

The Basic Properties of Building Materials

This chapter discusses the components, the structures of materials and the influence of their compositions on the properties; it emphasizes on the physical properties and the mechanical properties of materials; and also it introduces the decorativeness and the durability of materials.

In the civil engineering, building materials plays different roles, so they should possess corresponding properties. For example, structural materials should have good mechanical characteristics; waterproof materials should be impermeable and water-resistant; wall materials should be heat-insulating and sound-absorbing. In addition, building materials should be durable because they often affected by various external factors, such as wind, rain, sun and frost.

The basic properties of building materials include physical property, mechanical property, durability and decorativeness. The commonness of the properties is discussed in this chapter and their specialties will be discussed in relevant chapters.

2.1 Compositions and Structures of Materials and the Influence of Their Constructions on the Properties

2.1.1 The Compositions of Materials

The compositions of materials include chemical compositions and mineral compositions which are the key factors for the properties of materials.

1. Chemical Composition

The chemical composition refers to the chemical constituents. Various chemical compositions result in different properties. For example, with the increase of carbon content, the strength, hardness and toughness of carbon

steel will change; carbon steel is easy to rust, so stainless steel comes into being by adding chromium, nickel and other chemical components into steel.

2. Mineral Composition

Many inorganic non-metallic materials consist of a variety of mineral compositions. Minerals are monomers and compounds with a certain chemical components and structures. The mineral compositions are the key factors for the properties of some building materials (such as natural stone, inorganic gel and other materials). Cement reveals different characteristics because of different clinkers. For example, in Portland cement clinkers, the condensation hardening is fast and the strength is high when the content of tricalcium silicate—the clinker mineral—is high.

2.1.2 Structures and Constructions of Materials

The structures of materials can be divided into macro-structure, meso-structure and micro-structure, which are the key factors related to the properties of materials.

1. Macro-structure

The thick structure above millimeter that can be identified with magnifying glass or naked eyes is called as macro-structure. It can be classified into the following types:

(1) Dense Structure

Basically, the inner side of the material is non-porous, such as steel, nonferrous metals, glass, plastic and dense natural stone.

(2) Porous Structure

The inside of this material has macro-pores, such as aerated concrete, foam concrete, foam plastics and artificial light materials.

(3) Micro-porous Structure

The inner side of this material is micro-porous which is formed by mixing plenty of water into the micro-pores, such as common fired brick, and architectural gypsum products.

(4) Fibrous Structure

This material has the internal organization with direction, such as wood, bamboo, glass reinforced plastic, and asbestos products.

(5) Laminated or Layered Structure

This material has composite structure which is layered structure formed agglutinated by different sheets or anisotropic sheets

(6) Granular Structure

This is a kind of loose granular material, such as sand, gravel, and expanded perlite.

2. Meso-structure

The micro-level structure that can be observed by optical microscope is called meso-structure or sub-microstructure. What is mainly studied in this structure are the size, shape and interface of grains and particles, and the size, shape and distribution of pores and micro-cracks. For example, the size and the metallographic structure of metal grains can be analyzed; the thickness of concrete, cement and the porous organization can be distinguished; and the wood fiber of timber, catheter, line, resin and other structures can be observed.

The micro-structure has a great influence on the mechanical properties and durability of materials. The grain refinement can improve the strength. For example, steel is mixed with titanium, vanadium, niobium and other alloying elements which can refine grains and significantly increase intensity.

3. Microstructure

The atomic and molecular structures of materials that can be studied by electron microscopy, X-ray diffractometer and other means are called microstructure. This structure can be divided into crystal and non-crystal.

(1) Crystal

The solid whose particles (atoms, molecules or ions) are packed in a regularly ordered, repeating pattern extending in all three spatial dimensions is known as crystal. It is characterized by a fixed geometric shape and anisotropy. The various mechanical properties of crystal materials are related to the arrangement pattern of particles and their bonding force (chemical bond).

Crystal can be divided into the following types by chemical bonds:

1) Atomic Crystal is formed by neutral atoms which are connected with each other by covalent bonds. The bonding force is strong. The strength, hardness, melting point and density of atomic crystal are high, such as diamond, quartz and silicon carbide.

2) Ionic Crystal is formed by cations and anions. The ions are related with each other by electrostatic attraction (Coulomb attraction) which is generally stable. The strength, hardness and melting point are high but volatile; some are soluble and density is medium. There is calcium chloride, gypsum, limestone and so on.

3) Molecular Crystal is formed by molecules which are tied to each other by molecular force (Van der Waals attraction). The bonding force is weak. The strength, hardness and melting point are low; most of them are soluble and the density is low. There is wax and some organic compounds.

4) Metal Crystal is formed by metal cations which are connected with each other by metal bonds (Coulomb attraction). The strength and hardness are volatile and the density is high. Because metal ions have free ions, the metal materials such as iron, steel, aluminum, copper and their alloys have good thermal conductivity and electrical conductivity.

Of crystal materials such as asbestos, quartz and talc, only a few ones have one combination bond, and others are complex crystal materials with more than two types of combination bonds.

(2) Non-Crystal

The fuse mass with a certain chemical constituents is cooled so rapidly that the particles cannot be packed in a regular ordered pattern, and thus it is solidified into a solid, known as non-crystal or vitreous body or amorphous body. Non-crystal is characterized by no fixed geometry shape and isotropy. A large number of chemicals cannot be released because of the rapid cooling, so non-crystal materials have chemical instability, easily reacting with other substances. For example, granulated blast furnace slag, volcanic ash and fly ash can react with lime under water for hardening, which are used as building materials. Non-crystal plays the role of adhesive in products of burned clay and some natural rocks.

2.2 Physical Properties of Materials

2.2.1 Density, Apparent Density and Bulk Density

1. Density

Density is the dry mass per unit volume of a substance under absolute compact conditions. It is defined by:

$$\rho = \frac{m}{V} \quad (2.1)$$

In this formula: ρ is the density (g/cm^3);

m is the mass under dry conditions (g);

V is the volume under absolute compact conditions (cm^3).

The volume under absolute compact conditions refers to the solid volume without the volume of inner pores. Except steel, glass, asphalt and a few other materials, most materials contain some pores in natural state. In the measurement of the density of a porous material, the material is ground into powder at first; the powder is dried to fixed mass; and then the solid volume is measured by Lee's density bottle; finally the density is calculated by the above formula. The finer the powder is ground, the more real the size will be. Thus the density value is more correct.

2. Apparent Density

Apparent density is the dry mass per unit volume of a substance under natural conditions. It is defined by:

$$\rho_0 = \frac{m}{V_0} \quad (2.2)$$

In this formula: ρ_0 is the apparent density (kg/m^3);

m is the mass under dry conditions (kg);

V_0 is the volume under natural conditions (m^3).

The volume of a substance under natural conditions refers to the solid volume and the volume of inner pores. If it is a regular shape, the volume can be directly measured; if it is in an irregular shape, the volume can be measured by the liquid drainage method after sealing pores with wax; the liquid drainage method can be directly used to measure the volume of sandstone aggregate utilized in concrete but the volume here is the solid volume plus the volume of closed pores—without the volume of the pores open to the outside. Because the sandstone is compact with only a few pores, the volume of the pores open to the outside is little. Thus the volume measured by the liquid drainage method can be called apparent density which is called virtual density in the past.

The quality and volume change with the water content. Generally, apparent density refers to the density of a substance under dry conditions. Other moisture conditions should be specified.

3. Bulk Density

Bulk density refers to the per unit volume of a substance under the conditions that powdery or granular materials are packed. It is defined by:

$$\rho_0' = \frac{m}{V_0} \quad (2.3)$$

In this formula: ρ_0' is the bulk density (kg/m^3);

m is the mass under dry conditions (kg);

V_0' is the volume under packing conditions (m^3).

Bulk density is measure by volumetric container. The size of volumetric container depends on the size of particles. For example, 1L volumetric container is used to measure sand and 10L, 20L, 30L volumetric containers are used in the measurement of stone.

Bulk density is the packing density of a substance under dry conditions and others should be marked.

The density, apparent density and bulk density of common building materials are listed in Table 2.1.

Table 2.1 Density, Apparent Density, Bulk Density and Porosity of Common Building Materials

Name	Density (g/cm^3)	Apparent Density (kg/m^3)	Bulk Density (kg/m^3)	Porosity (%)
Steel	7.85	7850	—	—
Granite	2.6~2.9	2500~2850	—	0~0.3
Limestone	2.6~2.8	2000~2600	—	0.5~3.0
Gravels or Pebbles	2.6~2.9	—	1400~1700	—
Ordinary Sand	2.6~2.8	—	1450~1700	—
Sintered Clay Brick	2.5~2.7	1500~1800	—	20~40
Cement	3.0~3.2	—	1300~1700	—
Ordinary Concrete	—	2100~2600	—	5~20
Asphalt Concrete	—	2300~2400	—	2~4
Wood	1.55	400~800	—	55~75

2.2.2 The Solidity and Porosity

1. Solidity

Solidity refers to the degree how the volume of a material is packed with solid substances, which is the ratio of the solid volume to the total volume. It is defined by:

$$D = \frac{V}{V_0} \times 100\% \quad \text{or} \quad D = \frac{\rho_0}{\rho} \times 100\% \quad (2.4)$$

2. Porosity

Porosity (P) is the percentage of the pores volume to the total volume with the volume of a substance. It is defined by:

$$P = \frac{V_0 - V}{V_0} \times 100\% = \left(1 - \frac{V}{V_0}\right) \times 100\% = \left(1 - \frac{\rho_0}{\rho}\right) \times 100\% \quad (2.5)$$

The relationship between solidity and porosity can be expressed as:

$$D + P = 1$$

Both solidity and porosity reflect the compactness of materials. Porosity and characteristics of pores (including size, connectivity, distribution, etc.) affect the properties of materials greatly. Generally, for the same material, the lower the porosity is, the less the connected pores are. Thus the strength will be higher, the water absorption will be smaller, and the permeability and frost resistance will be better, but the thermal conductivity will be greater. Porosity of some common materials is listed in Table 2.1.

2.2.3 Fill Rate and Voidage

1. Fill Rate

Fill Rate (D') is the degree how granules pack the granular materials in the bulk volume. It is defined by:

$$D' = \frac{V_0'}{V_0} \times 100\% \quad \text{or} \quad D' = \frac{\rho_0'}{\rho_0} \times 100\% \quad (2.6)$$

2. Voidage

Voidage (P') is the percentage of the void volume among granules to the bulk volume in the bulk volume of granular materials. It is defined by:

$$P' = \frac{V_0' - V_0}{V_0'} \times 100\% = \left(1 - \frac{V_0}{V_0'}\right) \times 100\% \quad (2.7)$$

Voidage reflects the compactness among granules of the granular materials.

The relationship between fill rate and voidage can be expressed as:

$$D' + P' = 1$$

2.2.4 Hydro-properties of Materials

1. Hydrophilicity and Hydrophobicity

When the material is exposed to water in the air, it will be hydrophilic or hydrophobic according to whether it can be wetted by water or not. If it can be wetted by water, it is the hydrophilic material; if not, it is the hydrophobic material.

When materials are exposed to water droplets in the air, there will be two cases, shown as Figure 2.1. In the intersection of the material, water and air, a tangent is drawn along the surface of the water droplet, and the angle between the surface and the tangent is angle θ , known as wetting angle.

When angle θ is smaller than or equals to 90° ($\theta \leq 90^\circ$), the material is hydrophilic, such as wood, brick, concrete and stone. The attractive force between materials molecules and water molecules is stronger than the cohesive force between water molecules, so the materials can be wetted by water.

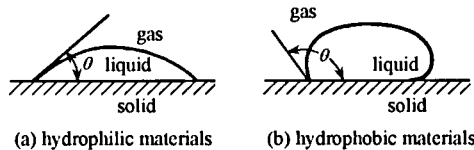


Figure 2.1 The Wetting Schematic Diagram of Materials

When angle θ is bigger than 90° ($\theta > 90^\circ$), the material is hydrophobic, such as asphalt, wax, and plastic. The attractive force between material molecules and water molecules is weaker than the cohesive force between water molecules, so the material cannot be wetted by water. The hydrophobic materials are moisture-proof and waterproof, usually used for water-resistant materials or the surface treatment for the hydrophilic materials in order to reduce water absorption and improve impermeability.

2. The Water Absorption and Hygroscopicity

(1) Water Absorption

Water absorption refers to the property of absorbing water when materials are exposed to water. It is expressed by the water-absorption ratio. And there are two types of expression:

1) Specific Absorption of Quality

Specific absorption of quality refers to the percentage of the absorbed water to the dry mass when the material absorbs water to saturation. It is defined by:

$$W_m = \frac{m_b - m_g}{m_g} \times 100\% \quad (2.8)$$

In this formula: W_m is the specific absorption of quality(%);

m_b is the mass when the material absorbs water to saturation(g);

m_g is the mass when the material is dry (g).

2) Specific Absorption of Volume

The specific absorption of volume refers to the percentage of the absorbed water's volume to the material's natural volume when the material absorbs water to saturation. It is defined by:

$$W_v = \frac{m_b - m_g}{V_0} \times \frac{1}{\rho_w} \times 100\% \quad (2.9)$$

In this formula: W_v is the specific absorption of volume(%);

V_0 is the volume of the dry material in natural state(cm^3);

ρ_w is the density of water(g/cm^3), usually $1.0\text{g}/\text{cm}^3$ at the room temperature.

The relationship between specific absorption of quality and that of volume is as follows:

$$W_v = W_m \cdot \rho_0 \quad (2.10)$$

In this formula: ρ_0 is the apparent density of the material in dry state (simply called dry apparent density)(g/cm^3).

The water absorption depends on not only hydrophilicity and hydrophobicity of the material but also the porosity and characteristics of the pores. For normal materials, the higher the porosity is, the stronger the water absorption is. The more the open and connected tiny pores are, the stronger the water absorption is; it is not easy for water to be absorbed if the pores are closed; if they are large and open, water is easy to be absorbed but is hard to be hold, and thus the water absorption is weak. The water-absorption ratios of various materials vary greatly. For example, the specific absorption of quality of granite rock is 0.2%~0.7%, that of ordinary concrete is 2%~3%, that of ordinary clay brick is 8%~20%, and that of wood or other light materials is often above 100%.

The water absorption will have a negative impact on materials' nature. If a material absorbs water, its quality will increase, its volume will expand, its thermal conductivity will increase and its strength and durability will decrease.

(2) Hygroscopicity

Hygroscopicity is the property of materials to absorb water in the air. It can be expressed by moisture content.

Moisture content is the percentage of the water quality contained in a material to its dry mass, expressed by W_h . It is defined by:

$$W_h = \frac{m_s - m_g}{m_g} \times 100\% \quad (2.11)$$

In this formula: W_h is the moisture content(%);

m_s is the mass when the material contains water(g);

m_g is the mass when the material is dry(g).

The hygroscopic effect is reversible. Dry materials can absorb moisture in the air and wet materials can release moisture to the air. The moisture content is called equilibrium moisture content if the content of a material equals to air humidity.

The hygroscopicity of materials is related to air temperature and air humidity. The higher humidity is and the lower the temperature is, the higher hygroscopicity will be; contrarily, the hygroscopicity will be low. Both the factors affecting hygroscopicity and the influence on materials' properties after absorbing water are the same to the water absorption of materials.

3. Water Resistance

Water resistance is the ability to maintain its original properties when the material is affected by water in a long-term.

The water-resistant ability of different materials varies in expressing ways. For example, the water resistance of structural materials mainly refers to the changes in intensity, and with softening coefficient it is defined by:

$$K_R = \frac{f_b}{f_s} \quad (2.12)$$

In this formula: K_R is the softening coefficient of a material;

f_b is the compressive strength of a material in water saturation state (MPa);

f_g is the compressive strength of a material in dry state(MPa).

The softening coefficient of a material K_R varies between 0 (clay) ~1 (steel). The value of K_R reveals the decreasing degree of the strength after the material absorbs water to saturation. The bigger K_R is, the stronger the water resistance is, which indicates that the decreasing degree of the strength in saturation state is low; contrarily, the water resistance is weak. Generally, the material whose K_R is bigger than or equals to 0.85 is known as water-resistant material. K_R is an important basis for selecting building materials. If the major structures are often in water or wetted seriously, the materials whose K_R is bigger than or equals to 0.85 ($K_R \geq 0.85$) should be chosen; if they are the minor structures or wetted lightly, the materials whose K_R is bigger than or equals to 0.75 ($K_R \geq 0.75$) should be chosen.

4. Impermeability

Impermeability is the ability of a material to resist the pressure water or the infiltration of other liquids. It is expressed by permeability coefficient which is defined by:

$$K = \frac{Qd}{AtH} \quad (2.13)$$

In this formula: K is the permeability coefficient (cm/s);

Q is the volume of water seepage(cm^3);

d is the thickness of a specimen(cm);

A is the seepage area(cm^2);

t is the seepage time(s);

H is the water head(cm).

Permeability coefficient K reflects the rate of water flowing in a material. The bigger K is, the faster the flow rate of water is and the weaker the impermeability is.

The impermeability of some materials (such as concrete and mortar) can be expressed by impermeable level which is represented by the maximum water pressure resisted by materials. For example, P6, P8, P10 and P12 reveal that the materials can resist 0.6MPa, 0.8MPa, 1.0MPa, and 1.2MPa water pressure without water seepage.

The impermeability of a material is related not only to its own hydrophilicity and hydrophobicity but also to its porosity and the characters of pores. The smaller the porosity is and the more the closed pores are, the

stronger the impermeability is. Impermeable materials should be used in water conservancy projects and the underground projects usually affected by pressure water. Waterproof materials should be impermeable.

5. Frost Resistance

Frost resistance is the property that a material can withstand several freeze-thaw cycles without being destroyed and its strength does not decrease seriously when the material absorbs water to saturation. It is expressed by frost-resistant level.

Frost-resistant level is indicated by the biggest freeze-thaw-cycle times of a specimen that both its quality loss and strength reduction are within provisions when it is affected by freeze-thaw cycles in water saturation state, such as F25, F50, F100 and F150.

The reason for the freeze damage is a volume expansion (about 9%) caused by freeze of the water within the material's pores. If a material's pores are full of water, its volume will expand and there will be a great tensile stress to pore walls when water is frozen into ice. If this stress exceeds the tensile strength, the pore walls will crack, the porosity will increase and the strength will decrease. The more the freeze-thaw cycles are, the greater damages there will be. And it will even cause the complete destruction of a material.

There are internal and external factors affecting frost resistance of a material. The internal factors are the composition, structures, construction, porosity, the characteristics of pores, strength, water resistance, and so on. The external factors are the water filling degree within a material's pores, freezing temperature, freezing speed, freeze-thaw frequency, and so on.

2.2.5 Thermal Properties

1. Thermal Conductivity

The property of a material that indicates its ability to conduct heat is known as thermal conductivity. It is expressed by the coefficient of thermal conductivity λ , which is defined by:

$$\lambda = \frac{Qd}{(T_2 - T_1)At} \quad (2.14)$$

In this formula: λ is the coefficient of thermal conductivity [W/(m • K)];

Q is the conducted heat quantity (J);

d is the thickness of a material (m);

A is the heat-transfer area (m²);

t is the time for the heat transfer (s);

$T_2 - T_1$ is the temperature difference of the two materials (K).

The smaller the value of λ is, the better insulation the material has.

The thermal conductivity of a material is related to its composition and structure, the porosity and the characteristics of its pores, the water content, temperature and other conditions. The coefficient of thermal conductivity of metallic materials is bigger than that of non-metallic materials. The bigger the porosity is, the higher the coefficient will be. Tiny and closed pores indicate low coefficient; big and open pores are easy to create convection heat, which indicates that the coefficient is high. The thermal conductivity coefficient of a material containing water or ice increases dramatically because the coefficient of water and ice is bigger than that of air.

2. Thermal Capacity

Thermal capacity is the property of a material to absorb heat when it is heated and to release heat when it is cooled. It is defined by:

$$Q = m \times C(T_2 - T_1) \quad (2.15)$$

or

$$C = \frac{Q}{m(T_2 - T_1)} \quad (2.16)$$

In this formula: Q is the heat absorbed or released by a material (J);

m is the mass of a material (g);

C is the specific heat of a material [J/(g·K)];

$T_2 - T_1$ is the temperature difference before and after heating or cooling (K).

The specific heat, also called specific heat capacity, is the measure of the heat energy that a substance in a unit quantity absorbs or releases when the temperature increases or decreases 1K. The bigger the specific heat is, the better the stability of the indoor temperature will be.

Thermal conductivity coefficient and specific heat should be known when thermal calculations are conducted to buildings. There are thermal conductivity coefficients and specific heat capacities of several common materials are listed in Table 2.2.

Table 2.2 Thermal Conductivity Coefficients and Specific Heat Capacities

Substance	Heat Conductivity Coefficient λ [W/(m • K)]	Specific Heat Capacity C [J/(g • K)]	Substance	Heat Conductivity Coefficient λ [W/(m • K)]	Specific Heat Capacity C [J/(g • K)]
Copper	370	0.38	Fiberboard for Thermal Insulation	0.05	1.46
Steel	55	0.46	Glass Wool Board	0.04	0.88
Granite	2.9	0.80	Foam	0.03	1.30
Ordinary Concrete	1.8	0.88	Sealed Air	0.025	1.00
Ordinary Clay Brick	0.55	0.84	Water	0.60	4.19
Pine (Cross Striations)	0.15	1.63	Ice	2.20	2.05

3. Thermal Deformation

Thermal deformation is the property of a substance to expand with heat and contract with cold, customarily called temperature deformation. It is expressed by linear expansion coefficient α , which is defined by:

$$\alpha = \frac{\Delta L}{L \times \Delta t} \quad (2.17)$$

In this formula: α is the linear expansion coefficient of a substance (1/K);

ΔL is the expansion or contraction value of a specimen(mm);

L is the length before heating or cooling(mm);

Δt is the temperature difference(K).

The bigger the linear expansion coefficient α is, the greater the thermal deformation will be.

The thermal deformation is detrimental to the civil engineering. For example, in a large-area or large-volume concrete project, temperature cracks can be caused if the expansion tensile stress is beyond the tensile strength of concrete; in a large-volume construction work, expansion joints are set to prevent the cracks caused by thermal deformation; and Petroleum asphalt will have brittle fractures when temperature drops to a certain extent.

4. Flame Resistance

Flame resistance is the property of a substance not to flame in case of contacting with fire in the air. Materials can be divided into non-flammable

materials, fire-retardant materials and flammable materials according to their reaction to fire.

(1) Non-flammable Materials

Non-flammable materials are the ones that cannot be fired, carbonized or slightly burned when contacting with fire or high temperature in the air, such as brick, natural stone, concrete, mortar and metal.

(2) Fire-retardant Materials

Fire-retardant materials are the ones that are hard to be burned or carbonized when contacting with fire or high temperature in the air and stop burning or slightly flaming immediately when leaving fire, such as gypsum board, cement asbestos board, and lath and plaster.

(3) Flammable Materials

Flammable materials are the ones that are ignited or flame immediately when contacting with fire or high temperature in the air and continue to burn or slightly flame when leaving fire, such as plywood, fiberboard, wood and foil.

In construction, the selection of non-flammable materials or fire-retardant materials depends on fire-resistant levels of buildings and the parts where materials are used. Fire prevention should be dealt with when flammable materials are used.

2.3 Mechanical Properties of Materials

2.3.1 Strength and Strength Grade of Materials

1. Strength of Materials

Strength is the greatest stress that a substance can bear under external forces (loads) without destruction. According to different forms of external forces, the strength includes tensile strength, compressive strength, bend strength, shear strength and others. These kinds of strength are all determined by static test, known as the static strength. The static strength is tested by destructive experiments based on standard methods (see Appendix).

The stress states of a material are shown in Figure 2.2.

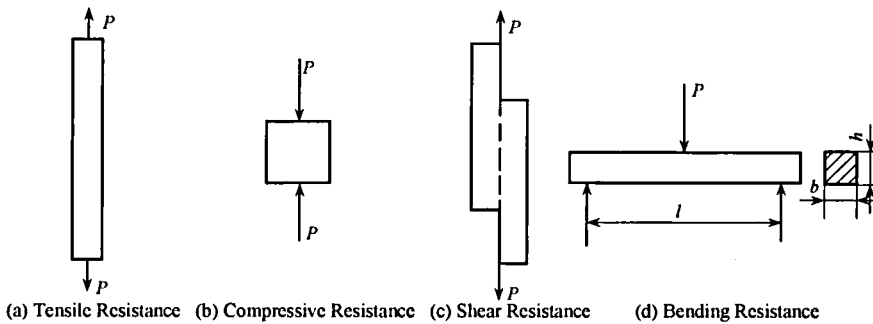


Figure 2.2 The Stress States of a Material

The tensile strength, compressive strength and shear strength can be defined by:

$$f = \frac{P}{A} \quad (2.18)$$

In this formula: f is the strength of a material (MPa);

P is the largest load of a specimen when it is destructed (N);

A is the force bearing area of a specimen(mm^2).

The bend strength is related to the force that a material bears and the cross-section shape. For the strip specimen with rectangular cross-section, when it is supported at both ends and a load converges in the middle, its bend strength can be calculated by:

$$f = \frac{3Pl}{2bh^2} \quad (2.19)$$

In this formula: f is the bend strength of a substance(MPa);

P is the largest load of a specimen when it is destructed(N);

l is the distance between two supporting ends(mm);

b is the width of the cross-section(mm);

h is the height of the cross-section(mm).

The strength of a material is related to its composition and structure. The strength will be different if the compositions of materials are the same but the structures are different. The bigger the porosity is, the smaller the strength will be. The strength is also concerned with testing conditions, such as the sample's size, shape, surface and water content, loading speed, temperature of the test environment, the accuracy of test equipment, and the skill level of the operators. China has provided various standard test methods of material

strength in order to make the results more accurate and comparable. These methods should be strictly followed when the strength is tested.

2. Strength Grade

The strength can be divided into a number of different grades in accordance with the ultimate strength of most building materials, known as strength grade. The grades of brittle materials are mainly divided based on their compressive strength, such ordinary clay brick, stone, cement and concrete; and those of plastic materials and ductile materials depend on their tensile strength, such as steel. It is significant to classify the strength grades for mastering functions and choosing proper materials.

3. Specific Strength

The specific strength is a material strength divided by its apparent density. It is an important index for measuring the high-strength and lightweight materials. The specific strength of ordinary concrete, low-carbon steel, and pine (along the grain) is respectively 0.012, 0.053 and 0.069. The higher specific strength is, the higher strength and lighter weight the material is. It is important to select materials with high specific strength or improve the specific strength in order to lift buildings' height, reduce structural weight and lower project costs.

2.3.2 Elasticity and Plasticity

1. Elasticity

The elasticity is the property of a substance to deform with external forces and return to its original shape when the stress is removed. The deformation fully capable of restoration is called elastic deformation. Within the range of the elastic deformation, the ratio of the stress (σ) to the strain (ϵ) is a constant (E) which is known as elastic modulus, namely, $E = \sigma / \epsilon$. The elastic modulus is a measure of the ability to resist deformation. The bigger E is, the more difficultly the material deforms. The elastic modulus of low-carbon steel is $E = 2.1 \times 10^5$ MPa; and the elastic modulus of concrete is a variable value, with its strength grades increasing from C15 to C60 and its elastic modulus E increasing from 1.55×10^4 MPa to 3.65×10^4 MPa.

2. Plasticity

The plasticity describes the deformation of a material undergoing non-reversible changes of shape in response to external forces. This non-reversible deformation is called plastic deformation.

Among building materials, there are no pure elastic materials. Some materials only have elastic deformation if the stress is not large, but plastic deformation will happen to them when the stress is beyond a limit, such as low-carbon steel. Under external forces, some materials will have elastic deformation and plastic deformation at the same time, but elastic deformation will disappear and plastic deformation still maintains when the stress is removed, such as concrete.

2.3.3 Brittleness and Toughness

1. Brittleness

Brittleness describes the property of a material that fractures when subjected to stress but has a little tendency to deform before rupture. Brittle materials are characterized by little deformation, poor capacity to resist impact and vibration of load, high compressive strength, and low tensile strength. Most of inorganic non-metallic materials are brittle materials.

2. Toughness

Impacted or vibrated by stress, a material is able to absorb much energy and deform greatly without rupture, which is known as toughness, also called impact toughness. Tough materials are characterized by great deformation, high tensile strength, and high compressive strength, such as construction steel, wood and rubber. Tough materials should be used in the structures bearing impact and vibration, such as roads, bridges, cranes and beams.

2.3.4 Hardness and Abrasive Resistance

1. Hardness

Hardness refers to the property of a material to resist pressing-in or scratch of a sharp object. The materials of different kinds of hardness need various testing methods. The hardness of steel, wood and concrete is tested by pressing-in method. For example, Brinell Hardness (HB) test is expressed by the pressure loaded on the press mark per unit area. The hardness of natural minerals is often tested by scratch hardness. Mineral hardness is divided into 10 grades, and the increasing order is: talc, gypsum, calcite, fluorite, apatite, orthoclase, quartz, topaz, corundum and diamond.

2. Abrasive Resistance

Abrasive resistance refers to the capacity of a material to resist abrasion. It is expressed by the abrasion ratio, calculated as:

$$N = \frac{m_1 - m_2}{A} \quad (2.20)$$

In this formula: N is the abrasion ratio(g/cm^2);
 m_1 is the mass before abrasion(g);
 m_2 is the mass after abrasion(g);
 A is the abrasive area(cm^2).

2.4 Decorativeness of Materials

Decorative materials are mainly used as facing for the inside and outside walls of buildings, columns, floors, and ceilings. They play decorative, protective, and other specific roles (such as insulation, moisture-resistance, fireproofing, sound-absorption, and sound-insulation). And decorative effects primarily depend on colors, textures and linetypes of the decorative materials.

1. Color

Color is an important factor for the appearance of buildings, even impacting on the environment. All the buildings are ornamented by colors. Generally, white or light-colored elevation hue often gives people a clean and fresh feeling; dark-colored elevation appears dignified and stable; people usually feel enthusiastic, excited and warm when see red, orange, yellow and other warm colors indoors; and green, blue, violet and other cold colors can enable people to be peaceful, elegant and cool.

As living conditions, climates, traditions, and customs are different, people have various feelings and evaluations on colors.

2. Texture

Texture is a comprehensive impression given by the appearance of a material, such as roughness, unevenness, grain, patterns, and color differences. For example, the rugged surface of concrete or brick appears relatively massy and rough; and the surface of glass or aluminum alloy is smooth and delicate which seems light and vivid. Texture is connected with characteristics,

processing degrees, construction methods, and the types and elevation styles of buildings.

3. Linetype

Linetype mainly refers to the decorative effect of the dividing joints and the convex lines ornamented on elevations. For example, plastering, granitic plaster, pebble dash, natural stone, and aerated concrete should be all latticed or divided, which will create various elevation effects and also prevent cracking. The size of dividing joints should be suitable for materials. Generally, the width should be 10~30mm, and the blocks of different sizes will create different decorative effects.

2.5 Durability of Materials

In the process of usage, materials are able to resist the erosion from various media around and maintain their original properties, known as durability. In this process, materials are subjected to physical, chemical, biological and other natural factors besides various kinds of stress.

Physical actions include wet-and-dry, temperature, and freeze-and-thaw changes, all of which will cause expansion and contraction of materials. And materials will be destroyed gradually by the long-term and repeated actions.

Chemical actions are the erosion of acid, alkali and salt aqueous solution which can change the compositions of materials and destroy them, such as the chemical erosion of cement and the corrosion of steel.

Biological action includes the destruction of fungi and insects which can mold or rot materials, such as the decomposition of wood and plant fiber.

Durability is a comprehensive property of materials. Materials of different compositions and structures have different kinds of durability. For example, steel is easy to be corroded; stone, concrete, mortar, sintering ordinary clay brick, and other inorganic non-metallic materials mainly resist frost, wind, carbonization, wet-and-dry change, and other kinds of physical action; when contacting with water, some materials can be destroyed by chemical changes; and asphalt, plastic, rubber and other organic materials will be damaged due to aging.

Questions

2.1 What are density, apparent density and bulk density? Explain their differences.

2.2 What are solidity and voidage? How to calculate? What's the relationship between them?

2.3 What's the difference between hydrophilic and hydrophobic materials? Is there any practical significance of the two materials in construction projects?

2.4 What is used to express the water absorption of materials? How to calculate? And what are the factors influencing the water absorption?

2.5 What are the definitions and indexes of hygroscopicity, water resistance, impermeability and frost resistance respectively? And are there any practical meanings?

2.6 What influences do porosity and the characteristics of pores play on density, apparent density, water resistance, impermeability, frost resistance, thermal conductivity, strength and other properties?

2.7 What is strength of a material? How to calculate various kinds of strength according to different types of stress? And how about their units?

2.8 What is strength grade? What's the difference between strength and strength grade?

2.9 What is elasticity? What is plasticity?

2.10 What is brittleness? What is toughness? What kinds of brittle and tough materials are often used in projects?

Exercises

2.1 There is a material whose dry mass is 105g, volume in natural state is 40 cm^2 , and volume in absolute compact state is 33 cm^3 . Calculate its density, apparent density, solidity and porosity.

2.2 A material has a volume of 1 m^3 and a mass of 2400kg in natural state. The volume of its pores accounts for 25%. Calculate its density.

2.3 A 10L volumetric container weighing 6.2 kg has been packed with gravel by the required method, and then the total weight is 21.3 kg. Calculate the bulk density of gravel. If water is filled into the container, the total weight

becomes 25.9kg after 24 hours. Calculate the apparent density and porosity of the gravel.

2.4 A concrete mixture needs 660 kg dry sand and 1240 kg dry stone. It is known that the water content of the existing sand is 4% and that of the stone is 1%. Calculate the amount of wet sand and wet stone respectively.

2.5 A steel bar with a diameter of 10 mm is used to test the tensile strength. And the tension measured at the destruction is 31.5 kN. Calculate the tensile strength of steel.

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