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Ю. И. Киреева  
Е. Н. Храмцова

# СТРОИТЕЛЬНЫЕ МАТЕРИАЛЫ И ИЗДЕЛИЯ

## BUILDING MATERIALS AND ITEMS

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*кафедра «Технология строительного производства»*  
Белорусского национального технического университета  
(зав. каф. – д-р техн. наук, проф. С. Н. ЛЕОНОВИЧ);  
*А. А. МЕЧАЙ*, канд. техн. наук, доц., зав. каф. «Химические  
технологии вяжущих материалов» Белорусского государственного  
технологического университета;  
*кафедра «Теория и практика перевода № 1»*  
Минского государственного лингвистического университета  
(зав. каф. – канд. филол. наук, доц. Е. Г. КАРАПЕТОВА)

**Киреева, Ю. И.**

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Рассмотрены основные свойства, способы производства и применения  
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иллюстративный материал, контрольные вопросы для самопроверки.

Предназначено для иностранных студентов учреждений высшего  
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полезно студентам и преподавателям строительных специальностей вузов.

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## PREFACE

The manual considers properties as well as techniques for manufacturing building materials and products on an industrial scale. The building materials industry plays an important role in the economy and progress of each country. It is in continuous development and there is a considerable variety in the range of products. Novel techniques for optimizing production processes are introduced on an industrial scale.

The multiformity of production process parameters and service conditions underlie a great variety of requirements upon building materials and a wide range of their properties. To cite but a few of these: strength at normal and high temperatures (the latter characterizing heat- or fire resistance of materials); water-resisting property; resistance to attack by various salts, acids and alkalis; resistance to erosion by slag (of a particular importance in metallurgical processes) and others. Permeability (or impermeability) of materials with respect to liquids, gases, heat, cold, electric current, and radioactive radiation is essential in construction and engineering. The materials for finishing residential and public building premises, gardens, and parks are required to be nice, durable and strong.

Yet a material with universal properties is a challenge of the future.

Building materials are widely used in construction as slabs for walls and foundations of buildings, as facing wares for exterior and interior walls and floors of buildings, for roads, sidewalks, and as heat- and water-insulating materials. All building materials are generally classified according to their purpose (constructional, foundry facing, acoustic, heat-insulating and others) and kind of materials (natural stone, ceramic, glass, polymers and others). The building materials are known to be organic (wood, polymers, bitumen) and mineral (stone, ceramic, glass, metal). Organic materials are produced from wood, oil, gas; mineral ones are obtained from mineral rocks (sand – glass, clay – ceramics, ore –metals). The shape of building materials may be friable (sand, crushed stone), leafy (glass, metal), little and big blocks (from natural stones, ceramics and concrete), and liquid (glue, paints).

Each building material is described in a State Standard (GOST), Technical Specification (TU) or EN ISO, which gives a definition (name) of the material and specifies its principal properties and requirements upon it, testing methods (to establish and quantify the properties) and rules for its acceptance, transportation and storage. In practical construction work, the State Standards, the Technical Specifications and EN ISO are complemented by Construction Norms and Rules. These documents are revised at regular intervals of time to keep pace with the continuous advances in techniques for manufacturing building materials and in construction practices, which impose ever-stringent requirements upon building materials and necessitate expansion of their application scope.

## Chapter 1. CHIEF PROPERTIES OF BUILDING MATERIALS

It is known that the application fields of building materials determine their properties.

The properties of building materials determine their chemical and mineralogical composition and their structure. According to microstructure, materials are classified into crystalline (stone, metals), amorphous (glass, bitumen), coagulation-viscous (paint compositions, metal and glass melts, plastic concrete mix). According to their macrostructure, materials are dense (metals), porous (bricks), layered (shale), fibred (wood) and friable (sand).

The properties of building materials are physical, chemical, mechanical, and technological.

The physical properties include characteristic density, structure, reaction to water, frost, heat, fire, sound and radioactive rays.

The chemical properties define the ability of materials to participate in chemical reactions decreasing or increasing their strength.

The mechanical properties determine resistance of materials to different forces.

The technological properties are necessary to receive manufactured items and constructions, for example, plasticity, viscosity and weldability (metals).

**The physical properties** of materials include true and average density ( $\text{kg/m}^3$ ), porosity (%) and hydro-physical, heat-physical, acoustic properties.

The true density is the mass (kg) of one cubic meter ( $\text{m}^3$ ) substance, which the material consists of. The true density is determined by the formula

$$\rho = \frac{m}{V},$$

where  $m$  is mass of a substance in the absolute dense state, kg;

$V$  is volume of a material,  $\text{m}^3$ .

The average density ( $\text{kg/m}^3$ ) is the mass of a unit volume of the material in the natural state (with voids and pores included),

$$\rho_{av} = \frac{m}{V},$$

where  $m$  is mass of a material in the natural state, kg;

$V$  is volume of a material,  $\text{m}^3$ .

The average density of a material may vary as a function of porosity and void content.

Loose materials (sand, crushed stone, cement and others) are characterized by their apparent density ( $p_f$ ). The volume of these materials includes both the pores and voids inside grains of the material and the voids between them.

$$p_f = \frac{m}{V},$$

where  $m$  is mass of loose material definite, kg;

$V$  is volume of material in loose state,  $m^3$ .

The porosity (%) of a material is the relative volume of the pores it contains.

$$P = \left(1 - \frac{\rho_{av}}{\rho}\right) \cdot 100,$$

where  $\rho_{av}$  is average density of material,  $kg/m^3$ ;

$\rho$  is true density of a material,  $kg/m^3$ .

Pores are small cells in a material filled with air or water. They may be open or close, little and large. Little close pores are filled with air.

The material, which has many close pores, possesses good heat insulation properties. The porosity of a material may influence its other properties such as average density, strength, thermal conductivity, frost resistance and water permeability. Walls of buildings are made from porous materials.

Voids are spaces between grains of a loose material (sand, crushed stone, etc.), filled with air. Thus loose materials are characterized by void content. The void content of sand and crushed stone ranges from 35 to 45%.

$$P_{v.c.} = \left(1 - \frac{\rho_f}{\rho_{av}}\right) \cdot 100,$$

where  $\rho_f$  is apparent density of a loose material,  $kg/m^3$ ;

$\rho_{av}$  is grain average density of a material,  $kg/m^3$ .

The properties of materials with respect to the action of water are characterized by their **hydro-physical properties**. These properties of building materials generally include hygroscopicity, water absorption, water release, water permeability, frost resistance and weathering or air resistance.

Hygroscopicity is the property of a material to absorb water vapor from air. It is dependent on the nature of substance involved, air temperature and relative humidity, the type of pores and their number and size. The surfaces of some materials (called hydrophilic) attract water well, while the surfaces of others (known as hydrophobic) repulse water.

Under other conditions being equal, materials hygroscopicity depends on its surface area including that of open pores and capillary channels. Materials of equal porosity but with smaller open pores and capillary channels prove to be more hygroscopic than materials with larger pores. Hygroscopicity is characterized by volume of absorbed water vapor from air (%).

Water absorption is the ability of material to absorb and retain water. It depends on the amount of water absorbed by an initially dry material plunge in water, and is expressed in percent of the mass (water absorption by mass) or of the volume (water absorption by volume) of the dry material.

The value of water absorption by mass (%) is calculated by the formula

$$\omega_m = \frac{m_2 - m_1}{m_1} \cdot 100,$$

and that by volume (%) by the formula (as 1 liter of water weighs 1 kg, thus, water density equals one kg/m<sup>3</sup>).

$$\omega_0 = \frac{m_2 - m_1}{V} \cdot 100,$$

where  $m_2$  is mass of a material in water saturated state, kg;

$m_1$  is mass of the material in dry state, kg;

$V$  is volume of the material in the natural condition, m<sup>3</sup>.

Water absorption is always less than the true porosity, since some of the pores are closed, i.e. isolated from ambient influence and not accessible to water. Water absorption by volume is always less than 100%, whereas water absorption by mass of very porous materials may exceed 100%.

The volume of pores, their shape and nature determine water absorption of building materials. It is also dependent on the nature of materials and their water-retaining properties. Saturation with water greatly affects the properties of materials: bulk, density and heat conductivity of some materials rise, whereas other materials, e.g. wood, clay, tend to swell, so that their volume increases and their strength decreases because the penetrating water molecules break links between the particles.

The ratio of compressive strength of material saturated with water ( $R_{cw}$ ) to that of material in dry condition ( $R_{cd}$ ) is called the coefficient of softening.

$$K_s = R_{cw}/R_{cd}.$$

It describes water resistance of materials. For soaking materials it equals 0 (clay), whereas other materials (metals, glass) fully retain their strength under the impact of water and their coefficient of softening is 1. Materials with the

coefficient of softening of 0.8 and higher are water-resisting materials. Materials with the coefficient of softening of less than 0.8 should not be permanently exposed to moisture.

#### Water release

The property of water release is reverse to water absorption. With fall of humidity and rise of temperature, the materials will release moisture into the environment. The rate of drying depends primarily on the temperature as well as on the difference between moisture of the material and the relative humidity of air: the greater the difference is, the more intensive drying of the material is. Secondly, the properties of the material and the nature of its porosity affect the rate of drying. Water repellents and materials with large pores release their moisture faster than fine-porous and hydrophilic materials. The intensity of water loss (%) at a relative air humidity of 60% and temperature of 20% determines the water release for building materials.

#### Air resistance (weathering resistance)

This property of material is its ability to endure repeated moistening and drying over a prolonged period without either considerable deformation or mechanical strength loss.

Humidity variations cause changes in volume of many materials: materials swell when moisture content increases and shrink when it decreases. Repeated moistening and drying cause alternating stresses in a building material and may result, in the course of time, in the loss of load-bearing capacity (failure).

Water permeability determines the capacity of a material to let through water under pressure. The coefficient of filtration determines this property, and it is equal to the volume of water penetrating through 1m<sup>2</sup> of the tested material at a constant pressure per hour. Water permeability depends on content of open pores. Dense materials (steel, glass, bitumen, most plastics) are impervious to water (waterproof).

Frost resistance is the ability of a water-saturated material to endure repeated freezing and thawing without visible signs of failure or considerable decrease of mechanical strength. Water increase inside the pores leads to disintegration, which increases in volume by up to 9% in the process of freezing.

Frost resistance of materials is determined by freezing water-saturated specimens at the temperature between -5 and -17°C and subsequently thawing them out.

Frost resistance of a material depends on its density and the degree of its saturation with water. Dense materials are frost resistant. Of the porous

materials, frost resistant are only those where most of the pores are closed. The material is frost resistant when its strength decreases by not more than 15 to 25% and the loss in weight, as a result of spalling, does not exceed 5% after the prescribed number of freezing and thawing cycles. When specimens show no signs of failure after freezing, their frost resistance is defined by the frost resistance coefficient, which is calculated according to the formula:

$$K_{fr} = R_{fr}/R_{ws},$$

where  $R_{fr}$  is compressive strength of material after the frost resistance test, Pa;

$R_{ws}$  is compressive strength of water-saturated material before the test, Pa.

The coefficient  $K_{fr}$  of a frost resistant material is not less than 0.75.

According to the number of freezing and thawing cycles which materials are capable to withstand, they are subdivided into grades frost resistance F 10, 15, ... 200 and over (F is an abbreviation for frost).

In laboratory conditions, specimens are frozen in refrigerating chambers. One or two freezing cycles in the chamber are equivalent to 3 or 5 years of atmospheric exposure. There is also a faster testing method where specimens are soaked in a 5% solution of chloride sodium and then frozen at the temperature to  $-18$  or  $-50^{\circ}\text{C}$ . Crystals of salt together with crystals of water formed inside pores of the stone, press against the walls of the pores even stronger than the freezing water. The reason for freezing the specimens at such a low temperature is explained by congeals in small capillary channels only at temperatures between  $-10$  and  $-50^{\circ}\text{C}$ . One cycle of faster testing is equivalent to 10 or even 20 cycles of direct freezing tests.

**Heat-physical properties** of materials include heat conductivity, heat capacity, thermal resistance, hot resistance, fire resistance, refractoriness.

Heat conductivity of a material is its ability to conduct heat. All materials conduct heat to a different degree. Heat conductivity of a material is quantitatively evaluated by a coefficient, which is equal to the intensity of heat flowing per hour through a specimen of  $1\text{m}^2$  area  $1\text{m}$  thick when the temperature difference between its opposite and parallel flat surfaces is  $1^{\circ}\text{K}$ .

Heat conductivity of a material depends on a number of factors: nature of the material, its structure, porosity, nature of pores, humidity and temperature heat exchange. Materials with closed pores have lower heat conductivity than those with communicating pores. Fine-porous materials have lower heat conductivity than those with large pores: the air inside large and communicating pores is freer to move, which enhances heat transfer. Heat conductivity of a homogeneous material depends on its average density. When it decreases, heat conductivity drops and vice versa.



Heat conductivity is greatly affected by humidity. Humid materials have a higher heat conductivity than dry ones, because heat conductivity of water is 25 times as high as that of air.

The coefficient of heat conductivity is the basic index for various heat insulating constructions, heat insulating materials and manufacturing products.

The values of heat conductivity for various categories of materials have been set as follows: ( $W/m^{\circ}C$ ).

Heat conductivity is of major importance for materials used to build walls of heated buildings and to insulate various thermal equipment.

Heat capacity of a material is its ability to absorb or give off heat when heated or cooled. The ability is described in quantitative terms by a coefficient which (kJ) is equal to the intensity required to heat 1 kg of material by  $1^{\circ}C$ . The heat capacity of steel is 0.46; of heavy concrete is 0.90; of wood is 2.4; water – 4.0 kJ/kg  $^{\circ}K$ .

Thermal resistance of a material is its ability to endure a certain number of cycles of sharp temperature variations without destruction. Thermal resistance depends on the degree of homogeneity of the material and coefficients of linear expansion of its constituents. The lower the latter values are, the higher the thermal resistance of the material is. Glass and granite are the examples of materials with poor thermal resistance.

Hot resistance is resistance of a material to operating temperatures from  $1,000^{\circ}C$  and below.

Under this condition, hot resistant materials neither increase their deformation nor decrease their strength.

Refractoriness is the ability of a material to withstand a prolonged exposure to high temperatures without melting or losing its shape. In this category, there are three varieties of a material—refractory, high-melting and low-melting. Materials capable of resisting a prolonged exposure to temperatures from  $1,580^{\circ}C$  and higher are known as refractory. High-melting materials withstand temperatures from  $1,350$  to  $1,580^{\circ}C$ , and low-melting materials withstand temperatures below  $1,350^{\circ}C$ .

Fire resistance is resistance of materials to fire without substantial deformation or loss of strength. According to their fire resistance, building materials are subdivided into noncombustible, fire-resistive and combustible. Noncombustible materials neither smolder nor char by fire. Natural (rock) and non-organic mineral materials (ceramics) belong to this category. However, some of these materials (glass, metals) suffer considerable deformation and melt. That is why they cannot be referred to noncombustible materials. Fire-resistive materials

are the ones that char, smolder and ignite with difficulty when exposed to flame but continue to burn or smolder only in flame. Combustible materials burn and smolder by fire and go on burning after the starting flame is removed. All organic materials, not treated with fire-proof compounds, fall into this category.

Acoustic properties of a material are their relation to sound waves and noises. Sound waves of lower or higher frequencies cannot be seen by human beings. Sounds may be divided into musical sounds, noises and sound pulses. The quantity of energy carried by a sound wave per 1 s through an area of 1 cm<sup>2</sup> is known as sound intensity. Sound intensity is measured in decibels and its physiological property (loudness) in pho-non. Velocity of sound in the air at 15°C is equal to 340 m/s. Noise is a combination of various sounds rapidly changing in pitch and intensity. In buildings noises may be audible and inaudible (ultrasound), and they may originate in the air or by direct impact. A prolonged action of audible sound that of a high pitch is detrimental to human health. Noise can be considerably lowered by constructional acoustics, which is concerned with sound insulation of exterior walls and floors against solid-borne noises and sound-absorbing for ceilings against air-borne noises. The sound-absorbing materials should probably contain a lot of open pores and soundproof materials should probably be springy. various engines and mechanisms are generally sources of high-intensity vibration noises. Spreading of vibration noises can be considerably lowered if vibration insulating and vibration-absorbing materials are used.

Radiation resistance is a physical property of a material characterized by its ability to resist radiation rays without substantial deformation and loss of strength. Radiation rays raise the temperature of materials and change their microstructure. Radiation resistant materials should arrest gamma rays and neutron fluxes, which are dangerous to living organisms. Materials with a large amount of combined water protect against neutron radiation. High-density materials (lead, extra-heavy concrete) protect against gamma rays.

**Chemical properties** form the ability of a material to withstand acids, alkalis, salt solutions and gases. Sanitary facilities; sewer pipes; materials for walls, floors, ceilings of chemical factors, and hydraulic engineering structures are most frequently attacked by corrosive liquids and gases and by sea water with a large quantity of dissolved salts.

Chemical resistance is defined by the chemical resistance coefficient, which is calculated according to the formula

$$K_{ch.res} = R_{C2}(m_2) / R_{C1}(m_1),$$

where  $R_{C1}(m_1)$  is compressive strength (or mass) of material before the test, Pa (g);

$R_{C2} (m_2)$  is compressive strength (or mass) of material after the chemical resistance test, Pa (g).

The coefficient ( $K_{ch.res.}$ ) of a chemically resistant material is not less than 0.90.

**Mechanical properties** describe resistance of building materials to all external actions, including force. Various mechanical properties generally fall into the following categories: compressive strength, bending strength and hardness.

Strength of building materials is characterized by their ultimate strength, which is the stress corresponding to the load destructing a specimen of the material. Ultimate strength (Pa) in compression and tension (R) is calculated according to the formula

$$R_C = P / F,$$

where  $P$  is breaking load, N (kgf);

$F$  is area of the specimen cross section,  $\text{mm}^2$  ( $\text{cm}^2$ ).

Compressive strength of a material is determined experimentally by testing specimens in mechanical or hydraulic presses. Specimens shaped as cubes with sides between 2 and 30 cm are specially prepared for the purpose.

Strength of a material depends on its structure, average density, moisture content, chemical composition, direction of load application and the rate of load application.

Bending strength (Pa) is determined by the following formulas:

– for a single concentrated load and a bar of rectangular cross section

$$R_f = 3Pl / 2bh^2;$$

– for two equal loads located symmetrically with respect to the bar axis

$$R_f = 3P(l-a) / 2bh^2,$$

where  $P$  is breaking load, N (kgf);

$l$  is span between supports, mm (cm);

$a$  is distance between loads, mm (cm);

$b$  and  $h$  are width and height of the bar cross section, respectively, mm (cm).

The values of safety factors, which are so vital for preservation and service life of constructions, are specified by design standards and depend on the type and quality of the material, service life of the building and special engineering calculations.

Hardness is resistance of a material to penetration of a harder body into its surface. Hardness of stone materials is determined with Moh's scale of hardness.

It is a list of ten minerals arranged in the order of increasing hardness. Hardness of a certain material is between the hardness of two adjacent materials, one of which scratches and the other is scratched by the tested material. Hardness of metals and plastics is determined by the diameter of a steel ball imprint on them.

Abrasion resistance of a material is the loss of its initial mass (kg) referred to 1 sq. meter ( $m^2$ ) of the surface area abraded. Materials tested to abrasion resistance are designed for floors, roadway wearing courses, stair treads.

Impact strength is of prime importance in materials for floors and road surfaces. The ultimate strength of material subjected to impact is described by the quantity of effort required to cause the failure of the specimen per its unit volume,  $J/m^3$ . Materials are tested for impact strength in an impact testing machine.

Wear is the failure of a material by the combined action of abrasion and impacts. Wear resistance is determined by the loss in mass expressed as a percentage of road surfaces, and materials for floors subject to wear in industrial enterprises.

**Durability** is resistance of a material to the combined action of atmospheric and other factors within many years. These include variations in temperature and humidity, attacks by gases contained in the air or salts dissolved in water, or the combined action of water, frost and insulation, and the application of force. Durability is defined by the years of building materials exploitation without substantial deformation or loss of strength.

### **Self-Check Questions (Self-Check Questions and Topics for Discussion):**

1. What physical properties of building materials do you know?
2. What mechanical properties of building materials do you know?
3. What hydro-physical properties of building materials do you know?
4. What heat-physical properties of building materials do you know?
5. What acoustic properties of building materials do you know?
6. How are the physical and mechanical properties of building materials determined?
7. What is common and what is different in the indices of water absorption and water permeability?
8. What determines heat conductivity of building materials?
9. Where are construction materials with low heat conductivity used?

## **Chapter 2. ORGANIC BUILDING MATERIALS**

Organic building materials include wooden materials and items, polymer-based materials, organic binders and bitumen-based materials.

### **2.1. Wooden Materials and Items**

In modern building practice wood is extensively used for walls and floors of buildings, carpentry and graded plank items, as well as prefabricated standard wooden cottages. A great volume of wood is consumed in building and installation work for making piles, poles, various loads-bearing components, casings, scaffolds.

Glued wood components, e.g. beams, trusses, arches, frames and roofs of buildings and structures, are very effective in chemically aggressive environment since their service life is 1.5 times as great as that of steel or reinforced concrete.

In building, coniferous (pine, spruce, larch, fir) and broad-leaved (oak, birch, alder, aspen, beech, lime, maple) wood species are used. Pine is used for building walls of residential houses, bridges, poles, window sashes, transoms, and floors. Larch is used for manufacture of poles, girders, and in general hydraulic engineering construction. Broad-leaved species are mostly used in building for trimming work as it has pleasant texture and color.

#### **2.1.1. Structure and Properties of Wood**

Wood is an organic natural, fibred, porous (macrostructure) material, which consists of living and dead cells of various size and shape (microstructure). A living cell ensures growth of a tree. After a while these cells die and become hard and strong. The macrostructure of wood is studied by cutting the trunk in three directions: cross-sectional, radial cut and tangential. The cross-section contains layers formed during the growing season (spring-fall). They are called annual rings. Each annual ring consists of light (early) wood, which is porous and unstable, and dark (late) wood, which is dense, water resistant and strong. The higher the percentage of the late wood is, the stronger the wood is.

Wood, as a building material, has a great number of valuable properties: high compressive and bending strength, small true and average density, low heat conductivity, easy mechanical working and decorativeness. Wood has several negative properties: its anisotropy results in different strength, heat conductivity and electrical conduction in length and across the fibers; it is a hydrophilic and combustible material.

Moisture content affects the properties of wood greatly. Therefore, its principal properties (strength, average density, heat conductivity) are calculated with the use of standard moisture sample equal to 12%. Wood may contain water in three forms: capillary (or free), hygroscopic and chemically bonded. Moisture content of wood exposed to prolonged contact with air of constant relative humidity and temperature is called the equilibrium moisture content. Because of structural non-uniformity, wood shrinks when dried or swells irregularly in various directions when moistened. Linear shrinkage along the fibers is between 0.1 and 0.3%, in radial direction it is between 3 and 6%, in tangential direction it is between 7 and 12%. To exclude any shrinkage during its exploitation, wood is dried up from 15 to 20% of moisture (air-dry) for outdoor use, or from 8 to 13% (room-dry) for indoor use.

The following drying methods are in current use: air (natural), chamber, electric, and in hot liquids with the chief methods being air and chamber drying.

The true density of wood is approximately equal for all species and averages  $1,540 \text{ kg/m}^3$ .

Average wood density depends on the volume of pores and moisture content. For various wood species, the average density is less than true. Average wood density has its own physical and mechanical properties (water absorption, heat conductivity and strength).

Heat conductivity of wood is low and depends on porosity, moisture content, orientation of fibers, species and average wood density. Heat conductivity of wood increases as the average density of wood and its moisture content become greater because the amount of air entrapped inside the cavities decreases.

Due to anisotropy, the resistance of wood to mechanical impact differs in fiber orientation. Compressive strength parallel to wood fiber at 12% moisture content varies greatly in wood species; it ranges from 30 to 100 MPa. Compressive strength perpendicular to wood fiber ranges from 20 to 25 MPa.

Wood of higher average density has greater strength; the latter is affected by the percentage of late wood. Wood withstands static bending well. Bending strength is equal to 50-100 MPa (at 12% moisture content), depending on the wood species.

Wood has a high tensile strength parallel to fibers. For the generally used species, this value ranges from 80 to 190 MPa.

However, wood cannot be extensively used in structure working under crushing and shearing stresses it poorly resists to. Defects, decay regions and a greater moisture content lower wood strength.

Departures from the normal structure and flaws, which affect wood engineering properties, are defects of wood. Defects appear both during tree growth and during wood storage and service. According to their causes, defects are divided into the following main groups: incorrect structure (trunk eccentricity, double heartwood, knotty wood and others), mechanical damage, damage by fungi and damage by insects. Damage caused by fungi is very widespread. Oxygen, moisture and favorable temperatures contribute to fungi development. Some fungi may develop only on growing trees, other fungi develop on felled ones, and others – both on growing and felled trees. Wood with a moisture content of 20% and less or wood placed in water or exposed to frost does not decay.

Decay stops as soon as it dries out and all the fungi perish. Fungi and insects may attack wooden constructions or wood in storage. Wood can be protected against decay and its service life in structures increases. To prevent wood humidification and increase the service life of wood, such ways as painting or coating, leaching and impregnating with antiseptics are used. Antiseptics are substances, which are poisonous for wood-attacking fungi. They should be harmless to people and domestic animals. Antiseptics fall into water-soluble, oil and paste varieties.

Water-soluble antiseptics are used for treating wood not exposed to moisture. Because of high inflammability and sharp odor, oil antiseptics are used only for impregnating or coating wood placed in the open air, soil or water. Antiseptic pastes are subdivided according to their binders into bitumen, silicate, etc.

Wood preservation with liquid compositions includes surface preservation, impregnation in hot-cold and high-temperature baths, and impregnation under pressure.

Wood is very inflammable, and it is one of its major drawbacks. To protect it against fire, wood is plastered, coated with gypsum or asbestos-cement sheets, or its surface is treated with fire resistant substances. There are two surface treatment techniques, namely, painting and impregnation with fire protection compounds, or antipyrines.

### **2.1.2. Materials, Items and Structures from Wood**

Building logs from coniferous and broad-leaved species should not be less than 14 cm thick at the top and from 4 to 6.5 m long. Logs are used for hydraulic engineering structures; they connect elements of power transmission and communication lines, and railway tracks.

Sawn timber is obtained by longitudinal cutting of logs planks and sleepers. Sawn timber for glued items and structures (arches, beams, farms) should have a moisture content of not more than 15%, and that one for bridge span structures and other load-bearing constructions should contain not more than 25% of moisture (Fig. 1, 2).

Factory plank used for various building applications, include plinths, finished floorboards, handrails for barriers, treads, window-sill board and exterior sheathing of house.

Floor materials include piece parquet, parquet boards, finish flooring boards, wood chipboards, wood laminates and wood fiber boards (Fig. 3).

Wood chipboards are sheet materials manufactured by hot-molding of wood chips impregnated with polymers. In the course of hot-molding, the chips are compacted, and the viscous polymers harden to cement the filler into a monolithic material. Wood chipboards are made from wood of coniferous and broad-leaved species. Resistance of wood chipboards to water biological agents and fire is enhanced by treating chips with antiseptics and antipyrens.

Wood fiber boards are sheet materials composed of organic fibrous fillers (wood, reed, hemp) polymer-bonded together by hot-molding. Culled wood is first cut into chips, then into fibers. The fibrous pulp is diluted with water and pumped to a reservoir for mixing with a solution of polymer, hydrophobic additives, antiseptics and antipyrens. The fibrous pulp is pumped from the reservoir to a long mesh molding machine for dehydrating and molding the pulp into a continuous sheet, which is passed to a machine where it is cut into boards. By their average density, wood fiber boards are available in three kinds: semi-hard (not less than  $400 \text{ kg/m}^3$ ), hard (not less than  $850 \text{ kg/m}^3$ ) and extra-hard (not less than  $950 \text{ kg/m}^3$ ). Soft boards are used for heat insulating of walls and floors, semi-hard and hard boards are used chiefly for facing walls, and the extra-hard ones—mostly for floors.

Veneer is manufactured by glueing together thin layers (thin sheets from 1.5 to 16 mm thick) of wood. Three kinds of veneer—glued, bakelite-treated and decorative – are generally used in building practices. Depending on the kind of glues, glued veneer is subdivided into veneer of high, medium and low water-resisting properties. By its jacket surface finish, veneer is subclassified into polished and unpolished types. Glued veneers of high water-resisting properties are used as load-bearing components (beams, arches, frames) of open-air structures that are protected against moisture by paint; for inside premises with air humidity less than 70% painting is not required. Veneer of medium and low water-resisting properties is used for partitions and inside finishing of buildings.



Bakelite-treated veneer is manufactured from birch sheets not more than 1.5 mm thick. The faces of veneer are impregnated with alcohol-soluble or (and) water-soluble resins. Decorative veneer is made from thin sheets of birch, alder and is subdivided into two kinds of facing: veneer faced with colorless glue painted film and veneer faced with film and decorative paper.

In building practices, decorative veneer is used for finishing interior wall partitions, panels, door panels and built-in furniture.

Fibrolite and arbolite are artificial materials manufactured from wooden wool, waste wood or shavings bound together by mineral binding materials (Portland cement, gypsum, air-hardening or hydraulic lime). These manufactured items are available in heat insulating, structural and press-board varieties, which differ in average density. Heat insulating wares are used for insulating walls, floors and roofs; structural variety, for filling walls partitions and roofs of frame buildings.

Xylolite is a hardened mass of sawdust and magnesian binder mixed with a liquor of magnesium chloride. Xylolite may contain such admixtures as asbestos, tripoli, quartz sand and dyes. If xylolite is intended for floors, it should have a plastic consistency. As soon as laid on a subfloor, the mass should be leveled and consolidated by vibration or tamping.

Industrial manufacture of xylolite slabs involves preparation of a harsh mass, which is then hot-pressed at pressure. Magnesian binding materials also serve as a basis for manufacture of foam and gas magnesite, which are highly efficient heat insulating materials. For this purpose, caustic magnesite, mixed with magnesium chloride liquor, is combined with foam or a gas forming agent.

Wood is used for manufacturing the following kinds of carpentry items: parts of doors, windows, partitions and panels (sheath, paneled, dead and glazed) for residential buildings and gates for industrial buildings (hinged, open, suspended and fixed, heat-insulated and non-heat-insulated). All types of carpentry items are made from coniferous wood, whereas only interior doors and transoms for premises with a relative air humidity of not more than 70% may be made from the broad-leaved species (beech, birch). Paneled doors, carpentry items and panels (of inside filling) are manufactured from waste of lag sawing, woodworking and veneer plants. Window sashes may also be produced from semi-finished materials with the use of water-resisting glues.

Wallpaper is a roll paper material with a printed pattern on it. It is used for decorative finishing of interior walls. According to its application and service characteristics, wallpaper is subdivided into common, washable and sound-absorbing varieties.

### **Self-Check Questions:**

1. What positive properties of wood do you know?
2. What negative properties of wood do you know?
3. How do wood properties depend on moisture?
4. What structural products of wood do you know? What is their application in construction?
5. What is the purpose of using wood chipboards and wood fiber boards in building practices?
6. What is the purpose of use in the construction of fibrolite and arbolite, the composition and properties of these products?
7. What roll and sheet materials from wood are used for interior walls?
8. What methods of wood product protection do you know?

## **2.2. Polymer Materials and Items**

Polymer materials (plastics) are a wide group of organic materials based on natural or artificial high-molecular compounds (polymers). Plastics are complex substances. Their chief components are a binder (a polymer), fillers (organic or mineral powders, fibers), plasticizers (improve moldability), curing accelerators and pigments, which are introduced to manufacture colored plastics.

### **2.2.1. Composition and Properties of Polymeric Materials**

Constructional polymers synthesized from the simplest substances, are subdivided into two classes according to the production techniques:

- polymers obtained by chain polymerization;
- polymers obtained by polycondensation.

The former polymers that are widely used in manufacture of construction materials and items are as follows: polyethylene, polypropylene, polyvinylchloride, etc. The latter ones include phenol, phenol-formaldehyde, epoxy, etc.

The structure of plastics is much affected by components other than polymers. According to it, plastics fall into the following subclasses: no-filler, expanded, filler and composite varieties. No-filler plastics consist of a polymer, sometimes a dye, a plasticizer and a stabilizer. Expanded plastics consist of the above mentioned materials and air or gas-filled cells produced by gas-forming or air-entraining substances. Constructional plastics are a polymer and a filler. There are powder, fibrous and laminated fillers.

Powder fillers are quartz powder, chalk, talcum and organic substances (ground sawdust). They provide plastics with valuable properties (heat resistance, acid resistance, etc.), improve their hardness and increase durability.

Fibrous fillers are asbestos, wood and glass fibers widely used in manufacture of plastics. They increase strength, reduce brittleness and enhance thermal resistance and impact strength of plastics.

Cloths and sheet fillers are paper, cotton and fiberglass cloths that make plastics very strong.

Plasticizers, dyes, catalyzers and other substances are introduced into plastics along with fillers. Porous plastics are manufactured with the use of pore-forming agents.

With respect to heating, plastics are subdivided onto thermoplastic and thermosetting varieties. Thermoplastic materials (polyethylene, polyvinylchloride and others) soften and become plastic when heated but harden again after cooling. These materials can be used to cast, draw and stamp various items. Their chief shortcomings are low mechanical strength and heat resistance. Thermosetting plastics change when heated into infusible and insoluble solid products, and irreversibly lose their ability to soften. These materials possess a higher heat resistance and include aminoplasts and plastics based on polyester and epoxy resins.

Chief properties of plastics (physical and mechanical) depend on the polymer and the production technology.

Average density of plastics is 10-2,200 kg/m<sup>3</sup>. Plastics, as a rule, are poor conductors of heat, their coefficient of heat conductivity is 0.33-0.80 W/m °C. Heat conductivity of foam and porous plastics is 0.06-0.028 W/m °C, which allows them to be widely used as heat insulating materials.

Plastics are not susceptible to corrosion: they resist attacks by solutions of weak acids and alkalis. Thus, they are used for building chemical structures, sewage systems and for insulating storage tanks.

Polymers are the basic materials for manufacture of adhesives for glueing plastics with other materials such as wood, metals, glass and fabrics. A valuable property of plastics is their high workability; they can be given any shape by various techniques: casting, pressing and extrusion.

A large group of plastics can be welded to each other, which allows manufacture of complicated piping and various storage tanks. Plastics can be welded together by mere heating to a temperature between 150 and 250°C.

However, plastics have a number of drawbacks. Most plastics have low heat resistance (70-200°C). Plastics have a high coefficient of thermal

expansion. They exhibit high creep. Plastics are susceptible to ageing, i.e. they disintegrate gradually, lose strength and hardness. Ageing of plastics is due to the action of light, air and temperature. When ignited, most plastics release toxic substances.

### **2.2.2. Polymer-Based Building Materials**

Polymer-based building materials are subdivided into:

- floor materials;
- materials for interior finishing of walls, ceilings and built-in furniture;
- synthetic glues and mastics;
- heat and sound insulating materials;
- roof, waterproof and sealing materials;
- sanitary equipment, piping and fittings;
- synthetic varnishes and paints;
- polymer-concrete and concrete-polymer constructions (Fig. 4, 5, 6).

#### **Floor Materials**

Polymer materials find an extensive application in making floors. They are resistant to abrasion, have a low heat conductivity and water absorption, sufficient hardness and strength; they fail to swell when moistened, readily take on varnishes and paints and meet all floor requirements.

Floor materials fall into three groups: roll (linoleum), tile and seamless floor varieties.

Floor roll materials manufactured from various polymers and fillers, are composed of plasticizers, pigments and process additives. According to the kind of polymer, floor roll materials are subdivided into polyvinylchloride, rubber (relin) varieties and others. As for the structure, they fall into the following types: with and without strengthening or heat and sound insulating backing; single- and multi-layer and carpet coverings with smooth and creased surfaces; single- and multi-colored textures.

Linoleums are manufactured either by rolling-and-calendaring (no-backing linoleum) or by coating technique (backing linoleum).

Polyvinylchloride linoleum is available with and without a fabric backing, the latter being a single-, double-, or multi-layer material. Backing of the linoleum may be of cord, half-cord, jute and jute-hemp cloth. Besides, linoleum is produced in heat and sound insulating varieties on a felt or porous backing. Polyvinylchloride linoleum is very strong, abrasion-resistive, non-susceptible to decay, has low thermal conductivity and is highly hygienic.

Vorsolin, a heat-and-sound insulating floor covering, is a non-woven two-ply material, where the top ply is a napped or plain pile of synthetic single- or multi-color yarn. It is used for covering reinforced concrete floors or subfloors in room-sizes in residential and public buildings to improve acoustic and heat-insulating properties.

Rubber linoleum (relin) is a two-layer roll material with a wear-resistant decorative top layer. Relin manufacture involves the following stages: crushing waste rubber, preparing a bitumen-rubber mixture for the bottom layer; calendaring the bitumen-rubber mixture into sheets; preparing a colored rubber mixture for the top layer; calendaring the colored rubber mixture into sheets; doubling the two layers; cooling, ageing, cutting to specified lengths and widths, inspection and packing. Relin is intended for floors in residential, public and industrial buildings of high atmospheric moisture content.

In current building practices, floors are frequently made with tiles manufactured from polymers, plasticizers, fillers and pigments.

Floor tiles are wear-resistant and chemically stable. They should be glued onto a perfectly levelled concrete, asphalt or xylolite bed with special adhesives or mastics. According to the kind of raw materials for their manufacture, floor tiles are subdivided into rubber, phenol polyvinylchloride and rubber varieties.

Floor tiles are available in a wide range of types: in shape, they are square, rectangular and figured; in design, they are single- and multilayer, with rectangular groove and tongue edges; in color, they are single- or multi-colored; and in texture, they are smooth or riffled. The manufacture of tiles involves preparation and proportioning raw materials, their thorough blending in a mixer, rolling, calendaring, tile stamping in a press, inspection and packing of finished tiles.

Tiles are used for floors in residential, public and industrial buildings.

Rubber tiles are made from waste rubber. They are highly resistant, chemically stable and have good dielectric properties. Rubber tiles possess not only high bending and compressive strengths but also an excellent impact strength, which is a major advantage for working conditions in industrial buildings. Rubber tiles are usable for floors of workshops at chemical plants, laboratories, power stations, etc.

Monolithic seamless floors from polymers are most hygienic and convenient in service and have a high wear resistance. Seamless floors are made from polymer binding and mineral fillers. According to the kind of polymer, binding seamless floors are divided into three types: polyvinylacetate, polymer cement and plastic concrete.

Polyvinylacetate mastics consist of a binder, a filler, a pigment and water. Polymer concrete seamless floors are manufactured from polyvinylacetate or

latex emulsion, Portland cement, sand, marble or granite crumbs and mineral pigments. By consistency the compositions may be plastic-concrete (laid by laying machines or vibrating devices) and fluid-mastics (sprayed or poured). Polymer concrete compositions demonstrate high adhesive properties. They provide a strong bond with the bed and have high mechanical strength. Polymer concrete can be used for residential, public and industrial buildings and structures. Polyvinylacetate mastics should not be used in premises with high atmospheric moisture, in industrial buildings where there is a risk of impact loads in unsprung transport vehicles.

### **Plastic Facing Materials for Walls**

Plastic facing materials surpass all other finishing materials in ornamental quality, variety of patterns, richness of colors and hygienic properties.

Interior walls and ceilings are generally finished with roll, sheet and tile plastics. Roll materials for interior finishing of premises are made from polymer plasticizers, fillers, pigments, with or without a backing, which may be of paper, cotton and glass cloth or any other suitable material. Polyvinylchloride film with an adhesive layer is used for finishing interior walls of residential and public buildings, washrooms, corridors, partitions, doorframes and built-in furniture. Paper-backed finishing polyvinylchloride film is used for finishing interior walls of residential, public and industrial buildings.

Lincrust is a roll material composed of a paper backing covered with a layer of plastic mass. The material is water and decay resistant, withstands high mechanical stresses and does not fade in sunlight. It is used for finishing walls, partitions and built-in furniture in residential, public and industrial buildings.

Imitation leather is used for finishing walls, partitions and furniture in residential, public and industrial buildings.

Sheet materials for interior finishing of buildings are manufactured in the following varieties: decorative paper laminate, decorative veneer from wood fibers and chipboards with decorative polymer surface, and profile polymer colored sheet of 2-3 m long.

Decorative paper laminates are a sheet material obtained by hot molding of special papers, impregnated with polymers. Decorative paper-plastic laminate is manufactured 1-3 m long, 600 or 1,000 mm wide and 1-5 mm thick. This material is made in single color and with textured surfaces, imitating valuable species of wood or stone. They withstand heating to 120°C, retain luster in boiling, and are sufficiently waterproof. They belong to the group of combustible materials, but if the paper is impregnated with antipyrens, laminates of reduced combustibility are produced.

Wood laminates are a sheet material from wood veneer impregnated with polymers and glued together by pressure thermal curing. These materials possess a sufficiently high heat resistance and a low heat conductivity; they withstand attack by oils, organic solvents and atmospheric agents, and are widely used in mechanical working. Wood laminates are used in residential, public and industrial buildings as a finishing-and-structural material. Wood chip and wood fiber boards may be faced with paper, impregnated with polymers. Facing with paper allows to manufacture a great variety of surface colors, patterns and textures. These items are used for interior facing of walls, manufacture of decorative panels, and covering of ceilings.

Facing polymer tiles are superior to any other facing materials in decorative properties (variety of colors and patterns). These tiles are manufactured from polystyrene. To enhance heat resistance and reduce the cost of tiles, powder fillers (talcum, kaolin, etc.) may be introduced. Polystyrene tiles are resistant to 10% solutions of acids and alkalis; have a high vapor and water resistance, high strength and good dielectric properties. On account of their combustibility, they cannot be used for facing fire-resistant structures and heated surfaces.

Polystyrene tiles are used for interior finishing of residential, public and industrial buildings of high hygienic requirements, and high temperature and moisture conditions (bathrooms, washrooms, hospitals, canteens and stores).

### **Polymer Building Materials**

Some of the polymer building materials characteristics are their small bulk density, high strength, good thermal, sound- and waterproofing properties and immunity to attacks by chemical substances. Plastics, such as glassfiber plastics, organic glass, sheet vinyl plastics, polymer-concrete and concrete-polymer, mostly reinforce structural polymer materials.

Glassfiber plastics are manufactured by laying stretched glass fibers parallel to one another and by applying a binder at the same time. The binders are modified phenol-, epoxy- and other polymers.

Glassfiber plastics are used for making transparent walls and partitions, light-transmitting cold and semi-cold openings in workshops with chemically aggressive atmosphere (in combination with a translucent material).

Organic glass (polymethylmetacrylate) is a highly transparent, light-resistant, relatively lightweight material. It neither becomes dull nor yellow after some time, does not embrittle, withstands attack by atmospheric agents. Organic glass is elastic and retains this property even at low temperatures when its

bending and tensile strengths increase, but it does not become brittle. Organic glass is 7 times as strong as silicate glass.

Organic glass is used for translucent walls and partitions of single- and double-layer vertical openings and overhead lighting domes of public and industrial buildings and greenhouses.

Polymer-concrete constructions are manufactured from hot mixture polymer-binding materials with mineral fillers.

Concrete-polymer constructions are manufactured by impregnation of concrete (reinforced) structures with a hot polymer solution.

Plastic pipes are made by extrusion. Plastic pipes are widely used in installation of various industrial piping, water supply conduits, sewer systems, oil pipelines, irrigation facilities, etc. The ones mostly used are polyvinylchloride, glassfiber plastic and organic glass pipes; then come pipes from polypropylene and phenolite. Polypropylene pipes easily withstand temperatures up to 100°C, whereas phenolite pipes show good stability in chemical environment. Plastic pipes are more durable than metal ones; weigh less and have a lower heat conductivity, high water, dielectric and chemical resisting properties. Cost and maintenance of plastic pipes are cheaper than those of metal pipes. A shortcoming of plastic pipes is their poor heat resistance; e.g. polyvinylchloride pipes are unsuitable for transporting liquids with temperatures above 60°C.

Plastics are used to manufacture various sanitary ware. They are pleasant to the eye, water resistant, lightweight, strong, corrosion resistant, and immune to the action of acids and alkalis. This type of items includes, washing racks and others.

Honeycomb plastics are characterized by cavities of regular geometric shape. These plastics are manufactured by hot molding of polymer impregnated paper, fabrics and veneer.

The materials are corrugated in a press. Corrugated sheets are coated with polymer, stacked, then glued together into blocks at normal or high temperature and pressed.

Physical and mechanical properties of honeycomb plastics depend on the honeycomb material, kind and quantity of polymer and size of cells.

Honeycomb plastics are used mainly as a filler of three-layer panels. Heat insulating properties of honeycomb plastics are enhanced by filling the cells with crumbs of heat insulating materials.

Rigid foam plastics consist of a system of isolated, non-communicating cells, filled with gas or a mixture of gases. Foam plastics can be made from



various bulk densities (60-220 kg/m<sup>3</sup>) depending on the quantity of the gas-forming agent. Foam polystyrene or polyvinylchloride plastics are used for making three-layer panels for walls and roofs of residential, public and industrial buildings. Three-layer panels are of glued design, the exterior layers being glassfiber plastics, asbestos-cement, aluminum and other materials. Foam polyurethane is also used in the form of shells intended for insulating piping of cold and hot water supply.

Slender and tubular items are manufactured by an extruder from polyvinylchloride, plasticizers, fillers and pigments in a great variety of profiles and colors for various applications, e.g. plinths, handrails and structural elongated materials.

All these items should meet the following general requirements: they should have no scratches, cavities, cracks and peeled surfaces; they should have homogeneous structure, uniform profile and color; they should be resistant to air, light and water.

### **Polymer-Based Glues, Mastics and Paints**

Polymer-based glues and mastics are used for glueing together cast, laminate and fibers, materials and elements of parts and structures manufactured from various building materials (wood, metals, concrete and others). Finishing materials and items, mastics and glues should be adhesive paste-like compositions consisting of an adhesive base, e.g. polymers, solvents, plasticizing compounds, fillers, diluents and sometimes hardeners. Glues and mastics intended for fastening finishing materials and items are subdivided into two groups. One group is used for glueing floor coverings and slender and tubular items, and the other one for securing materials in the finishing of walls, ceilings and built-in furniture. By the kind of adhesives, glues and mastics intended for finishing materials and items fall into bitumen, polymer, caoutchouc, nitrocellulose and casein varieties.

Mastics for glueing finishing materials should have good adhesive properties, withstand temperatures up to 50-60° C, be easy to apply and spread in a uniform layer of 0.3-0.5 mm thick. Mastics should be homogeneous and odorless, resistant to biological agents.

Mastics are applied by spraying from pneumatic guns.

Surfaces of building structures are firmly glued at temperatures from –30 to +60 ° C and sometimes down to – 60° C. Structural glues are resistant to water and its vapors.

Varnishes and paints are natural, artificial or synthetic materials applied in a thin (60-500 μm) layer upon a surface to be protected, which forms solid

impermeable films bonded strongly to the surface. These films should have sufficiently strong and highly durable both physical and mechanical properties and decorative qualities. Varnishes and paints should be harmless for the item to be protected and living organisms. Coating materials are subdivided into paints, varnishes and auxiliary materials. Paints provide opaque colored decorative and protective coating, whereas varnishes provide translucent covering and the final decorative finishing of painted surfaces. Auxiliary materials, such as putties and priming compounds, prepare surfaces for painting and varnishing. A dissolvent decreases working consistency of polymer varnishes and paints. Diluents (water, oil) decrease working consistency of water-emulsion and oil paints respectively.

Constituents of varnishes and paints are subdivided into pigments, fillers and vehicles. Pigments provide the desired colors of paints. Pigments are colored finely ground mineral or organic substances, insoluble in water and organic solvents. Metal powders (aluminum, bronze) may also be used as pigments. Pigments fall into natural or artificial and mineral or organic categories. Each pigment possesses its own characteristic color and properties. The general properties of pigments include covering power, coloring capacity, fineness, light and fire resistance, chemical stability, resistance to atmospheric agents.

Covering capacity is characterized by pigments consumption per 1m<sup>2</sup> of the painted surface.

Coloring capacity is the ability of pigments to convey their color when mixed with white, black and blue pigments.

Fineness of pigments greatly affects both the covering power and the coloring capacity. The finer the pigment is, the greater these properties are.

Fire resistance of pigments is their ability to withstand high temperatures without deterioration and change in color. Organic pigments are not fire resistant, whereas mineral pigments react differently to temperature fluctuations.

Anticorrosive capacity is the ability of pigments, in combination with binders and fillers, to protect concrete and metals against corrosion. For example, iron, minium and white lead have good anticorrosive properties. Natural mineral pigments are used in producing lime, cement and glue paints, putties and colored building mortars. Metallic powders (aluminum, bronze and gold dust) are suitable for decorative painting of metals.

Organic pigments are used to tint paint compositions on various binders. However, their light resistance is relatively low. Fillers are insoluble mineral substances, mostly white, which are added to paints to save pigments and impart particular properties to these materials, e.g. high strength, acid resistance, fire

resistance and low deformation. By the kind of binder, painting compositions are subdivided into oil, glue and polymer paints.

The binders in oil paints are linseed oil and oil varnishes. They form the body and enhance film-formation in varnish or paint coats. In glue paints, the binders are animal, plant, artificial and synthetic glues, and in polymer paints, the binder is a polymer.

Natural drying oils are vehicles that harden in thin layers to form strong and elastic surface coats. Drying oils are used to dilute paints, manufacture prime coats and putties, coat wood, plasters, and other surfaces. Drying oils should dry in thin layers within 24 hrs. of application at the temperature of 20°C and should not peel off. Dryers (siccatives) are added to hasten the hardening of drying oils.

Artificial synthetic drying oils, in contrast to natural or semi-natural ones, do not contain more than 35% of organic oils.

Glues are used as binders in glue and water painting compositions, for glue primers and putties, and as stabilizers in the production of water-color emulsions. There exist animal (casein), plant (dextrin), artificial glues. Artificial glue is a solution of artificial resins in water or of polymer glues. Polymer glues are polymer synthetic substances of high glueing power, manufactured from polyvinylacetate resin. This glue is used in the form of water-and-alcohol solutions and of water-diluted emulsions for glueing film materials and wallpaper.

Diluents dissolve pigment pastes or dry mineral paints. In contrast to solvents, diluents contain a film-forming agent in amounts sufficient to obtain a quality varnish or paint coat.

Emulsion diluents provide poor quality coats, and therefore they are limited in use.

Thinners are liquids that adjust consistency of a paint for application. Common thinners are turpentine, coal solvent, white spirit and others.

Varnishes are solutions of resins in volatile thinners. The latter evaporate from the varnished surface, leaving a thin resin film, which gives the surface luster and hardness. There are two groups of varnishes: oil-resin and oilless synthetic.

Paint compositions fall into oil paints and varnishes, volatile resin (polymer) varnishes, enamel and water-emulsion paints.

Oil paints are mixtures of pigments and fillers, ground in paint grinders together with plant drying oils. Oil paints are available both as pigment pastes

(to be diluted with drying oil to painting consistency prior to use) and as ready-to-use paints. Oil paints are used for exterior and interior painting of metal, wood, plaster and concrete.

Oil paints diluted with organic drying oils should be used only on dry plaster and hardened concrete.

Enamel paints are suspensions of mineral or organic pigments and of synthetic or oil varnishes. The widely used enamel paints are alkyd, epoxy and urea-formaldehyde varieties. Enamel paints possess good light resistance, anticorrosion properties; they dry rapidly. They are used for painting metal, wood, concrete and plaster of interior and exterior surfaces.

Emulsion (latex) paints are pigment emulsions or polymer dispersions in water. Emulsion paints that find application in building practices are as follows: polyvinylacetate and acril emulsions are a water emulsion of polyvinylacetate or acril with a pigment. They are manufactured at plants and supplied in paste form, diluted with water prior to use; they are usable for exterior and interior painting of concrete, plaster, wood and sheet materials – lincrust and cardboard.

In finishing, primers (paint compositions, consisting of pigments or paints, fillers and binders or vehicles) reduce the porosity of surfaces to be painted and thus the consumption of expensive paints, improve the application of coatings, enhance anticorrosion protection of metallic surfaces, provide prime coats on wood and other surfaces to be varnished, and establish stronger bonds between the paint and the supporting surface.

### **Self-Check Questions:**

1. What components are included into the composition of polymeric materials? What is their purpose?
2. What are the positive properties of polymeric materials?
3. What are the negative properties of polymeric materials?
4. What polymeric materials are used for finishing floors in various purpose rooms?
5. What polymeric materials are used for internal furnishing of walls in various purpose rooms?
6. What polymeric engineering materials, their properties, and applications do you know?
7. What is the composition, properties and application of polymer adhesives and mastics?
8. What is the composition and usage of polymeric colorful materials?

## 2.3. Bitumen and Bitumen-Based Materials

Bitumen is a complex mixture of high-molecular hydrocarbons and their non-metallic derivatives. Its physical and mechanical properties vary with temperature. By consistency (at 18°C), bitumen is subdivided into solid, semisolid and liquid.

Chief properties of bitumen are water impermeability; resistance to acids, alkalis, aggressive liquids, and gases; adhesiveness to rock, wood and metals; ability to become plastic when heated and to thicken rapidly when cooled. In the building materials industry and practices, bitumen is used to produce asphaltum concrete; roof, water-proofing and steamproofing materials in the form of sheet products, mastics, emulsions, varnishes and paints (Fig. 7).

According to the origin of materials bitumens fall into natural and petroleum ones. Pure natural bitumen is used very rarely. Rocks (limestones, sandstones, soils) impregnated with bitumen are found more frequently.

Natural bitumen originates from petroleum as a result of a slow spontaneous distillation of lighter and medium fractions, of polymerization and oxidation.

Petroleum has accumulated in the top layers of the Earth's crust through migration, filling pores and cavities of rocks and impregnating them over the millennia under high temperature and pressure.

Natural bitumen is a black or dark-brown organic substance which, when heated, gradually softens and turns to liquid state but solidifies, if cooled. Natural bitumen is insoluble in water but dissolves fast in organic solvents. Structure of natural bitumen, its physical, chemical, and mechanical properties are close to those of petroleum bitumen.

Natural bitumen may be extracted from bitumen rocks by boiling it in kettles or dissolving in organic solvents.

Bituminous limestone and dolomite rocks are used as a fine powder (asphaltum powder) to manufacture asphaltum mastics and asphaltum concrete.

Petroleum bitumens are products of processing of crude oil and its resinous residues. By viscosity petroleum bitumens are divided into solid, semi-solid and liquid varieties, and by processing techniques – into residual asphaltums and extracted bitumens. Petroleum bitumens are poured while still hot into metal containers and shipped to consumers after cooling.

### 2.3.1. Chief Properties of Bitumen

Physical and mechanical properties of bitumen describe the molecular structure of the material and the combination of its inherent properties.

Solid and semi-solid bitumens fall into marks, with the division based on viscosity, plasticity and their reaction to temperature.

Viscosity is the property of a material to resist the mutual motion of particles under the influence of external forces. Viscosity of bitumen depends greatly on its temperature. At lower temperatures, viscosity of bitumen is great and it acquires the properties of a solid body; as temperature rises, viscosity decreases and bitumen turns into a liquid state. Viscosity of bitumen is estimated in conventional units of hardness, which is the depth of penetration of a needle under the weight of 100 g applied for 5 s at 25°C and 0°C. Depth of penetration is determined with a special apparatus called the penetrometer. It is expressed in degrees (1° = 0.1 mm) and designated as Π25, the subscript indicating the temperature of the material during testing.

Ductility of viscous bitumen is characterized by extensibility, which is determined with a ductilometer. Bitumen test specimens have a standard “figure 8” shape and size. Ductility of bitumen is a distance (in cm) over which it will elongate before breaking when two ends of a briquette specimen of the material are pulled apart. This test is carried out at a speed of 5 cm/min and temperatures of 25° C and 0°C.

Similar to viscosity, ductility of bitumen depends on its temperature, composition, and structure. Plastic properties are observed in bitumens that contain a considerable amount of resins, an optimum quantity of asphaltenes and oils. Viscous bitumens, containing solid paraffins at low temperatures, are not very ductile.

A third major property of bitumens is their softening point, which is determined in an apparatus called “ball and ring”. A brass ring 16 mm in diameter and 6.4 mm high is filled with bitumen, and a ball 9.5 mm in diameter and a mass of 3.5 g is placed upon the latter.

Softening point is the temperature of water in the apparatus when the bitumen softens and the ball sinks to the bottom shelf of the frame.

Along with such chief properties of bitumen as viscosity, extensibility and the softening point, which serve as a basis for its grading, bitumen has a number of other characteristics, e.g. stability in water, which depends on the content of oils, resins and asphaltenes; cohesiveness, which is an intermolecular bond strength, depending on physical and chemical properties of bitumen, its adhesiveness with respect to stone materials; weather resistance of bitumen, i.e. ability to withstand atmospheric agents in structure elements.

### **2.3.2. Bitumen-Based Materials**

In building industry the bitumen is used to produce protective varnishes and paints, emulsions mastics, pastes, asphaltum concrete, for manufacturing roof, waterproofing, steam-proofing and sealing materials and items.

Varnishes and paints based on bitumen are solutions of bitumen in vegetable oils and organic thinners (benzene or gasoline). Bitumen varnishes and paints are usually black or brown; they are resistant to acids and alkalis and used for anticorrosion steam- and waterproofing coats, finishing stoves, gas ovens and other surfaces.

Emulsions are disperse systems composed of two immiscible liquids, one of which is finely dispersed throughout the body of the other. Bitumen emulsions are disperse systems where water is a dispersion medium, and bitumen is a dispersed phase. To obtain emulsions, bitumen should be finely dispersed, their particles uniformly distributed in water and prevented from sticking together into larger aggregates. An emulsion is formed and stabilized by introducing special emulsifiers – surfactant substances or finely dispersed solid powders, which, on the one hand, lower the surface tension between bitumen and water and thus contribute to finer dispersion, and on the other hand, charge the particles electrically so as to prevent their flocculation. Bitumen emulsions are obtained by mechanical dispersion in extra-high-speed rotary mechanisms (homogenizers) where a mixture of molten binder and water with an emulsifier is fed through a slot between the disks and the casing of the machine. Rapid rotation of disks causes bitumen to disperse in water under the influence of centrifugal forces. The emulsifier in water coats particles of the binder stabilizes them. Acoustic dispersing means have recently found use in preparing bitumen emulsions.

The quality of a bitumen emulsion is characterized by its disintegration rate, which depends on the emulsifiers properties and the emulsion fineness. When mixing with fine materials, emulsions should not disintegrate until fully combined with the latter. Emulsions used for treating moist surfaces should be stable in water. Bitumen emulsions, once applied to a surface, should rapidly give off bitumen in the form of a thin solid film, which should not turn again into emulsion by water.

Emulsions are used for water- and steam-proof coatings, surfaces preparation for waterproofing, painting pieces and coil materials, and making surfaces hydrophobic.

Emulsions are stored in metal containers in closed premises at a temperature not below 0°C; the containers should be clean as impurities may cause rapid disintegration of emulsion. Emulsions should be transported in barrels or tanks.

Bitumen paste protects water- and steam-proofing coatings, primes surfaces before they are insulated; it is used to fill roof joints and prepare cold mastics, where it acts as a binder.

Bitumen pastes are produced from bitumen, water, and emulsifiers. The latter are nonorganic finely dispersed mineral powders, containing active colloidal particles smaller than 0.005 mm, which are added to water to produce pastes. Common emulsifiers are lime, clay. Most water-resisting pastes are made with adding lime emulsifiers.

Mastics are produced from organic binders and fillers. The latter are used for raising thermal resistance, decreasing low-temperature brittleness and consumption of binder. Mastic fillers fall into powder, fibrous and combined (a mixture of powder and fibrous fillers) types. The powder fillers are lime, dolomite, quartz, talcum, and many others; and the fibrous fillers are chrysolite asbestos, asbestos dust, and short-fiber mineral wool.

By the kind of original binder, mastics are subdivided into bitumen, bitumen-polymer (including bitumen-caoutchouc), and rubber-bitumen varieties.

By the laying technique, mastics fall into hot and cold types. Hot mastics should be preheated to temperatures not more than 70°C. Cold mastics are used without preheating at ambient temperatures down to 5°C. Cold mastics are manufactured from diluted binder and bitumen pastes.

By application, hot mastics are divided into glueing, roofing-and-waterproofing varieties. Glueing mastics are intended for glueing soft roof covering in multilayer roofs and for waterproofing.

Roofing- and- waterproofing mastics are used for glueing, and for manufacturing roofing sheets. Glueing and roofing-and-waterproofing hot mastics should be solid at  $18\pm 2^\circ$  C, homogeneous, free from visible inclusions and impurities, and contain no filler particles without bitumen coating. Waterproofing hot mastics should not expand in volume under vacuum; in fact, mastics should absorb no water under vacuum.

Cold mastics at temperatures of  $18\pm 2^\circ$  C should be mobile, homogeneous and free from visible inclusions. Mastics produced from diluted binder are used for glueing roll roofing, building protective coverings and water-and steam-proofing.

Cold mastics on bitumen pastes are produced by mixing bitumen pastes with mineral fillers and antiseptics, where the diluents are water. Cold mastics on bitumen pastes are used for making cast and plaster water-proofing, filling expansion joints and building roofs in climatically warm areas.

**Asphaltum concrete** is an artificial material manufactured by compacting a special mixture composed of crushed stone or gravel, sand, mineral powder, and bitumen. It is generally used in road construction. Depending on the



temperature of laying and compaction in a road covering and the viscosity of bitumen, asphaltum concrete falls into:

- hot concrete is produced from viscous bitumen at temperatures of 140-180°C and laid in the covering at a temperature of not lower than 130°C; concrete structure formation is practically completed during compaction;
- warm concrete is produced from bitumen of a lower viscosity at temperatures of 90-160° C and laid in the covering at a temperature of 30-100°C; the structure formation is practically over before compaction;
- cold concrete is produced from liquid bitumen and laid in the covering at temperatures in the 80-120°C range; the structure formation lasts for 20-30 days. Classed with cold concrete are asphaltum concrete mixtures on bituminous emulsions that are laid at normal temperatures.

By maximum size of mineral grains, asphaltum concrete is subdivided into coarse-grained (maximum size of grains is 40 mm), medium-grained (25 mm), fine-grained (15 mm), and sand-grained (5 mm).

By structure characteristics, asphaltum concrete falls into a dense variety of an overall porosity of 3-5% and a large-poured variety of 5-10% porosity.

Coarse-grained asphaltum concrete is used for base courses of roads.

Medium-grained asphaltum concrete is used for single layer coverings and for the top layer of two-layer roads.

Fine-grained asphaltum concrete possesses a sufficiently high resistance to mechanical and atmospheric impact, and is used in wearing courses of high-intensity traffic high-ways and for top courses of two-layer roads.

Sand asphaltum concrete has a high plasticity and is easily compacted, its chief applications are floor coverings in industrial building workshops, sidewalks, and light-traffic roads.

### **Roofing, Water-and Steam-Proofing Materials**

Steam-proofing materials are used to protect exterior wall structures against vapor moisture. Roofing, water-and steam-proofing materials based on bitumen binders, are subdivided into coiled and sheet materials; emulsions and pastes; mastics and concrete products; varnishes and paints. By kind of binders and their mixture, roofing and water- and steam-proofing materials fall into:

- bitumen composed of petroleum bitumen or of petroleum and natural bitumen alloys;
- rubber-bitumen materials manufactured by combined processing of petroleum bitumen and waste rubber;
- polymer-bitumen composed of petroleum bitumen and polymer.

Bituminous roofing and waterproofing materials widely used in the building industry, are generally of the following two types. The first type is produced by impregnating special cardboard or glass cloth or polymer cloth with petroleum bitumen or bitumen-polymers compounds and subsequently coating it with a compound of higher melting temperature and a granular material (gravel or sand). The other type is fabricated by calendaring thermally and mechanically processing mixtures of binders and additives into sheets of prescribed thickness.

By kind of binder, impregnated roll materials are subclassified into bitumen and bitumen-polymer varieties.

By structure, roll materials are subdivided into coated and non-coated types; with and without backing.

Backing roll materials are produced by impregnating roof cardboard or glass or polymer cloths with soft bitumen or bitumen-polymer, subsequently coating it on one or both sides with high-melting bitumen or bitumen-polymer varieties and finally facing it with finely-ground mineral powder, mica, colored mineral granules, metallic foil or polymer film. The other side is coated with finely-ground mineral powder or polymer film. The mass of 1m<sup>2</sup> of roll materials is indicated in kilogramms.

Roofing and waterproofing roll materials with no backing are subdivided, by kind of a binder, into rubber-bitumen, bitumen-polymer and polymer varieties. Rubber-bitumen materials are used best. These materials are durable, elastic, resistant to decay, and do not absorb water. They are manufactured from materials containing caoutchouc or crushed rubber in combination with bitumens, coal resins or bitumen-polymer binders, mineral fillers (powder or asbestos fibers) and a plasticizer.

These materials are used for anticorrosion protection of underground metal piping, as a glued material on hot bitumen and mastics for waterproofing buildings and structures, and as a component of two- or three-ply sloping flat roofs.

### **Piece Waterproofing Items**

Piece waterproofing items are of three kinds: waterproofing asphalt slabs, waterproofing stone and prefabricated concrete items.

Waterproofing asphalt slabs are manufactured by covering pre-impregnated fiberglass or metal mesh with a hot-process waterproofing mastic or sand asphalt concrete, or by hot-pressing of waterproofing mastics or sand asphalt concrete mixture. Slabs are either reinforced or non-reinforced. Non-reinforced slabs are made 90-100 cm long, 50-60 cm wide and 1-2 cm thick, whereas reinforced slabs are 100-120 cm long, 75-120 cm wide and 2-4 cm thick.

Waterproofing asphalt slabs are used for glued-on waterproofing work and filling deformation joints. They may be used in winter.

Waterproofing stones are manufactured by impregnating artificial or natural porous materials (bricks, concrete, tuft, etc.) with bitumen or coal tar products to a depth of 10-15 mm. Stones should be waterproof. They are used for waterproof brickwork with cement and asphalt mortars.

Prefabricated waterproofing reinforced concrete items are manufactured by impregnating prefabricated reinforced concrete elements (piles, slabs, sections of pipes, etc.) with organic binders to a depth of 10-15 mm. These items are used for anticorrosion waterproofing of structures exposed to simultaneous impact loads and mineralized water.

Sealing materials are used for filling exterior joints between elements of buildings and structures. Depending on the purpose of the sealing joint, sealing materials are used for thermal insulation, waterproofing, sound insulation and airproofing. Sealing materials are generally divided into elastic liners and sealing mastics.

Elastic liners are manufactured in the form of porous or monolithic braids of various shapes. They are placed dry or on special glueing mastics.

Sealing mastics are subdivided into packing and protective types. The packing mastics are manufactured by mixing high-molecular polymer or bitumen, rubber and filler.

Roofing, waterproofing, steam-proofing and sealing materials and items from organic binders should be stored in the original packing, protected against damage, atmospheric impact and contamination. In transit, particular care should be taken to protect them against atmospheric agents.

### **Self-Check Questions:**

1. What are the positive properties of bitumen?
2. What are the negative properties of bitumen?
3. What are the main properties and parameters determining application of bitumen?
4. Where are bitumen emulsion, paints, and mastics used?
5. What bituminous roofing materials do you know? What properties should they have?
6. What are waterproofing and sealing bituminous materials like? What are their properties and applications?
7. What are the composition and application of asphalt concrete?

## **Chapter 3. MINERAL BUILDING MATERIALS**

Mineral building materials are widely used in construction as facing and slabs for walls and foundations of buildings. Wares are used for both exterior and interior walls and floors of buildings, for roads, sidewalks, and as heat- and water-insulating materials. Mineral building materials are produced from mineral rocks (sand-glass, clay-ceramics, ore-metals). The shape of building materials may be friable (sand, crushed stone), leafy (glass, metals), little and big blocks (from natural stones, ceramics, concrete) and liquid (glue, paints).

By kind of original raw material, mineral building materials are subdivided into natural rock, ceramics, glass, materials from mineral melts, metallic items and mineral binding materials used for manufacturing mineral-body paints, building mortars, asbestos-cement items and concrete.

### **3.1. Materials and Items from Natural Rock**

The Earth's crust is composed of rocks.

Rock is a mineral mass of a more or less uniform composition, consisting of a single (monomineralic) or of several (polymineralic) minerals. Monomineralic rocks may be exemplified by quartz sand, chemically pure gypsum, magnesite, and polymineralic ones are granite and basalt.

A mineral is a body homogeneous in chemical composition and physical properties. Minerals are products of physical and chemical processes occurring in the Earth's crust.

Owing to their universal occurrence and various physical and mechanical properties, natural rock materials are widely used for building purposes. They are used as mined (gravel, sand) or processed mechanically (crushed, sawn, dressed, polished) to crushed stone, plates, piece stones, various architectural and decorative items (Fig. 8-12).

Rocks are the main source material for the manufacture of both mineral binding materials such as gypsum, lime, cement and artificial rock materials: bricks, items from concrete and mortars.

#### **3.1.1. Genetic Classification of Natural Rocks**

Reference to the classification of rocks based on their origin (genetic classification), greatly facilitates the study of natural rock materials properties. The origin and conditions of rock formation predetermine their chemical and mineralogical composition, crystalline structure and texture. According to the

genetic classification, rocks fall into three large groups: igneous, sedimentary and metamorphic.

**Igneous rocks** were formed from fused magma ejected from the Earth's interior and solidified by cooling. Diverse conditions of cooling resulted in formation of igneous rocks of various textures and properties. In some cases, magma did not come out on the Earth's surface but solidified underneath its upper layers, giving rise to deep-seated rocks. In other cases, magma flew out and solidified on the surface of the Earth to form effusive rocks.

Deep-seated rocks originated under a considerable pressure exerted by the upper layers; they cooled slowly and relatively uniformly. These conditions favored crystallization of minerals producing rocks. Owing to this, deep-seated rocks are massive and solid and often consist of relatively large crystals tightly pressed together; they have a high bulk density and heat conductivity, great compressive strength and frost resistance, and low water absorption.

Deep-seated rocks have granular crystalline structure, sometimes referred to as a granite structure.

Among the igneous rocks, distinction is made between the massive and the fragmental varieties, the latter resulting from disintegration of massive rocks. The chief samples of massive deep-seated rocks are granites, syenites, diorites and gabbro.

Granite is used for facing slabs, staircases, floors, curb stones, crushed stone, etc. Besides it is also used in hydraulic engineering structures and for monuments.

Syenites, which are softer and more resilient than granite and show greater amenability to polishing, are used for the same purposes as granites.

Diorites are hard to work with, and have good polishing qualities, high resistance to abrasion and to weathering. Diorites are used for road construction and as facing slabs.

Gabbro is resistant to weathering, hard to work with, but its polished surfaces are very durable. It is used for hydraulic engineering and other kinds of structures in the form of rubble, facing slabs, etc. Labradorite of beautiful coloring is used as a facing material.

Effusive solid rocks were formed near or on the Earth's surface in the absence of pressure by rapid cooling of the effusive magma, which also carried crystals of various minerals. That is why the majority of effusive rocks consist of separate perfectly-formed crystals impregnated into the body of the cryptocrystalline mass. When effusive rocks cooled near the Earth's surface in a massive layer, their structure was similar to that of deep-seated rocks. When on the Earth's surface, the layer was relatively thin, upper layers of the effusive

lava became porous because of an intensive release of gases from the magma as pressure diminished. Referred to these rocks are pumice and volcanic ash, which cemented to give volcanic tuffs. Therefore, the structure of effusive rocks may be semicrystalline, glassy or granular.

Diabase, basalt, and andesite have a semicrystalline structure.

Diabase is amenable to polishing; its color is dark grey. It is used as crushed or piece stone, slabs, paving blocks and facing material. Various products may be cast from molten diabase at temperatures between 1,200 and 1,350°C. Cast diabase is resistant to acids and alkalis, has good dielectric properties and the compressive strength around 500 MPa.

High hardness and strength of basalts make them suitable for road pavings and manufacture of cast stone moldings.

Andesite as an acid-resistant material is used both as a component in acid-resistant concrete and for special facing.

Pumice occurs in fragments 5 to 50 mm across ejected during volcano eruptions. Bulk density of lump pumice is 400 to 1,400 kg/m<sup>3</sup>; porosity is up to 80%; compressive strength is 0.4 to 2.0 MPa. Pumice is used as a component for lightweight concrete, as a heat insulating material and as an active mineral admixture (puzzolana admixtures) to lime and cement.

During volcanic eruptions, ashes and sands mixed with molten lava to form tuff lava. Cemented tuff lava is called volcanic tuff. Bulk density of lump tuff is from 1,250 to 1,350 kg/m<sup>3</sup>; porosity is from 40 to 70%; compressive strength is from 8 to 19 MPa. Its color is pink-violet. Tuff is used as a component for lightweight concrete and mortars, for large wall slabs, and as an active admixture to air-setting lime or cement. Excellent decorative qualities and frost resistance predetermine its wide use as a facing material for facades of buildings.

**Sedimentary rocks** were formed by sediments of substances from solvents, mainly water. Precipitation occurred periodically and resulted in separate layers and strata. By character of formation and composition, sedimentary rocks fall into three groups: chemical, organic and mechanical.

Chemical sedimentary rocks (e.g. gypsum, anhydrite) were formed by precipitation of mineral substances from water solutions, the deposits then consolidating and cementing themselves.

Chemical deposits comprise gypsum, anhydrite, magnesite, dolomite and lime tuffs.

Gypsum (CaSO<sub>4</sub> · 2H<sub>2</sub>O) is used for manufacture of air-setting binder (building gypsum) and as a facing material (artificial marble) for building interiors.

Anhydrite ( $\text{CaSO}_4$ ) is used for facing and as a source material for manufacture of anhydrite cement.

Magnesite ( $\text{MgCO}_3$ ) is also a raw material for air-setting binding materials (caustic magnesite) and refractories.

Dolomite ( $\text{CaCO}_3 \cdot \text{MgCO}_3$ ) is a source material for crushed stone, facing slabs, refractories and binding materials (air-setting binder: lime and caustic dolomite).

Lime tuffs are used as raw materials for production of lime, whereas dense tuffs with fine and uniformly distributed pores are used as piece stones for walls and an aggregate for lightweight concrete.

Organic rocks were formed of remnants of seaweeds and living organisms that consolidated and cemented together.

Organogenous rocks comprise limestone, shell limestone, chalk, diatomite and tripoli.

Limestones are used for manufacture of crushed stone, facing slabs, architectural items and for production of lime and Portland cement.

Shell limestone is a porous rock composed of shells and their fragments that are cemented together by lime. It is used for manufacture of wall stones and blocks (slabs), and as an aggregate for lightweight concrete.

Chalk is a highly dispersed material. Its color is white and it is used as a white pigment and in manufacture of putty, lime, white Portland cement and glass.

Diatomite is a very porous (60-70%) poorly cemented siliceous rock formed of diatom algae. Tripoli is a lightweight, clay-like rock. Its porosity equals 60 to 70%.

Diatomites and tripoli are used for manufacture of heat insulation materials, lightweight bricks, and as an active mineral admixture in hydraulic-setting binding materials.

Mechanical sediments (fragmental rock) resulted from deposition or accumulation of loose products in the process of physical and chemical disintegration of rocks. Products of disintegration were transported by winds and particularly by water streams over long distances and then settled, thus giving origin to clays, sands, crushed stone and gravels from massive rocks. Part of them was subsequently cemented by clay substances, ferrous compounds, carbonates or other carbonaceous cement to give cemented sedimentary rocks, conglomerates, and breccias.

Clay results from weathering of eruptive feld spathic rocks. In fact, weathering involves mechanical and chemical disintegrations. Clay is an earthen

mineral mass or fragmentary rock capable of mixing with water and forming a plastic viscous mass, which on drying retains the shape it was given and after burning acquires the strength of a stone.

Sand is a loose mixture of grains of various rocks ranging in size from 0.14 to 5.0 mm. By their origin, sands fall into rock, river, sea, etc., varieties.

Gravel is rounded off stones and natural rubble from 5 to 70 mm in size. It is used as an aggregate for concrete.

Sandstones are rocks composed of grains of quartz and cemented by claylike, siliceous or limestone substances. Sandstone strength depends on the kind of a binding substance, size and shape of cemented grains. These rocks are used as crushed stone for concrete, for facing bridge piers and building foundations and for road surfaces since they are highly resistant to frost and abrasion.

Rocks consisting of cemented stone fragments are called breccia, and those of grains of gravel are called conglomerates. Conglomerates and breccias are used as crushed stone for concrete, as well as for piece stones and facing slabs.

**Metamorphic rocks** were formed as a result of more or less complete modification of eruptive or sedimentary rocks under the influence of high temperature and pressure. Metamorphic rocks may have recrystallized without melting, and became more compact than original sedimentary ones. Metamorphism has also affected the structure of the rocks. Depending on direction of pressure under the Earth they should have a monolithic structure (quartzite's marble) or a shaly structure (gneisses slate). They are used mainly as facing slabs, rubble, stone for foundations and walls of non-heated buildings, paving stones for sidewalks. Clay shales are composed of solid shaly clays. Their color is dark grey, sometimes black. Clay shales split easily, are weather-resistant and durable, which makes them particularly suitable for use as roofing materials. Marble is a crystalline rock, formed of limestones or dolomites. Its crystals are bound together without a cementing agent. It can be sawn and polished and is applied for facing building interiors, as its poor chemical resistance against some gases and atmospheric moisture makes it unsuitable for external application. Quartzites are metamorphic varieties of siliceous sandstones with recrystallized quartz grains intergrown to such a degree that the cementing substance is indistinguishable. Quartzites are fireproof, weather and acid resistant. Applications of quartzites include facing of buildings, bridge piers and manufacture of refractory items.



### 3.1.2. Materials and Items of Natural Stone

Possessing high resistance to atmospheric agents, high mechanical strength and pleasant colors, natural stone materials are widely used in construction as slabs for walls and foundations of buildings and structures, as facing slabs and stones for exterior and interior walls of buildings and structures. Besides, they are used for roads, sidewalks, piers, unloading walls and other structures, where the material is the subject of a particular mechanical strength, durability and decorative requirements.

Foundations, hydraulic engineering structures, bridges and walls of underground parts of buildings are erected from quarry, split and sawn stones from igneous sedimentary and metamorphic rocks. The coefficient of softening of stones used for these purposes should not be less than 0.8, the frost resistance is not less than F25, and compressive strength is not less than 15 MPa. Piece stones, sawn and split from limestones, dolomite, sandstones, and volcanic tuffs are used for above-ground walls (piers of bridges, embankment and side slope reinforcements, relieving walls). Faces of wall stones and large wall slabs should be adequately decorative.

Facing slabs and stones, parts of stairs and landings, parapets and guard rails are made from slabs sawn or split from natural stone (granite, basalt, marble, limestone, volcanic tuffs) and their front face is worked by mechanically. Pedestal slabs and stones for framing doorways, belts of cornices, corner and window-sill slabs fall into the category of profile wall facing elements.

The following materials and items from natural stones are used in road construction: curbstones, paving blocks, hewn stone or cobblestone, crushed stone, sand and mineral powder. Materials and items for road construction are produced from igneous and sedimentary rocks.

Materials and items from natural stones for use in high-temperature or corrosive environments should be manufactured from non-proof rocks. Materials and items for high-temperature working conditions are made from basalt, diabase, andesite and quartzite. Elements of buildings and structures are protected against acids by facing slabs made from syenite, quartzite, andesite, basalt and diabase. Protection against alkalis is ensured by the use of solid limestones, dolomites and magnesite. Materials intended for protection against corrosion should have resistance to acids and alkalis, which is not lower than 95%.

Cast stone materials also possess a high strength, resistance to abrasion and attack by corrosive agents. Source materials for cast stone are rocks of magmatic origin, mainly basalt and diabase, which feature low viscosity in

molten state. Basalts are more uniform in chemical composition, and the stones cast from them possess high chemical and abrasion resistance.

Source materials for manufacture of light-colored cast stones are quartz sand and dolomite. The source materials are charged into bath furnaces, where materials melt at a temperature of 1,450°C. Finished melt trickles out of the bath into a forehearth where it cools to 1,250°C. Cooling of the melt prior casting affects the structure of items favorably and reduces the number of shrinkage defects (cracks and cavities).

Internal stresses due to cooling are lessened by crystallizing and annealing the casting. The degree of crystallization of the melt varies with its properties and dimensions of the items. The items are crystallized and annealed in special furnaces at temperatures between 800 and 900°C, and then the items are transferred to the annealing zone, and then the finished items go to storage. Cast stone slabs are effectively used instead of metal ones to pave floors in corrosive-environment workshops and to line structures exposed to severe abrasive conditions.

Crushed stone is a mixture of jagged stone fragments from 5 to 70 mm in size that is obtained by crushing various rock. The strength of crushed stone depends on the ultimate strength of the source rock. As far as its use is concerned, the quality of crushed stone is determined by grain size, content of foreign and harmful impurities, grindability and frost resistance.

Gravel is a loose agglomeration of more or less rounded rock fragments from 5 to 70 mm in size.

Sand is a loose mass of mineral and rock particles measuring from 0.14 to 5 mm across. By mineralogical composition, sand is divided into quartz, feldspar and carbonaceous varieties. It is used for mortars and concrete, for making road beds and drainage structures.

### **3.1.3. Protection of Natural Stone Materials against Disintegration**

Stone materials may disintegrate when attacked by water acting as a solvent; water containing carbon dioxide, sulphurous and other acid compounds is particularly aggressive. Stone materials disintegrate when exposed to alternate action of water and frost. A rock composed of several minerals may decay on account of temperature variations because of a difference in linear expansion coefficients of various minerals.

Organic acids may also attack rocks. Dust particles of non-organic and organic origin (from domestic or industrial waste of cities) settle on the surface and penetrate into the pores of stones; their wetting with water initiates

bacteriological processes, the resultant microorganism producing acids, which attack the stones. The rate of rock decay is also determined by its quality and structure, or, more specifically, by presence of microcracks, microstratifications, soakable and soluble substances.

To preserve stone materials against decay, it is necessary, first of all, to prevent the penetration of water and solutions deep into the materials by the technique known as fluating (fluosilicate coating). Treatment of limestone by fluates produces salts in stones and thus enhances its impermeability to water and resistance to weathering.

To protect against carbon dioxide and formation of sulphates, facing stones are impregnated to a depth of 1 cm by hot linseed oil. Stones are made waterproof by impregnating with a turpentine solution of wax, a turpentine or kerosene solution of wax; turpentine and kerosene are oil distillation products.

### **Self-Check Questions and Tasks:**

1. What classification of rocks is based on conditions of their formation?
2. Give an example of how the formation conditions of igneous rocks affect their properties.
3. Give examples of sedimentary rocks: chemical, organic, and mechanical groups used in construction.
4. Give examples of metamorphic rocks of monolithic and layered structures. Specify conditions of their formation.
5. What causes of natural stone destruction do you know?
6. What protection methods of natural stone products are used in construction?
7. Specify the technology of mineral wool products manufacture and application.
8. Describe the application of natural stone materials in construction.

## **3.2. Ceramic Materials and Items**

Ceramic materials are manufactured from clay compositions by molding and subsequent burning, intermediate drying of freshly molded items as a frequent practice.

Universality of properties, a wide range of products, high strength, durability and reasonable cost of ceramic items are a reason of their wide use in various subassemblies of buildings and structures, such as walls, heating units, wall and floor facing materials, sewage pipes, lining materials for chemical industry equipment, and light porous aggregates for prefabricated reinforced concrete items (Fig. 13–17).

### **3.2.1. Raw Materials and Properties of Clays**

Clay results from weathering of eruptive feldspathic rocks. Weathering involves mechanical and chemical disintegrations. Clay rocks are capable of mixing with water and forming a plastic viscous mass, which on drying retains the shape it was given and after burning acquires the strength and water resistance of stone. To improve workability of clay and its products and enhance their physical and chemical properties, clay is blended with quartz sand, chamotte (refractory clay burned at 1,000-1,400°C and then crushed), slag, sawdust and pulverized coal.

Clay possesses such properties as plasticity, cohesion and cohesiveness and their reaction to drying and high temperature.

Plasticity is an essential working property of clays, which allows molding various ceramic materials and items. Degree of clay plasticity depends on its mineralogical and granulometric composition, on the shape and character of grain surface, on the content of soluble salts and organic impurities and on the volume of water used for clay mass. High plasticity clay products let to shrinkage during drying (air shrinkage) and burning (fire shrinkage), therefore, leaner (non-plastic) substances (sand, slag and fireclay) are added to the clays.

Cohesion and cohesiveness. Clays with high content of clay fractions feature high cohesion. Cohesiveness of clays drops with an increase in content of sand and dust fractions. This property of clays is of great importance in the molding process. Cohesiveness of clay is characterized by its ability to bind together particles of non-plastic materials (sand, chamotte and others) and to form on drying a sufficiently strong item of a desired shape.

Effect of high temperature on clays. An important property of clays is their ability to turn into stone in the process of burning. Mechanically mixed water disappears at the initial temperature increase; the organic impurities burn out when the temperature ranges from 550 to 800°C with the effect that clay loses its plasticity. Burning is a process taking place when the temperature rises above the 800°C mark; in the process, the easy-fusing clay components melt, spread out and envelop particles that are still solid; when cooled, the molten mass solidifies and cement the particles. Burning of clay transforms it into stone. The color of burned clays is affected mainly by the content of iron oxides, which give the ceramic items a red color.

### **3.2.2. General Production Flowsheet for Ceramic Items**

Despite the wide range of ceramic items, their shape varieties and physical and mechanical properties of raw materials, the basic production steps

are common to all the items and involve the following operations: mining of raw materials, raw paste preparation, molding of items, drying, burning of items, finishing of items (trimming, glazing, etc.) and packing.

Raw materials are quarried by the open pit method with power shovels. Preparation of raw materials involves disintegration of clay's natural structure, removal or grinding of large inclusions, mixing the clay with admixtures and water until a moldable mass is obtained.

Depending on the raw material properties and on the kind of items produced, a ceramic mass is prepared by stiff-mud, soft-mud and slip casting methods.

In the stiff-mud method, clay is first crushed and dried, then ground and molded in hydraulic or mechanical presses at pressures of 15 MPa and over with a moisture content from 8 to 12%. The soft-mud molding method involves crushing of clay, then processing it in a mixer, where it is mixed with lean admixtures and simultaneously humidified until a homogeneous plastic mass of moisture content from 20 to 25% is obtained. In the soft-mud method, ceramic items (bricks for walls, pipes and tills for facing walls) are manufactured mainly in auger machines.

In the slip casting method, the starting materials are ground and then mixed with a large amount of water (up to 60%) until a homogeneous paste (slip) is obtained. The mass is directly cast into molds. Using this method, small-size ceramic tiles for facade decoration and sanitary ceramic items are manufactured. Items after drying are burned at temperatures between 900 and 11,000°C until they acquire such important building properties as stonelike, strong and hard, resistant to frost and others.

### **3.2.3. Ceramic Materials and Items**

Ceramic items used in building industry are classed according to their applications: wall materials – bricks and clay building stones for special purposes, ceramic items for floors, ceramic items for facade and interior decoration, roof materials, sewage and drainage ceramic pipes, acid-resistant lining items, sanitary ceramic items, ceramsite gravel and refractory materials.

#### **Wall Ceramic Materials**

Wall materials are common clay bricks, perforated clay bricks, porous and perforated stiff-mud bricks, hollow clay dry-press bricks, perforated plastic, molded ceramic stones and lightweight building bricks.

Clay bricks, both solid and hollow, of either soft-mud or stiff-mud molding, are an artificial stone manufactured from clay with additives (sand,

slag, sawdust and others) and burned. Bricks should be shaped as a parallelepiped with straight edges, right angles and smooth faces. Bricks are available in normal size 250×120×65 mm and module size 250×120×88 mm, 288×138×65 mm and 250×54×88 mm. The module brick with molded voids is not more than 4.3 kg in mass. There are eight grades of bricks designated 75, 100, 125, 150, 175, 200, 250 and 300 (7.5-30 MPa), which indicate respective compressive strengths. Bricks of each grade should also meet specific requirements regarding their bending strength from 2 to 4.4 MPa respectively. It is necessary that normally burnt bricks should have a water absorption of not less than 8% of the weight of a brick dried to constant mass. By their frost resistance, bricks are subdivided into six grades: F15, F25, F35, F50, F75 and F100; bulk densities are from 1,450 to 1,600 kg/ m<sup>3</sup>.

Common clay bricks are used for brickwork of outside and inside walls, pillars, foundations and other bearing constructions.

Hollow clay bricks are manufactured by soft-mud and stiff-mud molding methods with special devices (punches) for making holes (voids) in the bricks. Voids should be located at the right angle to the bed. In shape, they may be round (diameter is not more than 15 mm) and rectangular (slot width is not more than 15 mm). Hollow bricks are manufactured in sizes of 250×120×65 mm, 250×120×88 mm, 288×138×65 mm and 250×120×138 mm. In compressive strength the grades are 25, 35, 50, 75, 100 and 125; the bulk densities vary from 950 to 1,400 kg/m<sup>3</sup>; the water absorption is not less than 6% and their frost resistance is not less than F50. Hollow clay bricks are used for outside and inside bearing walls, partitions and other parts of buildings and structures. The bricks should not be used for foundations, pedestal and walls of premises of high moisture content.

Lightweight building bricks are burnt artificial stones from diatomites or tripoli with admixtures of clay or a combination of clay and burning-out admixtures (sawdust). When compared to common bricks, lightweight bricks have a lower bulk density and heat conductivity. Their use allows to reduce wall thickness and weight of structures and to increase floorspace of buildings. The bricks are manufactured in sizes of 250×120×65 mm, 250×120×88 mm with a bulk density from 950 to 1,400 kg/m<sup>3</sup>, and they have a compressive strength of 7.5-12.5 MPa. Their frost resistance should not be less than F50.

Ceramic stones have smooth or riffled surfaces and through or closed voids. Dimension of stones are as follows: length, 250 to 510 mm; width, 120 to 250 mm; thickness, 138 to 219 mm; bulk density, 790 to 1,300 kg/m<sup>3</sup>; water absorption, not less than 11%, and frost resistance, not below F75. Ceramic stones have a compressive strength from 10 to 25 MPa.

## **Ceramic Items for Building Facades and Interior Facing**

Building facades are finished with various ceramic materials such as facing bricks and stones, ceramic tiles. They differ not only in shape and dimensions but also in the ornamental effect they produce. These items should have not only a low weight, high strength and frost resistance but also a beautiful natural color.

Facing bricks and stones are not only decorative items; they are laid together with the wall brickwork and serve as structural bearing members along with common bricks. Facing bricks and stones are available in solid and hollow types. The surface of facing bricks is covered with specially developed variously colored and frost resistant engobe or glaze compositions (white, green, sky blue, etc.). The face of bricks and stone may be smooth, rifflled or textured. Facing bricks and stone are available in compressive strength grades of 75, 100, 125 and 150, with water absorption from 6% to 14% and frost resistance not less than F25. Hollow and solid facing bricks and stone are used for exterior brickwork of building facades and for interior walls laid simultaneously with the exterior walls, and for internal finishing of warehouses, workhops and protective enclosures in gardens and parks. Only glazed bricks or the ones with water absorption of not more than 5% should be used for water pools and reservoirs and other similar structures.

Mosaic facing tiles are small-size and thin, variously colored tiles glued upon a paper sheet to form a mosaic. Mosaic facing tiles are generally manufactured by casting. Tiles may be manufactured either in various colors, or shiny and lusterless, or coated with translucent or opaque glazes. They are manufactured in a range of 32 types and sizes, in square, rectangular, triangular, rhombic and trapezoidal shapes with sides measuring from 25 to 125 mm. Mosaic ceramic tiles should meet the following requirements: water absorption is not less than 6% and not more than 12%; frost resistance is F25.

Ceramic tile facing of bathrooms, bath houses, laundries, hospitals and other premises has two types of tiles; wall and floor varieties are used for the purpose. Wall tiles are divided into majolica and faience kinds, according to the raw materials used. Majolica tiles are manufactured from low-heat clays, to which up to 20% of calcium carbonate is added in the form of chalk. Burning produces a porous tile shell, its face side is glazed, and the back side is fluted to improve adhesion to the wall surface. Faience tiles are made from refractory clays with additions of quartz sand and fusing agents (as a rule, fluorspar and limestone or chalk), which lower their melting point. The tiles have a white or a slightly colored shell, whose face side is coated with white or colored,

translucent or dead glaze. Their back side is generally riffled. Tiles are available in square, rectangular and other shapes intended for angles, cornices and plinths. Tiles for interior facing are manufactured in the following sizes: length–150 mm, width –25, 50, 75 and 150 mm. Thickness of tiles of all sizes should be from 6 mm to 12 mm. The quality of tiles for interior facing must be very high. The tiles should be of regular geometric shape, free of bulges, hollows or cracks.; they should be sufficiently heat resistant, i.e. withstand alternate cycles of heating to 100°C and cooling in water at 20°C without any cracks, chips or crackles appearing on the glazed surface. Water absorption of tiles should not exceed 16%. Wall tiles are used to face walls of premises requiring extra cleanliness, sanitary closets, kitchens and premises of high moisture content.

Ceramic floor tiles are extensively used in residential. They are durable and impervious to water, resist abrasion well and wash well. On the other hand, ceramic materials have a number of drawbacks: high heat conductivity, low impact strength and small dimensions. The two methods of preparing molding masses generally used in tiles manufacture are soft-mud and stiff-mud methods. Altogether, tiles are manufactured with sides measuring from 50 to 150 mm, and from 10 to 13 mm thick. Tiles should be of regular shapes, have sharp edges and angles and be free from bulges, hollows and cracks. They should be very dense, and their water absorption should not exceed 4%; their resistance to abrasion should be high (loss in mass of tiles tested for abrasion should not exceed 0.1 g/cm<sup>2</sup> for floors subjected to severe abrasion and 0.25 g/cm<sup>2</sup> for floors of other premises). Ceramic floors are intended for premises with intensive pedestrian traffic and high moisture level, such as sanitary and service, premises, lobbies, halls, entrances to public, industrial buildings and underground railway stations.

### **Ceramic Materials for Special Purposes**

Ceramic materials for special purposes are stones for sewage structures, brick clinker for road surfaces. The above mentioned materials have to meet stringent requirements: mechanical strength, resistance to frost, abrasion and impact.

Bricks (clinker) for road surfaces are artificial stones molded from clay. The raw materials used are high-heat clays. Clinker is manufactured in a single size of 220×110×65 mm.

Clay roof tiles are relatively cheap and possess good ornamental properties. Their drawback is a considerable weight (up to 65 kg per 1m<sup>2</sup> roof). Roof tiles should be well burned, uniformly colored, have an even and smooth surface (no cracks), be sufficiently strong (breaking load not less than 70 kgf), impervious to water and frost resistant (not less than F25).



Ceramic sewage pipes are used for industrial and fecal sewage systems, and for draining systems for corrosive water. Sewer pipes are available in diameters from 150 to 600 mm, and in lengths from 800 to 1,200 mm. Water absorption of the pipe should be from 9% to 11%. The pipes are rated to withstand hydraulic pressures not less than 0.2 MPa and the shell's resistance to acids should not be less than 90%. Draining pipes are manufactured in diameters from 25 to 250 mm, in lengths of 333-500 mm. They should be sufficiently frost resistant (F not less than 15). Acid-resistant ceramic pipes are glazed on both sides. Acid-resistant pipes are distinguished by high density and strength, low water absorption and high resistance to acids. Acid-resistant pipes are used for handling non-organic and organic acids and gases in vacuum or at pressures up to 0.3MPa.

Acid-resistant bricks are used for foundations and linings of chemical structures, floors and discharge troughs at chemical plants. Acid-resistant bricks are manufactured in two kinds: straight and wedge. Acid-resistant bricks should have an acid resistance of not less than 92-96%, water absorption of not more than 8-12%, compressive strength of not less than 15-25 MPa, heat resistance (number of thermal cycles) of not less than 2. Acid-resistant ceramic tiles are available in two types: acid-resistant (K) and thermal-and-acid resistant (TK). Tiles have a solid burnt body, high strength (compressive strength is not less than 39 MPa and bending strength is not less than 15 MPa), low water absorption (not more than 6 to 9%), high acid resistance (not less than 96-98%), and high heat resistance (not less than 2 and 8 thermal cycles). The tiles are used for lining chemical structures and floors at chemical plants.

Sanitary ware items are manufactured mainly from white-burning refractory clays, kaolins, quartz and feldspar. There are three groups of sanitary ceramics: faience, semi-porcelain and porcelain, which differ in degree of caking and as a consequence, in porosity. Items from faience have a porous shell, and items from porcelain – a solid shell, while those from semi-porcelain are of intermediate densities. The various degrees of caking of faience, porcelain and semi-porcelain, made from the same raw materials, are due to the latter's different proportion in the working mass. Solid faience is used mainly to manufacture toilet bowls, wash basins, toilet tanks and bath tubs. Items are glazed, since unglazed faience is water permeable. Porcelain outer shell is impervious to water and gases and possesses high mechanical strength and resistance to heat and chemical agents. Porcelain is used to manufacture insulators, for power transmission lines, chemical laboratory vessels, etc.

Materials resistant to temperatures above 1,580°C are called refractories; generally, they have to meet certain specifications as regards refractoriness, compressive and bending strengths, resistance to loads at high temperatures, spalling resistance, gas impermeability, resistance to slag, constancy of volume and shape. Such refractory materials as siliceous (silica) 1,670-1,790°C, chamotte 1,670-1,790°C, high-alumina 1,820-1,960°C, are most widely used for special purposes. Refractory materials are used for roofs in metallurgical, ceramics furnaces, and glass tanks.

Ceramsite is a lightweight porous material of cellular structure with closed pores. It is used mainly as aggregate for lightweight concrete and as heat-insulating material. Ceramsite is manufactured from low-heat clays. The clay is crushed, dried, ground, thoroughly mixed with organic additives (pulverized coal, peat crumbs) and finally pelletized to produce balls of 10 to 20 mm in diameter. In the process of burning, the materials soften, and the evolving gases and water vapors cause the semi-liquid mass to expand and form pores. Ceramsite gravel is classified by pellets size, bulk density and mechanical strength. It is available in pellets from 2.5 to 20 mm in diameter; grains smaller than 5 mm are called ceramsite sand. By its bulk density, gravel is divided into grades from 200 to 900 kg/m<sup>3</sup>, with compressive strengths from 0.5 to 10.0 (in MPa).

### **Self-Check Questions:**

1. What technological and operational properties of clays do you know?
2. What is the general technology of ceramic material production?
3. What are wall structural ceramic materials, their properties and applications?
4. What ceramic materials are used for buildings' facades? What are their properties?
5. What ceramic materials are used for interior walls? What are their operating conditions and their quality?
6. What ceramic materials are used for flooring? What are their operating conditions? What is the quality of the products?
7. What ceramic materials are used for thermal insulation of building structures?
8. What technology is used to reduce the thermal conductivity of ceramic products?
9. What refractory ceramic materials do you know? What determines their resistance and use?

### 3.3. Materials from Mineral Melts

Mineral melts may be divided according to their source material into glasses, slags and stones. These materials possess good physical and mechanical properties (are resistant to acids and abrasion, impervious to water and decorative).

Materials and items from glass melts, such as various glasses and finished items, have found extensive application in construction, architecture, sanitary engineering, chemical and other industries (Fig. 18-20).

Glass has a number of properties, which other building materials lack, the most characteristic of which are brittleness and transparency. Compressive strength of glass may be as high as 700 to 1,000 MPa, tensile strength, 30 to 80 MPa. Common silicate glass is transparent to the entire visible part of the spectrum and practically opaque to ultraviolet and infrared. Transparency of glass within the above range of wavelengths may be controlled through its chemical composition and color. Silicate glass is highly resistant to attack by various agents, except for phosphoric acids.

#### **Variety and Application of Sheet Glass**

Window sheet glass is a widely used kind of flat glass; it is available in thicknesses from 2 to 6 mm. Light transparency of window glass ranges from 85 to 90%, depending on its thickness.

Source materials for structural sheet glass manufacture are quartz sands, sodium sulphate, limestone, dolomite and a number of other substances. Structural glass manufacture consists of the following main operations. The preparation of constituent materials involves drying, crushing, proportioning and mixing the ingredients. Once a mix is prepared, it is melted in special furnaces, at 1,100-1,200°C. Next, the melt is taken up by a vertical or horizontal type drawing machine and shaped into a sheet by passing between rolls, then cooled using a special mode to reduce brittleness. Sheet glass may also be manufactured by casting and subsequent rolling. For this purpose, glass melt is poured on a smooth surface of melt stannum ( $t=2,320^{\circ}\text{C}$  – float method) and rolled between smooth or figured rolls.

Window sheet glass is available in the following varieties:

1. Decorative glass: one side has a smooth surface and the other side has a relief and figured one.
2. Wire glass is obtained by continuous rolling with simultaneous embedding of a wire mesh. Wire glass may be smooth, or variously figured and colorless or colored. The glass is used for guarding balconies, loggias, stairs,

elevator pits, for decorative translucent domes and partitions in residential houses, resort centers, recreation centers and public catering.

3. Safety glass is obtained in vertical drawing machines from the glass of a special composition. The chemical composition and the processing conditions may be adjusted to produce glass with different light and heat transmission and reflection characteristics for various spectrum ranges. Safety glass is used for buildings glazing.

4. Heat-absorbing glass, colored throughout its body, contains special additives, which selectively absorb infrared rays of the solar spectrum. It is intended to reduce insolation. Transmission of visible light amounts is not less than 65%, and that of infrared rays is not more than 35%.

5. Shop window glass is manufactured from polished and unpolished glass, 6 to 12 mm thick, in sheets of 4 to 12 m<sup>2</sup>. It may be either flat or curved. Shop window glass is used for glazing inside and outside shop windows and openings in stores, restaurants and airports. Sheets glass is used for glass slabs and door panels.

6. Glass slabs are two or a number of glass sheets fused together hermetically along the perimeter. The cavities between the glass sheets contain dry air. Glass slabs are manufactured from window, show window, armoured, art, etc. glass, from 2 to 8 mm thick, of surface areas up to 5.0 m<sup>2</sup>, with the panes spaced from 5 to 20 mm apart. Glass slabs are capable of withstanding greater wind loads than separate glass sheets of the same thickness. Glass slabs are also good sound insulators, too. They are used for glazing industrial, residential and public buildings.

7. Door panels are made from special heat-cured (tempered) glass sheets with thickness from 10 to 15 mm. The available range of door glass panels is as follows: colorless, transparent, with polished or unpolished surfaces; colored and colorless light diffusing with art or worked faces. Colorless glass panels are used for outside and inside doors in residential, public and industrial buildings. Colored and colorless panels from rolled art or figured glass are used inside premises where no through visibility is desired.

### **Constructions Items from Glass**

Profile structural glass is channel and boxed elements, which may be colorless or stained, in length up to 6,000 mm and in width from 244 to 294 mm. Manufacture of profile glass of channel cross section reinforced with steel wire mesh is introduced industrially now. It is highly fire-resistant and splinter-proof.

Constructions from glass parts should be interlayered with various sealing devices, such as putties or specially designed profiled parts from foam rubber or synthetic materials.

Profile glass is used for translucent partitions and self-supporting walls in industrial, residential and agricultural construction work, and for interior partitions and transparent flat roofs in various types of buildings. Profile glass may also be used in the form of large-size panels. This glass resists attack by concentrated acids, alkalis and humidity. Profile glass may be used in combination with metals, concrete, bricks or wooden construction elements.

Glass blocks are hollow translucent items with variously figured inside and outside surfaces. Glass blocks are obtained by fusing two preheated half-blocks together. The air enclosed inside the slab (at a low vacuum) lowers the heat conductivity coefficient of the blocks. Glass blocks produce soft diffuse lighting, enhance natural lighting depth and eliminate through visibility. Enclosing structures built of glass blocks excellently resist fire. Glass blocks have also high sound insulation properties. They are durable and hygienic. Glass blocks are used for fronts of industrial buildings, and for day-light illumination of stairways of residential buildings and various storage premises. Glass blocks are also used for ornamental purposes, and find application in stores with aggressive atmosphere, which require illumination. Glass blocks are used wherever the type of production process requires invariable climatic conditions.

Glass-concrete structures, depending on their supporting power, opaqueness, sound insulation and other properties, are subdivided into wall, floor, roof and dome constructions, where the bearing part is a reinforced concrete carcass filled with glass blocks. Glass-concrete wall structures may be effectively used for industrial and service premises, railway stations and exhibition pavilions. Wall structures (panels) possess adequate heat and sound-insulating properties, provide good lighting of premises, are hygienic and require no special finishing.

### **Facing Items from Mineral Melts**

Facing glass is used in the following varieties: sheet glass, coated on one side with solid ceramic paints of various colors (stemalite) or with metallic oxide in not transparent glass melt (marblite), and carpet-type art glass tiles. Sheet glass is from 6 to 12 mm thick, with surface areas up to 3.0 m<sup>2</sup>. Tiles, available in sizes of 18×18×4, 20×22×4, and 23×23×3 mm, are durable and color-fast\ strong. These tiles are intended for outside and inside buildings walls facing.

Sitals and slagsitals are vitrified crystalline materials. Molten slag or glass is blended both with admixtures to improve its composition and with crystal modifiers (generally, TiO<sub>2</sub>, CaF<sub>2</sub>, and P<sub>2</sub>O<sub>5</sub>) to accelerate the crystallization of molten. As the modifiers are partly soluble in the body of mineral molten, they

serve as crystallization nuclei. Next step is molding of items from improved and modified molten. The major problem in molding of items is to create the right heat treatment conditions.

A material of required mechanical and thermal properties may be obtained through controlling the degree of crystallization and the composition of the crystalline phase. When comparing to the manufacture of these items, that of sitals and slagsital, both of them require thermal curing to transform glass to a vitrified crystalline state. Sitals may be dark, brown, grey, creamy light in color and either dead (opaque) or transparent. Sitals and slagsital items possess excellent physical and engineering properties, high resistance to abrasion and attack by chemical or atmospheric agents and are non-toxic. They may compete with basalts and granites in durability. The combination of physical and mechanical properties of sitals and slagsitals predetermines their wide use in construction: they are used for floors of industrial and residential buildings, decorative and protective facing of exterior and interior walls, partitions, socles, lining of structural elements subject to corrosive or abrasive conditions, roof coverings of industrial buildings and facing of laminated panel walls of multi-storeyed buildings.

### **Specific Use of Mineral Melts Items**

Glass pipes are available in diameters from 15 to 65 mm. They have found extensive application in food, pharmaceutical, chemical and other industries for handling corrosive liquids. Glass pipelines are transparent, hygienic and smooth, a factor minimizing resistance to the flow of liquid.

Glass (slag) wool is a material composed of thin 5 to 6 mm flexible threads. Glass wool has high tensile strength and chemical resistance, low sound- and heat-conductivities and is obtained by mechanical drawing, centrifugal or blowing techniques.

In the centrifugal method, the source materials are furnace slags or glass bottle waste, which are washed and charged into a special ladle, where it melts, and at 1,300 to 1,400°C flows into a pot. Next, the glass mass is blown in a thin jet onto a rapidly rotating disk. The centrifugal force causes the molten mass to break away from the disk and stretch into thin threads.

In the blowing technique, the threads are formed by breaking up the molten glass (slag) by a gas jet. A high-speed gas jet draws the glass mass into thin threads, which are then taken up by a fine wire conveyor and transferred to subsequent processing stages.

The manufacture of items (mats, slabs) from mineral fiber comprises the following operations: mixing of fibers with synthetic binders, molding, thermal

processing, cutting and packing. The mats and rigid slabs are good heat-insulating and acoustic materials, which in recent years have been increasingly used in construction.

Items from mineral fiber are used for heat insulation of building structures (walls, floors, roofs), refrigerators and pipes at temperatures between  $-60$  and  $+180^{\circ}\text{C}$ .

Acoustic materials by application are subdivided into two main groups: soundproofing and sound-absorbing ones.

Soundproofing materials and items are used chiefly in the form of liners and interlayers in floors, interior and exterior walls and other parts of buildings in order to damp impact noises transmitted through floors (walking), vibration (machine operation), etc. These materials are of a porous-fibrous structure (based on slag or glass wool), which are shaped as slabs, rolls, mats, strips, and piece liners. By the relative compression under load, a distinction is made between rigid, semi-rigid and soft sound-insulation materials. Glass and mineral wool mats and slabs on synthetic binder have a bulk density of  $50\text{-}225\text{ kg/m}^3$ , a relative compression factor of  $15\text{-}40\%$  under a load of  $0.02\text{ MPa}$ , and a dynamic ratio of elasticity of  $0.3\text{-}0.7\text{ MPa}$ .

Sound-absorbing materials lower audible noise (a combination of numerous sounds rapidly varying in frequency and amplitude) in industrial and public buildings. Sound-absorbing materials on the base of mineral fiber have a porous-fibrous structure. They are divided into soft, semi-rigid and rigid varieties. Sound-absorbing materials are available as boards, coiled and loose materials; they are also used in the form of plaster boards having a smooth-porous, perforated and grooved structure.

Mineral wool acoustic (soundproofing) boards are manufactured from mineral fibers by impregnating them with a synthetic binder or granulated mineral wool and compositions of a starch binder with additions and subsequently submitting them to thermal and moisture curing in special chambers. The face of boards may also have directional cracks similar to the texture of weathered limestone. Excellent ornamental properties of the mineral wool acoustic boards ensure their wide use for facing ceilings, entrance halls, theaters, concert halls, radio studios and noisy premises.

Cellular glass is obtained by causing molten glass to expand when mixed with a substance (limestone, coal) capable of giving off gas at temperatures of  $750$  to  $850^{\circ}\text{C}$ . This glass is a good heat-insulating and acoustic material, and has small bulk density ( $140\text{-}350\text{ kg/m}^3$ ) and a low coefficient of heat conductivity ( $0.06$  to  $0.11\text{ W/m }^{\circ}\text{K}$ ). Cellular glass finds practical use as a heat-insulating

material (slab, bloc) in floors, walls; and as a sound-absorbing material in public and service premises.

Thermosite (slag pumice) is a cellular material obtained by expanding molten slag when rapidly cooled. Thermosite bulk density ranges from 300 to 1,100 kg/m<sup>3</sup> depending on the size of lumps and the expansion degree. Thermosite is a good aggregate for manufacture of lightweight concrete. Items of various profiles and configurations may be obtained by casting molten slag into special molds.

Internal stresses may be lessened and cracks prevented during crystallization and subsequent cooling by placing a steel reinforcement into the molds before slag is poured.

### **Self-Check Questions:**

1. What are the positive properties of glass?
2. What are the negative properties of glass?
3. What is the general technology of obtaining products of glass melts?
4. What are the types of sheet glass? What is their use in construction?
5. What structural glass products do you know? What is their use in construction?
6. What are the production technology, properties and applications of sitalts?
7. What are the production technology, properties and application of fiberglass products?
8. What materials from glass melts are used for indoor and outdoor decoration of buildings?
9. What are the production technology, properties and application of products from cellular glass?

## **3.4. Metals and Metal Items**

Metals and metallic alloys are crystalline bodies composed of a host of separate grains consisting of crystalline formations strongly bound together. Iron may exist in several crystalline forms that differ in arrangement of atoms.

In the process of melt solidification, regularly shaped fine crystals are first formed and, as the metallic body cools, they increase in size and grow together into deformed irregularly shaped crystals (crystallites), which are well visible through a microscope.

This phenomenon is known as allotropism. Allotropic changes are caused by variations in temperature.



Allotropy is of great significance in hot working and heat treatment of cast iron and steel and in adjustment of their properties through hardening, annealing and other techniques providing required mechanical properties of steels.

Metal items are produced for bearing structures, roofing and finishing materials (Fig. 21–23).

### **3.4.1. Chief Properties of Metals**

Physical properties of metals and alloys are color, density, melting point, heat conductivity and thermal expansion coefficient.

Density of most metals is higher than  $7,000 \text{ kg/m}^3$ , but that of light metals (aluminum) is less than  $3,000 \text{ kg/m}^3$ . The lower is the density, the lighter and more efficient are the metal structures made from it. This explains why constructions from aluminum-based alloys are used on ever increasing scale in construction.

Metal melting points are major factors in their hot working and casting procedures. The melting point can be changed by adding other substances. Variation of metals melting temperature depends on the content of other substances and is described by the phase diagram.

Metal thermal expansion is expressed by coefficients of linear and volumetric expansions. This property should be taken into account when designing metal structures, since excessive expansion or contraction may cause their failure. It is very important to consider this phenomenon in the process of welding as the items welded together may crack as a result of local heating. Metal thermal expansion is taken into account in manufacture of reinforced concrete items, where reinforcement is tensioned by electric heating.

Metal mechanical properties are their strength, hardness, resilience (impact strength), fatigue and creep. Strength is the ability of a metal or an alloy to withstand external forces. Depending on the nature of the forces, distinction is made between tensile, compressive, bending and torsional strengths, presented by corresponding ultimate strengths, i.e. stresses causing the tested specimen to fail. The tensile test is a universal test for all metals and alloys. Compressive and bending tests are specific for grey iron. When testing metals for tensile strength, distinction is made between the ultimate strength (breaking point) and the yield point, or a stress when the specimen elongates while the load remains constant. This characteristic is the main factor in metal constructions' estimates.

Specimens of steels and non-ferrous heavy and light alloys used for making parts working under repeated alternate tensile, bending, compressive, torsional, impact and other kinds of stresses, are tested for fatigue, or endurance.

Metals operating under continuous stresses are tested for creep, i.e. deformation under a constant load. Creep may cause excessive sag in constructions and loss of stability. Creep in the reinforcement of prestressed concrete constructions is particularly hazardous, since it may lead to the loss of pretension by the reinforcement, formation of cracks in concrete and failure of the entire construction.

Hardness of a metal is defined by its resistance to penetration of a hard steel ball (Brinell hardness), or a diamond cone or a pyramid.

Viscosity is generally considered in static and impact (dynamic) aspects. Static viscosity is expressed in terms of relative elongation, and impact viscosity by the amount of work required to cause failure of the impact test specimen.

Workability of a metal is its amenability to various mechanical processing. The term workability includes plasticity (which allows to produce metal items by forging, rolling and drawing), machinability and weldability (which is the ability of metals to give strong joints when heated locally to a plastic or liquid state).

Interaction of metals with ambient conditions may result in its disintegration, or corrosion. Distinction is made between chemical and electrochemical corrosion. Chemical corrosion arises whenever metals are attacked by dry gases and solutions of oils, gasoline, kerosene, etc. An example of chemical corrosion of metals is their oxidation at high temperatures and as a result, their surface becomes covered with scale. Electrochemical corrosion arises when metals are attacked by acids and alkalis. The metals give off their ions to the electrolyte and disintegrate in the process. The degree of corrosion depends on the temperature, kind and concentration of the electrolyte. Acids and alkalis attack steel because they are capable of dissolving the resultant compounds.

Carbon dioxide or sulphurous gas in the air enhances corrosion, since metal attacking acids are formed when the surface of metals is humidified.

Corrosion may be local, when only certain areas are affected; it may be uniform, when metals are attacked evenly over their entire surface; it may be intercrystalline when only the boundaries of grains disintegrate.

There is a number of means to protect metals against corrosion, the simplest of which is to coat them with paints, varnishes and enamels. The resultant film isolates metals from ambient influences (gases, moisture). There are also more efficient means of corrosion protection:

- alloying, or introducing substances which enhance corrosion resistance of metals;
- coating with a different metal, which is less susceptible to corrosion under given conditions (zinc, tin); e.g. surfacing with a metal from an electrolyte

(galvanic plating), spraying or dipping in a bath containing some other molten metal.

### **3.4.2. Classification of Metals**

Metals for construction work may be broadly classified as ferrous and non-ferrous.

Ferrous metals (black metals) are alloys of iron and carbon. Besides carbon, ferrous metals may contain small amounts of silicon, manganese, sulphur and other chemical elements. Ferrous metals are given specific properties by adding to them the so-called alloying substances, such as copper, chromium and others. By their carbon content, ferrous metals are divided into cast irons and steels.

Production of cast iron is the first step of metallurgical processes in manufacture of ferrous metals from natural iron ores, which are a mixture of iron oxides and minerals called gangue and composed chiefly of silica, alumina, limestone and other compounds.

The products of blast-furnace process are cast iron, blast-furnace slag, glue gas and dust.

Cast iron is an alloy of iron and carbon (from 2 to 4.3%). In some specific kinds of cast irons the amount of carbon may be as high as 5% or more. Silicon, manganese, phosphorus and sulphur greatly affect the properties of cast irons. Sulphur and phosphorus embrittle them, whereas admixtures of chromium, nickel, magnesium, aluminum and silicon enhance their heat, wear and corrosion resistances. When these elements are added, cast irons are called alloyed. Depending on the form of carbon in cast irons, the latter are subdivided into grey (foundry) and white varieties. Conversion iron accounts for about 80% of the output. Conversion iron is generally processed to steel. Cast iron of grade C4 is grey iron, and that of MC4 is modified (high-strength) grey iron. Mechanical properties of cast irons are as follows: grade C4: 120-280 to 280-480; MC4: 280-480 to 380-600 (the first two figures indicate the tensile strength in MPa, and the two last figures show the bending strength in MPa). Grey iron is generally used for building purposes. In load-bearing constructions, cast iron is used chiefly in compression elements (footings, columns); cast iron is also widely used for manufacturing sanitary engineering fixtures (heating radiators, pipes), architectural and ornamental items. A considerable amount of cast iron goes for manufacture of tubings for underground railway tunnels.

Steel is obtained from iron by lowering the content of carbon and other impurities. Modern techniques for manufacturing steel are oxygen-converter, open hearth and electric steelmaking processes. Irrespective of the methods, the

steelmaking process consists in oxidation of undesirable impurities, which later turn into slag or burn. Steel contains carbon in amounts of up to 2%. In contrast to the brittle cast iron, steel is plastic, elastic and mechanically very workable. By application, steels fall into structural (0.02 to 0.85% carbon) and tool (0.65 to 1.4%) varieties. Structural steels used in construction engineering, reinforced concrete and machine industry are very plastic and negligibly brittle. Greater amount of carbon makes tool steels very hard but increases their brittleness.

By chemical composition, steels are divided into carbon and alloyed varieties. In their turn, carbon steels are available in the following grades: common; high-quality structural (for general machine building and critical structures); and tool (for manufacture of cutting tools and dies). Common grade carbon steel finds its basic application in construction work. It contains, besides carbon (0.06-0.62%), some silicon and manganese. Most undesirable is phosphorus, which causes brittleness at low temperatures (cold brittleness), and sulphur, which induces hot brittleness.

Steels intended for structures are distinguished by quality, application and a melting technique (open-hearth or converter steel).

Mechanical and physical properties of steels (heat resistance, abrasive wear and corrosion) are enhanced by admixtures of nickel (Ni), chromium (Cr), cobalt (Co), copper (Cu), aluminum (Al), silicon (Si), manganese (Mg), etc., called alloying elements; the corresponding steels are known as alloyed steels. Steels are considered low-, medium- and high-alloy when the content of alloying substances is respectively below 2.5%, 2.5-10%, and over 10%. Low-alloy steels are widely used in construction. Alloyed steels consist of structural, tool and special-kind varieties, the latter having a number of specific properties (stainless, possessing acid-resistance, scale- and heat-resistance and high electric resistance).

The grade designation of alloyed steel, for instance, 25XГ2C steel for reinforcing prestressed concrete, indicates that it contains 0.25% of carbon, 1% of chromium, 2% of manganese and 1% of silicon. Thus, the first two figures indicate the content of carbon in hundredths of a per cent, and the figures that follow show the content in full per cent of the alloying element whose code letter precedes the figure.

### **3.4.3. Nonferrous Metals and Alloys**

Nonferrous metals and alloys are used on an ever increasing scale in manufacture of building components of high engineering properties. Aluminum alloys, that were subsequently developed, rapidly replaced carbon-metal alloys

with great engineering and economic advantages. Alloys of copper, zinc, lead, tin, manganese find use in special kinds of building work.

Aluminum alloys are widely used for manufacture of rolled sections, such as angles, channels, round and rectangular pipes. Aluminum alloys are much used for manufacture of rivets, bolts and sheets. Items manufactured of aluminum alloys are easy to produce, nice, resistant to seismic activity and cold, feature good fire-resisting and antimagnetic properties and durability, which makes them competitive with steel and other building materials. The scope of application of aluminum constructions and semi-products is at present expanded by developing structural and facing materials with various protective and ornamental coats of polymer, varnish, paint, enamel and electrolytic types. Aluminum structures are widely introduced in residential, industrial and farm constructions.

Copper alloys are used for any practical building purposes in the form of brasses and bronzes. Brass is an alloy of copper and zinc (up to 40%) and bronze is an alloy of copper with tin or any other metal, except for zinc. Brasses and bronzes possess many important engineering properties, they are adequately strong (from 300 to 600 MPa), can be produced with high surface hardness (from 200 to 500 HB) and have excellent corrosion resistance. Copper alloys are used in construction work only for manufacture of sanitary ware (stop cocks, valves) and in special cases for finishing and decoration purposes.

Lead and zinc find much wider use in construction work. Zinc is chiefly used for roofs, cornices and drain pipes. Zinc resists corrosion caused by ambient influence. Lead applications include lining of acid-resistant chemical equipment, special kinds of waterproofing and screens for radiation protection.

#### **3.4.4. Manufacture and Application of Metallic Items and Constructions**

Metallic items may be manufactured either by pouring molten iron or steel into specially shaped forms, called molds, and then working ingots weighing from 500 kg to several tons (sometimes tens of tons) by mechanical means or by direct casting the finished items of a required shape, size and properties. Mechanical working is based on good plastic properties of metals. In fact, metals are rolled, forged, drawn, stamped and pressed.

Rolling is a universal and cheap method of manufacturing metallic items. Rolling consists in breaking down metal between rotating rolls, the starting blank is reduced in cross section, drawn and given the shape of the rolls if the latter are not smooth. Metals are rolled either cold or hot. Cold rolling is used

for metals of high plasticity (lead, tin) or thinnest steel sheets (because they cool down rapidly). Most steel items are generally hot-rolled at temperatures between 900 and 1,250°C. A steel ingot is broken down to a required shape in several successive steps by passing it through a number of roll pairs, each subsequent pair sets closer to one another than the preceding one. Most steel building components—beams, rails, steel leaves, bars, reinforcement, and pipes—are manufactured by rolling.

Forging is a deformation of metal by repeated strikes of a hammer or a press. Metals may be either forged free, when they are free to spread in all directions while they are hammered, or die-forged, when they flow under the blows of a hammer to fill the inside of a die, excess metal is forced out into a special groove and cut off. Die-forged parts have very accurate dimensions. In construction practice, free forging methods are generally used for manufacture of various parts (bolts, cramps and anchor bolts).

Drawing is pulling of metallic blanks through a drawing die orifice whose cross section is less than that of the blanks, with the effect that metal is reduced in cross section and given strictly a shape of the hole. The blanks are pre-rolled or pre-pressed bars or pipes. Metals are generally drawn cold; finished items are smooth and true to the required dimensions. Thin-walled items (tubes) and round, square, hexagonal rods of small cross-sectional areas (up to 10 mm<sup>2</sup>) are manufactured by drawing.

Drawing of metals results in hardening, or increase in strength due to plastic deformation. Hardening increases hardness of steel but lowers its plasticity and resilience. Cold working may cause steel fatigue, or structural changes, which make steel brittle. On the other hand, cold working finds extensive practical use in mechanical strengthening of reinforcement steel with a view to raise its yield point.

Heat treatment provides steel items with specific mechanical properties such as high hardness (greater resistance to wear), low brittleness (improved machinability or impact strength), etc. This is achieved by heating and cooling steel according to a strictly predetermined temperature schedule, with the effect that steel undergoes structural changes and acquires specific mechanical properties. There is a great number of heat treatment techniques, e.g. hardening, tempering, annealing, normalizing and case-hardening.

Hardening is a heat treatment of steel involving heating to a predetermined temperature, holding for some time required for the completion of phase transformations and rapid cooling in water, oil and other liquids. Hardening enhances hardness and strength but lowers resilience. Hardened steel

is brittle and thus not suitable for practical use. To reduce brittleness and relieve internal post-hardening stresses, steel is tempered, i.e. heated to a temperature lower than that of hardening and then gradually cooled in the air. Depending on the kind of tempering, items are heated to 150-550°C. The higher the temperature of tempering, the greater are the changes in the mechanical properties of hardened steel: ultimate strength and hardness decrease, while relative elongation and resilience increase.

Annealing reduces heterogeneity in the structure of steel, gives it a fine-grained texture, relieves stresses from mechanical working (forging, drawing) or founding and improves machinability of steel.

Normalizing, in fact, is an annealing process. Steel items are heated to and maintained at a temperature somewhat below the hardening point, then cooled in the air. The effect is a more fine-grained, harder, stronger, and more resilient steel than that one after annealing.

Case-hardening of steel consists in changing the chemical composition of the surface layer of a steel item by saturating it with certain substances such as carbon, nitrogen, and chromium with a view to enhance hardness, wear resistance or corrosion resistance of the item's skin, while retaining the high mechanical properties of its interior core.

Cementing of a steel part consists in saturating its skin with carbon. It is achieved by heating the item to a temperature between 880 and 950°C in a carbon rich environment.

Nitriding consists in saturating the surface layer of a steel item with nitrogen while heating it to a temperature between 500 and 700°C in an atmosphere of nitrogen; the treatment enhances steel corrosion resistance, hardness, wear and fatigue resistance. The nitride layer is from 0.01 mm to 1.0 mm thick.

Steel resistance to corrosion by fresh and sea water, nitric acid is improved by chroming, i.e. saturating its surface layer with chromium.

### **Self-Check Questions:**

1. What general properties of metals do you know?
2. What is the production technology of variously shaped metal products? What are their purposes?
3. What is the impact of carbon content on properties and applications of iron-carbon alloys?
4. How are iron-carbon alloys properties regulated?
5. What classification of iron and steel do you know?

6. How are steel products and structures used in construction?
7. What are the ways to protect steel products and structures from corrosion?
8. What non-ferrous metals and alloys do you know?
9. How are non-ferrous metals and alloys used in construction?
10. What are the types and purpose of heat treatment of metal products?

### 3.5. Mineral Binders Substances

Mineral binders are fine powders that produce a plastic pasty mass on mixing with water, and turn to stony state when exposed to physical and chemical influence. This property makes binders suitable for mortars, concrete – artificial cast stone materials and items.

Mineral binders are subdivided into air-setting and hydraulic setting varieties.

Air-setting binding materials are substances that turn into a stone state, gaining and retaining mechanical strength in the air only. Examples of air-setting binding materials are gypsum, magnesian binding materials, air-hardening lime and acid-resistant cement.

Hydraulic-setting binding materials are substances that get into a stone state, gaining and retaining strength not only in the air but in water as well. The group of hydraulic-setting binding materials includes hydraulic lime, Portland cement and its varieties, puzzolana and slag binding materials, alumina and expanding cements and others. They are used in below-ground and underwater constructions.

Distinction is made from autoclave-setting binding material, which set only when treated in autoclaves with saturated steam at pressures from 0.8 to 1.2 MPa and temperatures between 170 and 200°C. They form an autoclave-setting group of lime-silica and lime-slag binders.

#### 3.5.1. Air-Setting Binding Materials

**Gypsum binding materials.** The source materials for manufacture of gypsum binding materials are natural gypsum rock  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  and natural anhydrite  $\text{CaSO}_4$ , as well as chemical industry waste containing phosphorous gypsum.

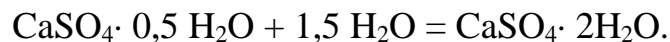
Gypsum binders are subdivided into two groups: low- and high-burning varieties. Low-burning gypsum binders are obtained by heating dehydrate gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) to a temperature of 140-180°C; dehydrate gypsum is



partially dehydrated and converted to semihydrate gypsum ( $\text{CaSO}_4 \cdot 0,5\text{H}_2\text{O}$ ) – building and extra strong gypsum. High-burning (anhydrite, estrich gypsum) binding materials are obtained by burning dihydrate gypsum at a higher temperature (700-1,000°C) to a complete loss of chemically bound water and formation of anhydrous calcium sulphate, the anhydrite ( $\text{CaSO}_4$ ). Building and extra strong gypsum fall into a low-burning category, and anhydrite cement and estrich gypsum fall into a high-burning category.

Building gypsum. Manufacture of building gypsum involves crushing, grinding and thermal processing (dehydration) of gypsum rock ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). The obtained building gypsum ( $\text{CaSO}_4 \cdot 0,5\text{H}_2\text{O}$ ) is then finely ground in mills.

When water is added to gypsum powder, the semihydrate calcium sulfate  $\text{CaSO}_4 \cdot 0,5\text{H}_2\text{O}$  contained in the latter dissolves until a saturated solution is formed; at the same time, the semihydrate hydrates by taking up 1.5 moles of water and converts to dihydrate  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  according to the reaction



The fine particles accumulate, bond together to cause thickening (setting) of the pulp, then crystallize to form a strong gypsum stone. A further increase in the strength of gypsum takes place by drying the setting mass and its further crystallization.

Building gypsum is a quick setting and quick hardening binder. Setting of building gypsum should begin not earlier than within 2 min and end not earlier than within 6 min and not later than 30 min after it has been mixed with water. The prescribed fineness of building gypsum in terms of the total retained on sieve No. 02 (size of sieve mesh is 0.2 mm in the clear) is as follows: for grade I – up to 23%, for grade II – 14% and for grade III – up to 2%. The finer the size content of gypsum is, the greater its strength is. Bending strength of specimen bars measuring 4×4×16 cm 2.0 hours after mixing of gypsum with water should be 1.2-8 MPa. Compressive strength of the halves of specimen bars should be 2-25 MPa respectively.

Very rapid setting of gypsum makes it difficult to use it for some purposes and requires adding special setting retarders, in amounts from 0.1 to 0.3% of the gypsum weight.

Extra-strong gypsum is obtained of natural gypsum by steam at a pressure of up to 0.2- 0.3 MPa followed by drying at 160-180°C. The process results in formation of larger crystals, due to a lower hygroscopicity (40-45% water) and gypsum stone of greater density and strength. This type of gypsum is called extra-strong: in 7 days it attains a strength of 15-40 MPa. Low-burning gypsum binders ( $\text{CaSO}_4 \cdot 1,5\text{H}_2\text{O}$ ) are used for manufacture of gypsum and gypsum-

concrete structural items for buildings interiors (partition slabs panels, plaster boards), for gypsum and complex mortars and for manufacture of ornamental and finishing materials (e.g. artificial marble).

Anhydrite cement is obtained by burning natural gypsum at a temperature of 600-700°C and then grinding the product together with hardening catalyzers (lime, slag, etc.). Anhydrite cement can also be obtained by grinding natural anhydrite with the above additives. Anhydrite cement is a slowly setting binder; its setting starts not earlier than within 30 min and ends not later than in 24 h. By compressive strength, this cement is available in grades 5, 10, 15 and 20 MPa. Anhydrite cement is used for bricklaying and plastering mortars, concrete, heat insulating materials, artificial marble and other ornamental items.

Estrich gypsum (high-burned gypsum). A variety of anhydrite cements is estrich gypsum. It is manufactured by burning natural gypsum or anhydrite at a temperature between 800 and 1,000°C followed by fine grinding. This results not only in complete dehydration but also in partial decomposition of anhydrite with formation of CaO (3-5%) according to the reaction  $\text{CaSO}_4 = \text{CaO} + \text{SO}_3$ . When estrich gypsum is mixed with water, CaO acts as a catalyzer, which promotes hardening. Estrich gypsum is used in bricklaying and plastering mortars, to build mosaic floors, manufacture artificial marble, etc. Items from high-burned gypsum have low heat and sound conductivity, higher frost and water resistance and a smaller tendency to plastic deformation than products from building gypsum.

To import hydraulic properties to gypsum binders, they are mixed with Portland cement and active mineral addition (puzzolana or blast furnace slag). The resultant binders (gypsum + cement + puzzolana – GCP, and gypsum + cement + slag – GCS) refer to hydraulic binders. The latter are used for floor bedding, internal wall panels, and for prefabricating toilet and washroom units and other items, which can be used for work in humid conditions.

Gypsum-based products can be obtained both from gypsum paste, i.e. from a mixture of gypsum and water, as well as from a mixture of gypsum, water and aggregate. The former are called gypsum, and the latter, gypsum-concrete products. Gypsum and gypsum-concrete items are manufactured from building or high-strength gypsum, water-resistant gypsum-cement, puzzolana mixture and anhydrite cement. Gypsum concrete aggregates are natural materials (sand, pumice, tuffs) and industrially manufactured lightweight porous aggregates (slag pumice, ceramsite gravel, etc.). Organic aggregates are sawdust, shavings, paper waste, stalks or fibers of cane reed, refuse of dressed flax, etc.

Highly porous heat-insulating items are manufactured from gypsum mass by introducing gas-forming or foam-forming agents.

Although it possesses a number of valuable engineering properties, gypsum is very brittle. Therefore, gypsum items are artificially strengthened by reinforcing (with fibrous) materials that are introduced into the molding mass or are part of the item. Thus, the reinforcement in the plaster board is the outside cardboard envelope, whereas that one in rolled partition gypsum-concrete panels is the wooden lath carcass. Metal bars, wire or wire mesh may also be used as reinforcement, but it should be borne in mind that steel reinforcement in gypsum items is susceptible to corrosion and so requires a protective coat. Organic fibers uniformly distributed throughout the body of a molded item may also serve as reinforcement.

According to their application, gypsum and gypsum-concrete items are subdivided into partition panels and slabs, facing sheets (gypsum plaster and gypsum fiber plaster boards), heat-insulating slabs, floor items, refractory fire-resisting items and architectural items. Gypsum items can be either solid or hollow, reinforced or non-reinforced.

Gypsum items have a number of valuable properties, such as relatively small bulk density; they are incombustible, good sound absorbers, etc. Among their drawbacks one should mention poor strength in wet state and high creep under load, particularly in moist environment. Therefore, gypsum-based items should be used only in dry state and in premises of not more than 60% relative air humidity. To improve moisture-resistance and water-resisting properties of gypsum items, the latter are coated with waterproof paints; an alternative technique is to add gypsum cement-puzzolana or gypsum-cement-slag binding material.

Gypsum and gypsum-concrete items are molded by various methods, such as casting, vibrating, pressing, rolling, when they acquire a considerable strength.

The process of manufacture of items from gypsum or gypsum-concrete involves the following operations: proportioning of ingredients (binding material, aggregates, water and materials affecting the setting time); preparing mortar or concrete mixes; molding items; hardening items by drying them to air-dry state.

**Building lime (CaO)** is produced by burning (to eliminate carbon dioxide) calcium-magnesium rocks such as limestone –  $\text{CaCO}_3$ , dolomite –  $\text{CaCO}_3 \cdot \text{MgCO}_3$  containing less than 6% clay impurities. Lime manufacture consists in quarrying and crushing and screening rocks and their burning. The

temperature of limestone burning is set generally between 1,000 and 1,200°C, with due regard for limestone density, content of impurities.

The main stage in lime manufacture is burning, where limestone decarbonizes and turns into lump lime according to the reaction



After burning lump lime is ground to unslaked powder lime or is slaked with water to yield slaked lime.

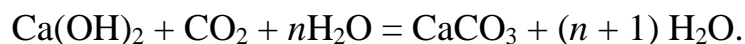
As specified in the State Standard, content of active CaO + MgO in unslaked lime should be 70-90%, ground to a fineness of not more than 1.5 and 15% oversize on screens No. 02 and 008, respectively. Building air-hardening lime is manufactured in three grades: I, II and III.

Air-hardening lime differs from other binders in that it may be powdered not only through grinding but also through slaking: by pouring water upon lumps of unslaked lime with a release of a considerable amount of heat (kJ) according to the reaction



Depending on its slaking rate, air-hardening lime is divided into the following kinds: rapid slaking lime with a slaking time of not more than 8 min; medium-slaking lime, of up to 25 min; slowly-slaking lime, of not less than 25 min.

According to the reaction below, hardening of lime mortars thus results from their drying and forming a crystalline aggregate  $\text{Ca(OH)}_2$ , and from crystallization of calcium carbonate on the surface of items



Ground unslaked lime may be used as such, presenting a number of advantages: no unslaked grains of lime are lost; the heat released by hydration of lime speeds up the setting and hardening processes. Items from this kind of lime are denser, stronger and more water-resistant. Slaked lime hardens slowly and the of lime mortars strength is low.

The faster calcium oxide hydrate crystallizes, the greater the evaporation of water is, and therefore an above-zero temperature is essential for lime hardening.

Air-hardening lime is widely used in mortars for bricklaying and plastering and as painting compositions. Lime is used in manufacture of lime-puzzolana, lime-sand and lime-slag hydraulic binding materials. These bindings are used to produce artificial stone materials, such as silicate bricks and slabs, large-size items from autoclaved silicate concrete and autoclaved aerated items.

Under natural conditions sand in a lime-sand mixture is an inert material incapable of interacting with lime, thus the strength of the mixture is due primarily to lime hardening. However, in a steam-saturated atmosphere (100% humidity), steam curing at a pressure of 0.8-1.6 MPa and temperature of 170-203°C (autoclave hardening), sand silica becomes chemically active and quickly combines with lime and consequently forms calcium hydrosilicates of great strength and high water-resisting properties. Lime-sand mixtures serve for manufacturing silicate large-size prefabricated items (blocks and panels for floors and walls) such as silicate bricks and wall stones, as well as slabs for facing facades.

Silicate bricks are similar in shape, size and chief applications to clay bricks. Lime-sand bricks should not be used for foundations and pedestals because they are less water-resistant than clay bricks. The bricks are not suitable for furnace brick work, since prolonged exposure leads to high disintegration.

Both lime-slag and lime-ash bricks are a variety of silicate bricks, but they differ in a lower bulk density and better heat insulating properties. These items are used for erecting walls of low (up to three storeys) buildings and walls of upper storeys of multi-storeyed buildings.

Silicate concrete is an autoclaved and compacted mix composed of quartz sand (70-80%), ground sand (8-15%) and ground unslaked lime (6-10%). Dense silicate concrete is a variety of heavy concrete. Large-size silicate items have a compressive strength of 15-60 MPa; bulk density of 1,800-2,300 kg/m<sup>3</sup>; frost resistance of 50 cycles and over. Dense silicate items are used for residential, industrial and public buildings; they should not be used for foundations and other structures exposed to high humidity.

Facing materials are the subject of two essential requirements – durability and high ornamental qualities. These requirements are met by silicate slabs, which are pure white or can easily be colored by mineral alkali-resisting pigments. Silicate facing slabs are manufactured from mixes of ground unslaked lime and quartz sand. Silicate facing slabs can be used for finishing brick walls of residential, public and industrial buildings, except for buildings of a high relative humidity of premises (bath houses, laundries, etc.). The slabs should not be used for facing pedestals, parapets, exterior window sills, belt courses and other projecting parts of buildings, exposed to rain and thawing snow, unless adequately protected by waterproof coats.

Autoclaved aerated items of cellular. Their structure features provide low bulk density and heat conductivity. Autoclaved aerated items are available in two kinds—foam and gas silicate. Foam silicate items are manufactured from a

mixture composed of lime up to 25% and ground sand (sometimes part of the sand is unground). Ground sand may be replaced by ground slag and cinder. Gas silicate items of cellular structure are formed by introducing aluminum powder into the mixture. Items from autoclaved aerated concretes are manufactured both with and without reinforcement (Fig. 24).

In reinforced autoclaved silicate concrete, steel reinforcement and inserts are susceptible to greater corrosion than in cement concrete. To correct this, the reinforcement bars in the aerated items are coated with cement-casein and polymer-cement compositions, or metallized. Autoclaved aerated items are generally used for outside walls of buildings, partitions and for roofs of industrial buildings where the load-supporting and heat-insulating properties of autoclaved aerated concrete are utilized to their full advantage.

**Magnesian binding materials.** Caustic magnesite (MgO) and caustic dolomite (a mixture of MgO and CaCO<sub>3</sub>) are two varieties of magnesian binders.

Caustic magnesite is obtained by burning magnesite rock MgCO<sub>3</sub> in shaft or rotary furnaces at temperatures of 650 to 850°C, with the effect that MgCO<sub>3</sub> decomposes according to the reaction  $MgCO_3 = MgO + CO_2$ .

The solid residue (magnesium oxide) is ground to fine powder.

Caustic dolomite is obtained by burning natural dolomite (CaCO<sub>3</sub> · MgCO<sub>3</sub>) and grinding the product to fine powder. As dolomite is burned, CaCO<sub>3</sub> is not decomposed and remains inert as a ballast, thus reducing the binding activity of caustic dolomite as compared to caustic magnesite.

Magnesian binders are mixed not with water, but with aqueous solutions of magnesium sulphate or chloride for accelerating the setting.

Caustic magnesite hardens relatively fast. It should begin to set not earlier than 20 min and harden not later than 6 h. from the time it is mixed. Caustic magnesite compressive strength is dependent on the grades: from 40 MPa through 60 MPa after 28 days of ageing in the air. Caustic dolomite is available in grades from 10 MPa to 30 MPa.

Magnesian binders, being air-setting, have a poor resistance to water. They may be used only in an environment of a relative humidity of not more than 60%. Xylolite (a mixture of sawdust and binders), used to make floors, as well as fibrolite and other heat-insulating materials, are manufactured from magnesian binders, which are also used for fabricating items for interior facing of buildings, subflooring and sculptures.

**Acid-resistant cements** consist of an aqueous solution of sodium silicate (soluble glass), acid-resistant aggregate and additive (hardening accelerant). The

microaggregates are quartz, quartzites, andesite, diabase and other acid-resistant materials; the hardening accelerant is sodium fluosilicate.

The binding material in the acid-resistant cement is soluble glass – a water solution of sodium silicate  $\text{Na}_2\text{O} \cdot n\text{SiO}_2$  or potassium silicate  $\text{K}_2\text{O} \cdot n\text{SiO}_2$ .

Soluble glass is melted from quartz sand, ground and thoroughly mixed with soda ash, sodium sulphate or potassium carbonate in glass tanks at a temperature between 1,300 and 1,400°C. Melting takes from 7 to 10 h. The resultant glass mass flows from the furnace into cars where it cools rapidly and breaks up into pieces called ‘silicate lumps’. This glass is soluble in water under normal conditions, but when exposed to high-pressure steam (0.5-0.6 MPa at about 150°C), it becomes liquid quite easily.

Soluble glass hardens in the air. But this process is very slow in the air. Hardening of soluble glass is accelerated by adding catalyzer sodium fluorosilicate ( $\text{Na}_2\text{SiF}_6$ ), which interacts rapidly with soluble glass to produce silicate gel.

Soluble glass is used for acid-resistant and heat-resistant (to 1,000°C) coatings, mortars and concrete. It should not be used in constructions subjected to water, alkalis, and phosphoric, hydrofluoric or fluosilicic acids for long periods of time.

### 3.5.2. Hydraulic Binder Substances

**Hydraulic lime** is a fine powder product of moderate burning (at temperatures between 900 and 1,100°C) of marly limestone containing from 6 to 20% of argillaceous impurities. Part of CaO resulting from the decomposition of calcium carbonate, combines in solid state with oxides  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  contained in clay minerals to form silicates ( $2\text{CaO} \cdot \text{SiO}_2$ ), aluminates ( $\text{CaO} \cdot \text{Al}_2\text{O}_3$ ) and calcium ferrites ( $2\text{CaO} \cdot \text{Fe}_2\text{O}_3$ ) that are capable of hardening not only in the air but in water as well.

Since hydraulic lime contains free calcium oxide CaO, it slakes like air hardening lime upon contact with water. The more the amount of free CaO in hydraulic lime is, the less its ability to harden in water is.

Commercial lime is generally characterized by hydraulic or basic modulus (BM) whose value for hydraulic lime ranges from 1.7 to 9 as calculated by the formula below

$$BM = \frac{\text{CaO}}{\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3},$$

where CaO,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  are measured in %.

Hydraulic lime is available in two kinds: weak hydraulic lime with a modulus of 4.5 to 9 and strong hydraulic lime with a modulus of 1.7 to 4.5. If a burning product has a hydraulic modulus of less 1.7 it refers to Roman concrete (BM from 1.1 to 1.7) and if it has a modulus greater than 9, it refers to air-hardening lime.

Hydraulic lime, after it is mixed with water and begins to harden in the air, continues to harden in water as well, where the physical and the chemical air-hardening processes combine with those of the hydraulic hardening. As water evaporates, calcium oxide hydrate gradually crystallizes and carbonizes due to the carbon dioxide in the air.

Hydraulic hardening of lime takes place through hydration of silicates, aluminates and ferrites of calcium. Compressive strength over 7 days in the air and 21 days the hydraulic hardening is from 2.0 (weak hydraulic lime) to 5.0 (strong hydraulic lime) MPa.

Hydraulic lime is used either for construction mortars intended for service in dry or moist surroundings or as an admixture to lower grades of concrete.

**Portland cement** is a hydraulic binding material, which hardens in water and in the air. It is manufactured by fine grinding of a mixture comprising limestone (1 part) and clay (3 parts by weight). The mixture is burned until the components are caked (a temperature of about 1,500°C); and clay in the mixture ensures predominance of calcium silicate in the clinker, which is a mixture of raw materials burned to fusion and composed of grains up to 40 mm in size. The quality of clinker governs major properties of cement: strength and rate of strength gain, durability and resistance to various service conditions.

There are two chief techniques for manufacturing Portland cement: the wet and the dry ones, which differ in the way the raw material mixture is made. Using the wet technique, the source materials are ground and mixed with water, and the mixture is burned in the form of a pulp (slime of liquid consistence); in the dry technique, the materials are ground, mixed and burned dry. Along with the two main techniques, there is an increasing trend to use a combined technique, which incorporates the advantages of the dry and the wet techniques. According to this technique, the raw mixture is prepared by the wet method, then slime is dewatered and processed to granules which are burned by the dry method.

The hot clinker thus obtained is transferred to a cooler, where it is rapidly cooled by a countercurrent of cold air. Clinker is ground with the admixtures of gypsum and active mineral admixtures in mills. Portland cement size composition is defined by screen No. 008, oversize of not more than 15%.



Finely ground “pure” clinker is characterized by a short setting time (from 3 to 5 min), and as such, is not suitable in pure state for any practical purposes.

Cement setting time is controlled by adding gypsum during grinding in amounts from 1.5 to 3.5% of the weight of cement. Portland cement containing gypsum within the above mentioned range, meets the standard specifications, as its setting begins not earlier than 45 min and ends not later than 12h. from the moment it is mixed with water.

Portland cement may be manufactured with or without active mineral hydraulic admixtures (puzzolana: volcanic ashes, diatomites, opoka or granulated blast-furnace slabs), added in amounts from 6 to 80% of the weight of cement. When the admixtures amount is increased puzzolana Portland cement, slag Portland cement or composite cement may be produced.

The effect of hydraulic admixtures is explained in the following way. They consist chiefly of amorphous silica, which interacts readily with  $\text{Ca(OH)}_2$  with the effect that the soluble calcium oxide hydrate resulting from the hydration of  $\text{C}_3\text{S}$  is bound chemically into a practically insoluble calcium hydrosilicate  $\text{CaO} \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O}$ , thus enhancing the water resisting property of cement stone.

The major properties of cement: strength and rate of strength gain; durability; resistance to various service conditions. They depend on the quality of clinker, its chemical and mineralogical compositions. Limestone consists chiefly of two oxides ( $\text{CaO}$  and  $\text{CO}_2$ ) while clay is composed of various minerals containing basically three oxides ( $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ ). Carbon dioxide  $\text{CO}_2$  is removed by burning the raw mixture, the four remaining oxides  $\text{CaO}$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$  forming the clinker minerals whose relative amount in Portland cement is as follows (in %):

- tricalcium silicate  $3\text{CaO} \cdot \text{SiO}_2$  (alite) – 33-73;
- dicalcium  $2\text{CaO} \cdot \text{SiO}_2$  (belite) – 2-38;
- tricalcium aluminate  $3\text{CaO} \cdot \text{Al}_2\text{O}_3$  (celite) – 7-15;
- tetracalcium alumferrite  $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$  – 9-14.

Mixing of Portland cement with water results in a sticky cement paste, which gradually thickens and becomes stonelike. Hardening of Portland cement involves very complicated chemical and physical phenomena. When water is added, each of the minerals reacts with it to yield new crystal compounds, which give a strong artificial stone. Hardening of Portland cement stone is thus dependent on hydration of silicates, aluminates and aluminoferrites of calcium.

The rate of setting and the rate of hardening are of major importance in hardening of Portland cement. Clinker minerals differ in rate of reaction with

water. The fastest to react is  $C_3A$ , followed by  $C_4AF$  and  $C_3S$ , and the slowest is  $C_2S$ . Hydration rate of clinker minerals also governs the rate of their hardening: the faster mineral hydrates, the faster its strength grows.

Hardening of Portland cement involves changes in its volume. When the process takes place in the air, the cement stone may shrink due to evaporation of water. Shrinkage is particularly undesirable, as the artificial stone may then crack.

To prevent shrinkage deformations, hardening of cement, in particular in its initial stages, should be carried out in humid conditions.

Hardened cement stone is a microscopic heterogeneous system composed of crystalline concretions and gel masses consisting of colloidal particles. Cement stone structure is made more inhomogeneous by grains of cement, which only partly react with water.

The difference in physical and mechanical properties of crystalline and gel-like matter is one of the causes why mineralogical composition of clinker affects some of the essential structural properties of cement stone, such as deformation, resistance to freezing-and-thawing and to humidifying-and-drying cycles. This allows to control the properties of Portland cement rationally choosing its mineralogical composition and thus obtaining cements that meet specific working conditions requirements.

Cement stone structure is greatly affected by its porosity due to the initial content of water in the mixture. Satisfactory mixture of cement and water is made by adding from 2 to 3 times the amount of water required to interact with cement.

Thus, the greater part of mixing water remains free and causes numerous fine pores in hardened stone. Therefore, whenever a solid structure of cement stone is desired, a minimum amount of water should be used. The effect achieved is that strength and frost resistance of cement stone are enhanced.

Cement stone structure, in particular its pores, predetermines its tendency to deform in wet conditions. When humidified, it swells and when dried, shrinks. Alternating compressive and tensile stresses, caused by changes in ambient humidity, loosen and weaken cement stone structure. The extent of humidity-caused deformations depends on the ratio of gel-to-crystalline phases in cement stone. The greater the part of crystalline phase is, the greater cement stone air-resistance is.

According to the State Standard, the strength of Portland cement is defined by its compressive and bending strengths. Cement grade is determined by measuring bending strength of slab specimens,  $40 \times 40 \times 160$  mm in size, and

by compressive strength of slab specimens halves made from plastic mortar composed of 1 part of cement and 3 parts of sand (by weight), and tested after 28 days. During this period the specimens are placed in moist conditions (moisture 95-98 %) at a temperature of  $20\pm 2^{\circ}\text{C}$ . The breaking strength of 28-day-old cement is called cement activity.

To eliminate the effect of sand quality upon cement strength and to obtain comparable results, specimens are produced from pure quartz sand of specified size and chemical composition.

When attributing a certain grade to Portland cement (CEM I 32.5; 42.5; 52.5), the compressive strengths of 28-day-old cement should be not less than 32.5 – 2.5 MPa; 42.5 – 62.5 MPa; 52.5MPa respectively.

Portland cement gains strength not at a uniform rate. It rises to about 40-50% of the cement grade on the third day and to 60-70% on the seventh. Subsequently, the rise in strength of cement slows down even more, and cement attains its grade strength by the 28th day.

However, under favorable conditions, the hardening of Portland cement may go on for months and even years with the effect that the final strength is higher than the grade (28-day-old) strength.

The strength of cement stone and the rate of its hardening depend on the mineralogical composition of clinker, cement fineness, water content, ambient humidity, temperature and duration of ageing.

The strength gain of clinker minerals composing Portland cement shows a great variety of patterns. Tricalcium silicate ( $\text{C}_3\text{S}$ ) is the fastest one to gain strength: after 7 days of hardening it attains about 70% of its 28-day-old strength, and then the strength gain of  $\text{C}_3\text{S}$  slows down considerably.

Hardening of dicalcium silicate follows an absolutely different pattern. During the initial period of hardening, the  $\text{C}_2\text{S}$  strength gain is small and amounts to about 15% of 28 days, but during the period that follows, dicalcium silicate hardens at a high rate. Therefore, whenever high-strength concrete is required within a short period of time, use is made from cement with a high content of tricalcium silicate and, conversely, if high strength is desired at a later date (as in hydraulic engineering constructions), cement with a high content of  $\text{C}_2\text{S}$  should be used. Tricalcium aluminate has low strength, but it greatly speeds up cement stone hardening during the initial period of time. This property of  $\text{C}_3\text{A}$  is used to produce quick-hardening Portland cement. In mineralogical composition, it is high in  $\text{C}_3\text{A}$  and  $\text{C}_3\text{S}$  (about 60 to 70%, including up to 10% of  $\text{C}_3\text{A}$ ).

The finer cement is, the greater its strength is, and the greater its degree of hydration is, the higher the content of crystals mineral hydrates is, and the greater the cement stone strength is. Optimal Portland cement size is about 40  $\mu\text{m}$ .

Cements may have fineness defined by a total retained on sieve No. 008 of not more than 15%.

Cement fineness may also be described by the unit surface area ( $\text{cm}^2/\text{g}$ ), i.e. by the total surface area of grains ( $\text{cm}^2$ ) per 1g of cement. The unit surface area of cement is 3,000 to 4,000  $\text{cm}^2/\text{g}$ .

In some cases, clinker is ground to a greater fineness to increase its activity and obtain quick-hardening cement.

Hardening of cement stone and growth of its strength may continue only in water, since hardening is, first of all, a hydration process.

Practical means of humidifying cement stone as it hardens are as follows: spraying of concrete with water; putting wet sawdust sand, bast mats on concrete structures and periodically spraying them with water; coating concrete with bitumen emulsion and other materials, which form vapor tight films and prevent evaporation of water; and, finally, covering concrete with polyethylene film.

Strength gain of cement stone is greatly affected by ambient temperature. The rate of chemical reactions between clinker minerals and water and the rate of consolidation of hydration products greatly increase when temperature rises.

Hardening of cement stone may take place in practice within a wide range of temperatures: normal hardening in the open air at positive temperatures; steam curing in cells between 50 and 90°C; autoclaving between 170 and 200°C at steam pressures from 0.8 to 1.2 MPa.

The quickest strength gain of cement stone takes place in the process of steam curing under pressure in autoclaves, concrete attaining its grade strength in 4-6 h.

When concrete is steam-cured at normal pressure, it hardens about twice as long as in autoclaves. Concrete subjected to heat and humidity curing at a temperature up to 90°C generally attains only 70 % of its grade strength in 12-15 h.

Portland cement stone does not harden at below-zero temperatures since water turns to ice.

Cement tends to lose its activity even when stored under the most favorable conditions. After three months of storage the loss in activity may be as high as 20%, and after a year, 40%. Cement of greater fineness loses its activity at a faster rate, as air moisture causes its premature hydration.

After a prolonged storage, cement can be reactivated by fresh grinding.

Cement stone may be subjected to corrosive ambient influence: exposure to fresh and mineralized water, combined influence of water and frost, alternative humidification and drying.

According to major characteristics, cement stone water corrosion may be divided into three types.

In the first type of failure fresh running water dissolves and washes out calcium hydroxide, resulting from the hydration of tricalcium silicate. Cement stone becomes porous and loses strength. To substantially enhance cement stone resistance to fresh water under pressure and raise its density, hydraulic admixtures to the cement are introduced.

Hydraulic admixtures bind  $\text{Ca}(\text{OH})_2$  into a poorly soluble compound – calcium hydrosilicate ( $\text{CaO} \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O}$ ).

The second type of corrosion is the failure of cement stone by water carrying acid or sour salts that enter into exchange reaction with the cement stone constituents, the products which are either highly soluble substances that are well carried away by water filtering through the cement stone, or precipitating as amorphous mass that possesses no binding properties.

The changes cause greater reduction of strength. All types of cement have no resistance to water carrying acid or sour salts.

Cement stone failures caused by sulphates refer to the third type of corrosion. Poorly soluble substances in water or products resulting from their interaction with cement stone constituents accumulate in cement stone.

Their accumulation and crystallization cause considerable tensile stresses in pore walls and may ultimately lead to cement stone failure.

Cement of low tricalcium aluminate content is more resistant to sulphates.

Combined influence of water and frost leads to cement stone failure. At below-zero temperatures, water in cement stone pores turns into ice, which means an expansion of about 9% as compared to the volume of water. Ice exerts pressure against pore walls and causes their failure.

Frost resistance of cement stone depends on mineralogical composition of clinker, fineness of cement and water-to-cement ratio.

A considerable amount of admixtures in cement adversely affects frost resistance of cement stone because of high porosity and low frost resistance of the products resulting from interaction of admixtures with cement stone constituents.

Among clinker minerals, the less frost resistant is  $\text{C}_3\text{A}$ , and, therefore, its content in cement for frost-resistant cement stone should not exceed 5 to 7%.

A higher water-to-cement ratio lowers cement stone frost resistance because of its increased porosity.

Thus, cement stone frost resistance may be enhanced by use of low  $\text{C}_3\text{A}$  content cement and minimum of active mineral admixtures, and by cement

mixtures of the lowest possible water-to-cement ratio, these mixtures are thoroughly compacted during placing.

### **Varieties of Portland Cement**

High-early strength Portland cement has a more intensive – as compared to common grades – strength gain during the initial period of hardening. This is achieved by a finer grinding of cement and appropriate correction of its mineralogical composition. The  $C_3A + C_3S$  sum should be 60-65%.

According to the State Standard bending and compressive strengths of quick-hardening Portland cement after 3 days, should be not less than 4 and 25 MPa, respectively, and after 28 days, its compressive strength must be at least 50-60 MPa. This kind of cement has a high heat release.

Sulphate-resistant Portland cement is manufactured from clinker of a predetermined mineralogical composition. The amount of  $C_3S$  in cement should be not higher than 50%, of  $C_3A$ , not more than 5%, and the  $C_3A + C_4AF$  sum should be not more than 22%. This kind of cement is rather slow in hardening and has a low heat release during the initial period. Sulphate-resistant Portland cement is available in grade 42.5 MPa. In other respects, it meets the same requirements as Portland cement.

White and colored Portland cement types are manufactured from raw materials having a minimum coloring oxides content (iron, manganese and chromium).

The source materials are “pure” limestone or chalk and white kaolin clays; and the fuel is gas or fuel oil, causing no ash contamination of clinker.

White cement main property is its degree of whiteness. White cement is available in grade 42.5 MPa. This type of cement has low frost resistance.

Colored Portland cement is manufactured by combined grinding of white cement clinker and alkali-resistant mineral paints: ochre (yellow), ultramarine (blue), chromium oxide (green) and smoke (black).

White and colored cements are used for finishing works, in manufacture of facing tiles, stairs treads, window-sill slabs, textured panel faces and artificial marble.

Portland cement with active mineral admixtures. This group of hydraulic binding materials comprises cement types obtained by combined grinding of Portland cement clinker and an active mineral admixture. Depending on the kind of the initial binder constituent and that of the admixture, cement with active mineral admixtures is divided into puzzolana and slag Portland cement.

Active mineral (hydraulic) admixtures are finely ground natural or artificial substances which, when added to Portland cement and mixed with

water, interact chemically in normal conditions with calcium oxide hydrate –  $\text{Ca}(\text{OH})_2$ . The obtained stone has low solubility and high improving water-resisting properties.

Puzzolana Portland cement is obtained by combined fine grinding of clinker, a predetermined amount of gypsum (up to 3.5%) and an active mineral admixture (of volcanic origin and sedimentary origin from 11 to 55%).

Setting time and fineness of puzzolana cement are the same as for common Portland cement, although puzzolana Portland cement types are characterized by a smaller strength gain during the initial period of hardening. Puzzolana cement is produced in grade CEMIV 32.5; 42.5.

There are two stages in hardening of puzzolana Portland cement: the first is hydration of Portland cement clinker minerals; the second is interaction of an active mineral admixture with calcium oxide hydrate released during hardening of clinker. At the same time,  $\text{Ca}(\text{OH})_2$  is bound into water-insoluble calcium hydrosilicate, therefore, cement stone from puzzolana Portland cement acquires greater water-resisting property than cement stone from common Portland cement.

A relatively small amount of heat is released during puzzolana Portland cement setting and hardening, a fact which makes the cement suitable for large concrete constructions. Puzzolana Portland cement is not suitable for elements exposed to continuing moistening and freezing or drying conditions.

Cement stone from puzzolana Portland cement has lower water permeability than the one from common Portland cement because of admixture expansion making cement stone denser.

Puzzolana cement types are particularly suitable for underwater and underground concrete and reinforced concrete constructions where concretes are expected to be extra water-impermeable and water-resisting.

Slag Portland cement is a hydraulic binding material obtained by combined grinding of Portland cement clinker, granulated blast-furnace slag and gypsum. The part of granulated blast-furnace slag in Portland cements should be not less than 35% and not more than 80% of the finished product weight.

Hardening of slag Portland cement may be divided into two processes: the primary one consisting of hydration and hardening of cement clinker part and the secondary one involving chemical interaction of clinker part hydrated products with granulated blast-furnace slags.

As compared to common Portland cement, slag Portland cement features a slower strength gain during the initial period of hardening, but its grade strength and subsequent gains are approximately the same. Strength gain of slag

Portland cement falls off sharply, and appropriate humidity favors hardening of slag Portland cement to a greater extent than that of Portland cement. By compressive and bending strengths, slag Portland cement is divided into grades CEMIII 32.5; 42.5; 52.5.

Water resistance of cement stone from slag Portland cement is higher than that of common Portland cement because of absence of free calcium oxide hydrate. Slag Portland cement stone has satisfactory frost and air resistances, but it is resistant to higher temperatures (700°C) in comparison with the stone from Portland cement (300°C).

Slag Portland cement is used for similar purposes as common Portland cement. But, due to its higher water-resistance, lower water permeability, higher salt-resisting property; it should be preferred in hydraulic engineering structures and in constructions to be operated in wet conditions. Slag Portland cement is also used for hot-resisting concrete. This cement should not be used in constructions exposed to frequent freezing-and-thawing or moistening-and-drying conditions.

Cement with surfactants organic admixtures. This group of hydraulic binding materials comprises cement types obtained by combined grinding of Portland cement clinker and surfactants organic admixtures of 0.06 to 1.0%. Depending on the kind of admixture (hydrophilic or hydrophobic), cement types are divided into plasticized and hydrophobic Portland cement.

Plasticized Portland cement differs from the common grades by plasticizing admixture, which enhances mobility, and if to reduce the water-to-cement ratio, the hardened cement stone can be made highly frost resistant. Plasticized Portland cement is available in two grades: 42.5 and 52.5 MPa.

Water coat admixture molecules surround cement grains and thus act as a lubricant, which reduces grains friction and enhances cement grout plasticity. Plasticized cement – whose strong points are better placeability and greater frost resistance – may be used along with cement of common grades. They find particularly wide use in road, air-field and hydraulic engineering construction.

Hydrophobic Portland cement differs from common grades by hydrophobic surfactant admixtures.

Hydrophobic admixtures form thin (monomolecular) films on the surface of cement grains and thus decrease their water absorption. This type of cement neither loses activity nor forms lumps in moist conditions. At the same time, when cement mixture is prepared, absorption films are torn off the cement grains surface and thus do not prevent normal hardening of cement.

Hydrophobic cement features greater water resistance, water impermeability and frost resistance of cement stone.



Weak point of hydrophobic cement is its small strength gain during the initial period because of hydrophobic films on cement grains, preventing their interaction with water, but its 28-day strength is equal to that of common Portland cement. Hydrophobic Portland cement is available in two grades: 32.5 and 42.5 MPa.

### **Special Varieties of Cement**

Aluminous cement is a quick-hardening hydraulic binding material obtained by fine grinding of a burned (melting or caking at a temperature of about 1,600°C) bauxites and limestone mixture with prevailing amount of highly active calcium aluminates in the product. When aluminous cement is mixed with water, the formation of plastic paste, its subsequent consolidation and hardening are similar to those of common Portland cement. Aluminous cement gel consolidates and crystallizes at a very high rate, with the effect of rapid strength gain. After approximately 5 to 6 h., aluminous cement may attain  $> \text{ or } = 18.0$  MPa and over its grade strength value, and after a day of hardening,  $> \text{ or } = 4.0$  MPa and at the end of 3 days, the grade strength.

Aluminous cement is a quick-hardening but not a quick-setting binding material, it should begin to set not earlier than 90 min and end not later than 12 h. after mixing with water.

By compressive strength, aluminous cement is divided into three grades – by strengths 40, 50, and 60 MPa – after 3 days of hardening in normal condition. Most favorable for aluminous cement hardening are moisture atmosphere and normal temperature ( $20 \pm 5^\circ\text{C}$ ). Strength gain slows down at temperatures above  $25^\circ\text{C}$ . Strength can even drop and cement stone can disintegrate as a result of recrystallization of the new formation.

Therefore, no steam curing of aluminous cement items is allowed.

Aluminous cement hardens satisfactorily at temperatures below normal or close to zero, which is due to its high heat of hydration. Over a period of 1 to 3 days, aluminous cement releases from 1.5 to 2 times as much heat as Portland cement.

Large heat release limits the use of aluminous cement in heavy constructions, since heating of concrete inside the body of a construction and its cooling on the outside cause tensile stresses in the outside layers and lead to cracks.

Artificial stones from aluminous cement are air-, water-, and frost-resistant and show good service in fresh and sulphate waters but disintegrate in alkali water.

Use of aluminous cement is substantially limited by its cost (which is 3 to 4 times as high as that of Portland cement), although in physical and mechanical properties (hardening rate, resistance to various media), it is superior to other cementing materials, including Portland cement. In practice, aluminous cement is used in urgent repair work (repair of dams, pipes, roads, bridges and urgent laying of foundations), where its specific properties find the most rational application.

Chemical stability of aluminous cement allows its use for plugging up oil and gas wells, in food industry plants, in pickling and dye works and for lining shaft pits and tunnels.

When compared with other binding materials, aluminous cement is resistant to high temperatures (from 1,200 to 1,400°C and over), a property which makes it suitable for manufacture of heat-resistant concrete for lining thermal units.

The next group of binding materials encompasses cement that shows a slight increase in volume during hardening in moist conditions, or that do not shrink when hardened in the air.

Expanding cement is a quick-setting and quick-hardening hydraulic cementing material obtained by grinding or mixing finely ground aluminous cement, gypsum, and high basicity calcium aluminate in a ball mill. Setting begins not earlier than 4 min and ends not later than 10 min after water is added. Setting may be retarded by special admixtures. Compressive strength of cement paste specimens should not be lower than: in 6 h. – 7.5 MPa; in 3 days – 30 MPa; in 28 days – 50 MPa. After a day of hardening, specimens should be fully impermeable to water applied under pressure of 0.6 MPa. Linear expansion after one day of hardening should be not less than 0.2 and not more than 1%.

Water impermeable expanding cement is used for repairing concrete and reinforced concrete constructions, for water-proofing tunnels and pit shafts, in underground and underwater constructions and for water-impermeable joints.

Gypsum-aluminous expanding cement is a quick-hardening hydraulic binding material obtained by combined fine grinding or mixing of high-alumina slag and natural dehydrate gypsum (30%).

Gypsum-aluminous cement is available in two grades – 400 and 500. Setting begins not earlier than 20 min and ends not later than 4 h. after mixing with water.

Specimens from gypsum-aluminous cement paste should be, after one day, impermeable to water applied at a pressure of 1 MPa.

Linear expansion of cement after one day of hardening should be not less than 0.15% and not more than 1.0%, its average value after 28 days is from 0.1 to 0.3%.

Gypsum – aluminous cement is used for manufacture of non-shrinking and expanding water-impermeable mortars and concrete, for caulking joints and for water-proofing underground mines.

### **Self-Check Questions and Tasks:**

1. Name the classification of mineral binders according to the condition of hardening and exploitation of the materials obtained on their basis.
2. What production technology of mineral binders do you know?
3. What indicators determine general properties of mineral binders?
4. Which mineral binders are air-setting? What is their use in construction?
5. Which mineral binders are hydraulic? What is their use in construction?
6. Specify the purpose of water and mineral binders in building materials.
7. What properties and application of gypsum do you know?
8. What properties and use of air and hydraulic building lime do you know?
9. What kinds of Portland cement do you know?
10. Speak about the use of Portland cement in construction.
11. What special types of cement, their properties, and use in construction do you know?

## **3.6. Artificial Stone Products from Mineral Binding Materials**

Mineral binding materials are used for manufacturing mineral-body paints, building mortars, asbestos-cement items and concrete.

### **3.6.1. Mineral-Body Paints**

Mineral body paints are mixtures of alkali and light-resistant pigments, fillers and non-organic vehicles with various additives, thinned with water to painting consistency.

By the kind of vehicle, mineral-body paints are available in lime water, silicate and cement types.

Lime water paints are composed of lime and a pigment. They are used for painting bricks, concrete and plastered surfaces of interior premises.

Silicate paints are made from mixtures of finely dispersed chalk, talcum, white zinc, alkali-resistant pigment and sodium or potassium soluble glass.

Silicate paints of two kinds are available in shops – for finishing facades and interiors. Facade paints are used for painting facades and interiors of premises with normal and high atmospheric moisture; paints for interior finishing are used for coating concrete plaster and resin free wood fiber boards.

Shop cement paints are mixed with water prior to use. They are used for exterior and interior coating of premises with high atmospheric moisture, for cellular concrete and for relief finishing.

Polimer-cement paints are obtained from cement, alkali-, and light-resistant pigments with additions of synthetic resins, and are available in various colors for both summer and winter work. Summer-work paints are mixed with water-dispersed polymer prior to use; their application is exterior and interior finishing of various quality surfaces.

Plant-fabricated winter-work polimer-cement paints are used for exterior finishing of building fronts and constructions.

Painting requires a number of auxiliary materials, such as fillers and primers.

Fillers are finishing compounds for smoothing surfaces prior to painting. They are available in various compositions, depending on the kind of paint to be used (gypsum, cement, soluble glass).

In finishing, primers (lime water, soluble glass) are used to reduce porosity of surfaces to be painted and thus the consumption of expensive paints, and to provide stronger bonds between the paint and the surface.

### **3.6.2. Building Mortars. Their Classification and Properties**

Building mortar is a mixture consisting of a mineral binding material, fine aggregate (sand) and water. Mortars are classified by their bulk density, kind of binding material, application, and physical and mechanical properties.

By their bulk density in dry state, mortars fall into the following kinds:

- heavy mortars of a bulk density of 1,500 kg/m<sup>3</sup> and over, which are manufactured from heavy quartz or other sands;
- lightweight mortars of a bulk density less than 1,500 kg/m<sup>3</sup>, where aggregates are light porous sands from pumice, tuffs, slags, ceramsite and other fine aggregates.

By the kind of binding material, building mortars are subdivided into the following varieties:

- cement mortars from Portland cement or its varieties;
- lime mortars, where the binding material is an air-hardening or hydraulic-hardening lime;

- gypsum mortars from gypsum binding materials, such as building gypsum and anhydrite binding materials;
- composite mortars obtained from cement-lime and cement-clay binding materials.

The kind of binding materials for mortar is selected according to its application, requirements, hardening temperature, moisture conditions and expected operating conditions of the building or structure.

By application, building mortars are subdivided into:

- masonry mortars for brickwork and walls from large components;
- finishing mortars for architectural or ornamental parts, decorative layers on wall blocks and panels;
- mortars with specific properties (acoustic, heat-insulating, waterproofing and X-ray shielding).

The basis for general classification of mortars by their physical and mechanical properties are two major characteristics – strength and frost resistance, which determine durability of mortars. By compressive strength, building mortars are subdivided into nine grades ranging from 4 to 300 Pa. There are nine frost resistance grades – from F10 to F300 – the figures indicating the number of freezing-and-thawing cycles mortar can withstand.

Mortar composition is designated by the volume or weight of material in 1m<sup>3</sup> of mortar or by the relative amount of initial materials, with the amount of binding material taken as unity. For simple mortars, composed of one kind of binding material and containing no mineral admixtures (cement or lime mortars), the composition will be designated the following way – one part (by weight or volume) of binding material and 6 parts of sand. Combined mortars composed of two binding materials (cement + lime) or containing mineral admixtures (lime + clay) are identified by three figures, e.g. 1 : 0.4 : 5 (cement : lime : sand or lime : clay : sand).

Fine aggregates for heavy mortars are natural quartz sand or sand obtained by crushing solid rocks; for lightweight mortars they are pumice, tuff, shell and slag sands.

Chief properties of mortar mixtures are mobility and water retention, and as for mortars it is strength.

Mortar mixture consistency depends on its composition. Mortar mixture mobility is determined by a metal cone, weighing 300 g sunk into the mixture. Mortar mixture mobility determines its placeability, i.e. placing it in a thin and uniform layer that makes a strong bond with the surface of the bed.

Water retention is ability of mortar mixture not to stratify during transportation and to retain adequate humidity in a thin layer spread over

a porous bed. When laid upon a porous bed (clay bricks, concrete and wood), mortar mixtures of low water retention give their water to the bed. Mortar may lose so much water that the amount left may be insufficient for its hardening, when the required strength is not attained.

Mineral and organic admixtures are introduced into Portland cement mortars to enhance placeability. Clay or lime in the form of paste are effective mineral admixtures to cement mortars. They improve water retention and placeability of cement mortars and save cement. Such non-organic disperse admixtures as diatomite, tripoli and ground slags, are used as active mineral substances. Surfactants organic admixtures when introduced in tenths and hundredths of 1% from the binding materials quantity, improve plasticity of mortar mixtures and reduce binding materials consumption. Strength of hardened mortar depends on binding materials activity, content of finely ground admixtures and cement-to-water ratio mortar. Strength is also determined by cement consumption and quality of sand.

Mortar strength is designated by its grade, which is equal to compressive strength (P) of cubic specimens with a side measuring 70.7 mm and produced from working mortar mixture on a water sucking bed after 28 days of hardening at a temperature of 15-25°C.

When mortars from slag Portland cement and puzzolana Portland cement are used, the rate of strength gain is lower at temperatures below 10°C.

### **Building Mortars of Various Use**

Composition of masonry mortars and the kind of binding material depend on the construction and its working conditions.

Building masonry mortars are available in four kinds: cement, cement-lime, cement-clay and lime mortars.

Portland cement and slag Portland cement types are used for walls from panels and large concrete and brick blocks, for common masonry (from high-grade mortars) and for masonry performed by freezing method.

Cement-lime and cement-clay mortars are easily placeable, very strong and highly frost-resistant. They are used for underground and above-ground parts of buildings.

Lime mortars have a high plasticity, good cohesiveness with other surfaces and shrink very little. They are sufficiently durable but harden slowly. Lime mortars are used for constructions of lightly loaded above-ground parts of buildings.

Mobility of masonry mortars depends on their application (vertical and horizontal joints) and kinds of wall materials: concrete blocks, bricks,

lightweight rock stones and rubble. Mobility and water retention of mortars are adjusted by addition of non-organic or organic plasticizers.

Finishing mortars include common plasters and ornamental mortars. Plastering mortars are made from cements and cement-lime, lime, lime-gypsum and gypsum binding materials.

Plasters for exterior stone and monolithic concrete walls of buildings with relative air humidity up to 60% should be mixed cement-lime mortars, and those for exterior wooden and gypsum surfaces in regions with a stable and dry climate should be made from lime-gypsum mortars. Socles, belt courses, cornices and other parts of walls exposed to repeated wetting should be plastered on the outside with cement and cement-lime mortars from Portland cement. Interior plasters for walls and floors of buildings with relative air humidity up to 60% should be made from lime, gypsum, lime-gypsum and cement-lime mortars.

Binding materials for ornamental mortars are as follows:

- Portland cement (common, white and colored) for finishing lamellar reinforced concrete panels and lightweight aggregate concrete panels;
- lime or Portland cement (common, white and colored), for face finishing of lime-sand panels and for colored plasters of facades;
- lime and gypsum for colored plasters of buildings interiors.

Aggregates for colored ornamental mortars are washed quartz sand and sand obtained by crushing granite, marble, tuff and other white or colored rock. Maximum size of sand should not exceed 2.5 mm.

Finishing coat can be given a decorative luster by adding mica or crushed glass to mortar. Plasters are colored by alkali-resistant and artificial pigments.

Depending on application, finishing mortars are subdivided into mortars for exterior and interior plastering. Plastering mortars are composed according to their use and working conditions of buildings and structures. Plastering mortars should have adequate degree of mobility, good cohesiveness with the bed and small volumetric variations in the process of hardening, so as not to cause cracking.

Mobility of plastering mortars and the largest grain size of sand for each plaster coat (rendering and finishing coats) are different.

Plaster mortars should have high mobility. Mobility, water retention and resistance to atmospheric exposure of ornamental colored mortars can be improved by introducing hydrophobic or plasticizing admixtures.

### **Special Mortars**

Mortars for filling joints between parts of prefabricated reinforced concrete constructions, injection mortars, floor mortars, damp-proofing mortars,

plugging mortars, sound-absorbing and X-ray shielding mortars are known as special mortars.

Mortars for filling joints between prefabricated reinforced concrete components (mounting mortars) are produced from Portland cement and quartz sand and have a mobility of 7-8 cm.

Mortars intended to support design load should be of a grade equal to that of concrete joined constructions, whereas non-load-bearing mortars should have strength not less than 10.0 MPa. Whenever joints include reinforcement or insertion pieces, mortars should carry no admixtures liable to cause corrosion of metal.

Cement-sand and cement paste injection mortars for filling grooves inside prestressed constructions must comply with stringent specifications as to strength (not less than 30.0 MPa), water retention and frost resistance.

Floor mortars are subdivided into the following varieties: cement-sand, metal-cement, cement-sawdust and polymer-cement. Cement-sand mortars for grouting floors should have adequate strength and good mobility.

Cement-sand mortars for floors from paving blocks clinker bricks, concrete slabs, mosaic and ceramic tiles, cast iron perforated plates and xylolite tiles should have adequate strength and viscosity.

Metal-cement mortars are manufactured from degreased steel shavings 1-3 mm in size, water and cement of 40.0-50.0 MPa strength and of both high and low mobility.

Cement-sawdust mixes consist of Portland cement or anhydrite binding materials, sand and fine sawdust. These mortars are used as bedding courses for floors.

In recent years there has been an increasing trend in construction to make floors from polymer-cement mortars produced by mixing cement and aqueous polymer suspension (synthetic latex). Floors on such mortars possess adequate strength, corrosion resistance, hygienic properties and high wear resistance.

Damp-proofing mortars are produced from cement types of higher strength (40.0 MPa and over) and quartz sand or sand from crushed solid rock. Damp-proofing courses are built with sulphate-resisting Portland cement as binding materials. Cracks and caverns both in concrete and stone masonry can be filled and plastered, respectively, by guniting or by conventional methods with cement mortars carrying admixtures of sodium aluminate, polymers and bitumen emulsions.

Waterproof seams and joints are made from damp-proofing mortars with waterproof expanding cement.



Packing mortars are subdivided into cement-sand, cement-sand-loam and cement-loam varieties and are used to pack oil wells. The properties required of them are high homogeneity, water resistance and mobility; predetermined setting time, adequate water yield under pressure and ability to form solid waterproof plugs in cracks and voids of rocks; resistance to subsoil water pressure and aggressive media. Suitable binding materials for packing mortars are Portland cement; for aggressive water, they are slag Portland cement, puzzolana and sulphate-resisting Portland cement; and expanding cement is used when there is water pressure.

Sound-absorbing mortars have a bulk density of 600-1200 kg/m<sup>3</sup> and are used as sound-absorbing plaster to reduce noise level. The binding materials involved are Portland cement, slag Portland cement, lime, gypsum or their mixtures – single-size fraction sands (from 3 to 5 mm) from lightweight porous materials, such as pumice, perlite, cinders, ceramsite, etc. Quantity of binding materials and aggregate grain composition in sound-absorbing mortars should ensure open porosity of mortar.

X-ray shielding mortars for plastering walls and ceilings of X-ray cabinets are heavy mortars of a bulk density over 2,200 kg/m<sup>3</sup>. Binding materials are Portland cement and slag Portland cement, and aggregates, barite and other heavy rock in the form of sand (up to 1.25 mm in size) and dust. Admixtures (hydrogen, lithium, cadmium) are added to X-ray shielding mortars to enhance their protective properties.

Building mortars are produced in two kinds: as ready to use mortar mixtures of adequate mobility and as dry mortar mixtures requiring water and, sometimes, special admixtures.

At present, commercial mortars are produced in a centralized manner at specialized plants and are transported to construction sites as dry mixes or finished mortars of specified consistency, grade, and quality.

Dry mortar mixtures are classified by binding material (cement, lime, gypsum, polymer) and application (masonry, finishing, decorative, heat-insulating, waterproofing).

### **3.6.3. Asbestos-Cement Items**

Asbestos cement is an artificial stone material obtained by hardening a mixture of cement, water and asbestos. The latter reinforces cement stone in asbestos cement and provides high tension and bending strengths of items.

Asbestos cement possesses high mechanical strength in binding, small bulk density, low heat conductivity, high resistance to mineralized aqueous solutions, high water tightness and frost resistance.

Its drawbacks are low strength when saturated by water, brittleness and warping during humidity fluctuations.

The main raw materials for manufacture of asbestos-cement items are chrysotile-asbestos and Portland cement.

Asbestos-cement items are manufactured from chrysotile-asbestos mixture in the amount of 10 and 20%, and part of Portland cement is 80 to 90%.

The binding material in asbestos-cement is Portland cement, which must hydrate rapidly but set relatively slowly and not earlier than 1.5 h. from the time it is mixed with water. After items are manufactured, their strength gain should be rapid enough to allow the semi-product to turn into a finished item.

Asbestos minerals are fibrous in structure and split into fine fibers by mechanical force. Diameter of chrysotile-asbestos fibers is between 0.00001 and 0.00003 mm but in practice, chrysotile-asbestos can be luffed to fibers of a mean diameter of 0.02 mm, and, therefore, such fiber is actually a bunch of numerous elementary fibers. Their strength drops to 600-800 MPa, which corresponds to the strength of high-quality steel wire.

Asbestos has a good adsorption capacity. When mixed with Portland cement and wetted by water, it absorbs, i.e. retains firmly on its surface, asbestos fibers, and, therefore, asbestos-cement can be considered a finely reinforced cement stone. Chrysotile-asbestos is incombustible; however, it melts at a temperature of about 1,550°C.

Asbestos has low heat and electric conductivity, high resistance to alkali and poor resistance to acids.

The quality of asbestos is critically affected by fibers length, and, therefore, this characteristic serves as a basis for classifying asbestos into eight grades.

Water used for production of asbestos-cement items should be free from clay impurities, organic substances and mineral salts. Optimum temperature of water is 20-25°C.

Wall tiles and sheets may be tinted by colored cement or mineral alkali-resistant pigments, which possess high coloring capacity, high light stability and resistance to atmospheric impact and cement hydration products.

Sheets for facing walls and panels of sanitary units and kitchens are coated with water-impervious enamels and varnishes manufactured from polymers.

Asbestos-cement items are currently manufactured by two methods: from an asbestos-cement suspension, the wet method (sheets, pipes); from an asbestos-cement-sand mass, the semi-dry method (sheets, slabs).

The most extensively used technique is the wet method.

The flowsheet of manufacturing asbestos-cement items comprises the following main stages:

- composing a mixture from asbestos of a number of grades and marks;
- fluffing asbestos mixture;
- producing asbestos-cement (asbestos-cement-sand) mass;
- forming asbestos-cement items.

Pipes and sheets obtained by wet method are molded in sheet-forming and pipe-forming machines. In order to obtain greater mechanical strength and density (semi-dry method) facing sheets and roof tiles items are compacted in hydraulic presses at pressure up to 40 MPa.

Asbestos-cement items from Portland cement harden in two stages. First, they are pre-hardened in tunnel bath-type steam curing chambers at temperatures between 50 and 60°C for 12 to 16 h. After final forming, the sheets are transferred to a heated storage area, where the second stage of hardening takes place over a period of not less than 7 days. Formed asbestos-cement items from asbestos, sand and Portland cement are charged into autoclaves for steam curing at temperatures of 172-174 °C and a working pressure up to 0.8 MPa. After curing to the required strength, items are dressed.

By application, asbestos-cement items fall into roof and wall items, pipes and special items.

Sheet asbestos-cement materials are extensively used in construction. Corrugated sheets of periodic profile in colored or non-colored varieties are available in length of 2,000 and 2,500 mm, widths of 1,154 and 1,150 mm and 1,093 mm and thicknesses of 6 to 8 mm. These sheets are used for exterior walls in various types of buildings.

Asbestos-cement corrugated sheets of standard profile are intended for garretless and heat-insulated roofs and walls of industrial and farm buildings and structures.

Facing asbestos-cement slabs with ornamental polymer coat (sizes of 150×150×4 mm) are used to line walls of shops, cafeterias, underground railway stations, street underground crossing, public premises and walls of bathrooms.

Standard asbestos-cement wall panels consist of three layers, where the facing asbestos-cement sheets are secured to a wooden carcass by aluminum cramps and the interior asbestos-cement sheathing from grey sheets, by screws with countersunk heads; the heat insulating materials are glass wool slabs.

Asbestos-cement pipes are available in pressure, pressureless and ventilation types. Pressure-type pipes are used for water supply lines, for district heating, and for oil and gas pipelines.

Pressureless asbestos cement pipes are used for exterior pressureless sewers, drainage headers, land reclamation systems and telephone cable ducts.

Asbestos-cement troughs rectangular in cross section are used as ventilation ducts for industrial auxiliary premises and welfare blocks, industrial, residential and public buildings.

Special asbestos-cement items are large-size textured sheets for arched roofs, water towers and grain driers.

### **Self-Check Questions and Tasks:**

1. What types of mineral binders do you know? What is their application in construction?

2. What is the composition of building mortar mixtures? What is the purpose of their components?

3. What technological properties of construction mortar mixtures do you know?

4. What is the classification of mortars according to the type of applied mineral binder and their purpose?

5. What performance properties of mortars depending on their purpose do you know?

6. What technological properties of construction mortar mixtures do you know?

7. What is the composition of asbestos-cement mixtures? What is the purpose of their components?

8. What production technology of asbestos-cement products for various purposes do you know? What is their use in construction?

### **3.7. Concrete. Classification of Concrete**

Concrete is an artificial stone resulting from hardening of a rationally chosen mixture of binding material, water and aggregate (sand and crushed stone or gravel). The mixture before it hardens, is called a concrete mix.

Particles of sand and crushed stone form a stone carcass in concrete. Cement paste resulting from the interaction of concrete mix with water coats sand grains and crushed stone, fills voids between them, lubricates aggregate, and imparts mobility to the concrete mixture. When cement paste hardens, it binds the aggregate into an artificial stone or concrete.

Concrete combined with steel reinforcement is called reinforced concrete.

Concrete is classified according to the following main characteristics: bulk density, type of binding material and aggregates, structure, strength, frost resistance, water tightness and application.

By application, concrete is divided into the following kinds:

- constructional, for concrete and reinforced concrete supporting elements of buildings and structures (columns, beams, plates):
- special, such as acid- and heat-resistant concrete; extra-heavy concrete for protection from nuclear radiation; hydraulic engineering for dams, sluices, etc.

By their bulk density concrete is divided into super-heavy concrete with a bulk density over 2,600 kg/m<sup>3</sup>, heavy concrete with a bulk density of 2,000 to 2,600 kg/m<sup>3</sup> and lightweight concrete with a bulk density between 200 and 2,000 kg/m<sup>3</sup>.

By the maximum size of aggregate, concrete is subdivided into fine-grained varieties with aggregates of up to 10 mm in size and coarse grained varieties, the maximum size of aggregates ranging to 150 mm.

According to the kind of aggregates concrete have dense, porous or special aggregates.

According to the kind of binding material, concrete is available in the following varieties:

- cement concrete manufactured from hydraulic binding materials, such as Portland cement and its varieties;
- lime-sand (silicate) concrete, from lime binders in combination with silicate compound;
- gypsum concrete, from gypsum-anhydride binding materials;
- concrete from organic binding materials.

Strength and frost resistance are the major characteristics of concrete quality. Heavy concrete has compressive strength between 10 and 115 MPa, lightweight concrete between 2.5 and 30 MPa. By frost resistance, concrete is subdivided into grades: heavy concrete – from F 50 to F 300; lightweight concrete – from F 10 to F 200.

Heavy concrete is manufactured from cement and common dense aggregates, and light weight concrete is produced from cement and natural or artificial porous aggregates.

### **3.7.1. Materials for Concrete**

Heavy concrete for foundations, columns, beams, bridge spans and other supporting elements and constructions of industrial and residential buildings and engineering structures should acquire a predetermined strength after a certain period of hardening, whereas the concrete mix should be easily placeable.

Concrete is used for production of bearing reinforced concrete structures on the workplace (monolithic concrete); for manufacture of large-size

constructions (slabs, blocks) in a plant and also for small-pieces roofing and finishing materials (Fig. 25–28).

When used in locations exposed to weather conditions, concrete should have a high density and adequate frost and corrosion resistances.

Lightweight concrete of low heat conductivity on porous aggregates serves to manufacture panels for walls and floors of heated buildings.

Depending on application and working conditions, the ingredients of concrete must meet various requirements.

Concrete is made from Portland cement, plasticized Portland cement, slag Portland cement, etc. The type of cement is chosen according to the demands placed upon concrete (strength, frost resistance, chemical stability, water impermeability, etc.).

Water for concrete mixtures should be free from harmful impurities, which may hinder the normal hardening process of concrete. Classed with these impurities are acids, sulphates, grease, vegetable oil, sugar, etc. No swamp or drainage water or water contaminated by harmful impurities should be used.

Sea and other types of water, containing mineral salt, may be used if their amount is limited to 2%.

Various additions improve properties of concrete mixtures and concrete. By their kind and application, the additions may be classed as follows: early-strength admixtures; surfactants; foam and gas forming agents; combined and special-purpose additions.

Early-strength admixtures speed up hardening of concrete particularly during the initial stages.

Surfactants (0.05 to 0.2% of cement mass) are a particular group of organic substances, whose introduction into concrete (mortar) mixtures substantially improves the latter's placeability. At the same time, surfactants lower water-cement ratio and, accordingly, cement consumption with no adverse effect upon the strength of materials and items.

Surfactants additions used in cements, mortars and concretes may be classed on the basis of the effect they exert upon cement systems into three groups: hydrophilic, hydrophobic and air-entraining.

Hydrophilic admixtures for a certain time prevent cement particles from sticking to one another while binder is mixed with water. Because of this a specified placeability of such a mix is attained at a lesser amount of mixed water than is the case for an admixture-free mix.

Hydrophobic admixtures, as a rule, substantially enhance resistance to unmixing and cohesiveness of concrete mix at rest. In addition, the admixtures protect cements against a rapid loss of activity during transportation or storage.

Air-entraining additives provide concrete mixes with some additional amount of air that enhances their placeability and concrete frost resistance.

Foam- and gas-forming agents are used for lightweight cellular concrete. They are distinguished by a high porosity (up to 80-90%) with uniformly distributed pores, up to 3 mm in size.

Combined additives, such as a plasticizer, a hardening accelerator with inhibitor, contribute to cement saving.

Special additives make it possible to obtain water-proof concrete and to control hardening time in cold weather.

Petty aggregate is sand, which is a loose assembly of particles 0.14 to 5 mm in size, formed as a result of natural disintegration of massive rocks (natural sands). Along with natural sands, use is made from artificial ones obtained by crushing granulating metallurgical slags or fuel cinders, or specially produced materials, such as ceramsite, agloporite. Of all natural sands mostly quartz sands are used for concrete.

Concrete quality is greatly affected by granulometric (size) composition of sand and amount of various dust, slime, clay and organic impurities, whose content is found by elutriation. Their amount in sands should not exceed 3%. Most harmful in sand are clay impurities, which coat sand particles and prevent their bonding with cement stone, thus diminishing the strength of concrete. Clayey and dust impurities in sands increase water-requirement of concrete mixes, lower their strength and frost resistance of concrete.

The granulometric composition of sand is of prime importance for manufacture of high-quality concrete.

Sand for concrete should be composed of particles of different sizes (from 0.14 to 5 mm) so as to minimize the volume of voids in it; the less the volume of voids in sand is, the less is the amount of cement required to obtain dense concrete. The granulometric composition of sand is determined by screening the latter through a standard set of sieves with sizes of openings of 10;5; 2.5; 1.25; 0.63; 0.312; 0.14 mm. The amount of particles in the 5 to 10 mm range should not exceed 5% by mass.

On the basis of its size, sand is classified into coarse, medium, fine and extra-fine varieties.

Coarse aggregate for heavy concrete is usually composed of gravel or crushed rock.

Gravel is a conglomeration of fragments from 5 to 70 mm in size, formed by natural disintegration of rock. Gravel particles have a well-rounded shape and a smooth surface. By the size of particles, gravel is subdivided into the

following fractions: 5-10; 10-20; 20-40; 40-70 mm. Gravel frequently occurs together with sand. When the amount of sand in gravel amounts to 25 to 40%, the material is called sand-gravel mix.

Crushed stone is obtained by crushing massive rocks, gravel to particles measuring 5 to 70 mm. Best crushed stone is the one that approximates to cubes and tetrahedrons form. Because of a ragged surface, crushed stone provides a better bond with cement than gravel. However, a concrete mix with crushed stone is less mobile.

It is less expensive to produce concrete with coarse gravel and crushed stone since its smaller surface area requires less cement to obtain strong concrete. Admissible size of particles depends on the constructions to be made from concrete. Easy placing of concrete mix requires gravel or crushed stone to be not coarser than  $\frac{1}{4}$  of the minimum size of construction cross section and not larger than the least distance between reinforcement bars. In slabs, where it is easier to place concrete mix, larger particles may be used, their size not exceeding  $\frac{1}{2}$  of the slab thickness. Gravel and crushed stone larger than 70 mm are used in concrete for massive hydraulic engineering structures.

A good concrete mixture composition is the one containing particles of various sizes as this minimizes the volume of voids.

Strength of gravel and crushed stone particles used in industrial and residential construction should be at least 1.5 times as high as that of concrete of grades below 300, and at least twice as high as that of concrete of grade 300 and over.

Gravel and crushed stone for concrete exposed to water and low temperatures should have a certain frost resistance, in terms of which they are classed into grades F 15, 25, 50, 100, 150, 200 and 300. Frost resistance is determined by direct freezing. Gravel or crushed stone are considered frost-resistant if being water-saturated, they withstand more than 15 cycles of alternate freezing at  $-17^{\circ}\text{C}$  and thawing, the loss in mass after the tests amounting to not more than 10%.

Aggregates for lightweight concrete are natural and artificial loose porous materials with a bulk density of not more than  $1,200 \text{ kg/m}^3$  for particles in sizes up to 5 mm (sand) and not more than  $1,000 \text{ kg/m}^3$  for particles ranging in size from 5 to 40 mm (crushed stone, gravel).

Natural porous aggregates are obtained by crushing lightweight rock, such as pumice, volcanic cinder and tuff, porous limestone, shell limestone and limestone tuffas.

Artificial porous aggregates are obtained from industrial waste (slag) or through thermal processing of raw silicate materials, which are screened or crushed and then screened.



Granulated slag is a porous fine material obtained by rapid cooling of molten metallurgical slags.

Slag pumice (thermosite) is obtained in lumps of cellular structure by expanding molten slag as it solidifies. Strength of slag pumice ranges from 0.4 to 2.0 MPa depending on its bulk mass (400 to 800 kg/m<sup>3</sup>).

Agloporite is an artificial porous aggregate ranging in size from 5 to 20 mm with bulk mass from 400 to 700 kg/m<sup>3</sup> and compressive strength from 0.4 to 1.5 MPa. Raw materials for manufacture of agloporite are clay and waste of coal mining. Agloporite crushed stone is manufactured by sintering raw mixture then it is crushed and screened.

Classed with the specially prepared aggregates are ceramsite gravel and sand, which are rounded materials, obtained by burning the clay. A porous structure is achieved by expanding a clayey substance heated to plastic state by gases evolving from it during heating. Manufactured ceramsite gravel strengths ranges from 0.6 to 6 MPa, and bulk mass ranges from 150 to 800 kg/m<sup>3</sup>. Ceramsite sand is obtained by crushing and screening ceramsite gravel, or as an independent size fraction directly in burning.

Expanded pearlite is manufactured in the form of stone and sand by short-time-burning of volcanic water-containing glass rocks. Pearlite stone and sand for concrete have a bulk mass of 150 to 450 kg/m<sup>3</sup> whereas the perlite sand used for heat insulating fillings is produced in bulk masses of 50 to 100 kg/m<sup>3</sup>.

### **3.7.2. Composition and Properties of Concrete Mixes**

By compressive strength, concrete depends on cement activity, water-to-cement ratio, quality of aggregate, degree of compaction of concrete mix and hardening conditions, and the first two of these are the determining factors. Cements of higher activity produce stronger concrete, but concrete with cement of constant activity may show different strengths depending on the quantity of water in the mix.

In order to obtain concrete mix of adequate placeability the water-to-cement ratio is usually maintained between 0.4 and 0.7, whereas the amount of water necessary for chemical interaction between cement and water is not more than 20% of the cement mass.

Excess water, which has not reacted with cement, evaporates and forms pores in concrete, thus lowering the density and, therefore, the strength of concrete. It follows then that concrete strength may be increased by bringing down the water-to-cement ratio.

Aggregate strength does not affect concrete strength greatly as long as it is higher than the design grade of concrete. Use of aggregates whose strength is

lower than that of the desired concrete grade may substantially lower the latter's strength or lead to a higher cement consumption.

Surface roughness of aggregates also affects concrete strength.

In contrast to gravel, crushed stone has a developed rough surface, which provides better cohesion with cement stone, whereas concrete from crushed stone has greater strength than concrete mixed with gravel, provided all other conditions are the same.

Along with the above factors (activity and quality of cement, water-to-cement ratio and quality of aggregates), concrete strength is greatly affected by concrete mix compaction, duration and conditions of hardening.

Actual concrete strength in structure is determined by testing specimens made from working concrete mixes.

Concrete strength gain is greatly affected by ambient influence. Conditions generally accepted as normal for concrete hardening are as follows: relative air humidity is from 90 to 100%; temperature is  $20\pm 2^{\circ}\text{C}$ . High air humidity is necessary to minimize evaporation of water from concrete, which may cause the hardening process to stop.

The higher the temperature is, the greater the rate is, and vice versa. Thus, over 10-14 hours of hardening in a steam saturated environment (steam curing) at a temperature between 80 and 90°C, concrete may attain from 60 to 70% of its 28-day grade strength.

Concrete hardening is accelerated by such admixtures as calcium and sodium chloride, which is of great practical significance for concreting in a cold season, as the accelerants allow to mix concrete capable of hardening at below-zero temperatures.

Even with high-quality materials, concrete can be made strong and durable only if the mix is thoroughly compacted when placed into a construction. Molding capacity of concrete mix is determined by two factors – mobility and plasticity. Plasticity is an indicator of internal cohesion of concrete mix, its ability to be molded and to acquire a prescribed shape without breaks and stratification.

Concrete mix mobility is evaluated by its ability to flow under its own weight or under vibration. This characteristic is determined by means of a conical mold, which is filled with a concrete mix; the latter is compacted and the mold is then taken off. The resultant cone of concrete mix slumps under its own weight. The slump of the cone (cm) is a measure of concrete mix mobility, which allows the following classification of concrete mixes: cast mix, slump over 20 cm; mobile mix, slump from 10 to 20 cm; poorly mobile mix, slump from 1 to 9 cm, stiff and extra stiff, no slump, less than 1 cm.

The ability of concrete mix to flow under vibration is termed stiffness. The vibration time in seconds is the measure of concrete mix stiffness.

Cast and mobile mixes have a stiffness of 0 s; poorly mobile mixes have a stiffness of 4 s and less; stiff mixes stiffness is from 5 to 40s; and extra stiff mixes stiffness is over 40 s. Stiffness of concrete mixes is determined with a technical viscosimeter. Concrete mix mobility is affected by such factors as type of cement, content of water and cement paste, size of aggregates, shape of aggregate ingredients and sand content.

Concrete mixes of the same composition made from different cement types have different mobilities because of their different water requirements. Concrete mixes from Portland cement types with hydraulic admixtures have a lower mobility than those from Portland cement, whereas the amount of water for preparing the mix is the same.

The greater the water content (cement consumption is the same) is, the greater mobility of concrete mix is, but concrete strength is lower. The greater the amount of cement paste in concrete mix is, the greater the latter's mobility is, post-hardening strength remaining practically unchanged. This is due to the fact that as the content of cement paste increases it does not only fill the voids between the aggregate particles and coats them but also pushes them apart; the effect is that cement paste forms thick interlayers, which reduce friction between the particles and thus increase mix mobility.

When coarser aggregate is used, the total surface area of particles is smaller, and, therefore, for the same amount of cement paste, the interlayers separating the aggregate particles are thicker, which enhances concrete mix mobility. The increase in the amount of sand above the optimum value, based on practical data, reduces concrete mix mobility because of a greater surface area of the aggregate.

Particle shape affects mix mobility: total surface area of aggregate and friction are less when the particles are rounded and smooth than when they are sharp-edged and rough. Therefore, concrete mix from gravel and rounded sand is more mobile than that of from crushed stone and rock sand.

Concrete mix mobility should be as low as possible but consistent with adequate placeability. When choosing concrete mix mobility, size and character of construction, the simplicity should be taken into account.

The aim of designing concrete composition is to determine such an amount of materials per  $1\text{m}^3$  of concrete mix which provides the most economical composition of a well placeable concrete, as well as its frost and water resistance and special properties, whenever these are required.

Concrete mix composition is expressed as a mass ratio (seldom, as a volume ratio, which is less accurate) of cement, sand and crushed stone (or gravel) with the indication of water-to-cement ratio, to the quantity of cement taken as unit.

Therefore, in its general form concrete mix composition is shown as a ratio of cement : sand : crushed stone = 1 :  $x$  :  $y$  with  $W/C = z$  (for instance 1 : 2.4 : 4.5 with  $W/C = 0.45$ ).

Distinction is made between two compositions of concrete: nominal (laboratory) composition for dry materials and industrial (field) composition for materials of natural humidity.

The quality of source materials (cement, water, sand and crushed stone or gravel) should be evaluated in accordance with the state standard specifications before concrete mix composition is estimated.

The initial data for estimating concrete mix composition are as follows: concrete grade; mobility or stiffness of concrete mix; ingredients parameters, such as activity and bulk density of cement, density and bulk density of sand or gravel, and voidage of crushed stone or gravel.

The procedure for concrete composition estimation is as follows:

- determination of water-to-cement ratio ensuring manufacture of concrete of the prescribed strength;
- determination of water consumption;
- determination of the required consumption of cement, crushed stone (or gravel) and sand;
- test of concrete mix mobility;
- preparation of specimens for strength tests after their hardening;
- correction of concrete mix composition when mobility and strength indexes deviate from the design requirements;
- re-calculation of the nominal composition in terms of industrial composition.

Should the concrete mix prove to be less mobile than required, the amounts of cement and water are increased, the cement-to-water ratio remaining unchanged. If the mobility is higher than required, sand and aggregate are added by small portions in a predetermined ratio until proper mobility is reached. When changing the content of sand and crushed stone (gravel), their humidity must be taken into account.

When concrete components are mixed, smaller particles of ingredients occupy the space between the larger fragments; aggregate fills the voids between crushed stone or gravel, and cement paste, between sand particles. The

volume of concrete mix ( $V_{con}$ ) is, therefore, always less than the sum of bulk volumes of dry loose ingredients. This calls for introduction of concrete yield factor  $\beta$  which is the ratio of concrete mix volume  $V_{con}$  in compacted state to the sum of bulk volumes of dry loose ingredients ( $V_c, V_s, V_{cs(g)}$ )

$$\beta = \frac{V_{com}}{V_c + V_s + V_{cs(g)}}.$$

Factor  $\beta$  is used to calculate the amount of concrete mixture materials of specified volume  $V$  in a concrete mixer or for performing a given construction work.

$$C_v = \frac{\beta V}{1000} C, \quad W_v = \frac{\beta V}{1000} W,$$

$$S_v = \frac{\beta V}{1000} S, \quad CS_v = \frac{\beta V}{1000} CS,$$

where  $C_v, W_v, S_v, CS_v$  are amounts of cement, water, sand and crushed stone (or gravel), respectively, required to make a batch in a concrete mixer, kg;

$\beta$  is concrete yield factor;

$C, W, S, CS$  are consumption of cement, water, sand and crushed stone (or gravel), respectively, kg/m<sup>3</sup> of concrete mix.

Basic considerations for choosing the composition of lightweight concrete from given materials are concrete's lowest possible cost consistent with good placeability and adequate strength, as well as specified bulk density for the lowest cement consumption.

### 3.7.3. Manufacture of Reinforced Concrete Constructions and Items

Reinforced concrete is a building material that combines advantageous features of concrete and steel, differing greatly in mechanical properties. Similar to other rock materials, concrete operates well in compression, but it is brittle and poor in tension.

Tensile strength of concrete is equal to 1/15 – 1/10th of compression strength. Since it is bad to use it in constructions exposed to tensile stresses, the units must be made very heavy. But steel, which is very strong in tension, is capable of resisting tensile forces that may arise in reinforced concrete units.

Reinforced-concrete items are most advantageous in units subject to bending when both tensile and compressive stresses take place. In this manner the load-resisting features of steel and concrete are combined in a single material – reinforced concrete.

Successful combination in reinforced concrete of two materials with greatly differing properties is based on the following factors:

- strong bond of concrete with steel reinforcement so as to provide a combined resistance to loads;
- almost equal thermal expansion coefficients of steel and concrete, this making reinforced concrete a monolithic item;
- concrete is not only non-aggressive with respect to steel, but it also protects it against corrosion.

Depending on the reinforcing technique and the state of reinforcement, distinction is made between common and prestressed reinforced concrete. In the same class with reinforced concrete there are products whose strength is enhanced by placing steel bars, wire meshes or carcasses into concrete. However, this reinforcing method fails to prevent cracks in the stretched parts of concrete, since the latter's stretchability is poor (1-2 mm per 1 m), whereas the tensile strength of steel is 5-6 times as great as that of concrete. Cracks adversely affect the working properties of reinforced concrete units; camber increases, moisture and gases penetrate into the cracks and there is a risk of reinforcement corrosion.

Cracks in reinforced concrete can be prevented by compressing concrete at points subject to tensile stresses. Prestressed concrete cracks only if the tensile stresses exceed the prestress value. There are two kinds of tensioning: pretensioning, or tensioning the reinforcement before concrete hardens, and post-tensioning, or tensioning concrete after it acquires a specified strength. If reinforcement is prestressed before the concrete is placed reinforcement is laid inside the form and fastened after being tensioned. Once the mix is placed and concrete has hardened, the reinforcement contracts as soon as it is relieved of extraneous tension, and in so doing drags along the surrounding concrete, compressing the unit throughout its body.

If reinforcement is to be tensioned after concrete hardens it is inserted inside a channel and is tensioned and secured at its ends. Concrete mix is poured inside the channel. Once the concrete has hardened the reinforcement contracts, it is relieved of extraneous tension. The mix poured inside the channel, bonds the reinforcement to the concrete and so provides monolithic prestressing of the reinforcement.

Reinforcement prestressing does not only prevent cracking in stretched concrete, but it also reduces the weight of reinforced concrete constructions, enhances their rigidity, increases durability and lowers steel consumption. That is why construction engineers pay so much attention to the development of

prestressed reinforced concrete structures. Reinforced-concrete items and constructions can be produced at the construction site (monolithic) and at a plant (prefabricated).

Manufacture of reinforced concrete items and constructions generally involves the following sequence of operations: preparation of concrete mix and reinforcement; forming; hardening of concrete to provide necessary strength by a specified time.

In the present-day industry of prefabricated reinforced concrete, process operations are organized and carried out by means of corresponding equipment in accordance with the three flowsheets below:

1. Items are cast in stationary forms; all process operations, from preparation of forms to stripping of hardened items are performed at a single station (trusses; sanitary closets are made from a monolithic reinforced concrete, three-dimensional shell cast in special boxes).

2. Items are made in mobile forms, process operations being performed at specialized stations. The form and the item it contains are transferred from station to station as separate operations are performed (single-, two- and three-layer wall panels).

3. Continuous casting. The unit in which items are manufactured by the continuous casting technique is a vibro-rolling mill (partition panels are made from all kinds of concrete).

The main concrete mixes preparation operations are proportioning and mixing of ingredients. According to the existing norm, proportioning tolerances are  $\pm 1\%$  by mass for cement, water and admixtures and  $\pm 2\%$  for aggregate.

Concrete mixes are prepared in stationary and mobile concrete mixers

The stirring duration of concrete mixes depends on the latter's mobility and the capacity of a concrete mixer. The less concrete mix mobility is and the larger the mixer's working capacity is; then the greater is the optimum time of mixing.

During transportation of concrete mix to the site of placement, its homogeneity and mobility should be preserved. On the way, concrete mixes may thicken because of hydration of cement, adsorption of water by the aggregate, and evaporation; in no case, however, should a mix be placed in a construction unless its mobility is in compliance with the design value.

When considering the haulage of concrete, account should be taken of distance, time of transportation and mobility of the mix. Plastic mixes may be conveyed through great distances via pipes with aid of pneumatic devices. Concrete mixes are carried to concreting sites in transit or in agitating trucks where the mix is made ready roughly 5 minutes before it is delivered.

Each batch of concrete is accompanied by a certificate from the ready-mix plant with the name and address of the plant, number and date of issue of the certificate, amount of mix ( $m^3$ ), consumption of cement per cubic meter of concrete mix, size content of crushed stone or gravel, mobility, stiffness and grade of concrete mix and results of checks on control samples of concrete strength. To prevent early thickening of mixes, especially in hot weather during long transits, mixes are doped with surfactants which slow down structure formation of mixes in the initial 2 to 4 h.

Placing of a concrete mix and compaction inside a form is one of the most labor- and power-consuming operations. One of the most widely used techniques for compacting concrete mixes is vibration.

The type of vibrator should suit the kind, shape and size of the concreted construction. Large open concrete surfaces (floors, slabs, roads) should be compacted with external vibrators, which transmit vibrations to the concrete mix via a metallic platform (float), carrying the vibrators.

Internal vibrators are used for compacting concrete mixes in massive constructions of great thickness.

Vibrating plates are much in use at prefabricated concrete plants.

Methods of mix compacting are closely related to properties of mixes, in particular, to mobility. Thus, harsh non-flowing mixes require vigorous compaction and the items made from them should be intensely vibrated or vibrated with weighting (or applying a load). Harsh mixes may also be compacted by tamping, pressing and rolling. Mobile mixes are readily and effectively compacted by vibration.

Mixes for casting are so mobile that they are capable of compacting under their own mass. To enhance compaction, they are sometimes vibrated for a short period.

Thus, all the known methods of concrete compaction fall into the following categories: vibrating, pressing, rolling, tamping and casting. Both from engineering and economic points vibrating is the most effective and the most extensively used method. It is successfully used in combination with other mechanical compaction techniques, such as tamping (vibro-tamping), pressing (vibro-pressing) and rolling (vibro-rolling). A variety of mechanical compaction is centrifuging, which is applied to molding hollow tubular items (pipes, power transmission line poles).

Concrete mix is compacted by centrifuging due to centrifugal forces arising during rotation. Concrete is compacted in centrifuges which are tubular forms rotating at 600 to 1,000 rpm. Concrete mix of adequate mobility is forced



against the inside of the form and thus compacted by the forced arising from its rotation. Centrifuging also removes from 20 to 30% of water, a fact greatly contributing to the manufacture of high-density, of high strength (40 to 60 MPa), and concrete durability.

Pipes, power transmission line poles and lighting fixture posts are cast by centrifuging.

#### **3.7.4. Hardening of Concrete Items and Constructions**

Hardening is the final operation in the manufacture of reinforced concrete constructions and items. Depending on the ambient temperature, there are three different hardening modes: normal treatment at a temperature from 15 to 20°C, thermal treatment at a temperature below 100°C and normal pressure; autoclave treatment involving steam curing at high steam pressure and temperature higher than 100°C. Normal hardening conditions may be attained naturally, with no consumption of heat whatsoever. Under natural conditions, concrete gain the necessary shipping strength (70% of the grade strength) during 7-10 days. There already exist concretes which gain 40-50% of grade strength in one day under normal conditions. This is achieved by using high-grade quick-hardening cements, stiff concrete mixes, intensive vibration with additional loading, hardening accelerators, vibroactivating and preheating concrete mixes prior to casting.

Irrespective of the hardening module, relative ambient humidity should be close to 100%, otherwise concrete will dry up and slow down or even stop gaining strength, since hardening of concrete is basically hydration of cement, i.e. cement and water interaction.

Curing of concrete involves means that provide normal hardening of concrete mixes and prevent damage to green concrete structures. Curing should be organized immediately after concrete is placed and compacted. First, it is necessary to protect the surface against drying.

An efficient means of curing freshly placed concrete in road construction is to coat its surface by film-forming substances, such as bitumen emulsions, latex, synthetic rubber, etc. Along with this, horizontal surfaces of products are covered with sand or sawdust after concrete has set, the materials being wetted at regular intervals. Moistening time is a function of atmospheric conditions: in hot weather, it is up to two weeks; in cold weather, several days. In cold seasons, concrete should be protected against excessive cooling, which slows down hardening, and the more so against freezing.

When concrete is placed in freezing weather, it should be protected against freezing until it acquires 50% of its design strength. Normal hardening of concrete at subzero temperatures may be acquired by two methods: by utilizing the internal heat of concrete or by supplying an additional amount of heat from outside.

To reduce the time of hardening it is necessary to use such cements as Portland cements of high grades or aluminous cements, lower the water-to-cement ratio, intensify the compaction of concrete mixes and introduce hardening accelerants, such as calcium chloride, etc.

A reserve of internal heat is ensured by heating concrete mix ingredients (water, sand and crushed stone or gravel) in a manner to bring the concrete mix temperature on discharge from a concrete mixer to not higher than 30°C. The reason for this is that a mix tends to thicken rapidly and lose its workability when temperature level exceeds. Mixing water may be heated to 80°C, and the aggregate, to 40°C. In addition, heat that is released by chemical reactions between cement and water (heat is released during cement hydration) counteracts cooling of the constructions.

In order to retain heat during a predetermined time, concrete constructions are covered with heat insulating materials (sawdust, slag, pressboard, flax waste), as soon as concrete mix is placed, the thickness of the coat is determined on the basis of thermal considerations; the technique is called “thermos”. The technique is applied to heavy constructions with a surface modulus (which is the ratio of concrete cooling surface  $F$  to its volume  $V$ ) not greater than 6.

In thin and sometimes in massive freshly placed constructions, concrete mix is heated from the outside by steam or electric current (electric heating). This technique allows to achieve within one or two days a strength gain of 60 to 70% of the grade strength (after 28 days of hardening).

Concrete can be heated by alternating current, which is supplied through electrodes of two types: surface electrodes (in the form of steel plates placed on the surface) and internal electrodes (steel bars laid horizontally or stuck in vertically). In a reinforced concrete construction, the reinforcement serves as one of the electrodes.

As current flows through concrete, it releases heat with the effect that concrete hardens rapidly. However, concrete should not be heated to a temperature higher than 60°C; otherwise a local overdrying may occur.

Thermal-and-moist curing under normal pressure. There are several methods for thermal-and-moist curing of reinforced concrete items under normal pressure: steam curing in chambers; electric heating; contact heating. Among the

great variety of techniques, chamber steam curing is still the most advantageous method. This method is implemented in batch-type and continuous chambers. In the latter freshly cast items are continuously charged on cars at the end of the chambers tunnel and hardened products are discharged at the other end. Hardening involves curing in preheating, isothermal (of constant peak steam curing temperature) and cooling zones. This type of steam curing equipment is currently found at conveyor-type plants only.

Among the batch-type chambers, the most used ones are pit chambers, which are about 2.0 m deep, rising from 0.5 to 0.7 m above floor level. Chamber dimension corresponds to the size of items. The most advantageous size of the chamber is the one corresponding to the size of a single item.

Items are charged into the chamber by a crane in several layers.

Steam curing conditions are characterized by duration of temperature rise, holding at peak temperature, cooling time and peak temperature during isothermal curing. Hardening modes are drawn with due regard of the cement and its kind, properties of concrete mix (stiff or mobile), kind of concrete (heavy or lightweight) and size of item (thin-walled or massive). An average schedule may be exemplified by the following parameters: heating at a rate of 25-35°C/h, cooling at a rate of 30-40°C/h, and isothermal holding for 6-8 h. at a peak temperature of 80-90°C. Thus, the total steam curing time for items from common Portland cement averages from 12 to 15 h. In the first place, hardening conditions are determined by the kind of cement. Quick-hardening cements reduce duration of isothermal holding to half the time. Moreover, optimum heating temperature of these cements is 70 to 80°C, which also brings down heating and cooling time substantially. As a result, the overall thermal treatment time for items from quick-hardening Portland cement is brought down to 6-8 h., the strength of cured items being 70-80% of its grade value.

Slow-hardening cement (puzzolana and slab Portland cement) requires more time for isothermal holding (up to 10-14 h.) and a higher isothermal heating temperature (up to 95-100°C). Thus, the overall steam curing time for concrete items from puzzolana or slab Portland cement is from 16 to 20 h.

Use of stiff concrete mixes of low initial water content reduces duration of steam curing by 15 to 20%.

Items from lightweight concrete heat up slowly because of their high heat-insulating properties, and thus require prolonged thermal curing schedules.

Autoclaving. The rate of most chemical reactions, including interaction of cement with water, concrete hardening is based on, increases with the rise in temperature. Moreover, concrete hardening requires a moist atmosphere. These

two factors are successfully combined in curing of items by high pressure steam. Saturated steam temperature rises with pressure. At normal pressure, saturated steam temperature (100% relative humidity) cannot be higher than 100°C. Should this temperature be exceeded, the relative humidity will drop to below 100%, and concrete items start drying.

Items are generally autoclaved at a pressure between 0.8-1.6 MPa, corresponding steam temperature approximating 170-203°C, the items then gaining grade strength within 8 to 10 h., which provides a sizeable economic effect.

A major virtue of concrete autoclaving is that sand, which is inert at normal temperature, becomes active at higher temperatures and interacts vigorously with lime to yield concrete of a strength of 20 MPa and over. This ensures a wide use of concrete for manufacturing strong, water-resisting and durable items by autoclaving. An autoclave is a steel cylinder of 2m in diameter, up to 20 m long, tightly sealed at the ends by heads.

However, autoclaves are much used in manufacture of items from lime-sand items: bricks, large-size items from dense lime-sand concrete (heavy concrete), and items of cellular structure feature low bulk density and heat conductivity (lightweight concrete).

Cellular lime-sand items are available in two kinds – foam and gas lime-sand.

### **3.7.5. Properties of Concrete**

Concrete strength. Concrete should acquire its design strength at a given time and possess such qualities as are required of the construction being manufactured from it (water and frost resistance, density, etc.). In addition, concrete mix should have adequate mobility.

In buildings and structures, concrete may be subjected to various stresses, such as compression, tension, bending and spalling. Concrete is best in compression, this being its basic mechanical property.

Concrete grade is determined by the compressive strength of a cubic specimen with sides measuring 15 cm, made from a working concrete mix after 28 days of hardening in normal conditions. By compressive strength, concretes is available in grades B10 ...B115 (MPa).

Cement concrete continually gains in strength at favorable temperature and humidity. For the first 7 to 14 days concrete strength grows rapidly, and then it slows down by the 28th day and gradually stops increasing; in a moist warm environment concrete strength may grow for many years.

Variation of concrete strength with time roughly follows the logarithmic law; on this basis, the concrete strength may be roughly calculated for different periods of hardening by means of the empiric formula

$$R_{cn} = R_{c28} \log n / \log 28,$$

where  $R_{cn}$  is compressive concrete strength after  $n$  days, Pa;

$R_{c28}$  is compressive concrete strength after 28 days, Pa;

$n$  is hardening period, days.

This formula can be used for a rough estimation of concrete strength from Portland cement after 7 days. Actual concrete strength in structure is determined by testing specimens prepared from working concrete mixes.

Density and impermeability of concrete. High-density concrete is obtained by a rational choice of aggregate (of minimum voidage), use of concrete mixes of low water-to-cement ratio, intensive compaction and introduction of plasticizing and hydrophobic surfactant admixtures.

One should remember, however, that there is no such thing as absolutely dense concrete. Its porosity is due to evaporation of water, which has not interacted chemically with cement as it hardens and to incomplete removal of air bubbles during compaction of the concrete mix, etc. Therefore, concrete is a material permeable to gases.

To make concrete constructions gas-impermeable, their interior surfaces are coated with gas-impermeable films, such as plastic.

An adequately thick construction from dense concrete with a fine pore structure is practically watertight. Water impermeability of concrete is characterized by the highest pressure of water which concrete is capable of resisting without letting water through. According to water impermeability, concretes fall into grades: W2, W4, ... , W20 that correspond to pressures of 0.2, 0.4, ... , 2.0 MPa, respectively.

Thinner constructions can be made perfectly watertight by using hydrophobic cement. Another method consists in applying a coat of waterproof plaster by pneumatic techniques (quniting).

Dense concrete can be made impermeable not only to water but also to viscous oil products, such as fuel oil and heavy oil. Light medium oil fractions, e.g., gasoline and kerosene penetrate concrete with greater ease than water. In order to protect concrete and reinforced concrete structures intended for storage of heavy oil products, their surfaces are coated with water glass; to protect them against penetration of light and fluid oil products (gasoline, kerosene, etc.), their surfaces are covered with special gasoline-proof membranes, special coats

(plastic films) or with building concrete, impervious to the above mentioned fluids.

Frost resistance is one of the major requirements upon concrete for hydraulic engineering structures, road surfaces, bridge piers, etc. Frost resistance of concrete is characterized by the maximum number of freezing-and-thawing cycles that 28-days specimens are capable of withstanding without losing more than 5% of their strength and more than 3% of their mass.

The State Standard for heavy concrete types including hydraulic engineering concrete, specifies a few grades in terms of frost resistance: F15, F25, ..., F100. Concrete grade is chosen by its frost resistance according to the climatic conditions (i.e. the number of fluctuations of the water level that washes concrete or the number of freezing-and-thawing cycles during winter season).

Generally, frost-resistant concrete is of high density. Production of such concrete has been discussed previously. Aggregates play an important part in frost resistance of concrete. The grade of aggregate in terms of its frost resistance should be not lower than that of concrete.

Deformation properties of concrete. In the process of hardening, concrete undergoes volumetric changes. Hardening of concrete in the air (with the exception of concrete from non-shrinking and expanding cements) is accompanied by a decrease in its volume, i.e. by shrinkage.

When concrete hardens in water, its volume increases during the initial period of hardening; under air-setting conditions, concrete shrinks. Concrete from fluid mixes (with high cement consumption and high water-to-cement ratio) shrinks considerably. Shrinkage is maximum during the initial period of hardening, its value being from 60 to 70% of the shrinkage after a month of hardening. This is due to the fact that cement paste loses water at a high rate owing to evaporation and absorption of water by cement as it hydrates. Dehydrated particles draw close together, and the cement stone shrinks.

Volumetric changes in massive concrete constructions during the initial period of hardening are due to the expansion caused by heat released during exothermic reactions between cement and water, which may raise the temperature inside heavy concrete constructions up to 50°C. Volumetric changes of concrete may cause considerable deformation and even cracking of constructions. To prevent such things, special expansion joints are provided in massive concrete constructions, and use is made from cements with low heat release.

Shrinkage of Portland cement concrete depends on mineralogical composition and fineness of cement, the shrinkage increasing with fineness.

Corrosion of concrete and means of protection. Practice has shown that concrete constructions may fail under physical and chemical influence of liquids and gases. Concrete is corroded mainly through disintegration of cement stone (while the aggregate may have been chosen adequately resistant). Physical and chemical processes taking place during cement corrosion have already been discussed in Chapter 3.5.2.

Concrete corrosion is due to penetration of an aggressive substance into the body of concrete; corrosion is particularly intensive when such substances continuously filtrate through cracks and pores in concrete. Therefore, the principal means of protection against corrosion is to make concrete as dense as possible and to design correctly the constructional components, so as to ensure uniform deformation of concrete in the process of hardening (free from cracks).

Corrosion of concrete may be prevented by using cements containing substances that chemically bind the lime that is given off in the hydrolysis of tricalcium silicate, and which carry active mineral admixtures and small amounts of tricalcium aluminate. Classed with this type of cements are Portland cement with hydraulic admixtures, slag Portland cement, aluminous cement, sulfate-resistant cement. It is common practice to impregnate concrete with cement mortar and soluble glass (a water solution of sodium silicate or potassium silicate). Concrete can be protected against corrodents by surface coats, (facing with solid impermeable ceramic tiles or stones laid with acid-resistant cement); facing with waterproof bituminous materials.

High-temperature resistance. Concrete is a fire-resistant mineral material as it is capable of withstanding high temperatures during fires. Fire resistance of concrete allows to use it for building chimney stacks of industrial furnaces and their foundations. Fire resistance of concrete depends not only on the kind of cement but also on the nature of aggregates. If aggregates are composed of crystalline quartz rock, concrete may crack at about 600°C because of a considerable increase in the volume of quartz.

When designing concrete constructions that are continuously exposed to high temperatures, it should be remembered that the strength of concrete from Portland cement drops by 25% at temperatures between 150 and 250°C. It should also be pointed out that if concrete is heated above 500°C and then wetted, it will disintegrate.

Special heat-resisting concrete is used in constructions exposed to high temperatures (above 250°C) for long periods of time; slag Portland cement is resistant to 700°C, aluminous cement is resistant from 1,200 to 1,400°C.

### 3.7.6. Varieties of Heavy Concrete

Heavy concrete (for construction and special structures) is manufactured from cement and common dense aggregates.

By application special heavy concrete is divided into the following kinds: hydraulic engineering concrete, acid-resistant concrete, refractory concrete, colored concretes and road concrete.

Hydraulic engineering concrete is a variety of heavy concrete that is characterized by high water resistance, water impermeability, frost resistance, low heat release and adequate resistance to chemical attack in aggressive media. Hydraulic engineering concrete is used for structures or parts of constructions periodically or continuously washed by water.

The classification of hydraulic engineering concrete takes into account zones where concrete is used:

- underwater concrete, permanently located in water;
- concrete in of fluctuating water level zone;
- concrete located above fluctuating water level.

Underwater concrete, as well as both concrete of fluctuating water level type and the one exposed to subsoil waters, should be resistant to corrosion by water of a given composition.

By compressive strength, hydraulic engineering concrete is determined at the age of 28 and 180 days.

Quality of hydraulic engineering concrete is favorably affected by active mineral admixtures to Portland cement, which interact with calcium oxide hydrate and consolidate concrete, thus improving its water-resisting property and reducing heat release.

Water requirement of concrete mix and cement consumption can be reduced, and the density and frost resistance of hydraulic engineering concrete is enhanced by surfactants.

Natural aggregates (sand and gravel) for hydraulic engineering concrete should meet more stringent requirements than common concrete. Granulometric composition of aggregates should provide minimum voids and the greatest possible amount of large particles, so as to lower cement consumption and, therefore, reduce heat release and tendency to deformation in the process of concrete hardening.

As it hardens, concrete should be given thorough care; it should be supplied with adequate humidity and maintained at a constant temperature to avoid volumetric deformations of constructions.

Acid-resistant concrete is obtained from acid-resistant cement, which consists of aqueous solution of sodium silicate (soluble glass), acid-resistant



aggregate in powder form (finer than 0.15mm) and an additive (hardening accelerant-sodium fluosilicate  $\text{Na}_2\text{SiF}_6$ ) and aggregates (quartz sand, crushed stone from andesite, diabase and other acid-resistant materials).

Acid-resistant concrete should be hardened in a warm air-dry atmosphere (in contrast to common concrete).

Acid-resistant concrete features solid cohesion with steel reinforcement, resistance to attack by sulphuric, hydrochloric, nitric, and other acids (except hydrofluoric acid), a 3-day and 28-day compressive strength of 12 and 20 MPa, respectively.

Acid-resistant concrete disintegrates gradually when acted upon by water and weak acids. The concrete well withstands concentrated acid but decays rapidly when attacked by alkali liquors.

Acid-resistant concrete is used for various constructions and for lining floors and walls in chemical industry.

Refractory concrete is capable of retaining (within specified limits) its physical and mechanical properties under prolonged exposure to high temperatures. By the kind of binding material, heat-resistant concrete fall into the following categories:

- concrete from Portland cement (to 300°C);
- concrete from slag Portland cement (to 700°C);
- concrete from water glass (to 1,000°C);
- concrete from high-alumina cement (to 1,400°C).

Aggregates for refractory concrete are sand and crushed stone from chromite (to 1,400°C), chamotte, fire-clay, blast-furnace slag, basalt and diabase (to 1,000°C). This variety of concrete is used for building stacks and foundations of blast furnaces, open hearth and other types of industrial furnaces.

Decorative concrete is obtained by introducing alkali- and light-resistant pigments into the mix in amounts ranging from 8 to 10% of the weight of cement (ochre, mummy, minimum and others) or by using colored cement. Sometimes it is made with aggregates possessing the required color, e.g. tuffs, red quartzites, marble and other colored rocks.

Decorative concretes are used for ornamental purposes in construction buildings and structures, underground pedestrian crossings, separating lines on traffic lanes, park lanes and for the manufacture of items for public welfare (Fig. 27, 28).

Road concrete. Road concrete is subdivided according to its application into concrete for single-layer roads, for surface courses of two-layer concrete roads, for bed courses of two-layer roads and super-highways.

Service conditions of road concrete are very severe. It is exposed to repeated wetting and drying, freezing and thawing, and wear by vehicle wheels, and, therefore, it must meet stringent requirements as regards strength, wear and frost resistances, as well as resistance to atmospheric erosion.

The grade of concrete by strength depends on its application.

A major strength characteristic of road cement and concrete is tensile strength in bending.

Surface courses are made durable not only by proper manufacturing procedures but also by the use of high-quality materials.

Road concrete is prepared from Portland cement and its varieties, such as plasticized and hydrophobic Portland cement.

Hardening accelerants, particularly effective in freezing weather, are admixtures of calcium chloride and sodium chloride in amounts up to 3% for non-reinforced, and 2% for reinforced surface courses and also sodium nitrite and potassium carbonate.

Concrete for radiation shielding. The use of nuclear energy for peaceful purposes has necessitated means for protecting the personnel against radiation hazards caused by nuclear reactors, nuclear power plants, plants for manufacturing and processing isotopes, etc.

The degree of protection is determined by thickness of the shield and bulk density of fillers. The material that possesses both properties required for radiation protection is concrete.

Aggregates used for shielding concrete are heavy materials, such as barite, magnetite, limonite and metal scrap, e.g. cast-iron shot, reinforcement and rolling mill waste, metal shavings, etc. The bulk density of protective superheavy concrete depends on the kind of aggregate.

Binding materials for preparing superheavy shielding concrete are Portland cement, slag Portland and aluminous cement.

### **3.7.7. Lightweight Concrete**

Concrete of bulk density less than  $2,000 \text{ kg/m}^3$  is referred to a group of lightweight concrete of high porosity.

By the method of achieving artificial porosity, concrete falls into the varieties below:

- lightweight concrete from lightweight porous aggregate;
- large-pored (sand-free) concrete from single-size fraction solid or porous coarse aggregate containing no sand;
- cellular concrete with artificial cells, which act as aggregate particles.

Concrete is a variety of cellular concrete only with porous big aggregates (porosity of concrete is 7-25%).

By application, lightweight concrete is classified as follows:

- heat insulating concrete whose chief purpose is to enhance thermal resistance of exterior walls; its bulk densities are less than  $600 \text{ kg/m}^3$ ; and heat conductivity coefficients are not higher than  $0.17 \text{ W/m}^\circ\text{C}$ ;
- structural concrete that carries large loads in buildings and structures; its bulk density is  $1,400\text{-}2,000 \text{ kg/m}^3$ , its strength grade is not less than 15 MPa, and frost resistance is not less than F25.
- structural and heat insulating concrete which combines the properties of the two above kinds of lightweight concrete; its bulk density is from 600 to  $1,400 \text{ kg/m}^3$ ; heat conductivity coefficient is not higher than  $0.6 \text{ W/m}^\circ\text{C}$ , and strength grade is not less than 3.5 MPa.

Lightweight concrete from porous aggregates differs principally from common heavy concrete due to the specific properties of porous aggregates. The aggregates have lower bulk densities than the solid ones, considerably smaller strengths, frequently below that of concrete, and highly developed and rough surfaces. These properties of lightweight aggregates govern those of lightweight concrete mixes and concrete.

Water requirements and water content of concrete mixes change sharply with the type of aggregate.

Optimum amount of water for lightweight concrete depends mostly on water requirements of the aggregate and of the binding material (fineness and composition), mix compaction and concrete composition.

Water requirement of aggregate depends on its granulometric composition and porosity, and commonly it increases with the total surface area and porosity of its particles.

The fact that water is sucked from cement, paster or mortar by aggregates during preparation and placing of concrete mix, accounts for the latter's relatively rapid thickening, which causes stiffness and poor placeability. This specific property is also caused by the rough and highly developed surface of the porous aggregate. To improve mix mobility, greater amount of water should be added to it as compared to common (heavy) concrete.

Bulk density and strength of lightweight concrete depend mostly on bulk density and grain composition of the aggregate, consumption of binding material and water and on the method of mix compacting. Quality of porous aggregate may serve as an indication of concrete strength to be expected.

A special property of lightweight concrete is that their strength depends not only on the quality of cement but also on its quantity, strength and bulk

density of concrete rising with cement consumption. This is due to the fact that the greater the quantity of cement paste is, the better the compactness of lightweight concrete is and the higher the content of cement stone is, which is the strongest and the heaviest ingredient.

It is a good practice to use highly active binding materials whenever bulk density of concrete is to be reduced and its strength retained.

Heat insulating properties of lightweight concrete are function of the porosity and the nature of pores. In lightweight concrete, heat is transmitted through the solid carcass and the air filling the pores. Therefore, the bigger the volume of pores is, the better its heat insulating properties are.

Due to porosity, lightweight concrete is less frost-resistant than the heavy one, but it is still suitable for exterior walls and other structures of buildings and structures.

Frost resistance of lightweight concrete can be enhanced by artificial porous aggregates, processing low water absorption (e.g. ceramsite) and by increasing cement stone porosity. Frost resistance of lightweight concrete can also be improved by hydrophobic admixtures.

Versatility of lightweight concrete makes it suitable for various structural components of buildings and structures.

Thus, lightweight concrete of low heat conductivity on porous aggregates serves to manufacture panels for walls and floors of heated buildings.

Cellular concrete is a variety of lightweight concrete with uniformly distributed pores (up to 85% of the total volume of concrete); it is obtained through hardening of a pre-expanded (by a pore-forming agent) mixture of binder, (cement or lime) water and siliceous component. This concrete does not have big aggregates.

By the kind of binder, cellular concrete is divided into the following groups: gas and foam concrete based on Portland cement or a cement-lime binder; gas-lime silicate and foam-lime-silicate concrete based on a mixture of quicklime and quartz sand; gas-slag and foam-slag concrete obtained from a mixture of lime and fine blast-furnace granulated slag or entrained cinder.

The cellular structure in concrete is formed by means of foam-and gas-forming agent. The foam-forming agents are some varieties of surfactants substance that favor generation of stable foam.

Widely used as gas forming agent is aluminum powder, which reacts with aqueous solution of calcium hydroxide to give off hydrogen. The evolving hydrogen swells the mix, which then hardens, while retaining a porous structure.

In Portland cement concrete, calcium hydroxide is formed as a result of the hydration reaction of tricalcium silicate; in lime-silicate concrete it is formed as a result of hydration reaction of quicklime.

By hardening conditions, cellular concrete is divided into steam cured (gas and foam concrete) and autoclaved classes (autoclaved aerated concrete).

By application, cellular concrete is divided into heat insulating concrete with a bulk density in dry state of up to  $500 \text{ kg/m}^3$  and compressive strength grades up to 25; structural-and-heat-insulating concrete, with a bulk density of  $500$  to  $900 \text{ kg/m}^3$  and compressive grades from 25 to 75; and finally, structural cellular concrete, with a bulk density of  $900$  to  $1,200 \text{ kg/m}^3$  and compressive grades from 75 to 200.

Cellular concrete is very porous and features low bulk density and, accordingly, relatively low strength. In the ideal, structure of cellular concrete is composed of closed cells from  $0.4$  to  $1.5 \text{ mm}$  across. Heat conductivity coefficient of cellular concrete ranges from  $0.07$  to  $0.25 \text{ W/m}^\circ\text{C}$ .

Frost resistance grades for concrete are as follows: F10, 25, 35, 50, 100 and 200. High frost resistance and low coefficient of heat conductivity of cellular concrete depend on its structural peculiarities, or on numerous closed pores filled with air or gas. Blocks from cellular concrete are applied in heated buildings.

### **Self-Check Questions and Tasks:**

1. Describe the composition of concrete mixtures and selection of components.
2. What are some technological properties of concrete mixtures and methods of their regulation?
3. Name and describe the operational properties of concrete: physical and mechanical.
4. What are the ways of improving the service properties of concrete: strength, frost resistance, water resistance?
5. What special types of heavy concrete do you know? How are they used in construction?
6. Speak about production technologies of lightweight concrete.
7. What classification of lightweight concrete do you know? What is their application in construction?
8. Specify the purpose of concrete and reinforcing steel in reinforced concrete structures.
9. Describe the technology of monolithic reinforced concrete structures at construction sites in summer and winter conditions.
10. Describe production technologies of precast concrete structures at a plant.
11. Describe the features of production technology for prestressed concrete structures, their properties and applications.

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