation.

Wheels of a coarse grain are used for rough-grinding operations, whereas wheels of a fine grain (micropowders) are used for *finishing.* In the last case the feeding motion is very small, or equal to zero during last passage (reciprocation).

Honing (Fig. 6.28a) is the application of bonded abrasive sticks, held on a honing tool, to surfaces for the purpose of limited stock removal and to obtain a suitable surface finish. The honing tool rotates continuously in one direction and simultaneously reciprocates axially.

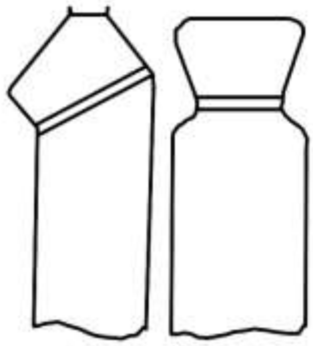


Fig. 6.27. Lathe tools for finish cutting

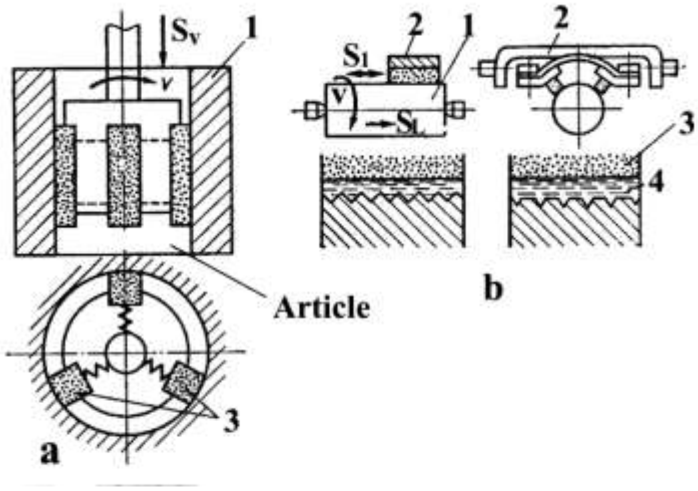


Fig. 6.28. Finishing methods of machining: a – honing; b – superfinish;
1-work; 2-tool holder; 3 – abrasive tool; 4 - mineral oil

The most honing is done on internal surfaces, or holes, such as automobile cylinders. Since it can remove up to 0.7 mm of stock, honing can correct some out of roughness, taper, and axial distortion. It cannot correct hole location or perpendicularity.

The usual amount of stock removal is from 0.10 to 0.25 mm, and as low as 0.01 mm. Honing is applicable in a wide size range: holes of a diameter as small as 3 mm and as large as 1000 mm can be successfully honed. The length of the honed surface may in some cases reach 30 m.

Lapping is final machining operation, applied to produce a very smooth surface. It consists in charging the surfaces of the work or tool (called a lap) with special abrasive pastes or loose-grain abrasive flours mixed with oil or similar fluid. The abrasive is applied to the work by means of lapping belts, shoes, or disks, which are made of a material softer than the work to be lapped (cast iron, copper, wood, felt).

The purpose of lapping is to correct minor surface imperfections, to provide a close fit between mating parts, and to produce a smooth surface. The object of lapping is not to remove metal, since it is not economical as a material-removal operation, but rather to finish to some size or surface finish. The material removal depth is usually less than 0.025 mm although rough lapping may remove as much as 0.075 mm and finish lapping as little as 0.0025 mm.

Superfinishing (Fig. 6.28b) is used to obtain a surface of the highest class of finish. This process is similar to honing with small allowances but differs in the large variation of different tools (abrasive stones and wheels), work motions involved (sometimes up to 12) and the lower cutting speed at lower pressure of the stones on the work surface.

A notable feature of superfinishing is the sharp reduction in metal removal after the ridges and peaks, produced by previous machining, have been removed.

Table 6.2 - Comparative data of surface roughness achieved by various machining methods

Process	Average height of microirregulatarities Z, mkm	Designations	
		R_Z, mkm	R_A, mkm
Rough turning, milling, planing	320...80	R_Z 320	R_a40
Finish turning	40...12.5	R_Z 40	R_a 5
Precision turning	12.5...1.25	R_Z 12.5	R_a 4
Drilling	160...80	R_Z 160	R_a 40
Counterboring	40...12.5	R_Z 40	R_a 10
Grinding	12.5...1.25	R_Z 12.5	R_a 4
Honing	1.25...0.13	R_Z 1.25	R_a 0.4
Lapping	0.25...0.08	R_Z 0.6	R_a 0.04
Superfinishing	0.25...0.01	R_Z 0.6	R_a 0.04

6.13 Electrophysical and Electrochemical Machining

In comparison with the common methods of metal cutting, *electrophysical machining* can offer the following advantages:

- shape the parts made of hard alloys, ruby, diamond, ferrites, and quartz, which are difficult or impossible to machine by common methods;
- cut holes with curvilinear axes and irregularly shaped holes;
- increase the life of the cutting edges of tools and service life of parts.

The electrophysical methods of cutting metals and non-metals include: *electric spark, electric pulse, electric resistance machining, laser processing,* and *electron-beam machining.*

The first three methods are the ones of electroerosion machining of current-conducting metals and alloys. They are based on the effect of the local destruction of metal under heat generated by electric current supplied to a zone of machining. The heat of the electric discharge causes the minutae particles of metal to melt and vaporize from the workpiece.

The process of electric spark machining (Fig. 6.29) uses short electric sparks generating the light heat, which causes electric erosion of the part 3, thus effecting the metal removal from the surface. The process is carried out in a special machine in a container 5 filled with a dielectric liquid 2, such as oil or kerosene, where particles ejected from the workpiece 3 cool and settle down to the bottom 4.

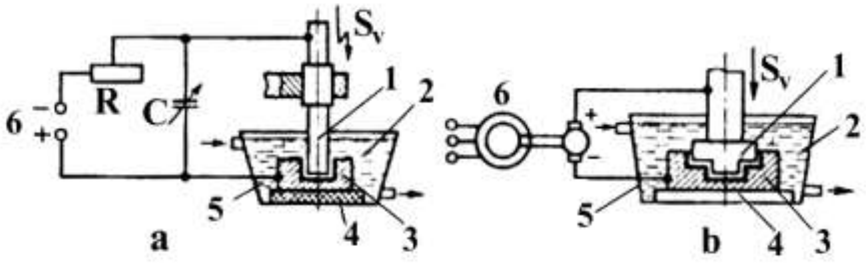


Fig. 6.29. Electric spark (a) and electric pulse (b) machining: 1 – tool (electrode); 2 – dielectric liquid; 3 – workpiece; 4 – dielectric bottom; 5 – container; 6 – impulse generator; R – electric resistance; C – condenser

This process has received the widest acceptance for piercing holes of any shape in poorly workable materials, including hard current-conducting alloys. The dimensional accuracy and surface finish depend on the conditions of machining. The latter ranges from R_z 160 to 0.8 mkm.

Electrochemical cleaning of contaminants, electrochemical polishing and processing in a circulating electrolyte belong to the electrochemical methods of machining of metals and alloys, which have wide application in industry. Chemical-mechanical methods include lapping, finish machining, and surface grinding.

Electrochemical machining relies on the effect of anodic dissociation of a metal acting as an anode when direct current flows through the electrolyte solution.

DICTIONARY

PREFACE

structural material, engineering material	конструкционный материал	конструкційний матеріал
skillful	умелый	умілий
spear	копье	спис
spike	шип, наконечник (копья)	шип, наконечник (списа)
axe	топор	сокира
chisel	резец; зубило; долото	різець; зубило; долото
divider	циркуль	циркуль
steam engine	паровой двигатель	паровий двигун
semiconductor	полупроводник	напівпровідник
machine tool	станок	верстат
macrostructure	макроструктура	макроструктура
microstructure	микроструктура	мікроструктура
melting	плавление	плавлення
metallurgy	металлургия	металургія
foundry practice	литейное производство	ливарне виробництво
metal forming, plastic metal working, plastic working	обработка металлов давлением (ОМД)	обробка металів тиском (ОМТ)
welding	сварка	зварювання
metal cutting, machining, machine tool operations	обработка металлов резанием	обробка металів різанням

1 STRUCTURAL MATERIALS

1.1. CLASSIFICATION AND GENERAL PROPERTIES OF STRUCTURAL MATERIALS

acid	кислота	кислота
alkali	щелочь	луг
brass	латунь	латунь
brittleness	хрупкость	крихкість
bronze	бронза	бронза
cast iron	чугун	чавун
ceramic	керамика	кераміка
cold resistance	хладостойкость	холодостійкість
composite material	композиционный материал	композиційний матеріал
corrodent	вещество, способствующее коррозии	речовина, що сприяє корозії
creep	ползучесть	повзучість
device	прибор, устройство	прилад, пристрій
durability	долговечность	довговічність
elasticity	упругость	пружність
electrical conductivity	электропроводность	електропровідність
fatigue strength	усталостная прочность	втомна міцність
ferrous alloy	сплав на основе железа	сплав на основі заліза
glass	стекло	скло
hardening	упрочнение	зміцнення
hardness	твердость	твердість
heat conductivity, thermal conductivity	теплопроводность	теплопровідність
hot resistance	жаростойкость	жаростійкість
hot strength	жаропрочность	жароміцність

impact strength	ударная вязкость	ударна в’язкість
inclination	склонность	схильність
interaction	взаимодействие	взаємодія
iron	железо	залізо
leather	кожа	шкіра
machinability	обрабатываемость резанием	обробка різанням
magnetic permeability	магнитная проницаемость	магнітна проникність
magnetic saturation	магнитное насыщение	магнітне насичення
malleability	ковкость	ковкість
mass density	плотность	щільність
melting point, melting temperature	температура плавления	температура плавлення
non- ferrous alloy	цветной сплав	кольоровий сплав
oxidation resistance	сопротивление окислению	опір окисленню
plastic	пластмасса	пластмаса
plasticity	пластичность	пластичність
reliability	надежность	надійність
rubber	резина	гума
service life	срок эксплуатации	термін експлуатації
shrinkage	усадка (литейная)	усадка (ливарна)
steel	сталь	сталь
strength	прочность	міцність
thermal expansion	тепловое расширение	теплове розширення
wear resistance	износостойкость	зносостійкість
weldability	свариваемость	зварюваність

1.2. MECHANICAL PROPERTIES

1.2.1. STRESS AND STRAIN

axial tension	осевое растяжение	осьове розтягування
bending	изгиб	згинання
compression	сжатие	стиснення
damage	повреждение	пошкодження
deformation	деформация	деформація
permanent deformation	остаточная деформация	залишкова деформація
shear deformation	деформация на срез	деформація на зріз
design engineer	конструктор	конструктор
elastic strain	упругая деформация	пружна деформація
failure	поломка	поломка
penetration	проникновение, внедрение	проникнення
permanent load	статическая нагрузка	статичне навантаження
plastic strain	пластическая деформация	пластична деформація
process engineer	технолог	технолог
slip	скольжение	ковзання
specimen, sample	образец	зразок
stress	напряжение	напруження
tests	испытания	випробування
cyclic t., alternating t.	циклические испытания	циклічні випробування
dynamic t., impact t.	динамические испытания	динамічні випробування
static t.	статические испытания	статичні в.
torsion	кручение	скручування

1.2.2. TENSION TESTS

cross section	поперечное сечение	поперечний переріз
elongation	удлинение	здовження
gauge,gage	измерительный прибор	вимірювальний прилад
limit	предел	границя

l. of proportionality	п. пропорциональности	г. пропорційності
elastic l.	п. упругости	г. пружності
yield l., yield point	п. текучести	г. текучості
necking	сужение	звуження
percent elongation, relative elongation	относительное удлинение	відносне здовження
percent reduction in area, relative reduction in area	относительное сужение	відносне звуження
tensile modulus, modulus of elasticity	модуль упругости	модуль пружності
tensile strength, ultimate strength	предел прочности	границя міцності
true stress	действительное напряжение	дійсне напруження
versus (vs)	в зависимости от, против	в залежності від, проти

1.2.3. HARDNESS OF METALS

apex	вершина	вершина
dial	шкала (прибора)	шкала (приладу)
dimension	размерность	розмірність
face	грань	грань
hardened steel	закаленная сталь	загартована сталь
impression, indentation	отпечаток	відбиток
indentor, penetrator	индентор	індентор
polished	полированный	полірований
tetrahedral pyramid, square-based pyramid	четырехгранная пирамида	чотиригранна піраміда

1.2.4. MECHANICAL PROPERTIES DETERMINED IN DYNAMIC TESTS

impact toughness	ударная вязкость	ударна в’язкість
notch	надрез	надріз
notched bar	призматический образец с надрезом	призматичний зразок з надрізом
pendulum testing machine	маятниковый копер	маятниковий копер
striker	нож (копра)	ніж (копра)
support	опора	опора
susceptibility	чувствительность	чутливість

1.3. ATOMIC-CRYSTAL STRUCTURE OF METALS

1.3.1. GENERAL FEACHURES OF METALS

amorphous body	аморфное тело	аморфне тіло
arsenic	мышьяк	миш’як
crystal structure	кристаллическая структура	кристалічна структура
crystalline body	кристаллическое тело	кристалічне тіло
germanium	германий	германій
silicon	кремний	кремній
superconductivity	сверхпроводимость	надпровідність
tellurium	теллур	телур
temperature coefficient of electrical resistance	температурный коэффициент электрического сопротивления	температурний коефіцієнт електричного опору

1.3.2. CONCEPT OF CRYSTAL LATTICE

angstrom unit	ангстрем (10^{-10} м)	ангстрем (10^{-10} м)
body-centered crystal lattice (bcc)	объемно-центрированная кубическая решетка (оцк)	об’ємно-центрована кубічна решітка (оцк)
center of gravity	центр тяжести	центр ваги

coordination number	координационное число	координаційне число
face-centered cubic lattice (fcc)	гранецентрированная кубическая решетка (гцк)	гранецентрована кубічна решітка (гцк)
hexagonal close packed lattice (hcp)	гексагональная плотноупакованная решетка (гпу)	гексагональна щільно упакована решітка (гщу)
indices of atomic planes	индексы атомных плоскостей	індекси атомних площин
indices of directions	индексы направлений	індекси напрямків
lattice constant	постоянная решетки	постійна решітки
lattice points (sites)	узлы решетки	вузли решітки
notation	обозначение	позначення
origin of coordinates	начало координат	початок координат
periods of lattice	периоды решетки	періоди решітки
space factor	коэффициент компактности	коефіцієнт компактності
space lattice, crystal lattice	кристаллическая решетка	кристалічна решітка

1.3.3. ALLOTROPIC (POLYMORPHIC) TRANSFORMATIONS

allotropy	аллотропия	алотропія
iron	железо	залізо
alpha iron	альфа железо	альфа залізо
beta iron	бета железо	бета залізо
delta iron	дельта железо	дельта залізо
polymorphic	полиморфный	поліморфний
rearrange	перестраиваться	перешиковуватися

1.3.4. ANISOTROPY OF PROPERTIES OF METALS

anisotropic	неоднородный	неоднорідний
crystallite	кристаллит, мелкий кристалл	кристаліт, дрібний кристал
isotropic	однородный	однорідній
monocrystal	монокристалл	монокристал
polycrystal	поликристалл	полікристал

1.3.5. DEFECTS OF CRYSTAL LATTICE

convex	выпуклый	опуклий
defect	дефект	дефект
linear d.	линейный д.	лінійний д.
plane d.	плоский д.	плоский д.
dislocation	дислокация	дислокація
edge dis.	краевая дис.	крайова дис.
screw dis.	винтовая дис.	гвинтова дис.
dislocation density	плотность дислокаций	щільність дислокацій
extra plane, atomic half plane	экстраплоскость, атомная полуплоскость	екстра площина, атомна напівплощина
grain	зерно (кристаллит)	зерно (кристаліт)
interface	поверхность раздела	поверхня розділу
interstitial atom, Frenkel defect	атом внедрения, дефект Френкеля	атом проникнення, дефект Френкеля
subgrain	субзерно	субзерно
vacancy, Shottky defect	вакансия, дефект Шоттки	вакансія, дефект Шотткі

1.3.6. THEORETICAL AND ENGINEERING STRENGTH OF METALS

annihilation	аннигиляция	анігіляція
Burgers' vector	вектор Бюргерса	вектор Бюргерса
contour of Burgers	контур Бюргерса	контур Бюргерса
engineering strength	реальная прочность	реальна міцність

fibrous	волокнистый	волокнистий
filament-like crystal	нитевидный кристалл	нитковидний кристал
impede	препятствовать	перешкоджати
reinforcing	армирование	армування
relieve	освобождать	звільняти
shear modulus	модуль сдвига	модуль зрушення
theoretical strength	теоретическая прочность	теоретична міцність
transference	перемещение	переміщення
“whiskers”	«усы»	„вуса”

1.3.7. DIFFUSION

diffusion	диффузия	дифузія
impregnation	насыщение	насичення
phase transformation	фазовое превращение	фазове перетворення
predominantly	преимущественно	переважно
recrystallization	рекристаллизация	рекристалізація

1.4. SOLIDIFICATION AND METAL STRUCTURE

1.4.1. PRIMARY CRYSTALLIZATION OF METALS IN SOLIDIFICATION

admixture	добавка	добавка
critical radius	критический радиус	критичний радіус
degree of supercooling	степень переохлаждения	ступінь переохолодження
dendrite	дендрит	дендрит
dissipate	рассеивать	розсіювати
enthalpy	энтальпия	ентальпія
entropy	энтропия	ентропія
fine structure	мелкозернистая структура	дрібнозерниста структура
fluctuation	флуктуация	флуктуація
free energy	свободная энергия	вільна енергія
inoculant	модификатор	модифікатор
inoculation	модифицирование	модифікування
isomorphic impurity	изоморфная примесь	ізоморфна домішка
latent heat of solidification	скрытая теплота кристаллизации	прихована теплота кристалізації
long-range order	дальний порядок	дальній порядок
nucleus	зародыш	зародок
rate of growth of nuclei	скорость роста зародышей	швидкість росту зародків
rate of nucleation	скорость зарождения центров кристаллизации	швидкість зародження центрів кристалізації
short-range order	ближний порядок	ближній порядок
solidification, crystallization	затвердевание, кристаллизация	затвердіння, кристалізація
supercooling	переохлаждение	переохолодження
surface energy	поверхностная энергия	поверхнева енергія
surface tension	поверхностное натяжение	поверхневий натяг
volume energy	объемная энергия	об’ємна енергія

1.4.2. MACRO- AND MICROSTRUCTURE OF METALS AND ALLOYS

billet	заготовка	заготівка
casting	литье, отливка	литво, виливок
chemical compound	химическое соединение	хімічне сполучення
component	компонент	компонент
electron microscope	электронный микроскоп	електронний мікроскоп
forging	поковка	поковка
fracture	излом (сплава)	злам
grind	шлифовать	шліфувати

heat treatment	термическая обработка	термічна обробка
heterogeneous	гетерогенный, неоднородный	гетерогенний
homogeneous	гомогенный, однородный	гомогенний
ingot	слиток	злиток
intergranular, intercrystallyne	внутризеренный	інтеркристалітний
interstitial solid solution	твердый раствор внедрения	твердий розчин проникнення
liquid solution	жидкий раствор	рідкий розчин
macrostructure	макроструктура	макроструктура
magnification	увеличение	збільшення
microstructure	микроструктура	мікроструктура
optical microscope	оптический микроскоп	оптичний мікроскоп
phase	фаза	фаза
phase mixture	фазовая смесь	фазова суміш
physical metallurgy	металловедение	металознавство
polish	полировать	полірувати
revealing	выявление	виявлення
smelting	плавка	плавка
smith	ковка	кування
solid solution	твердый раствор	твердий розчин
solute	растворенный компонент	розчинений компонент
solvent	растворитель	розчинник
substitution solid solution	твердый раствор замещения	твердий розчин заміщення
transcrystallyne	межкристаллитный	міжкристалітний
valence	валентность	валентність

1.5. PHASE DIAGRAMS AND STRUCTURE OF ALLOYS. SYSTEM OF IRON-CARBON ALLOYS

15.1. ESSENCE AND PLOTTING OF PHASE DIAGRAMS

antimony	сурьма	сурьма
conoda	конода	конода
crucible	тигель	тигель
degrees of freedom	степени свободы	степені свободи
dendrite segregation	дендритная сегрегация	дендритна сегрегація
equilibrium diagram, **phase diagram,** **constitutional diagram**	диаграмма состояния, фазовая диаграмма	діаграма стану фазова діаграма
eutectic	эвтектика	евтектика
eutectoid	эвтектоид	евтектоїд
evolve	выделять	виділяти
inflection	отклонение	відхилення
interstitial compound	фаза внедрения	фаза проникнення
laves phase	фаза Лавеса	фаза Лавеса
lead	свинец	свинець
liquation	ликвация	ліквація
segregation	сегрегация	сегрегація
liquidus line	линия ликвидуса	лінія ліквідусу
metallic compound	металлическое соединение	металічне з’єднання
monovariant	моновариантный	моноваріантний
nonvariant	нонвариантный	нонваріантний
peritectic	перитектика	перитектика
phase rule	правило фаз	правило фаз
plot	строить (диаграмму)	будувати (діаграму)
rule of segments	правило отрезков	правило відрізків
simple multiple	простое кратное	просте кратне
singular point	сингулярная точка	сингулярна точка

solid solution	твердый раствор	твердий розчин
deficit s.s.	твердый раствор вычитания	твердий розчин вирахування
limited s.s	ограниченный т. р.	обмежений т.р.
ordered s.s.	упорядоченный т. р.	упорядкований т.р.
unlimited s.s	неограниченный т. р.	необмежений т.р.
solidus line	линия солидуса	лінія солідусу
solvus line	сольвус	сольвус
superstructure	сверхструктура	надструктура
thermo-couple	термопара	термопара

1.5.2. COMPONENTS AND PHASES OF IRON-CARBON SYSTEM

alloying element	легирующий элемент	легуючий елемент
austenite	аустенит	аустеніт
carbon	углерод	вуглець
cementite	цементит	цементит
ferrite	феррит	ферит
graphite	графит	графіт
ledeburite	ледебурит	ледебурит
pearlite	перлит	перліт
polyhedral	полиэдрический, многогранный	багатогранний

1.5.3. IRON-CEMENTITE EQUILIBRIUM DIAGRAM

cementite carcass (shell)	цементитная сетка	цементитна сітка
eutectic	эвтектический	евтектичний
eutectoid	эвтектоидный	евтектоїдний
granular pearlite	зернистый перлит	зернистий перліт
hypereutectic	заэвтектический	заевтектичний
hypereutectoid	заэвтектоидный	заевтектоїдний
hypoeutectic	доэвтектический	доевтектичний
hypoeutectoid	доэвтектоидный	доевтектоїдний
lamellar pearlite	пластинчатый перлит	пластинчастий перліт
secondary (proeutectoid) cementite	вторичный цементит	вторинний цементит
tertiary cementite	третичный цементит	третинний цементит

1.5.4. EFFECT OF CARBON AND MINOR CONSTITUENTS ON PROPERTIES OF STEEL

absorb	поглощать	поглинати
affinity	сродство	спорідненість
aluminium	алюминий	алюміній
cavity	полость	порожнина
chromium	хром	хром
cobalt	кобальт	кобальт
cold heading	холодная высадка (операция ОМД)	холодне висаджування (операція ОМТ)
crack	трещина	тріщина
deoxidation	раскисление	розкислення
drawing capacity	способность к вытяжке (технологическая пластичность)	здібність до глибокого витягування (технологічна пластичність)
embrittle	делать хрупким	робити крихким
flake	флокен	флокен
forging	ковка	кування
harmful	вредный	шкідливий
hydrogen	водород	водень
manganese	марганец	марганець

nickel	никель	нікель
niobium	ниобий	ніобій
nitride	нитрид	нітрид
nitrogen	азот	азот
non-metallic inclusion	неметаллическое включение	неметалеве включення
oxide	оксид	оксид
oxygen	кислород	кисень
phosphorus	фосфор	фосфор
red-shortness, hot-shortness	красноломкость	червоноламкість
rolled stock	прокат	прокат
rolling	прокатка	прокатка
scrap	скрап, лом	скрап, брухт
silicon	кремний	кремній
slag	шлак	шлак
sulphur	сера	сірка
tungsten	вольфрам	вольфрам
vanadium	ванадий	ванадій
violate	нарушать	порушувати
zirconium	цирконий	цирконій

1.6. HEAT TREATMENT OF STEEL

1.6.1 PHASE TRANSFORMATIONS IN IRON ALLOYS

actual grain	действительное зерно	дійсне зерно
austenite transformation diagram, C-curves	диаграмма распада аустенита, С-образная кривая	діаграма розпаду аустеніту С-образна крива
bainite	бейнит	бейніт
burning	пережог	перепал
coalescence	коалесценция	коалесценція
coherence	когерентность	когерентність
critical cooling rate	критическая скорость охлаждения	критична швидкість охолодження
degree of tetragonality	степень тетрагональности	ступінь тетрагональності
diffusionless transformation	бездиффузионное превращение	бездифузійне перетворення
ferrite-cementite aggregate	феррито-цементитная смесь	ферито-цементитна суміш
fine grain	мелкое зерно	дрібне зерно
heat treatment	термическая обработка	термічна обробка
incubation period	инкубационный период	інкубаційний період
inherently coarse-grained steel	наследственно крупнозернистая сталь	спадково крупнозерниста сталь
inherently fine-grained steel	наследственно мелкозернистая сталь	спадково дрібнозерниста сталь
intermediate (bainite) transformation	промежуточное (бейнитное) превращение	проміжне (бейнітне) перетворення
irremediable	неисправимый	непоправний
isothermal	изотермический	ізотермічний
isothermal austenite transformation diagram, TTT-diagram	диаграмма изотермического превращения аустенита	діаграма ізотермічного перетворення аустеніту
lower bainite	нижний бейнит	нижній бейніт
martensite	мартенсит	мартенсит
martensite decomposition	распад мартенсита	розпад мартенситу
martensite transformation	мартенситное превращение	мартенситне перетворення
mosaic structure	мозаичная структура	мозаїчна структура
nonequilibrium phase	неравновесная фаза	нерівноважна фаза
overheating	перегрев	перегрів
pearlite transformation	перлитное превращение	перлітне перетворення

precipitation	выделение	виділення
retained austenite	остаточный аустенит	остаточний аустеніт
sorbite	сорбит	сорбіт
supersaturated	пересыщенный	пересичений
suppress	подавлять	пригнічувати
thermokinetic diagram, CCT-diagram (continuous cooling transformation diagram)	термокинетическая диаграмма	термокінетична діаграма
troostite	троостит	тростит
upper bainite	верхний бейнит	верхній бейніт
Widmanstatten structure	Видманштетова структура	Відманштетова структура

1.6.2. PRACTICE OF HEAT TREATMENT OF STEEL

ageing	старение	старіння
artificial ageing	искусственное старение	штучне старіння
natural ageing	естественное старение	природне старіння
annealing	отжиг	відпал
first-type annealing	отжиг первого рода	відпал першого роду
full annealing	полный отжиг	повний відпал
isothermal annealing	изотермический отжиг	ізотермічний відпал
partial annealing	неполный отжиг	неповний відпал
second-type annealing	отжиг второго рода	відпал другого роду
stress-relief annealing	отжиг для снятия напряжений	відпал для зняття напружень
controlled (protective) atmosphere	контролируемая (защитная) атмосфера	контрольована (захисна) атмосфера
convection	конвекция	конвекція
critical diameter	критический диаметр	критичний діаметр
decarburization	обезуглероживание	зневуглецьовування
dew point	точка росы	точка роси
dispersity	дисперсность	дисперсність
distortion	деформация, искажение	деформація, викривлення
eddy currents	вихревые токи	вихрові токи
end quench test	торцевая проба	торцева проба
endothermic atmosphere	эндотермическая атмосфера	ендотермічна атмосфера
film boiling	пленочное кипение	плівкове кипіння
finished article, part	деталь (готовая)	деталь (готова)
hardenability	прокаливаемость	прогартовуваність
hardening	закалка	гартування
full h.	полная з.	повне г.
continuous h.	непрерывная з.	безперервне г.
high-frequency induction h.	з. токами высокой частоты	г. токами високої частоти
partial h.	неполная з.	неповне г.
precipitation h.	дисперсионное твердение	дисперсійне твердіння
surface h.	поверхностное упрочнение	поверхневе зміцнення
hardening capacity	закаливаемость	загартовуваність
holding time	время выдержки (при заданной температуре)	час витримки (при заданій температурі)
homogenization, diffusion annealing	гомогенизация, диффузионный отжиг	гомогенізація, дифузійний відпал
induction heating	индукционный нагрев	індукційне нагрівання
quenching	быстрое охлаждение	швидке охолодження
isothermal quenching	изотермическая закалка	ізотермічне гартування
normalizing	нормализация	нормалізація
ratio of excess air	коэффициент избытка воздуха	коефіцієнт надлишку повітря
recrystallization	рекристаллизация	рекристалізація
residual stresses	остаточные напряжения	залишкові напруження

grain-boundary segregation	зернограничная сегрегация	зернограничнa сегрегація
dendrite s.	дендритная с.	дендритна с.
transcrystalline s.	транскристаллитная с.	транскристалітна с
self-tempering	самоотпуск	самовідпуск
semimartensite zone	полумартенситная зона	напівмартенситна зона
skin effect	поверхностный эффект	поверхневий ефект
stepped quenching	ступенчатая закалка	ступінчасте гартування
sub-zero treatment, cold treatment	обработка холодом	обробка холодом
temper brittleness	отпускная хрупкость	відпускна крихкість
irreversible t.b., t.b. of the first type	необратимая о.х. (первого рода)	незворотна в.к. (першого роду)
reversible t.b., t.b. of the second type	обратимая о.х. (второго рода)	зворотна в.к. (другого роду)
tempered martensite	мартенсит отпуска	мартенсит відпуску
tempered troostite	троостит отпуска	тростит відпуску
tempering	отпуск	відпуск
high-temperature t.	высокий о.	високий в.
low-temperature t.	низкий о.	низький в.
medium-temperature t.	средний о.	середній в.
thermomechanical treatment (TMT)	термомеханическая обработка (ТМО)	термомеханічна обробка (ТМО)
high-temperature TMT	высокотемпературная ТМО	високотемпературна ТМО
low-temperature TMT	низкотемпературная ТМО	низькотемпературна ТМО
vapour blanket	паровая рубашка	парова оболонка
warping	коробление	жолоблення
weldment	сварное соединение	зварне з’єднання
workpiece, half-finished article	заготовка	заготовка

1.7. CHEMICAL HEAT-TREATMENT (CASEHADENING) OF STEEL

ammonia	аммиак	аміак
carbonitriding	нитроцементация	нітроцементація
carburizer	карбюризатор	карбюризатор
carburizing	цементация	цементація
gas c.	газовая ц.	газова ц.
pack c.	ц. в твердом карбюризаторе	ц. у твердому карбюризаторі
charcoal	древесный уголь	деревне вугілля
chemical heat-treatment, casehardening	химико-термическая обработка	хіміко-термічна обробка
cyaniding	цианирование	ціанування
diffusion coating	диффузионная металлизация	дифузійна металізація
immerse	погружать	заглиблювати, занурювати
impregnation	насыщение	насичення
nitriding	азотирование	азотування
peat coke	торфяной кокс	торф’яний кокс

1.8. CLASSIFICATION AND IDENTIFICATION OF IRON-CARBON ALLOYS

1.8.1. STEEL

alloyed cementite	легированный цементит	легований цементит
boron	бор	бор
carbide-forming elements	карбидообразующие элементы	карбідоутворюючі елементи
cemented carbides	твердые сплавы	тверді сплави
coil spring	пружина	пружина
copper	медь	мідь
creep limit	предел ползучести	границя повзучості

designation	обозначение	позначення
grade	марка (стали)	марка (сталі)
graphitizing elements	графитизирующие элементы	елементи, що сприяють графітизації
intercryslalline corrosion	межкристаллитная коррозия (МКК)	міжкристалітна корозія (МКК)
long-term strength	длительная прочность	тривала міцність
loop	петля	петля
magnetic permeability	магнитная проницаемость	магнітна проникливість
magnetically hard materials	магнитотвердые материалы	магнітотверді матеріали
magnetically soft materials	магнитомягкие материалы	магнітом’які матеріали
permalloy	пермаллой	пермалой
permanent magnet	постоянный магнит	постійний магніт
rare earths	редкие земли	рідкісні землі
red-hardness	красностойкость, теплостойкость	червоностійкість, теплостійкість
secondary hardness	вторичная твердость	вторинна твердість
selenium	селен	селен
shot peening	дробеструйная обработка	дробоструминна обробка
silchrome	сильхром	сильхром
steel	сталь	сталь
alloy s.	легированная ст.	легована ст.
austenitic s.	аустенитная ст.	аустенітна ст.
austenitic-carbide s.	аустенитная ст. с карбидным упрочнением	аустенітна ст. з карбідним зміцненням
austenitic-intermetallic s.	аустенитная ст. с интерметаллидным упрочнением	аустенітна ст. з інтерметалідним зміцненням
bearing s.	подшипниковая ст.	підшипникова ст.
boiler s.	котельная ст.	котельна ст.
carbon s.	углеродистая ст.	вуглецева ст.
casehardening s.	цементуемая ст.	ст., що цементується
common s., ordinary quality s.	ст. обыкновенного качества	ст. звичайної якості
quality s.	качественная сталь	якісна ст.
high-quality s.	высококачественная ст.	високоякісна ст.
super-quality s.	особовысококачественная ст.	особливо високоякісна ст.
die s.	штамповая ст.	штампова ст.
electrical s.	электротехническая ст.	електротехнічна ст.
electrical sheet s.	листовая электротехническая ст.	листова електротехнічна ст.
engineering s., machine s.	машиностроительная ст.	машинобудівна ст.
ferritic s.	ферритная ст.	феритна ст.
free cutting s.	автоматная ст.	автоматна ст.
heat-resistant s.	теплостойкая ст.	теплостійка ст.
high-speed s., rapid tool s., red-hard s.	быстрорежущая ст.	швидкорізальна ст.
high-strength s.	высокопрочная ст.	високоміцна ст.
ledeburitic s.	ледебуритная ст.	ледебуритна ст.
magnetic s.	ст. с особыми магнитными свойствами	ст. з особливими магнітними властивостями
marageing s.	ст. мартенситно-стареющая	ст. мартенситно-старіюча
rimming s.	кипящая ст.	кипляча ст.
s. for structural improvement	улучшаемая ст.	покращувана ст.
semiferritic s.	полуферритная ст.	полуферитна ст.
semikilled s.	полуспокойная ст.	напівспокійна ст.
stainless s., rustless s. corrosion-resistant s.	нержавеющая ст.	нержавіюча ст.
structural s.	конструкционная ст.	конструкційна ст.

super-grade s., super-quality s.	высококачественная ст.	високоякісна ст.
tool s.	инструментальная ст.	інструментальна ст.
wear-resistant s.	износостойкая ст.	зносостійка ст.
weldable s.	свариваемая ст.	зварювальна ст.
superalloys	жаропрочные сплавы (суперсплавы)	жароміцні сплави (суперсплави)
surface strain hardening	поверхностное упрочнение	поверхневе зміцнення
undergo	подвергаться	піддаватися

1.8.2. CAST IRONS

calcium	кальций	кальцій
cast iron	чугун	чавун
chilled c.i.	отбеленный ч.	відбілений ч.
graphitized c.i.	графитизированный ч.	графітизований ч.
grey c.i.	серый ч.	сірий ч.
high-strength c.i., nodular c.i.	высокопрочный ч.	високоміцний ч.
malleable c.i.	ковкий ч.	ковкий ч.
mottled c.i.	половинчатый ч.	половинчатий ч.
white c.i.	белый ч.	білий ч.
cerium	церий	церій
graphite	графит	графіт
lamellar g.	пластинчатый гр.	пластинчастий гр.
flacy g., flaced. g.	хлопьевидный гр.	пластівчастий гр.
spherical g., globular g., nodular g.	шаровидный, глобулярный гр.	кулястий, глобулярний гр.
magnesium	магний	магній
precipitate	выделяться	виділятися
tempered carbon	углерод отжига	вуглець відпалу

1.9. NON-FERROUS METALS

alpha-stabilizing agent (element)	альфа-стабилизатор	альфа-стабілізатор
babbitt	баббит	бабіт
beryllium	бериллий	берилій
beta-stabilizing agent (element)	бета-стабилизатор	бета-стабілізатор
cast alloy	литейный сплав	ливарний сплав
cladding	плакирование	плакування
congregation	сосредоточение	зосередження
degassing	дегазация	дегазація
duralumin	дюралюминий	дюралюміній
free-cutting brass	автоматная латунь	автоматна латунь
Guinier-Preston zone	зона Гинье-Престона	зона Гіньє-Престона
modification	модифицирование	модифікування
neutral strengthening agent (element)	нейтральный элемент	нейтральний елемент
non heat-treatable alloy	сплав, не упрочняемый термообработкой	сплав, що не зміцнюється термообробкою
silumin	силумин	силумін
sintered alloy	спеченный сплав	спечений сплав
sintered aluminium powder	спеченная алюминиевая пудра	спечена алюмінієва пудра
tin	олово	олово
wire	проволока	проволока
wrought alloy	деформируемый сплав	сплав що деформується
zinc	цинк	цинк

2 METALLURGY

2.1.MATERIALS USED IN METALLURGY

acid slag	кислый шлак	кислий шлак
anthracite	антрацит	антрацит
ash	зола	зола
basic slag	основной шлак	основний шлак
black oil	мазут	мазут
blast furnace gas	доменный (колошниковый) газ	доменний (колошниковий) газ
blast furnace shop	доменный цех	доменний цех
carbonate	карбонат	карбонат
chamotte	шамот	шамот
chrome- magnesite	хромомагнезит	хромомагнезит
clay	глина	глина
coke	кокс	кокс
coke-chemical plant	коксохимический завод	коксохімічний завод
coking coal	коксующийся уголь	коксівне вугілля
dinas brick	динасовый кирпич	динасова цегла
dolomite	доломит	доломіт
dressing	обогащение (руды)	збагачування (руди)
ferroalloys plant	ферросплавный завод	феросплавний завод
flux	флюс	флюс
foreign impurities	посторонние примеси	сторонні домішки
fuel	топливо	паливо
gravel	гравий	гравій
lining	футеровка	футеровка
machine-building plant	машиностроительный завод	машинобудівний завод
magnesite	магнезит	магнезит
mine	шахта	шахта
mine-dressing plant	горно-обогатительный комбинат	гірничо-збагачувальний комбінат
refining process	процесс обогащения	процес збагачення
ore deposit	месторождение руды	родовище руди
refractory material, **fireproof material**	огнеупорный материал (огнеупор)	вогнетривкий матеріал (вогнетрив)
acid r.m.	кислый о.	кислий в.
basic r.m.	основной о.	основний в.
inert r.m.	инертный о.	інертний в.
rolling shop	прокатный цех	прокатний цех
sand	песок	пісок
silica, silica sand	кварцит, кварцевый песок	кварцит, кварцовий пісок
silicate	силикат	силікат
slag basicity	основность шлака	основність шлаку
steel-making shop	сталеплавильный цех	сталеплавильний цех
sulfide	сульфид	сульфід

2.2. BLAST-FURNACE PROCESS

agglomerate	агломерат	агломерат
charge	завалка, шихта	завалка, шихта
combustion	горение	горіння
direct reduction	прямое восстановление	пряме відновлення
ferromanganese	ферромарганец	феромарганець
ferrosilicon	ферросилиций	феросиліцій
foundry iron	литейный чугун	ливарний чавун
fumigating chamber	распар	розпар
hearth	горн	горн
hearth bottom	днище печи	днище печі

hematite (Fe_2O_3)	гематит, красный железняк	гематит, червоний залізняк
indirect reduction	косвенное восстановление	непряме відновлення
lime (CaO)	известь	вапно
limestone ($CaCO_3$)	известняк	вапняк
limonite ($2Fe_2O_3$*$3H_2O$)	бурый железняк	бурий залізняк
magnetite (Fe_3O_4)	магнитный железняк	магнітний залізняк
pig iron, conversion iron	передельный чугун	переробний чавун
shaft	шахта	шахта
shoulders	заплечики	заплічки
siderite ($FeCO_2$)	шпатовый железняк	шпатовий залізняк
slag hole	шлаковая летка	шлакова льотка
tap hole	летка для чугуна	льотка для чавуна
top	колошник	колошник
tuyere	фурма	фурма

2.3. STEEL PRODUCTION

2.3.1. OXYGEN-CONVERTER PROCESS

blowing	дутье	дуття
deoxidizer	раскислитель	розкислювач
dephosphorization	дефосфорация	дефосфорація
desulphurization	десульфурация	десульфурация
lance	фурма	фурма
pear-like tank	сосуд грушевидной формы	посудина грушопо-дібної форми
steel tapping	выпуск стали (из печи)	випуск сталі (з печі)

2.3.2. OPEN-HEARTH PROCESS

checkerwork of brick	клетчатая кладка из кирпича	клітчата кладка з цегли
flue	газовый канал	газовий канал
open-hearth furnace	мартеновская печь	мартенівська піч
ore process	рудный процесс	рудний процес
pig-and-ore process	скрап-рудный процесс	скрап-рудний процес
pig-and-scrap process	скрап-процесс	скрап-процес
regenerator	регенератор	регенератор
valve	клапан	клапан
waste gas	отходящий газ	газ, що відходить

2.3.3. ELECTRIC STEELMAKING

admixture	примесь	домішка
alternating current	переменный ток	змінний струм
clamp	зажим	затискач
direct current	постоянный ток	постійний струм
drop-bottom bucket	корзина с раскрывающимся дном	кошик із дном, що розкривається
electric-arc furnace	электродуговая печь	електродугова піч
electrode	электрод	електрод
fasten	крепить	кріпити
fettling	заправка (печи)	заправка (печі)
flexible cable	гибкий кабель	гнучкий кабель
fluorspar (CaF_2)	плавиковый шпат	плавиковый шпат
induction furnace	индукционная печь	індукційна піч
plasma furnace	плазменная печь	плазмова піч
resistance furnace	печь сопротивления	піч опору
roller	ролик	ролик
shell	корпус, оболочка	корпус, оболонка
skim off	скачивать (шлак)	скачувати (шлак)

spout	желоб	жолоб
tap-to-tap time	время плавки	час плавки

2.3.4. TAPPING AND TEEMING OF STEEL

billet	заготовка	заготовка
continuous teeming, continuous casting	непрерывная разливка, непрерывное литье	безперервне розливання, безперервне лиття
dendrite segregation, droplet segregation	дендритная сегрегация	дендритна сегрегація
draw	тянуть, волочить	тягнути, волочити
fringe crystal, stretched crystal	вытянутый кристалл	витягнутий кристал
gating system	литниковая система	ливникова система
heterogeneous	неоднородный	неоднорідний
hot top	верх (надставка) изложницы	верх (надставка) виливниці
ingot mould	изложница	виливниця
nozzle	выпускное отверстие	випускний отвір
riser	прибыль	додаток
shrinkage cavity, pipe	усадочная раковина	усадочна раковина
stopper	стопор	стопор
stream	струя	струмінь
teeming ladle	разливочный ковш	розливний ківш
teeming, pouring	разливка (металла)	розливання (метала)
top pouring, direct pouring	разливка сверху	розливання зверху
uphill teeming	разливка снизу (сифонная)	розливання знизу (сифонне)
zone segregation	зональная сегрегация	зональна сегрегація

2.3.5. PRODUCTION OF HIGH-QUALITY AND SUPER-HIGH-QUALITY STEEL

contamination	загрязнение	забруднення
degassing	дегазация	дегазація
plasma jet	плазменная струя	плазмовий струмінь
remelting	переплав	переплавлення
electro slag r.	электрошлаковый п. (ЭШП)	електрошлакове п.
plasma arc r.	плазменно-дуговой п. (ПДП)	плазмово-дугове п.
vacuum arc r.	вакуумно-дуговой п. (ВДП)	вакуумно-дугове п.
seal	затвор	затвор
special electric metallurgy	специальная электрометаллургия	спеціальна електрометалургія
synthetic slag	синтетический шлак	синтетичний шлак

2.4. PRODUCTION OF NON-FERROUS METALS

2.4.1. PRODUCTION OF ALUMINIUM

alumina	глинозем	глинозем
aluminium hydroxide	гидрат окиси алюминия	гідрат окису алюмінію
anion	анион	аніон
anode	анод	анод
autoclave	автоклав	автоклав
bauxites	бокситы	боксити
(current) lead	токоподвод	стумопідведення
cathode	катод	катод
cation	катион	катіон
cryolite (Na_3AlF_6)	криолит	кріоліт
electrolysis	электролиз	електроліз
electrolyte	электролит	електроліт
leaching, lixiviation	выщелачивание	вилуження

pitch (fossil) resin	каменноугольная смола	кам'яновугільна смола
primary aluminium	первичный алюминий	первинний алюміній
rough aluminium	черновой алюминий	чорновий алюміній
sodium aluminate (Na_2AlO_3)	алюминат натрия	алюмінат натрію
specific strength	удельная прочность	питома міцність
tube furnace	трубчатая печь	трубчаста піч
electrolytic refining	электролитическое рафинирование	електролітичне рафінування

2.4.2. PRODUCTION OF COPPER

copper glance	медный блеск	мідний блиск
copper pyrite	медный колчедан	мідний колчедан
fire refining	огневое рафинирование	вогневе рафінування
hydrocarbon	углеводород	вуглеводень
matte	штейн	штейн
oxidizing roasting	окислительный обжиг	окисний випал
reverberatory furnace	отражательная печь	відбивна піч

2.4.3. PRODUCTION OF MAGNESIUM

carnallite ($MgCl_2*KCl*6H_2O$)	карналлит	карналіт
chloride	хлорид	хлорид
fluidized bed furnace	печь кипящего слоя	піч киплячого шару
fluoride	фторид	фторид
lithium	литий	літій
mixer, holding furnace	миксер	міксер
slurry, slime, sludge	шлам	шлам
sublimation	возгонка	сублімація

2.4.4. PRODUCTION OF TITANIUM

rutile	рутил	рутил
ilmenite	ильменит	ільменіт
oil coke	нефтекокс	нафтококс
briquette	брикет	брикет
rectification	ректификация (перегонка)	ректифікація
condensate	конденсат	конденсат
retort	реторта	реторта
sponge	губка	губка
distillation, distilling	дистилляция	дистиляція

3 FOUNDRY PRACTICE

3.1. THEORETICAL FUNDAMENTALS OF FOUNDRY

amenable	поддающийся	що піддається
casting	отливка, литье (процесс)	виливок, лиття (процес)
conform	соответствовать	відповідати
contraction	уменьшение размеров, усадка	зменшення розмірів, усадка
crack	трещина	тріщина
directional solidification	направленная кристаллизация	спрямована кристалізація
fluidity	жидкотекучесть	рідкотекучість
foundry	литейное производство	ливарне виробництво
foundry properties	литейные свойства	ливарні властивості
hot spot	термический узел	термічний вузол
mould	форма	форма
porosity	пористость	пористість
shrinkage	усадка	усадка

linear s.	линейная у.	лінійна у.
volumetric s.	объемная у.	об’ємна у.
shrinkage cavity	усадочная раковина	усадочна раковина
sound casting	плотная отливка	щільний виливок
surface tension	поверхностное натяжение	поверхневий натяг
viscosity	вязкость (жидк.), внутреннее трение	в’язкість (рідн.), внутрішнє тертя
wetability	смачиваемость	змочувальність

3.2. MANUFACTURE OF CASTINGS IN SAND MOULDS

aerator	аэратор	аератор
alumina (Al_2O_3)	глинозем	глинозем
auxiliary	вспомогательный	допоміжний
backing sand, floor sand	оборотная (наполнительная) формовочная смесь	оборотна (наповнювальна) формувальна суміш
bentonite (Al_2O_3*$4SiO_2$*H_2O)	бентонит	бентоніт
binder	связующее, крепитель	зв’язуюче
chromite (Cr_2O_3)	хромит	хроміт
clamp	скоба, зажим	скоба, затискач
cleaning, fettling	очистка (от пригара)	очищення (від пригару)
compliance, deformability	податливость (смеси)	піддатливість (суміші)
cope	верхняя часть (модели, формы)	верхня частина (моделі, форми)
core box	стержневой ящик	стрижневий ящик
core print	знак (знаковая часть стержня)	знак (знакова частина стрижня)
cutting of	обрубка (отделение литниковой системы и прибылей)	обрубка (відділення ливникової системи та додатків)
dextrin	декстрин	декстрин
dirt (slag) trap, crossgate	шлакоуловитель	шлаковловлювач
downgate (sprue)	стояк	стояк
drag	нижняя часть (модели, формы)	нижня частина (моделі, форми)
drawing	чертеж	креслення
dry sand	сухая формовочная смесь	суха формувальна суміш
edge-runner mills	бегуны	бігуни
facing sand	облицовочная формовочная смесь	лицювальна формувальна суміш
fin	заусенец, облой	задирка, облой
fireproof clay, fireclay, caolinite (Al_2O_3*$2SiO_2$*$2H_2O$)	огнеупорная глина	вогнетривка глина
flask, moulding box	опока	опока
foundry slope, pattern taper	литейный уклон	ливарний ухил
gas permeability	газопроницаемость	газопроникність
gating system	литниковая система	ливникова система
green sand	сырая формовочная смесь	вогка формувальна суміш
hopper	бункер	бункер
hydroblasting	гидравлическая очистка	гідравлічне очищення
ingate, runner	питатель	живильник
jolting knock-out grid	вибрационная выбивная решетка	вібраційна вибивна решітка
machining allowance	припуск на механическую обработку	припуск на механічну обробку
moulding	формовка	формування
nozzle	сопло	сопло
overflow, flow off	выпор	випор
overlap	напуск	напуск

parting line, joint line	линия разъема	лінія рознімання
pattern	модель	модель
pattern making	производство моделей	виробництво моделей
fireproof base	огнеупорная основа	вогнетривка основа
pouring basin (cup)	литниковая чаша	ливникова чаша
pouring weight	литейный груз	ливарний вантаж
ram	трамбовать, уплотнять	трамбувати
ramming-up board	подмодельный щиток	підмодельний щиток
ruler	линейка	лінійка
sawdust	древесные опилки	тирса
shaking out, knocking out	выбивка (отливок, стержней)	вибивання (виливків, стрижнів)
shipment	отгрузка	відвантаження
shot blasting	дробеструйная очистка	дробоструминне очищення
silica sand (SiO_2)	кварцевый песок	кварцовий пісок
slotted pattern key	шип для соединения верхней и нижней частей модели	шип для з’єднання верхньої та нижньої частин моделі
split pattern, cope and drag pattern	разъемная модель	рознімна модель
stove	сушильная камера	сушильна камера
superfluous	излишний	надлишковий
tumbling, rumbling	очистка в галтовочных барабанах	очищення в галтувальних барабанах
unit sand	единая формовочная смесь	єдина формувальна суміш
unsplit (solid) pattern	неразъемная модель	нерознімна модель
water glass ($Na_2O*mSiO_2$)	жидкое стекло, гидросиликат натрия	рідке скло, гідросилікат натрію
yoke	коромысло	коромисло

3.3. SHELL-MOULDING PROCESS

curing	отверждение	отвердіння
dimensional accuracy	размерная точность	розмірна точність
glue	клей	клей
phenol-formaldehyde resin	фенол-формальде-гидная смола	фенол-формальде-гідна смола
pulver-bakelite	пульвербакелит	пульвербакеліт
rate of production	производительность	продуктивність
shell-mould casting	литье в оболочковые формы	лиття в оболонкові форми
shot	дробь	дріб
spring-loaded ejector pin	подпружиненный выталкиватель	підпружинений виштовхувач
standard of surface finish	стандарт качества поверхности	стандарт якості поверхні
strip	снимать	знімати
zirconium sand	цирконовый песок	цирконовий пісок

3.4. METAL MOULD CASTING

chilling	отбел (чугуна)	вибілювання (чавуну)
heat erosion	высокотемпературная эрозия	високотемпературна ерозія
heat-insulting coat	теплоизоляционное покрытие	теплоізоляційне покриття
item	изделие, деталь	виріб, деталь
metal mould casting	литье в металлические формы, кокильное литье	лиття в металеві форми, кокільне лиття
metal mould, permanent mould	кокиль, металлическая форма, постоянная форма	кокіль, металева форма, постійна форма
rigid	жесткий	жорсткий
stud bolt, trunnion	штифт, цапфа, ось качания	штифт, цапфа, вісь хитання
thermal fatigue strength	термостойкость	термостійкість

3.5. CENTRIFUGAL CASTING

boring	растачивание	розточування
bushing	втулка, гильза	втулка, гільза
cap	крышка	кришка
centrifugal casting, spinning	центробежное литье	відцентрове лиття
chute	желоб	жолоб
hollow casting	пустотелая отливка	пустотілий виливок
hydrostatic pressure pipe	напорная труба	напірна труба
liner	вкладыш	вкладиш
overflow pipe	сливная труба	зливальна труба
piston ring	поршневое кольцо	поршневе кільце
pulley	шкив, ролик	шків, ролик
two-layer, bimetallic	двухслойный, биметаллический	двошаровий, біметалічний

3.6. PRESSURE-DIE CASTING

cold pressing chamber	холодная камера прессования	холодна камера пресування
duct	канал	канал
hot pressing chamber	горячая камера прессования	гаряча камера пресування
piston	поршень	поршень
plunger machine	плунжерная машина	плунжерна машина
pressure casting die, press mould	пресс-форма	прес-форма
pressure die-casting	литье под давлением	лиття під тиском

3.7. INVESTMENT CASTING

dipping	погружение	занурення
ethyl silicate	этил-силикат	етіл-силікат
expendable	расходуемый	що витрачається
fluidized sand	«кипящий» песок	«киплячий» пісок
shell mould	огнеупорная оболочка (в литье по выплавляемым моделям)	вогнетривка оболонка (при литті за витоплюваними моделями)
investment casting	литье по выплавляемым моделям	лиття за витоплюваними моделями
master die	пресс-форма	прес-форма
paraffin	парафин	парафін
pine	сосна	сосна
quartz	кварц	кварц
quartzite	кварцит	кварцит
rosin	канифоль	каніфоль
silica floor	маршалит	маршаліт
slurry, suspension	суспензия	суспензія
soldering	пайка	паяння
stearin	стеарин	стеарин
wax	воск	віск

3.8. MODERN PROCESSES OF METAL PRODUCTION FOR CASTINGS

3.8.1. CAST IRON PRODUCTION FOR CASTINGS

bott	пробка (летки)	пробка (льотки)
cerium	церий	церій
charge, burden	колоша, шихта	колоша, шихта
crucible (coreless) induction furnace	тигельная индукционная печь без сердечника	тигельна індукційна піч без сердечника
cupola	вагранка	вагранка
duplex process	дуплекс-процесс	дуплекс-процес

inductor	индуктор	індуктор
inoculation	модифицирование	модифікування
lanthanum	лантан	лантан
multiturn coil	многовитковая катушка	багатовиткова котушка
receiver	копильник	копильник
tilting mechanism	поворотный механизм	поворотный механізм
winding	обмотка (электр.)	обмотка (електр.)
yttrium	иттрий	ітрій

3.8.2. STEEL CASTINGS PRODUCTION

admixture	примесь	домішка
boiling	кипение	кипіння
critical castings, responsible castings	ответственные отливки	відповідальні виливки
deoxidize	раскислять	розкислювати
desulphurize	удалять серу	видаляти сірку
melting, smelting, fusion	плавление, плавка	плавлення, плавка
oxidizing melting	плавка с окислением	плавка з окисленням
remelting	переплав	переплавлення

3.8.3. MELTING OF COPPER-BASE ALLOYS

chloride	хлорид	хлорид
duct	канал	канал
exhaust pipe	дымоход	димохід
flotation	флотация	флотація
fluoride (CaF_2)	плавиковый шпат, фторид	плавиковий шпат, фторид
foundry alloy	лигатура, сплав для легирования	лігатура, сплав для легування
grate	решетка	грати
induction furnace with core	индукционная печь с сердечником	індукційна піч із сердечником
jet	горелка, форсунка, струя	пальник, форсунка, струмінь
magnetic flux	магнитный поток	магнітний потік
soda (Na_2CO_3)	сода, карбонат натрия	сода, карбонат натрію
step-down transformer	понижающий трансформатор	понижуючий трансформатор
stool	подставка	підставка
surface-active	поверхностно-активный	поверхнево-активний
tapping throat	горловина для выпуска металла	горловина для випуску метала

3.8.4. MELTING OF ALUMINIUM-BASE ALLOYS

chlorine	хлор	хлор
dilution	растворение	розчинення
graphite-chamotte	графито-шамот (огнеупор)	графіто-шамот (вогнетрив)
modifying mix	смесь для модифицирования	суміш для модифікування

4. METAL FORMING

4.1. PHYSICAL AND MECHANICAL FUNDAMENTALS OF METAL FORMING

anisotropy	анизотропия	анізотропія
displacement	перемещение	переміщення
equiaxed grain	равноосное зерно	рівновісне зерно
etchant	травитель	травник
etching	травление	травлення
fibrous structure	волокнистая структура	волокниста структура
globular structure	равноосная структура	рівновісна структура
impact force	ударная нагрузка	ударне навантаження
impede	препятствовать, замедлять	перешкоджати, сповільнювати

metal forming, plastic metal working	обработка металлов давлением	обробка металів тиском
peening, strain hardening, cold work hardening	наклеп, деформационное упрочнение	наклеп, деформаційне зміцнення
residual deformation	остаточная деформация	залишкова деформація
reveal	выявлять	виявляти
slip plane	плоскость скольжения	площина ковзання
squeezing pressure	сжимающее усилие	стискаюче зусилля
stress	напряжение	напруження
normal s.	нормальное н.	нормальне н.
principal s.	главное н.	головне н.
shear s.	касательное н.	дотичне н.
texture	текстура	текстура
thermomechanical treatment	термомеханическая обработка	термомеханічна обробка
utilization factor	коэффициент использования (металла)	коефіцієнт використання (металу)

4.2. RECOVERY AND RECRYSTALLIZATION

burning	пережог	перепал
cold deformation	холодная деформация	холодна деформація
hot deformation	горячая деформация	гаряча деформація
irremediable	неисправимый	невиправний
overheating	перегрев	перегрів
recovery	возврат	зворот
recrystallization	рекристаллизация	рекристалізація
collective r.	собирательная р.	збиральна р.
primary r.	первичная р.	первинна р.
relief	снятие, устранение	зняття, усунення
scale	окалина	окалина
stony fracture	камневидный излом	каменеподібний злом
threshold	порог	поріг

4.3. TECHNOLOGICAL PLASTICITY

pressing stress	сжимающее напряжение	стискаюче напруження
scheme of deformation	схема деформации	схема деформації
technological plasticity	технологическая пластичность	технологічна пластичність
tensile stress	растягивающее напряжение	розтягувальне напруження

4.4 HEATING OF METALS

furnace, heater	нагревательная печь	нагрівальна п.
chamber f.	камерная п.	камерна п.
continuous f.	методическая п.	методична п.
pit f.	колодец (нагревательный)	колодязь (нагрівальний)
nonoxidation heating	безокислительный нагрев	безокисне нагрівання
pusher	толкатель	штовхач

4.5. ROLLING

actuator	привод	привод
angle bar, angle iron	уголок, угловая сталь	кут, кутова сталь
bar	пруток	пруток
bloom	блюм	блюм
blooming	блюминг	блюмінг
coupling, clutch	муфта	муфта
double tee	двутавр	двотавр

drawing coefficient, extension coefficient	коэффициент вытяжки	коефіцієнт витягування
gap	зазор	зазор
gauge, roll pass	калибр	калібр
break-blowing g.	черновой к.	чорновий к.
closed g. (pass)	закрытый к.	закритий к.
finishing g.	чистовой к.	чистовий к.
open g. (pass)	открытый к.	відкритий к.
mandrel	прошивень, оправка	оправка
pipe	труба	труба
reduction gear	редуктор	редуктор
roll formed shape, roll formed section	гнутый профиль	гнутий профіль
rolled steel sections	стальной прокат	сталевий прокат
rolled stock	прокат	прокат
rolling	прокатка	прокатка
cross r.	поперечная п.	поперечна п.
helical r.	поперечно-винтовая п.	поперечно-гвинтова п
lengthwise r.	продольная п.	поздовжня п.
plain roll	гладкий валок	гладкий в.
rolling mill	прокатный стан	прокатний стан
cluster m.	многоклетьевой стан	багатоклітковий стан
duo m.	дуо-стан	дуо-стан
four-high m.	кварто-стан	кварто-стан
multiroll m.	многовалковый стан	багатовалковий стан
piercing m.	прошивной стан	прошивний стан
pilger m., paying out m.	пилигримовый стан, раскатной стан	пілігримів стан,
section m.	сортовой стан	сортовий с.
three-high m.	трио-стан	тріо-стан
universal m.	универсальный стан	універсальний стан
seamed tube	шовная труба	шовна труба
seamless tube	бесшовная труба	безшовна труба
shape rolled stock	сортовой прокат, сорт	сортовий прокат, сорт
sheet rolled stock	листовой прокат	листовий прокат
size roll	ручьевой валок	рівчаковий валок
sizing	калибровка	калібрування
skelp	штрипс	штрипс
slab	сляб	сляб
slabing	слябинг	слябінг
spindle	шпиндель	шпиндель

4.6. EXTRUSION OF METALS

cable sheating	оболочка кабеля	оболонка кабелю
container	контейнер	контейнер
die	матрица	матриця
direct (forward) pressing	прямое прессование	пряме пресування
extrusion ram	плунжер	плунжер
extrusion, pressing	экструзия, прессование	екструзія, пресування
hydraulic press	гидравлический пресс	гідравлічний прес
indirect (reverse) pressing	обратное прессование	зворотне пресування
orifice	отверстие	отвір
pressing rest	пресс-остаток	прес-залишок
pressing washer	пресс-шайба	прес-шайба

4.7. DRAWING

drawing	волочение	волочіння
reducing die, drawhole	волока	волока
grip	захватывать	захоплювати
lubricant	смазка	мастило
wire	проволока	проволока
drum mill	барабанный стан	барабанний стан
chain mill	цепной стан	ланцюговий стан
hard drawn wire	холоднотянутая проволока	холоднотягнута проволока
tool steel	инструментальная сталь	інструментальна сталь
hard-facing alloy	твердый сплав	твердий сплав
technical diamond	технический алмаз	технічний алмаз

4.8. HAMMERING

anvil	наковальня	ковадло
anvil block	шабот	шабот
bending	гибка	гнуття
block head	боек	бойок
chopping, cutting-off	рубка, отрезка	рубка, відрізка
cylinder	цилиндр	циліндр
drawing	протяжка	протягування
forge hammer	кузнечный молот	ковальський молот
fundament	фундамент	фундамент
hammer	молот	молот
hammering, black smithing, forging	ковка	кування
hand (machine) forging	ручная (машинная) ковка	ручне (машинне) кування
heading	высадка	висадження
lap	напуск	напуск
machinery allowance	припуск	припуск
mass of falling parts	масса падающих частей	маса частин, що падають
piercing	прошивка	прошивання
piston	поршень	поршень
piston rod	шток поршня	шток поршня
piston stroke, piston travel	ход поршня	хід поршня
pneumatic	пневматический	пневматичний
ring rolling, paying-out	раскатка	розкочування
size tolerance	размерный допуск	розмірний допуск
slider	ползун	повзун
squeezing	сжатие	стиснення
traverse	траверса	траверса
twisting	скручивание	скручування
upsetting	осадка	осадження
welding, bonding	сварка (кузнечная)	зварювання (ковальське)
forge pitch	кузнечный уклон	ковальський ухил

4.9. DIE FORGING

belt transmission	ременная передача	пасова передача
calibration, coining	калибровка	калібрування
closed die	закрытый штамп	закритий штамп
cold die forging	холодная объемная штамповка	холодне об’ємне штампування
cold extrusion	выдавливание	видавлювання
cold upset forging	высадка (холодная)	висадка (холодна)
connecting rod, coupler	шатун	шатун
crank press	кривошипный пресс	кривошипний прес

crank shaft	кривошип	кривошип
die forging	объемная штамповка	об’ємне штампування
die, stamp	штамп	штамп
fin, barb, flash	заусенец, облой	облой
flute	паз	паз
fly wheel	маховик	маховик
forming (cold)	объемная формовка (холодная)	об’ємне формування (холодне)
horizontal forging machine	горизонтально-ковочная машина (ГКМ)	горизонтально-кувальна машина (ГКМ)
hot die forging	горячая объемная штамповка	гаряче об’ємне штампування
impression, gauge	ручей	рівчак
knurling	накатка	накатка
open die	открытый штамп	відкритий штамп
output	выпуск, производительность	випуск, продуктивність
screw press	винтовой пресс	гвинтовий прес

4.10. STAMPING

bending	гибка	гнуття
bushing	втулка	втулка
case-reducing	обжим	обтиск
circular shears	дисковые ножницы	дискові ножиці
column	колонка	колонка
cutting-out, blanking	вырубка	вирубування
die	штамп	штамп
bed d.	матрица	матриця
follow d.	штамп последовательного действия	штамп послідовної дії
compound d.	совмещенный штамп	сполучений штамп
upper d.	пуансон	пуансон
drawing	вытяжка	витягування
flanging	отбортовка	відбортування
forming (shaping) operation	формоизменяющая операция	формозмінна операція
guillotine shears	гильотинные ножницы	гільйотинні ножиці
notching	надрезка	надрізання
punching	пробивка	пробивання
separating operation	разделительная операция	розділювальна операція
spring	пружина	пружина
stamping, sheet stamping	листовая штамповка	листове штампування
stampings	высечка (отходы)	висічка (відходи)
strip	полоса	смуга
tape	лента	стрічка

5 WELDING

5.1. PHYSICAL FUNDAMENTALS OF WELDING

consumable electrode	расходуемый электрод	електрод що витрачається
filler rod	присадочный пруток	присаджувальний пруток
nonconsumable electrode	постоянный электрод	постійний електрод
permanent joint	неразъемное соединение	нероз’ємне з’єднання
reel	бобина (проволоки)	бобина (дроту)
rivet	заклепка	заклепка
riveting	клепка	клепання
root gap	зазор (при сварке)	зазор (при зварюванні)
weld	сварной шов, сварное соединение	зварний шов, зварне з’єднання
weldability	сариваемость	зварюваність
welded-cast	сварно-литой	зварно-литий

welded-forged	сварно-кованый	зварно-кований
welding	сварка	зварювання
blacksmith w., **forge (fire) w.,** **hammer w.**	кузнечная св.	зв. куванням
capacitor-stored energy w.	конденсаторная св.	конденсаторне зв.
cold w.	холодная св.	холодне зв.
diffusion w.	диффузионная св.	дифузійне зв.
electric arc w.	электродуговая св.	електродугове зв.
electron-beam w.	электронно-лучевая св.	електронно-променеве зв.
electroslag w.	электрошлаковая св.	електрошлакове зв.
explosion w.	св. взрывом	зв. вибухом
friction w.	св. трением	зв. тертям
fusion w.	св. плавлением	зв. плавленням
gas w.	газовая св.	газове зв.
laser w.	лазерная св.	лазерне зв.
plasma-arc w.	плазменная св.	плазмове зв.
pressure w.	св. давлением	зв. тиском
pressure-gas w.	газопрессовая св.	газопресове зв.
resistance w.	св. сопротивлением	зв. опором
thermit (aluminothermit) w.	термитная (алюмотермитная) св.	термітне (алюмотермітне) зв.
ultrasonic w.	ультразвуковая св.	ультразвукове зв.
weldment	сварное соединение	зварне з'єднання

5.2. ARC WELDING

arc discharge	дуговой разряд	дуговий розряд
choke	дроссель	дросель
direct polarity	прямая полярность	пряма полярність
drop	капля	крапля
dropping	падающая	що падає
external terminals, **output terminals**	выходные клеммы	вихідні клеми
generator	генератор	генератор
gradually dropping	полого падающая	що плавно падає
input terminals	входные клеммы	вхідні клеми
intersect	пересекаться	перетинатися
open-circuit run	холостой ход	холостий рух
rectifier	выпрямитель	випрямляч
reverse polarity	обратная полярность	зворотна полярність
short circuit	короткое замыкание	коротке замикання
source of welding current, **welder**	источник сварочного тока	джерело зварювального струму
stable (rigid)	стабильная (жесткая)	стабільна (жорстка)
stable arcing	стабильное горение дуги	стабільне горіння дуги
static voltage current characteristic	статическая вольт-амперная характеристика	статична вольт-амперна характеристика
transformer	трансформатор	трансформатор
variable resistance	переменное сопротивление (реостат)	перемінний опір (реостат)
welder	сварщик	зварювальник

5.2.1. MANUAL ARC WELDING

arc rays	излучение дуги	випромінювання дуги
chalk	мел	крейда
coated electrode	электрод с покрытием	електрод з покриттям
eye shield	защитное стекло для глаз	захисне скло для очей

gelatin	желатин	желатин
helmet shield	шлем с прозрачным экраном	шолом із прозорим екраном
luting	покрытие электрода	покриття електрода
manual (hand) arc welding	ручная дуговая сварка	ручне дугове зварювання
marble	мрамор	мармур
oscillator	осциллятор	осцилятор
starch	крахмал	крохмаль
weld	сварной шов	зварний шов
butt w.	сварное соединение встык	стикове зварне з’єднання
corner w.	угловое соединение	кутове з’єднання
downhand (flat) w., down w.	нижний (напольный) ш.	нижній ш.
edge w.	торцевое соединение	торцеве з’єднання
horizontal w.	горизонтальный ш.	горизонтальний ш.
inverted w.	потолочный ш.	стельовий ш.
tee butt w., T-weld	тавровое соединение	таврове з’єднання
vertical w.	вертикальный ш.	вертикальний ш.
welding rod holder	держатель электрода	тримач електрода

5.2.2. AUTOMATIC ARC WELDING

arc torch	сварочная головка (при газоэлектрической сварке)	зварювальна головка (при газоелектричному зварюванні)
automatic arc welding, machine arc welding	автоматическая дуговая сварка	автоматичне дугове зварювання
automatic bare-wire submerged arc welding	автоматическая дуговая сварка под флюсом	автоматичне дугове зварювання під флюсом
bare-electrode welding	сварка электродом без покрытия	зварювання електродом без покриття
crater	кратер	кратер
filler wire	сварочная проволока	зварювальний дріт
initiate discharge	инициировать разряд (зажигать дугу)	ініціювати розряд (запалювати дугу)
overlaying metal	наплавляемый металл	метал, що наплавляється
semiautomatic gas arc welding	полуавтоматическая газоэлектрическая сварка	напівавтоматичне газоелектричне зварювання
shielding-gas arc welding, welding in shielding gases	дуговая сварка в среде защитных газов, газоэлектри-ческая сварка	дугове зварювання в середовищі захисних газів, газоелектричне зварювання
splashing	разбрызгивание	розбризкування
sustain arcing	поддерживать горение дуги	підтримувати горіння дуги
welding head	сварочная головка	зварювальна головка
welding tractor	сварочный трактор	зварювальний трактор

5.3. GAS WELDING

acetone	ацетон	ацетон
acetylene (C_2H_2)	ацетилен	ацетилен
acetylene generator	ацетиленовый генератор	ацетиленовий генератор
adjust	регулировать	регулювати
balanced pressure torch	горелка безынжекторного типа	пальник безінжекторного типу
bell	колокол	дзвін
calcium carbide (CaC_2)	карбид кальция	карбід кальцію
carbide-to-water	карбид на воду	карбід на воду
contact type, water recession	контактного типа	контактного типу
core of flame	ядро пламени	ядро полум’я
cut-off valve	отсечной клапан	відсічний клапан

explosive gas	взрывоопасный газ	вибухонебезпечний газ
gradual, smooth	постепенный, равномерный	поступовий, рівномірний
heat-producing ability	теплотворная способность	теплотворна спроможність
inclined	склонный	схильний
injector	инжектор	інжектор
kerosene	керосин	гас
natural gas (C_mH_n)	природный газ	природний газ
odorless	без запаха	без запаху
portable	переносной	що переноситься
pressure reducing regulator	редуктор (для газа)	редуктор (для газу)
protective water seal	защитный водяной затвор	захисний водяний затвор
reverse (inverted) impact	обратный удар	зворотний удар
steel cylinder	стальной баллон	сталевий балон
tap	кран, вентиль	кран, вентиль
tip, head	наконечник, мундштук	наконечник, мундштук
tongue, jet	факел	факел
water-to-carbide	вода на карбид	вода на карбід
welding flame	сварочное пламя	зварювальне полум’я
balanced f., normal f.	нормальное пл.	нормальне пол.
oxidizing f.	окислительное пл.	пол., що окислює
reducing f., carbonizing f.	восстановительное пл.	пол., що відновлює
welding torch	сварочная горелка	зварювальний пальник
welding zone	сварочная зона	зварювальна зона

5.4. RESISTANCE WELDING

abut	примыкать	примикати
ampere	ампер	ампер
cam drive	кулачковый привод	кулачковий привод
coalescence	соединение	з’єднання
current cut-off switch, contactor	прерыватель тока	переривач струму
current strength	сила тока	сила струму
electric resistance welding	контактная сварка	контактне зварювання
flash w., butt w.	стыковая св. оплавлением	стикове зв. оплавленням
seam w., roll spot w., pulse w., intermittent w.	шовная св.	шовне зв.
spot w.	точечная св.	точкове зв.
upset w.	стыковая св. сопротивлением	стикове зв. опором
end, face	торец	торець
Joule	Джоуль	Джоуль
lever-spring drive	рычажно-пружинный привод	важільно-пружинний привод
linkage	шарнир	шарнір
Ohm	Ом	Ом
persistent	постоянный	постійний
turn	виток (обмотки)	виток обмотки
voltage	напряжение (электр.)	напруга (електр.)
welding loop	сварочная цепь	зварювальний ланцюг

6 METAL CUTTING OPERATIONS

6.1. PRINCIPLES OF CUTTING AND SHAPING OF METALS

6.2. GEOMETRY OF A CUTTING TOOL

blade, tool point	режущая часть (вершина резца)	ріжуча частина (вершина різця)
chip	стружка	стружка
cutting angle	угол резания	кут різання
front clearance a.	задний у.	задній кут
top rake a.,back rake a.	передний у.	передній кут

wedge a., lip a.	у. заострения	кут загострення
cutting, machining	обработка резанием	обробка різанням
(cutting) face, true rake, back rake	передняя поверхность (резца)	передня поверхня (різця)
depth of cut, feed value, thickness of removal metal	толщина срезаемого слоя, глубина резания	товщина шару, що зрізується, глибина різання
detaching	удаление	видалення
dimension accuracy	размерная точность	розмірна точність
edge	кромка, острие	кромка, вістря
finishing mechanical treatment	окончательная обработка резанием	остаточна обробка різанням
flank	торец, боковая сторона	торець, бік
machine surface	обработанная поверхность	оброблена поверхня
machining allowance, stock	припуск на механическую обработку	припуск на механічну обробку
major cutting edge, leading cutting edge	главное режущее лезвие	головне різальне лезо
minor cutting edge, trailing cutting edge	вспомогательное режущее лезвие	допоміжне різальне лезо
point	вершина (резца)	вершина (різця)
shank	стержень (хвостовик) резца	стрижень (хвостовик) різця
shaping	придание формы	додання форми
transient surface	поверхность резания	поверхня різання
wedge	клин	клин
work surface	обрабатываемая поверхность	поверхня, що обробляється
working motion	рабочее движение	робочий рух
feed m.	дв. подачи	рух подачі
linear m.	прямолинейное дв.	прямолінійний рух
longitudinal m.	продольное дв.	поздовжній рух
primary (cutting) m.	главное дв.	головний рух
reciprocating m., alternate m.	возвратно-поступательное дв.	зворотно-поступальний рух
rotary m.	вращательное дв.	обертальний рух
setup m.	установочное дв.	установчий рух
transverse m.	поперечное дв.	поперечний рух

6.3. CUTTING SPEED AND CHIP FORMATION

blunt	тупой	тупий
chip (chips)	стружка	стружка
flowing ch., continuous ch.	сливная стружка	зливна стружка
shearing ch.	стружка надлома	стружка надлому
tearing ch., discontinuous ch.	стружка скалывания	стружка сколювання
coolant, cutting fluid	смазочно-охлаждающая жидкость (СОЖ)	мастильно-охолоджувальна рідина (МОР)
sharpened tool	заточенный инструмент	заточений інструмент

6.4. CUTTING MATERIALS

abrasive	абразивный материал	абразивний матеріал
belbor	белбор	белбор
cermets, ceramics, cemented oxides	керметы	кермети
diamond	алмаз	алмаз
elbor (cubic borous nitride)	эльбор	ельбор
elevated temperature	повышенная температура	підвищена температура
friction	трение	тертя

hard alloys, cemented carbides	твердые сплавы	тверді сплави
high-speed steel	быстрорежущая сталь	швидкорізальна сталь
ingredient	ингредиент, компонент	інгредієнт, компонент
insert	вставка	вставка
loose abrasive	незакрепленный абразивный порошок	незакріплений абразивный порошок
red hardness	теплостойкость	теплостійкість
silica carbide (SiC)	карбид кремния	карбід кремнію
sintering	спекание	спікання
temper	отпуск	відпуск
tool steel	инструментальная сталь	інструментальна сталь
wear	износ	зношування

6.5. MACHINE TOOLS CLASSIFICATION

lathe	токарный станок	токарний верстат
machine-tool, machine	станок	верстат
boring m.	расточной с.	розточувальний в.
broaching m.	протяжной с.	протяжний в.
cutting-off m.	отрезной с.	відрізний в.
drilling m.	сверлильный с.	свердлильний в.
gear- and thread-cutting machines	зубо- и резьбонарезные станки	зубо- і різенарізні верстати
grinding m.	шлифовальный с.	шліфувальний в.
high-precision m.	прецизионный с	прецизійний в.
microfinishing m.	доводочный с.	доводочний в.
milling m.	фрезерный с.	фрезерний в.
multi-spindle m.	многошпиндельный с.	багатошпиндельний в.
numeral control m.	станок с числовым программным управлением	верстат з числовим програмним керуванням
planer	продольно-строгальный с.	поздовжньо-стругальний в.
shaper	поперечно-строгальный с.	поперечно-стругальний в.
single-spindle m.	одношпиндельный с.	одношпиндельний в.
slotter	долбежный с.	довбальний в.
turret lathe	токарно-револьверный с.	токарно-револьверний в.

6.6. LATHE WORKS

apron	фартук	фартух
beveling	получение фасок	отримання фасок
boring	растачивание	розточування
bottom hole, blind hole	глухое отверстие	глухий отвір
carriage	каретка	каретка
chuck	патрон	патрон
contour	контур	контур
cutting tool	резец	різець
facing t.	торцевой р.	торцевий р.
forming t.	фасонный р.	фасонний р.
left-hand t.	левый р.	лівий р.
parting t.	отрезной р.	відрізний р.
right-hand t.	правый р.	правий р.
threading t.	резьбовой р.	різенарізний р.
turning t.	проходной р.	прохідний р.
facing	торцевание	торцювання
feed gear	коробка подач	коробка подач
finishing	чистовая обработка	чистова обробка
forming	получение фасонных поверхностей	отримання фасонних поверхонь

gear box	коробка скоростей	коробка швидкостей
gear cutting	изготовление зубчатых колес	виготовлення зубчастих коліс
headstock	передняя бабка	передня бабка
integrally cast hole	отверстие, полученное в отливке	отвір, отриманий у виливку
knurling	накатка	накатка
necking	прорезка кольцевой канавки	прорізання кільцевої канавки
parting	отрезка	відрізання
radius forming	закругление	заокруглення
roughing	черновая обработка	чорнова обробка
sleeve	втулка	втулка
slope	наклон	нахил
support	суппорт	супорт
tailstock	задняя бабка	задня бабка
taper	конус	конус
tapering	обработка конической поверхности	обробка конічної поверхні
through hole	сквозное отверстие	наскрізний отвір
turning	точение	точіння
V-belts	клиноременная передача	клинчасто-пасова передача

6.7. DRILLING

alignment	соосность	співвісність
bench-type drilling machine	настольный сверлильный станок	настільний свердлильний верстат
boring m.	расточной с.	розточувальний в.
fine boring m.	координатно-расточной с.	кординатно-розточувальний в.
radial drilling m.	радиально-сверлильный с.	радіально-свердлильний в.
upright drilling m.	вертикально-сверлильный с.	вертикально - свердлильний в.
body	рабочая часть (сверла)	робоча частина (свердла)
bolting	соединение болтами	з’єднання болтами
bore	зенкер	зенкер
boring	зенкерование, растачивание	зенкерування, розточування
counterbore	зенковка, цековка	зенківка, цековка
counterboring, countersinking	зенкование	зенкування
countersink	зенковка	зенківка
dead center	неподвижный центр	нерухомий центр
drill	сверло	свердло
enlarging	рассверливание	розсвердлювання
fillister-head screw	винт с потайной головкой	гвинт зі схованою голівкою
fitting	пригонка	припасовування
flute	выемка, канавка	виїмка, канавка
spiral f.	спиральная к.	спіральна к.
straight f.	прямая к.	пряма к.
gearcase	корпус редуктора	корпус редуктора
guide cylinder	направляющий цилиндр	направляючий циліндр
housing	корпус	корпус
lip	режущая кромка (сверла)	різальна кромка (свердла)
nut	гайка	гайка
overall length	полная длина	повна довжина
pinning	соединение шпильками	з’єднання шпильками
reamer	развертка	розвертка
reaming	развертывание	розвертання
riveting	клепка	клепка
shank	хвостовик (сверла)	хвостовик (свердла)
straight sh.	цилиндрический хвостовик	циліндричний хвостовик
taper sh.	конический хвостовик	конічний хвостовик
spot-facing	цекование	цекування
tang	лапка (сверла)	лапка (свердла)
tap	метчик	мітчик

threading die	плашка	плашка
twist drill	двухперовое сверло	двохперове свердло

6.8. PLANING, SHAPING AND SLOTTING

double-housing planer	двухстоечный продольно-строгальный станок	поздовжньо-стругальний верстат з двома стійками
groove	паз	паз
index	задавать определенное положение	задавати певне положення
planer, planing machine	продольно-строгальный станок	поздовжньо-стругальний верстат
planning	строгание на продольно-строгальном станке	стругання на поздовжньо-стругальних верстатах
relief-slotting machine	долбежно-затыловочный станок	довбально-затиловувальний верстат
shaper, shaping machine	поперечно- строгальный станок	поперечно-стругальний верстат
shaping	строгание на поперечно-строгальном станке	стругання на поперечно-стругальних верстатах
slotter, slotting machine	долбежный станок	довбальний верстат
slotting	долбление	довбання

6.9. MILLING

circumference	окружность	окружність
knee	консоль (станка)	консоль (верстата)
milling	фрезерование	фрезерування
cut-up m., conventional m.	встречное фрезерование	зустрічне фрезерування
down-cut m., climb m.	попутное фрезерование	попутне фрезерування
milling cutter,mill, cutter	фреза	фреза
angle cutter, corner c.	угловая фреза	кутова фреза
coned c.	коническая ф.	конічна ф.
disk c.	дисковая ф.	дискова ф.
end c., shank c.	концевая ф.	кінцева ф.
face c.	торцевая ф.	торцева ф.
form c., profile c.	фасонная ф.	фасонна ф.
gang c.	наборная ф.	ф., що набирається
gear (tooth) c.	модульная ф.	модульна ф.
hob c., worm gear hob	червячная ф.	черв’ячна ф.
plain milling c., shell-and-mill c.	цилиндрическая ф.	циліндрична ф.
overarm	хобот (станка)	хобот (верстата)

6.10. GEAR-CUTTING METHODS

cutting stroke	рабочий ход	робочий хід
form-cutting method	метод копирования	метод копіювання
gear cutting	изготовление зубчатых колес, нарезание зубьев	виготовлення зубчастих коліс, нарізання зубів
gear rack	зубчатая рейка	зубчаста рейка
generating process	метод обкатки (огибания)	метод обкатки (огинання)
meshing	зацепление	зачіп
return stroke	холостой ход	неробочий хід
rotary gear cutter, shaper	долбяк	довбальній інструмент
worm	червяк	черв’як

6.11. GRINDING

bakelite	бакелит	бакеліт

centerless grinding machine	бесцентрово-шлифовальный станок	безцентрово-шліфувальний верстат
cylindrical grinding m.	круглошлифовальный с.	круглошліфувальний в.
internal grinding m.	внутришлифовальный с.	внутрішньо-шліфувальний в.
surface grinding m.	плоскошлифовальный с.	плоскошліфувальний в.
electromagnetic work-holding fixture (table)	электромагнитный стол	електромагнітний стіл
grinding	шлифование	шліфування
quartzite	кварцит	кварцит
rubber	каучук	каучук
spark	искра	іскра

6.12. FINISHING AND MICROFINISHING PROCESSES IN MACHINING OF METALS

actual size	действительный размер	дійсний розмір
deviation	отклонение	відхилення
finish cutting	чистовая обработка резанием	чистова обробка різанням
finish grinding	чистовое шлифование	чистове шліфування
fit	пригонка	припасовування
honing	хонингование	хонінгування
impracticable	невыполнимый	нездійсненний
lapping	притирка	притирка
mating	сопряжение	сполучення
microirregularity	микронеровность	мікронерівність
nominal size, design size	номинальный размер	номінальний розмір
peak	выступ	виступ
permissible variations	допустимые отклонения	припустимі відхилення
precise	точный	точний
precision	точность	точність
ridge	гребень, выступ	гребінь, виступ
roughness	шероховатость	шорсткість
stock removal	припуск на механическую обработку	припуск на механічну обробку
superfinishing	суперфиниширование	суперфінішування
tolerance	допуск	допуск
valley	впадина	заглиблення

6.13. ELECTROPHYSICAL AND ELECTROCHEMICAL MACHINING

electrophysical and electrochemi-cal machining, electromachining	обработка с использованием электрического тока	обробка з використанням електричного струму
contact-initiated discharge machining, electric resistance arc machining	электроконтактная обработка	електроконтактна обробка
electrical discharge machining, spark erosion, electrospark machining	электроискровая обработка	електроіскрова обробка
electrical-pulse discharge machining, arc-erosion machining	электроимпульсная обработка	електроімпульсна обробка
electrochemical machining	электролитическая размерная обработка	електролітична розмірна обробка
electrolytically assisted discharge machining	анодно-механическая обработка	анодно-механічна обробка
electron-beam machining	электронно-лучевая обработка	електронно-променева обробка
ultrasonic machining	ультразвуковая обработка	ультразвукова обробка

bank of condenser	батарея конденсаторов	батарея конденсаторів
beam	луч, пучок	промінь, пучок
deep vacuum	глубокий вакуум	глибокий вакуум
duration	длительность	тривалість
electrolyte	электролит	електроліт
electrolytic etching	электролитическое травление	електролітичне травлення
electrolytic grinding, electrochemical grinding	электрохимическое шлифование	електрохімічне шліфування
electrolytic polishing	электролитическое (электрохимическое) полирование	електролітичне (електрохімічне) полірування
electrolytically assisted cutting-off machine	анодно-механический отрезной станок	анодно-механічний відрізний верстат
electron gun	электронная пушка	електронна пушка
emit	испускать, излучать	випромінювати
laser material processing	лазерная обработка	лазерна обробка
magnetostriction	магнитострикция	магнітострикція
roughing	обдирка, грубая обработка	обдирка
skin on castings	корка на отливках	кірка на виливках
spark gap	искровой промежуток	іскровий проміжок

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