Building materials in civil engineering

Editor-in-Chief: Haimei Zhang
Translator: Shuo Ma, Yanyan Wu

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Preface

As one of the Programming Textbooks for New-century Higher Vocational and Professional Civil Engineering, this book is published by Science Press in August, 2001. This book has won the special prize of 2001~2003 Programming Textbooks for National Higher Vocational and Professional Civil Engineering proposed by Textbook Construction Expert Committee of Chinese Academy of Sciences. It has gained good evaluations from peer experts, construction technicians and teachers. It is one of the "Eleventh Five-year Plan" National Textbooks for General Higher Education.

This book is suitable for students majoring in "Civil Engineering", "Construction Engineering", "Engineering Supervision", "Costing Engineering", and "Water Supply and Drainage Engineering", also for the engineers and technicians engaging in the relevant specialties.

For the sake of requirements for higher vocational and professional teaching and vocational education, this book not only focuses on cement, concrete, steel, new waterproof materials, but also introduces the environment-friendly materials. It tries to make the teaching materials more applicable, more substantial, more succinct, and more novel. Since it was published, this book has been amended and rewritten carefully to satisfy the new amended national regulations and standards. Due to the limited knowledge in the compilation of this book, mistakes and errors cannot be fully avoided. The comments and criticism from the readers will be highly appreciated.

Zhang Haimei
June, 2010

Contents

1

Introduction

This chapter focuses on the classifications and the technical standards of building materials; it summarizes the characteristics of building materials and their status in construction engineering briefly; and also it introduces the development of building materials.

1.1 Definitions and Classifications of Building Materials

In the general environment for humans' survival, all the materials or products used in structures or buildings are called building materials which are the material foundation for all the construction engineering. The building materials discussed in this course are all the materials used in building foundations, bases, floors, walls, beams, plates, roofs and architectural decoration.

There is a wide variety of building materials. They are usually classified from different angles for the sake of study, application and description. The most common classifications are based on their chemical components and functions.

1) According to the chemical components of building materials, they can be classified into inorganic materials, organic materials and composite materials, as follows:

- Building Materials
  - Inorganic Materials
    - Metal: Steel, Iron, Aluminum, Copper, Various Types of Alloys
    - Metalloid: Natural Stone, Cement, Concrete, Glass, Burned Soil Products,etc.
    - Metal-metalloid Composition: Reinforced Concrete, etc.
  - Organic: Materials
    - Wood, Plastics, Synthetic Rubber, Petroleum Asphalt, etc.
  - Composite Materials
    - Inorganic Metal-Organic Composition: Polymer Concrete, Fiberglass Reinforced Plastics, etc.
    - Metal-Organic Composition: Light Metal Sandwich Panels, etc.

2) According to the functions of materials, they can be divided into structural materials and functional materials:

Structural Materials: mainly used as load-bearing members, such as the materials used for beams, plates and columns.

Functional Materials: mainly possessing some special functions in construction, such as waterproof, ornamental and heat-insulating functions, etc..

1.2 Characteristics of Building Materials and Their Status in Architecture

Building materials are the material foundation for all the construction engineering. Building materials industry which is one of the important basic industries of national economy promotes the development of the construction industry.

Various buildings and structures are constructed by all kinds of building materials on the basis of reasonable design. The varieties, specifications and qualities of building materials are directly related to the applicability, artistry and durability of buildings and also to the cost of projects. A large number of high-quality industrial and civil buildings need to be built for the development of society. Meanwhile, a great deal of water conservancy projects, traffic engineering and port projects need to be built to adapt to the rapid development of the national economy. It requires lots of high-quality building materials which accords with the application environment of projects. Therefore, building materials industry is usually considered as the basic industry for the construction engineering.

Building materials not only have a large consumption, but also are expensive. In the total cost of the construction, the cost of building materials often accounts for about 50 percent. Thus, it is significant to properly choose and reasonably utilize building materials in the construction for the reduction of costs and the improvement of investment benefits.

A large number of new building materials continue to emerge, often promoting the innovation and development of construction techniques. For example, the emergence of clay bricks contributes to the brick-timber structure; the reinforced concrete structure comes from concrete and steel bar; light high-strength materials promote the development of modern buildings and high-rise buildings; the application of various functional materials in the construction industry continues to create diversified comfortable living and production environment and to conserve energy.

In short, the application of building materials in the projects must possess the following characteristics: the function required by projects, the durability proper for the environmental conditions, the rich resources to meet the needs of construction, and low price.

In the building environment, the ideal building materials should be light, high-strength, aesthetic, heat-insulating, sound-absorbing, waterproof, shockproof, fireproof, non-toxic, and efficient, etc..

1.3 The Development of Building Materials

Various building materials form the living environment of human beings, which reflects the cultural and scientific features of each era, becoming an important symbol of humans' material civilization.

Building materials develop with the improvement of the productivity and living standards. In the early age, human beings inhabited "cave dwelling". After the Iron Age, they began digging, chipping and logging with simple tools to build shabby houses by natural materials; and with the use of fire, people learned how to burn bricks, tiles and limes, in which way building materials entered the artificial production stage. In 18^{th} and 19^{th} century, steel, cement, concrete and reinforced concrete continuously emerged with the rise of capitalism, the rapid development and the improve of traffic, which pushed building materials into a new stage of development.

Since the 20^{th} century, the formation and development of material science and engineering had contributed to not only the improvement of building materials in function and quality, but also the varieties. Some new building materials with special functions came into being, such as heat-insulating materials, sound-absorbing materials, ornamental materials, heat-resistant and waterproof materials, impermeable materials and wear-resistant, corrosion-resistant, and explosion-proof, and anti-radiation materials, etc. In the second half of the 20^{th} century, building materials evolved towards light, high-strength and functional direction.

In the new century, as humans' awareness of environmental protection has been strengthened, non-toxic and pollution-free "Green Building Materials" are recommended increasingly and human beings can build their own "Green Home" with new building materials.

1.4 The Introduction of Building Materials' Technical Standards

The implementing standards should be established for the various techniques of material products because of the scientific management of the modern material production.

Product Standards are the standards established for products to meet some or all the requirements in order to guarantee the applicability of products. They generally includes product specifications, classifications, technical functions, testing methods, rules of inspection and acceptance, packaging, storage, transport and others. For example, cement, ceramic and steel have their own product standards.

Building Material Standards are the technical foundations for the inspection of product quality and the bases for the acceptance of product quality referred to by both sides of supply and demand. The structure designs and construction techniques can be standardized accordingly by the reasonable selection of materials in the construction engineering, which will accelerate the construction and maximize the benefit of the engineering practice.

Recently, there are three categories used in China, as follows:

(1) National Standards

National Standards include mandatory standards (code-named GB), and recommendatory standards (code-named GB / T).

(2) Industry Standards

Industry Standards include the construction industry standards (code-named JGJ), building material industry standards (code-named JC), metallurgical industry standards (code-named YB) and transport industry standards (code-named JT) and so on.

(3) Regional Standards (code-named DBJ) and Enterprise Standards (code-named QB)

The expression of regional standards includes the standard name, the department code, the serial number and the year of approval. For example:

The National Standard (Mandatory), *The Hot-rolled Ribbed Steel Bars for the Reinforced Concrete* (GB1499-1998).

The National Standard (Recommendatory), *The Decarbonized Hot-rolled Round Coiled Bar* (GB/T701-1997).

The Construction Industry Standard, *The Design Regulation of Common Concrete Mix Proportion* (JGJ55-2000).

The Construction Industry Standard, *The Technical Specification of Concrete Structures with Cold-rolled Ribbed Steel Bars* (JGJ95-2003).

The Regional Standard of Hebei Province, *The Technical Specification for the Application of Modified Gypsum Heat-insulating Mortar* [DB13/T(J) 25-2000].

The mandatory standards indicate that any technique (or product) should not fall below the requirements; the recommendatory standards indicate that other standards are allowed to be followed, but the recommendatory standards will become the mandatory standards once they are adopted by mandatory standards; the technical requirements regulated in regional standards or enterprise standards should be above national standards.

It is an important economic and technological policy for China to adopt international standards and advanced foreign standards which will promote technological progress, improve product quality, expand foreign trade and enhance China's standardization level.

International standards can be broadly classified into the following categories:

1) The "ISO" international standards adopted in the whole world.

2) The standards of the worldwide influential communities and companies, such as the ASTM (named American Society for Testing and Materials) Standards.

3) Regional Standards. They refer to the standards of industrialized countries, such as the DIN Standards of Germany, the BS Standards of the United Kingdom and the JIS Standards of Japan.

1.5 Characters, Purposes, Tasks and Learning Methods of Building Materials Curriculum

Building materials curriculum is the technical foundation course for the civil engineering specialty in higher vocational colleges. The purpose of this curriculum is to learn the knowledge about building materials related to the architectural design, the structural design, and construction projects, correctly recognize and reasonably choose the proper building materials, and master the information concerning the inspection, transportation and storage of the products in order to lay a foundation for the future work.

The course mission is to enable students to obtain the basic knowledge and the necessary theories related to the characteristics and application of building materials and access to the essential training skills relevant to the materials experiments.

Building materials course is very practical and applicable. Of the learning methods, the first one is to focus on the major content, that is, the construction function and reasonable application of the materials. The other contents are all concerned with this focus. It is incorrect to change the construction function into an invariable concept. The more important thing is to know the inherent factors and their mutual relationships. For the various materials of the same category, not only should their similarities be learned but also their respective characteristics. For example, the six common kinds of cement have many similarities and many specialties. They are used in the according conditions just based on their own features.

Experimental course is the important part of the teaching. Its task is to verify the basic theories, learn the experimental methods, and foster a scientific research capacity and the strict scientific attitude. In the experiments, it is necessary to be careful and serious, even the simple ones. It is necessary to know the influence of testing results on the testing conditions and make the correct analysis and judgment on the results.

The reflection questions, exercises in each chapter generalize the theories and practical application of materials of those chapters which should be mastered.

In order to know the functions and applications of materials, it is important to visit some building materials factories and applications of materials, master their practical applications in the construction projects, and know the new varieties and the new standards, for mastering and using the materials better.

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2

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 pearlite.

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:

$$\rho = \frac{m}{V} \tag{2.1}$$

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:

$$\rho_0 = \frac{m}{V_0} \tag{2.2}$$

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:

$$\rho_0' = \frac{m}{V_0'} \tag{2.3}$$

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:

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

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:

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

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:

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

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:

$$P'=\frac{V_0'-V_0}{V_0'}\times 100\%=(1-\frac{\rho_0'}{\rho_0})\times 100\% \tag{2.7}$$

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° ($\theta \leqslant 90°$), 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.

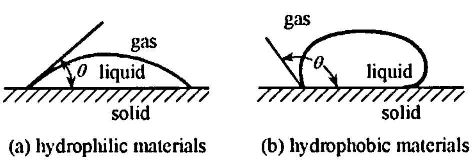


Figure 2.1 The Wetting Schematic Diagram of Materials

When angle θ is bigger than 90° ($\theta > 90°$), 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:

$$W_m = \frac{m_b - m_g}{m_g} \times 100\% \tag{2.8}$$

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:

$$W_V = \frac{m_b - m_g}{V_0} \times \frac{1}{\rho_w} \times 100\% \tag{2.9}$$

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 $1.0g/cm^3$ at the room temperature.

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

$$W_v = W_m \cdot \rho_0 \tag{2.10}$$

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:

$$W_h = \frac{m_s - m_g}{m_g} \times 100\% \tag{2.11}$$

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 humility 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:

$$K_R = \frac{f_b}{f_g} \tag{2.12}$$

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 ($K_R \geqslant 0.85$) 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 ($K_R \geqslant 0.75$) 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:

$$K=\frac{Qd}{AtH} \tag{2.13}$$

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:

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

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 (m^2);
t it 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:

$$Q = m \times C(T_2 - T_1) \tag{2.15}$$

or

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

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 quality 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:

$$\alpha = \frac{\Delta L}{L \times \Delta t} \tag{2.17}$$

In this formula: α is the linear expansion coefficient of a substance (l/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 factures 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.

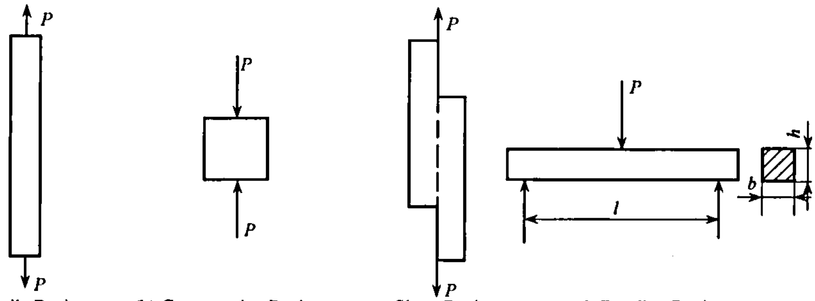
2.3 Mechanical Properties of Materials

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.



(a) Tensile Resistance (b) Compressive Resistance (c) Shear Resistance (d) Bending Resistance

Figure 2.2 The Stress States of a Material

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

$$f=\frac{P}{A} \tag{2.18}$$

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:

$$f=\frac{3Pl}{2bh^2} \tag{2.19}$$

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, $E=\sigma/\varepsilon$. 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 $E=2.1\times10^5$ 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:

$$N = \frac{m_1 - m_2}{A} \tag{2.20}$$

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 molder 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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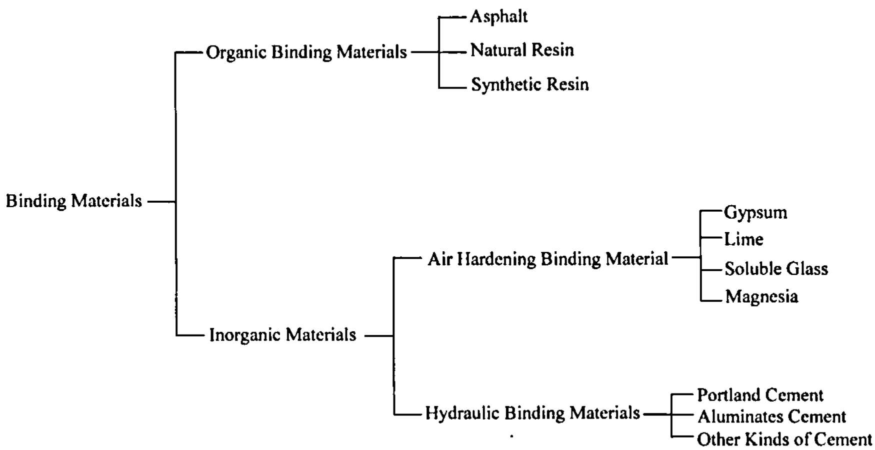
3

Air Hardening Binding Materials

This chapter mainly introduces the characteristics, technical requirements and applications of lime, gypsum, magnesia, and sodium silicate.

In construction projects, the materials that can conglutinate granular materials (such as sand and gravel) or bulk materials (such as bricks and stone) together as a whole are called binding materials, the important materials in construction projects. And the common binding materials can be divided into:



This chapter will introduce several air-hardening binding materials commonly used in construction projects. Such materials can only be hardened in the air (dry conditions) and their strength can maintain and develop only in the air.

3.1 Building Gypsum

Gypsum is an air-hardening materials mainly consisting of calcium sulfate. And its products have many excellent characters, commonly used in construction. There are various kinds of gypsum binding materials, such as building gypsum, high-strength gypsum, anhydrite cement, and high-temperature-calcined gypsum.

3.1.1 The Introduction of Building Gypsum Production

The raw materials to produce gypsum cement materials are natural dihydrate gypsum ($CaSO_4 \cdot 2H_2O$), natural anhydrite ($CaSO_4$), and chemical by-products composed of $CaSO_4 \cdot 2H_2O$ or $CaSO_4 \cdot 2H_2O$ and $CaSO_4$.

The gypsum used in construction is semi-hydrated gypsum ($CaSO_4 \cdot \frac{1}{2} H_2O$) processed by natural bihydrate gypsum, also known as calcined gypsum. Varieties of gypsum will be produced when the natural dihydrate gypsum is processed with the change of heating methods and temperatures. The main production procedures are breaking, heating and grinding.

The gypsum commonly used in construction projects is building gypsum, composed of β semi-hydrate gypsum. The natural dihydrate gypsum is calcined into semi-hydrate gypsum under the temperature of 107 ~ 170 ℃ and then is ground into powder which is the building gypsum. Its reactive mode is:

$$CaSO_4 \cdot 2H_2O + \xrightarrow[\text{air heating}]{107 \sim 170^\circ C} CaSO_4 \cdot \frac{1}{2} H_2O + \frac{1}{2} H_2O$$

3.1.2 Technical Requirements of Building Gypsum

Building gypsum is white and of 2.6~2.75g/cm^3 density and 800~1000kg/m^3 bulk density.

According to GB9776-88, building gypsum can be classified into high-class, first-class and acceptable grades in light of strength, fineness and setting time, shown in Table 3.1. Among them, bending strength and compressive strength are measured by letting samples contact with water for 2 hours.

Table 3.1 Technical Indicators of Building Gypsum

Indicators \ Grades		High-class	First-class	Acceptable
Strength (MPa)	Bending Strength (≥)	2.5	2.1	1.8
	Compressive Strength (≥)	4.9	3.9	2.9
Fineness (%)	Sieve Residue of 0.2mm Square-hole Sieve (≤)	5.0	10.0	15.0
Setting Time (min)	Initial Setting Time (≤)	6		
	Final Setting Time (≤)	30		

Building gypsum is tagged by the order of name, bending strength and standard number. For example, the building gypsum of 2.5MPa bending strength can be tagged as: Building Gypsum 2.5 GB 9776.

The hydration of building gypsum technically requires that water requirements accounts for 18.6% of the weight of semi-hydrate gypsum. But in fact, water often accounts for 60%~80% in order to make the gypsum slurry have certain plasticity. The excess water gradually evaporates in the hardening process, which leads to a large number of pores left in the hardened gypsum, with the porosity of 50%~60%. Thus, building gypsum has low strength, small apparent density, low thermal conductivity and high sound absorption after hardening.

In the process of storage and transport, building gypsum should not be exposed to moisture and mixed with sundries. Gypsum of different grades should be stored respectively and should not be mixed. The general storage period is three months. And the strength will reduce by 30% over 3 months. The gypsum beyond storage period needs to be re-examined to determine the grades.

3.1.3 The Hardening Mechanics of Building Gypsum

Mixed with water, building gypsum can be modulated into plastic slurry. And after a period of reaction, it will lose plasticity and condense into solid with certain strength.

The setting and hardening of building gypsum occur because water and semi-hydrate gypsum react mutually and then restore to dihydrate gypsum:

$$CaSO_4 \cdot \frac{1}{2} H_2O + 1\frac{1}{2} H_2O = CaSO_4 \cdot 2H_2O$$

Semi-hydrate gypsum dissolves in water and turns into a saturated solution soon. Combining with water, the semi-hydrate gypsum in the saturated solution becomes dihydrate gypsum. The saturated solution of semi-hydrate gypsum is oversaturated for dihydrate gypsum because the solubility of dihydrate gypsum is much smaller than that of semi-hydrate gypsum. Thus, the saturated solution precipitates the dihydrate gypsum in the form of colloid particle, which accelerates the semi-hydrate gypsum to dissolve and hydrate continuously till complete dissolution. In this process, the free water in the slurry decrease gradually because of hydration and evaporation, the colloid particles of dihydrate gypsum increase, the consistency of the slurry rises, and friction and cohesive forces between particles grow increasingly. Therefore, the plasticity of the slurry decrease gradually, called "setting". Subsequently, the slurry continues getting thicker, and colloid particles gradually turn into crystals. They become bigger, symbiotic and staggered, which enable the slurry to have strength. Such strength continues growing till complete dryness, and friction and cohesive forces between crystals stop increasing. At this moment, the strength stops developing. This whole process is called "hardening". In fact, setting and hardening of gypsum are continuous and complicated physical and chemical processes.

3.1.4 Characteristics of Building Gypsum

Compared with other binding materials, building gypsum has the following characteristics:

1. Fast Setting and Hardening

The setting time of building gypsum changes with the calcination temperature, grinding rate and impurity content. Generally, mixed with water, its initial setting needs just a few minutes at room temperature, and its final setting is also within 30min. Under the natural dry indoor conditions, total hardening needs about one week. The setting time can be adjusted according to requirements. If the time needs to be postponed, delayed coagulant can be added to reduce the solubility and the solution rate of building gypsum, such as sulfite alcohol wastewater, bone glue activated by borax or lime, hide glue, and protein glue; if it needs to be accelerated, accelerator can be added, such as sodium chloride, silicon sodium fluoride, sodium sulfate, and magnesium sulfate.

2. Micro-expansion

In the hardening process, the volume of building gypsum just expands a little, and there won't be any cracks. Thus, it can be used alone without any extenders, and can also be casted into construction members and decorative patterns with accurate size and smooth and compact surface.

3. Big Porosity

After hardening, the porosity of building gypsum can reach 50%~60%, so its products are light, insulating, and sound-absorbing. But these products have low strength and large water absorption due to big porosity.

4. Poor Water Resistance

Building gypsum has low softening coefficient (about 0.2~0.3) and poor water resistance. Absorbing water, it will break up with the freeze of water. Thus, its water resistance and frost resistance are poor, not used outdoors.

5. Good Fire Resistance

The main component of building gypsum after hardening is $CaSO_4 \cdot 2H_2O$. When it contacts with fire, the evaporation of crystal water will absorb heat and generate anhydrous gypsum which has good thermal insulation. The thicker its products are, the better their fire resistance will be.

6. Large Plastic Deformation

Gypsum and its products have an obvious performance of plastic deformation. Creep becomes more serious especially under bending load. Thus, it is not used for load-bearing structures normally. If it is used, some necessary measures need to be taken.

3.1.5 Applications of Building Gypsum

As mentioned above, building gypsum has excellent performance. It is suitable for indoor decoration, insulation and thermal retardation, sound absorption, and fire retardation. Generally, it is made into plaster mortar, architectural and decorative products, and gypsum plank.

1. Indoor Plastering and Painting

Mixed with water and sand, building gypsum will turn into gypsum mortar which can be used for indoor plastering. Such plastered wall is insulating, fire-resistant, sound-absorbing, comfortable, and aesthetic. The plastered wall and ceiling can be painted or pasted with wallpaper directly.

The gypsum mortar can be used as indoor coating material mixed with lime. The wall painted with this mortar is smooth, delicate, white, and beautiful.

Plastering gypsum should accord with *The Plastering Gypsum* (JC/T517-93), the industrial standard. And its main technical indexes are as follows: fineness: if it passes through the square-hole sieve of 25mm, there is no residue, and through the square-hole sieve of 0.2mm, the residue $\leqslant 40\%$; bending strength: that of the excellent plastering gypsum is 3.0MPa, and that of the first-class one is 2.0MPa; compressive strength: that of the excellent plastering gypsum is 5.0MPa, and that of the first-class one is 3.5MPa; setting time: the initial one ≥ 60min, and the final one ≥8h.

2. Decorative Products

As the main raw material, gypsum will be stirred into gypsum mortar with water, added a small amount of fiber-reinforced materials and plastic materials. By its micro-expansion performance, the gypsum mortar can be made into various plaster sculptures, decorative panels and accessories.

3. Gypsum Plank

China's current gypsum planks mainly include thistle board, decorative plaster plate, fibrous plaster board and others.

(1) Thistle Board

It uses gypsum as the core material and paper as the surface on the two sides. It is of 900~1200mm width and 9~12mm thickness. The length can be fixed according to needs. The thistle board is mainly used as inner wall, partition wall, and ceiling.

(2) Hollow Gypsum Strip

It uses building gypsum as the main raw material, specification for: (2500 ~ 3500) mm × (450 ~ 600) mm × (60 ~ 100) mm, 7 ~ 9 holes, and hole ratio of 30%~40%. This board has high strength which can be used as the inner wall and partition wall in residential and public buildings. And its installation does not need any keel.

(3) Decorative Plaster Plate

Building gypsum is the main raw material of decorative plaster board, specifications for square with the side of 300mm,400mm,500mm,600mm and 900mm. There are flat plates, porous plates, diamond plates, embossed plates and decorate plates which are diverse, colorful, and aesthetic, mainly used as walls and ceilings in public buildings.

(4) Fibrous Plaster Board

This board uses building gypsum, cardboard and short glass fiber as the main raw materials. With high bending strength, it can be used as inner wall and partition wall, or be used to make furniture instead of wood.

Besides, there are cellular gypsum boards, moisture-resistant gypsum boards, and compound mine-wool boards which can be used as thermal insulation panels, acoustic panels, inner walls, partition walls, ceilings, and floor basal plates.

If supported by fiber-reinforced materials and gelling agents, building gypsum can be made into gypsum coving, line board, corner pattern, lamp ring, Roman column, sculptures and other artistic gypsum products.

3.2 Lime

Lime is one of the earliest binding materials used in buildings because its raw materials are rich and widely distributed, the production process is simple and low-cost, and it is easy to use. Therefore, lime is still widely used in construction until now.

3.2.1 The Introduction of Lime Production

1. Raw Materials of Lime

The main raw material of lime is natural rock whose major component is calcium carbonate. The common lime includes limestone, dolomite, and chalk. These natural raw materials often contain clay impurities whose content should be controlled within 8%.

Besides the natural raw materials, another source of lime is the chemical industrial by-products. For example, the major component of the carbide slag remained in the preparation of acetylene from acetylene stone (calcium carbide) is calcium hydroxide, namely, hydrated lime.

2. Lime Production

After calcination, limestone generates quicklime. The reactive mode is:

$$CaCO_3 \xrightarrow{900℃} CaO+CO_2$$

In actual production, the calcination temperature is often controlled within 1000~1100℃ in light of the heat loss because limestone's dense degrees, sizes of block, and impurities are different. If the calcination temperature is too low and the calcination time is not sufficient, $CaCO_3$ cannot dissolve completely and will generate under-burnt lime. Under-burnt lime generates less mortar and the quality is poor, which lowers the utilization of lime; if the calcination temperature is too high, the dark-color over-burnt lime with high density will be generated which will affect the project quality.

Quicklime is a kind of white or grey block substance whose major component is CaO. The calcinated lime contains MgO correspondingly because its raw materials always contain some magnesium oxide components. According to JC/T480-92 *Building Quicklime* provision, the standard of China's building material industry, when the content of MgO is smaller than or equal to 5%, it is called calcium quicklime; when the content of MgO is bigger than 5%, it is called magnesia quicklime.

3. Aging of Lime

The process that quicklime (CaO) generates calcium hydroxide with water is known as the aging or digestion process of lime, of which the reactive mode is:

$$CaO+H_2O=Ca(OH)_2+64.9kJ/mol$$

The aging of lime releases much heat, and the volume of lime expands 1~2.5 times.

The theoretical water demand needed in the aging process takes only 32.1% of lime's mass. But the actual water demand (60%~80%) is more because part of the water will evaporate. If too much water is added, the temperature will drop and the aging process will slow down, which will extend the aging time. There are two methods used for lime aging on construction site: slurry process and powder process of hydrated lime.

Quicklime often contains over-burnt lime which is the fused mass with dark brown surface. The aging of over-burnt lime is very slow and the over-burnt particles start to age when lime has gotten hardened. Then the volume expands, leading to uplifting and cracking. In order to eliminate the destruction caused by over-burnt lime, lime mortar has to "be stabilized" in the lime storage pool for more than two weeks. In the period of "stabilization", there is a layer of water on the surface of lime mortar, and the lime mortar is isolated from air to prevent the carbonization of lime.

3.2.2 The Hardening of Lime

The hardening of lime in the air includes two processes:

1. Crystallization

In the use of lime mortar, $Ca(OH)_2$ solution is over-saturated and gradually precipitate crystals because the free water gradually evaporates and is absorbed by masonry. This process accelerates the hardening of lime mortar and meantime the mortar tightens and generates strength due to dryness.

2. Carbonization

With CO_2 in the air, $Ca(OH)_2$ generates the insoluble crystals of calcium carbonate, and the precipitated water gradually evaporates. The reactive mode is as follows:

$$Ca(OH)_2+CO_2+nH_2O=CaCO_3+(n+1)H_2O$$

This process is known as carbonization. And the precipitated $CaCO_3$ crystals make the hardened mortar compact and enhance the strength.

The content of CO_2 in the air is little. And carbonization mainly happens on the surface, contacting with the air. And the compact $CaCO_3$ film generated on the surface hinders the further infiltration of the air and prevents the inner water evaporating, which slow down the crystallization of $Ca(OH)_2$. As time passes, the thickness of $CaCO_3$ on the surface increases and the prevention become greater. In quite a long period, $CaCO_3$ is still the surface and $Ca(OH)_2$ is inside, so the hardening process of lime is very slow.

3.2.3 Technical Requirements of Lime

The lime used in construction can be divided into three varieties: building quicklime, building quicklime powder, and building hydrated lime powder. They can be classified into three grades respectively, according to the standards of the building industry, and the corresponding indexes are listed in Table 3.2, Table 3.3 and Table 3.4.

The product whose various technical indexes reach a certain grade set in the tables should be targeted with this grade. If one of its technical indexes is less than the qualified grade, it should be targeted as the ineligible product.

Table 3.2 Technical Indexes of Building Quicklime

Item	Calcium Quicklime			Magnesia Quicklime		
	High-class	First-class	Acceptable	High-class	First-class	acceptable
CaO+MgO content (%) (≥)	90	85	80	85	80	75
Residue (residue of 5mm round hole sieve) (%) (≤)	5	10	15	5	10	15
CO_2 (%) (≤)	5	7	9	6	8	10
Mortar Production (L/kg) (≥)	2.8	2.3	2.0	2.8	2.3	2.0

Table 3.3 Technical Indexes of Building Quicklime Powder

Item		Calcium Quicklime Powder			Magnesia Quicklime Powder		
		High-class	First-class	Acceptable	High-class	First-class	Acceptable
CaO+MgO content (%) (≥)		85	80	75	80	75	70
CO_2 (%) (≤)		7	9	11	8	10	12
fineness	Residue of 0.9mm Sieve (%) (≤)	0.2	0.5	1.5	0.2	0.5	1.5
	Residue of 0.125mm Sieve (%) (≤)	7.0	12.0	18.0	7.0	12.0	18.0

Table 3.4 Technical Indexes of Building Hydrated Lime Powder

Item		Calcium Quicklime Powder			Magnesia Quicklime Powder
		High-class	First-class	Acceptable	High-class
CaO+MgO content (%) (≥)		70	65	60	65
Free Water (%)		0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2
Volume Stability		Acceptable	Acceptable	—	Acceptable
fineness	Residue of 0.9mm Sieve (%) (≤)	0	0	0.5	0
	Residue of 0.125mm Sieve (%) (≤)	3	10	15	3

Item		Magnesia Quicklime Powder		Dolomite Hydrate Lime Powder		
		First-class	Acceptable	High-class	First-class	Acceptable
CaO+MgO content (%) (≥)		60	55	65	60	55
Free Water (%)		0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2	0.4 ~ 2
Volume Stability		Acceptable	—	Acceptable	Acceptable	—
fineness	Residue of 0.9mm Sieve (%) (≤)	0	0.5	0	0	0.5
	Residue of 0.125mm Sieve (%) (≤)	10	15	3	10	15

3.2.4 Characteristics of Lime

1. Good Water Retention

The lime mortar generated by the aging of lime has good water retention, so it can be mixed in cement mortar to improve the water retention of mortar to facilitate construction.

2. Slow Setting and Hardening, Low Strength

Because the carbonization of lime mortar in the air is very slow, the production of calcium carbonate and calcium hydroxide is a little and quite slow. And thus, the strength of hardened lime is low. According to tests, 1 : 3 lime mortar of 28d has only 0.2~0.5 MPa strength which should not be the basis for important buildings.

3. Poor Water Resistance

Calcium hydroxide is soluble in water, so if it is exposed to moisture or immerses in water for a long time, the hardened lime will scatter. If lime mortar is in humid environment before complete hardening, the water in lime cannot evaporate, and the hardening will be hindered. Therefore, lime should not be applied in humid environment.

4. Large Shrinkage

In the hardening process of lime mortar, a large amount of water evaporates, which cause the shrinkage of volume. And desiccation cracks will appear. Thus, lime mortar should not be used alone except for the lime cream for thin painting. In use, it is often mixed with sand, hemp fiber, paper pulp, and other things to resist cracking caused by shrinkage.

3.2.5 Applications and Storage of Lime

After being processed, quicklime can generate many varieties of lime, such as quicklime powder, hydrated lime powder, lime cream, and lime paste. And different varieties have different purposes.

1. Lime Powder

Lime powder can be made into silicate products mixed with materials containing silicon. With water, pulverized lime can be molded by being mixed with fiber materials (such as glass fiber) or lightweight aggregate. Then, it can be carbonized artificially with carbon dioxide for carbonized lime board. Carbonized lime board has a good processing property, suitable for the non-load-bearing inner partition and ceiling. Mixed with a certain percentage of clay, pulverized lime can generate limestone soil. Triple-combined soil can be generated by mixing lime powder with clay, gravel, and slag. Lime soil and triple-combined soil are mainly used for foundation, bedding cushion, and roadbed.

2. Lime Paste

The aged lime paste or hydrated lime can turns into lime milk, diluted with water, as paint of internal and external walls and ceilings; if mixed with a certain amount of sand or cement and sand, it can be prepared into lime mortar or compound mortar for masonry or finishing; it can be used to paint inner walls or ceilings by being mixed with paper pulp and hemp fiber.

3. Storage of Lime

Quicklime will absorb the water and carbon dioxide in the air, generate calcium carbonate powder and lose cohesive force. Thus, when stored on construction site, quicklime should not be exposed to moisture, not be more, and not stay for a long time. Moreover, the aging of lime will release a great amount of heat, so quicklime and inflammable matter should be stored separately in order to avoid fire. Usually quicklime should be stabilized immediately and the storage period should be changed into aging period.

3.3 Magnesia

Magnesia is an air hardening binding material. Its major component is magnesium oxide (MgO) which is a kind of white or yellow powder, belonging to magnesia cement materials. Its main raw material comes from natural magnesite ($MgCO_3$) and can also be extracted from serpentine ($3MgO{\cdot}2SiO_2{\cdot}2H_2O$), dolomite ($MgCO_3{\cdot}CaCO_3$), molten slag produced by smelting magnesium alloy (the content of MgO is not less than 25%), or seawater.

$MgCO_3$ in magnesite starts to decompose at 400℃ and reacts fiercely at 600~650℃. The calcination temperature is usually controlled at 750 ~ 850℃ when magnesia is generated. The reactive mode is as follows:

$$MgCO_3 \longrightarrow MgO + CO_2\uparrow$$

Magnesia will be gotten by grinding the block remained after calcination. Its density is 3.10～3.40g/cm^3 and bulk density is 800～900kg/m^3.

Magnesia should not be exposed to moisture in transport or storage and also cannot be stored for a long time. Because by absorbing the water in the air, magnesia turns into $Mg(OH)_2$ and then is carbonized into $MgCO_3$, finally losing its chemical activity.

In addition, dolomite ($MgCO_3 \cdot CaCO_3$) calcinated at 650~750 ℃ will generate a mixture composed of MgO and $CaCO_3$, known as caustic dolomite:

$$MgCO_3 \cdot CaCO_3 \longrightarrow MgO + CaCO_3 + CO_2\uparrow$$

Caustic dolomite also belongs to magnesia cement materials and has similar property and purpose with magnesia.

3.3.1 The Hardening of Magnesia

When magnesia is stirred with water, MgO reacts with water and generates $Mg(OH)_2$, releasing a lot of heat:

$$MgO + H_2O \longrightarrow Mg(OH)_2$$

When slurry is made with water, setting and hardening are very slow and the strength after hardening is very low. Thus, modifier is always used to accelerate the hardening process. The most common modifier is magnesium chloride solution, and the reaction is:

$$x MgO + y MgCl_2 \cdot 6H_2O \longrightarrow x MgO \cdot y MgCl_2 \cdot z H_2O$$

$$MgO + H_2O \longrightarrow Mg(OH)_2$$

The magnesium oxychloride ($xMgO \cdot yMgCl_2 \cdot zH_2O$) and Mg $(OH)_2$ generated by reaction precipitate from solution gradually, and condense and crystallize to harden the slurry. After adding modifier, setting and hardening will become faster, and also the strength will be improved markedly.

3.3.2 Technical Properties of Magnesia

According to JC/T449-91, magnesia can be divided into high-class grade (A), first-class grade (B) and acceptable grade (C) by the chemical and physical properties, and the main technical properties are listed in Table 3.5.

Table 3.5 The Technical Indexes of Magnesia

		High-class (A)	First-class (B)	Acceptable (C)
MgO (%) (≥)		80	75	70
Free CaO (%) (≤)		2	2	2
Residue of 0.08mm Square-hole Sieve (%)(≤)		15	15	20
Setting Time	Initial (min) (≥)	40	40	40
	Final (h) (≤)	7	7	7
Bending Strength (MPa) (≥)	1d	5.0	4.0	3.0
	3d	7.0	6.0	5.0
Compressive Strength (MPa) (≥)	1d	25.0	20.0	15.0
	3d	30.0	25.0	20.0

3.3.3 Applications of Magnesia

Magnesia and plant fibers bind strongly, which can avoid decomposition of fibers. Therefore, it is always mixed with wood chips and wood fibers to produce xylolite floor, wood-cement board, and xylolite slab.

In addition to wood chips and wood fibers, French chalk, asbestos, fine quartz sand, brick powder and other fillers are added to magnesia in order to improve the strength and wear resistance of products. Magnesia grindstone floor will be made by using marble or rock of medium hardness as the aggregate.

Magnesia floor is heat-retardate, dust-free, wear-resistant, fire-resistant, smooth, and elastic. It is a good floor material that can be colored by adding alkali-resistant mineral pigments.

Magnesia board has high tightness, high intensity, sound absorption and thermal insulation, which can be used as the inner wall, ceiling and other building materials.

Reinforced magnesia has high intensity and can be used as constructional element instead of wood, such as wood pad and column.

Magnesia can be made into light and porous thermal-insulating material by adding foaming agent.

The water resistance of magnesia is poor, so its products should not be stored in humid places for a long time. And its products should not be used with steel bars, for in the process of using magnesia, magnesium chloride solution is commonly used and the chloride ions can erode steel bars.

3.4 Soluble Glass

Soluble glass, also called foam alkali, is an alkali metal air hardening material. In construction, it is usually used to prepare sodium silicate cement, soluble glass mortar, and soluble glass concrete. Soluble glass is widely used in the anti-acid and heat-resistant engineering.

3.4.1 The Introduction of Soluble Glass

The main method to produce soluble glass is to grind and stir calcined soda and quartz sand which are the major raw materials, then fuse them in the melting pot of 1300~1400℃, and finally cool them into solid soluble glass. The reactive mode is as follows:

$$NaCO_3+nSiO_2 \xrightarrow{1300\sim1400℃} Na_2O \cdot nSiO_2+CO_2\uparrow$$

Liquid soluble glass is obtained in the way of stuffing solid soluble glass into autoclave and dissolving it by steaming, or putting quartz sand solution and sodium hydroxide solution into autoclave (20~30kPa), heating them by steam and stirring the solutions to make them react directly. Liquid soluble glass is alkali. Pure soluble glass solution should be clear and colorless liquid, but it often appears steel grey or yellow-green due to impurities.

3.4.2 The Hardening of Soluble Glass

Soluble glass solution absorbs carbon dioxide in the air to generate amorphous silicate and gradually becomes dry till hardening.

$$Na_2O \cdot nSiO_2+CO_2+mH_2O=Na_2CO_3+nSiO_2 \cdot mH_2O$$

The process is very slow. In the using process, soluble glass is often heated or mixed with sodium fluosilicate (Na_2SiF_6) as an accelerator for hardening to quicken the hardening speed. Sodium fluosilicate is added into soluble glass will react as follows, speeding up the precipitation of silicic acid gel.

$$2[Na_2O \cdot nSiO_2]+Na_2SiF_6+mH_2O=6NaF+(2n+1)SiO_2 \cdot mH_2O$$

The appropriate amount of sodium fluosilicate should account for 12%~15% of the weight of soluble glass. Sodium fluosilicate can also improve the water resistance of soluble glass.

3.4.3 Characteristics of Soluble Glass

According to the differences of alkali metal oxide, soluble glass can be divided into sodium silicate and potassium silicate, and sodium silicate is often used. Among the components of sodium silicate ($Na_2O \cdot nSiO_2$), the ratio of silicon oxide molecules to sodium oxide molecules (represented by "n") is known as the module of soluble glass, generally between 1.5 to 3.5. And the number of module decides the properties and performance of soluble glass. The solid soluble glass with low module is relatively easy to dissolve in water. The bigger the number is, the higher the viscosity is and the harder it dissolves in water; the soluble glass with low module, there are many kinds of crystal composition and the cohesive force is poor, and when the module number improves, the colloid component increases and the cohesive force rises.

Soluble glass solution can be mixed with water in any proportion. Different amount of water will lead to solutions of different density and viscosity. For the soluble glass solutions with the same module, the higher the density is, the stronger the cohesive force is. If urea is added into soluble glass, its cohesive force can be improved without modifying the viscosity.

Soluble glass also has strong acid corrosion that can resist the majority of inorganic acids, organic acids, and corrosive gases. The silicate gel precipitating during the hardening of soluble glass can block the capillary porosity of the material to prevent water infiltration. Soluble glass has good heat resistance, so it does not dissolve and its strength does not decrease and even increases at a high temperature.

In addition, the soluble glass can burn eyes and skin to a certain extent, so the security protection is needed.

3.4.4 Applications of Soluble Glass

1. Acid-proof Material

Soluble glass can be used as binding material to prepare acid-proof plaster, acid-proof mortar, and acid-proof concrete which are commonly used in anti-acid projects.

2. Heat-resistant Material

Soluble glass has a good heat resistance that can bear a certain high temperature and its strength does not increase. Thus, it can be made into heat-resistant concrete and mortar.

3. Coating

Soluble glass solution can be used to paint building materials or immerging porous materials. It can enhance the density and strength of materials and increase their resistance to weathering when infiltrating into the materials. But the solution can not be used to paint or immerge gypsum products because soluble glass can react with gypsum to generate sodium sulfate crystals which will expand in pores and destroy the gypsum products.

4. Grouting Material

Soluble glass solution and calcium chloride solution are injected into soil alternately, and the two solutions will cause chemical reaction to precipitate silicate gel which can cement or fill the pores of soil and prevent the infiltration of water to increase the density and strength of soil.

5. Water-proof Plugging Material

Soluble glass solution mixed with sand or cement can make setting and hardening occur quickly, for repairing or plugging structures. Moreover, mixed with various alum solutions, soluble glass can be used as water-proof agent for cement mortar or concrete.

Questions

3.1 Try to narrate the characteristics of air hardening binding materials and hydraulic binding materials.

3.2 What are the major chemical components of building gypsum? What are the characteristics? Where is it used?

3.3 Try to narrate the mechanics of setting and hardening of gypsum.

3.4 Why should the lime using on the construction site be aged?

3.5 What are under-burnt lime and over-burnt lime? And their characteristics.

3.6 What is stabilization? Why should lime be stabilized before use?

3.7 Try to explain the reason why gypsum and lime are not water-resistant.

3.8 Why can't magnesia be stirred with water alone in use?

3.9 What are the main characteristics and purposes of soluble glass?

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4

Cement

This chapter focuses on the composition, characteristics, quality standards, and the using scope of Portland cement; it expounds the composition and quality standards of the ordinary Portland cement, slag cement, Portland-pozzolana cement, Portland fly-ash cement, and composite Portland cement; it also introduces the characteristics and the usage of these six common cement; this paper generalizes the other varieties of cement.

Cement is a hydraulic mineral binding material. Blended with water, the pulverous cement can generate the plastic paste which will turn into hard cement block and bind granulated (or block) materials together after a series of physical and chemical effects. The hardening of cement paste will happen not only in the air but also in water and also can maintain and increase its strength.

Cement is one of the important materials for the construction of national economy. Also, it is the basic component for concrete, reinforced concrete, and prestressed concrete, commonly used in construction, transportation, water conservancy, electric power, national defense, and other construction projects.

According to the national cement naming standard, cement can be named based on its main hydraulic minerals as: Portland cement, aluminate cement, sulphate cement and sulpho-aluminate cement, and phosphate cement.

Among many varieties of cement, the commonly used one is the Portland cement (including Portland cement, ordinary Portland cement, Portland blast furnace cement, Portland pozzolana cement, Portland fly-ash cement, and composite Portland cement).

In projects, the varieties of cement should be selected reasonably based on the specific environment. As for the property of cement, Portland cement is the basic one. And this chapter will show a detailed exposition about the properties of Portland cement and briefly introduce those of other kinds of commonly used cement.

4.1 Portland Cement

Portland cement is the hydraulic binding material consisting of Portland cement clinker, 0~5% limestone or granulated blast furnace slag, and a limited amount of gypsum. There are two types of Portland cement: type I Portland cement without any hybrid materials whose code name is P • I and type II Portland cement, code-named P • II, which is mixed with less than 5% limestone or granulated blast furnace slag when the Portland cement clinker is ground.

4.1.1 Sintering and Mineral Composition of Portland Cement Clinker

1. Sintering of Portland Cement Clinker

The sintering of Portland cement clinker is simply called "twice grinding and once sintering", that is, ①grinding the cement with cement raw material; ② sintering the calcined part of the raw material into clinker; ③grinding the clinker with a limited amount of gypsum into Portland cement clinker. The sintering process of Portland cement clinker is shown in Figure 4.1.

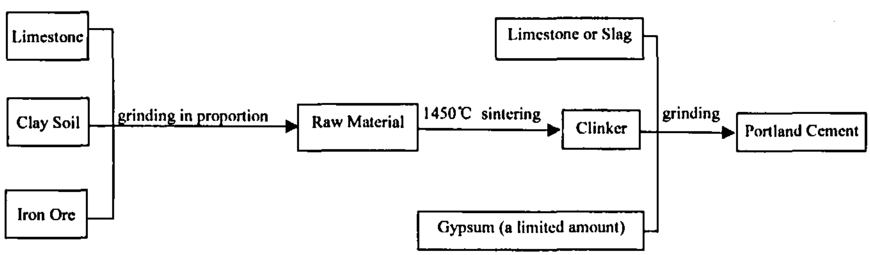

Figure 4.1 The Sintering Process of Portland Cement Clinker

Different proportions of cement raw materials directly affect the proportions of the mineral components of Portland cement clinker and the main building technical performance. The process that cement raw materials is sintered in a kiln is the key to the quality of cement clinker.

In the sintering process of cement raw material, the useful components decomposed by various raw materials at 1000℃ are mainly: calcium oxide

(CaO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3). And the solid-state reaction occurs to a small amount of oxide at about 800℃ which generates calcium aluminate, a small amount of dicalcium ferrite, and dicalcium silicate.

At 900~1100℃, tricalcium aluminate and tetracalcium aluminoferrite come into being.

At 1100~1200℃, a large number of tricalcium aluminate and tetracalcium aluminoferrite are generated. And the yield of calcium silicate is the most.

At 1300~1450℃, tricalcium aluminate and tetracalcium aluminoferrite are in molten state and CaO and part of dicalcium silicate are dissolved in the generated liquid phase. In this liquid phase, dicalcium silicate synthesizes tricalcium silicate by absorbing CaO which is the key to the sintering of cement. Sufficient time should be cost to make the free CaO in the raw material be absorbed, for the quality of cement clinker.

After rapid cooling of the cement clinker, there comes the cement clinker block.

2. The Mineral Composition of Portland Cement Clinker

The names and contents of the main mineral composition in Portland cement clinker are as follows:

Tricalcium Silicate ($3CaO•SiO_2$, abbreviated as C_3S), accounting for 37%~60%;

Dicalcium Silicate ($2CaO•SiO_2$, abbreviated as C_2S), accounting for 15%~37%;

Tricalcium Aluminate ($3CaO•Al_2O_3$, abbreviated as C_3A), accounting for 7%~15%;

Tetracalcium Aluminoferrite ($4CaO•Al_2O_3•Fe_2O_3$, abbreviated as C_4AF), accounting for 10%~18%.

In addition to these four major minerals, there are a small amount of free calcium oxide, magnesium oxide, and alkali in cement which are clearly prescribed in the national standards that the total amount should not be more than 10%.

3. The Hydrating Capacity of Cement Clinker Minerals

The building technical performance of cement mainly depends on the hydration of the several major minerals in the clinker. Table 4.1 shows the properties revealed in the processes that various minerals in cement separately react with water.

Table 4.1 The Hydration and Hardening Properties of Minerals in Portland Cement Clinker

Performance Index \ Name	Tricalcium Silicate(C_3S)	Dicalcium Silicate(C_2S)	Tricalcium Aluminate (C_3A)	Tetracalcium Aluminoferrite(C_4AF)
The Rate of Hydration and Setting & Harding	Fast	Slow	Fastest	Fast
28d Heat of Hydration	Much	Little	Most	Medium
Strength	High	Low in the earlier stage; High in the latter stage	Low	Low

From Table 4.1, it is known that the contents of various minerals in the clinker decide some particular aspects of the performance of cement. When the contents change, the property of cement will change correspondingly. For example, the increase of the content of C_3S can generate the cement with high strength; the cement with low heat of hydration can be obtained by decreasing the content of C_3A and C_3S and increasing the content of C_2S, such as cement dam.

The growth of the strength of various minerals in the cement clinker is shown in Figure 4.2.

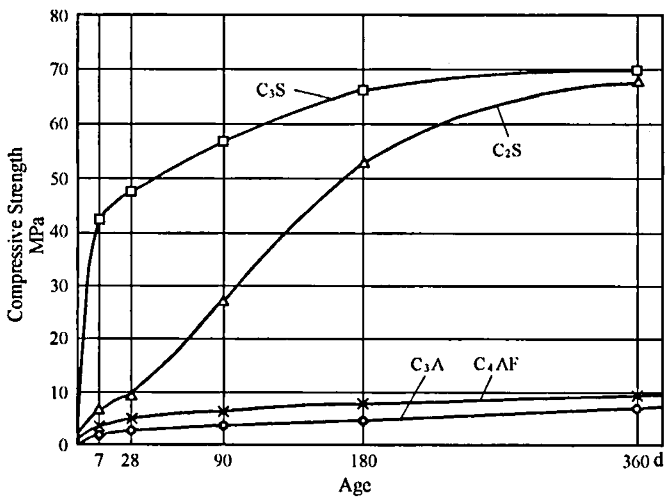

Figure 4.2 The Growth of the Strength of Various Minerals in the Clinker

4.1.2 Hydration and Setting and Hardening of Portland Cement

Mixed with a certain amount of water, cement can turn into the original plastic paste and the plasticity will be lost with the increase of time (but no strength), which is called the initial setting. And the final setting is the moment when the cement begins to have strength. The process from the initial setting to the final setting is known as condensation (or setting). Since then, the strength of cement becomes clear and finally the hard matrix—cement paste—comes into being, known as "hardening" of cement. The setting and hardening of cement are divided by humans themselves, but in fact they are a continuous and complicated physical and chemical changing process. All these changes decide some properties of hardened cement paste, which have an important impact on the application of cement.

1. The Hydration of Cement

When water is added, the cement particles are surrounded by water, the surface of the mineral granules in clinker reacted with water immediately, a series of new compounds are generated, and a certain heat is released. The reaction is as follows:

$2(3CaO \cdot SiO_2)+6H_2O=3CaO \cdot 2SiO_2 \cdot 3H_2O+3Ca(OH)_2$

$2(2CaO \cdot SiO_2)+4H_2O=3CaO \cdot 2SiO_2 \cdot 3H_2O+Ca(OH)_2$

$3Ca \cdot Al_2O_3+6H_2O=3CaO \cdot Al_2O_3 \cdot 6H_2O$

$4CaO \cdot Al_2O_3 \cdot Fe_2O_3+7H_2O=3CaO \cdot Al_2O_3 \cdot 6H_2O+CaO \cdot Fe_2O_3 \cdot H_2O$

In order to regulate the setting time of cement, a limited amount (about 3%) of gypsum should be added when the clinker is ground. The gypsum reacts with some of the calcium aluminate hydrate to generate insoluble needle-like crystals of calcium sulfate hydrate with significant cubical dilatation.

$3CaO \cdot Al_2O_3 \cdot 6H_2O+3(CaSO_4 \cdot 2H_2O)+19H_2O=3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$

To sum up, the Portland cement reacts with water and generates hydrate mainly containing calcium silicate hydrate, calcium ferrite hydrate gel, calcium aluminate hydrate, and the crystals of calcium sulfate hydrate. In the complete-hydrated cement paste, the calcium silicate hydrate accounts for about 50%, and the calcium hydroxide accounts for about 25%.

2. The Setting and Hardening of Cement

Mixed with water, the surfaces of cement particles react with water immediately and the generated colloidal hydrated products gather on the surfaces to slow down the chemical reactions and render the cement paste with plasticity. Hydrated products can dissolve in water immediately and new surfaces of cement particles appear. Then hydration continues. The generated colloidal hydrated products increase continuously and form a loose mesh structure by contacting with some points which make the paste lose mobility and plasticity, known as setting of cement.

Then, the calcium silicate hydrate gel, calcium hydroxide, crystals of calcium sulfate hydrate, and other kinds of hydrated products continue to increase and they contact with and adhere to each other, and then a closer mesh crystal structure is established. Hydrated products keep packing the mesh structure and begin to render cement with strength. With the extension of hardening time (age), the unhydrated inner parts of cement granules continue hydrating, the crystals gradually increase, and the gel gradually become more dense, which make the bonding capacity and strength of cement paste higher and higher. The increase of the strength leads to the cement paste with high strength, known as "hardening" of cement.

After the hardening process, the cement paste becomes a heterogeneous structure consisting of crystals, gel, unhydrated clinker particles, free water, and pores in various sizes, shown in Figure 4.3.

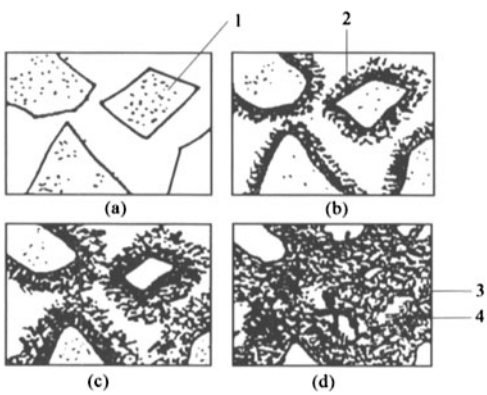

Figure 4.3 The Setting and Hardening Process of Cement

1. Unhydrated Cement Granules; 2. Cement Gel; 3. Calcium Hydroxide and Crystals of Calcium Aluminate Hydrate ; 4. Capillary Pore

At different ages of hardening process, the ratio of crystals, gel and unhydrated granules in cement paste will directly affect its strength and other properties. Moreover, the increasing of strength is connected with temperature and moisture. The higher the moisture is, the faster the hydration speed is and the quicker the setting and hardening is; otherwise, it will be slow. If the cement paste is in total dry state, the hydration cannot happen, the hardening process stops, and the strength cannot grow. Thus, watering maintenance should be strengthened after concrete structures have been casted. When the temperature is below 0℃, the hydration will nearly stop. Therefore, insulating measures should be adopted in winter construction to ensure the normal operation of the hardening process of cement.

3. The Main Factors Affecting the Setting and Hardening of Portland Cement

(1) The Impact of Cement's Composition

The mineral composition of cement and their ratios are the main factors affecting the setting and hardening of cement. As mentioned above, various mineral components will reveal different characteristics when reacting with water. For example, the increase of C_3A can speed up the setting and hardening rate of cement, and the heat of hydration is high at the same time. Generally speaking, if mixed materials are added into the cement clinker, the anti-erosion will increase, and the heat of hydration and the early strength will decrease.

(2) The Mixing Amount of Gypsum

Gypsum is called the retarding agent of cement which is mainly used for regulating the setting time of cement and is an indispensable component.

Without gypsum, cement clinker can condense immediately by mixing with water and release heat. The major reason is that C_3A in the clinker can dissolve in water quickly to generate a kind of calcium aluminate hydrate, a coagulant agent, which will destroy the normal use of cement. the retardation mechanism of gypsum is: when cement is hydrated, gypsum reacts with C_3A quickly to generate calcium sulfoaluminate hydrate (ettringite) which deposits and forms a protection film on the cement particles to hinder the hydration of C_3A and delay the setting time of cement.

If the content of gypsum is too little, the retardation affect will be unobvious. Too much gypsum will accelerate the setting of cement because gypsum can generate a coagulating agent itself. The appropriate amount of gypsum depends on the content of C_3A in the cement and that of SO_3 in gypsum, and it also related to the fineness of cement and the content of SO_3 in clinker. The amount of gypsum should account for 3%~5% of the cement's mass. If the content of gypsum exceeds the limit, it will lower the strength of cement and it can even lead to poor dimensional stability, which will cause the expanded destruction of cement paste. Thus, the national standard requires that the content of SO_3 should not be more than 3.5%.

(3) The Impact of Cement's Fineness

The size of cement particles directly affects the hydration, setting and hardening, strength and heat of hydration. The finer the cement particles are, the larger the total surface area is and the bigger the area contacting with water is. Thus, the hydration will be quick, the setting and hardening will be accelerated correspondingly, and the early strength will be high. However, if the cement particles are too small, it is easy for them to react with the water and the calcium dioxide in the air to destroy the storage of cement. If the cement is too fine, its shrinkage is large in the hardening process. Thus, the finer the cement is ground, the more energy will lose and the higher the cost will be. Usually, the grain size of the cement particles is within 7~200μm (0.007~0.2mm).

(4) The Impact of Curing Conditions

The curing environment has sufficient temperature and moisture which is conducive to the hydration and setting and hardening process of cement and benefits the development of the early strength. If the moisture of the environment is very dry, the water in the cement will evaporate, leading to insufficient hydration and ceasing of the hardening. Serious cracks will happen sometimes.

Usually, the temperature rises at the time of curing, and the hydration of cement and the development of early strength become fast. If the hardening process occurs at a low temperature, the final strength won't be affected though the development of the strength is slow. But if the temperature is under 0℃, the hydration of cement will stop and the strength will not only stop growing but also destroy the structure of cement paste due to the condensation of water.

In actual projects, the setting and hardening process of cement products is accelerated by stem curing and autoclave curing.

(5) The Impact of Curing Age

The hydration and hardening of cement is an ongoing process in a long period. With the increase of the hydrating degree of various clinker minerals in cement particles, gels will grow and capillary porosities will decrease, which enables the strength to rise with the increase of age. It is proved that cement develops rapidly within 28d and slowly after 28d.

(6) The Impact of the Mixing Water Content

If the cement consumption is unchanged, the increase of the mixing water content will enhance the amount of capillary porosities, lower the strength of cement paste, and extend the setting time. Therefore, in practical projects, the amount of water and cement will be changed without mortifying the water-cement ratio (the minimum amount of cement is regulated to ensure the durability of concrete) when the liquidity of cement concrete is adjusted.

(7) The Impact of Admixture

Hydration, setting, and hardening of Portland cement are constrained by C_3S, C_3A. And all the admixtures that affect the hydration of C_3S, C_3A can change the performance of the hydration, the setting and hardening of Portland cement. For example, the accelerator agents (such as $CaCl_2$, Na_2SO_4) can accelerate the hydration and the hardening of cement and improve its strength. On the contrary, the retarding agents (such as calcium lignosulphonate) can delay hydration and hardening of cement and affect the development of the early strength.

(8) The Impact of Storage Conditions

The inappropriate storage will expose cement to moisture. The particle surfaces agglomerate because of hydration which seriously reduces the intensity. Slow hydration and carbonization will happen due to the impact of the water and CO_2 in the air, even though the storage is good. The strength decreases by 10%~20% after 3 months, by 15%~30% after 6 months, by 25%~40% after 1 year, so the effective storage period of cement is 3 months and the cement should not be stored for a long time.

4.1.3 Technical Properties of Portland Cement

According to the national standard (GB17671-1999), the technical properties of Portland cement are required as follows:

1. Fineness

Fineness refers to the size of cement particles which directly affect the performance and the use of cement. All the products whose fineness cannot meet the requirements are sub-quality products.

The cement fineness is measured by sieve analysis method or specific surface area. Sieve analysis method requires that the screenings left on the square-hole sieve of 0.080mm should not exceed 10%. Specific surface area is calculated by the total surface area of 1kg cement (m^2/kg). The specific surface area of Portland cement should exceed 300 m^2/kg.

2. The Setting Time

The setting time of cement includes the initial setting time and the final setting time. The initial time refers to the time that cement turns into paste by mixing with water and begins to lose its plasticity. And the time that cement completely loses its plasticity by mixing with water and begins to have a certain structural strength is known as the final setting time. The national standards prescribe that the initial setting time of Portland cement should not be earlier than 45min and the final setting time should not be later than 6.5h. All the products off-grade at the initial setting time are spoiled products and those unqualified at the final setting time are sub-quality products.

The setting time of cement is measured by time determinator. The sample is the standard cement paste of which the temperature is 20℃±3℃ and humidity is more than 90%. Various mineral components of the cement clinker are different in the water consumption of their normal consistency. The finer the cement is ground, the more water the normal consistency will need. The normal consistency of Portland cement is within 24%~30%.

The setting time of cement is very important in the construction projects. The initial setting time should not be too fast in order to ensure that there is enough time to complete every process, such as casting, before the initial setting time; and the final setting time should not be too late in order to enable the cement to complete its setting and hardening as soon as possible after pouring and tamping to make the next process occur earlier.

3. Soundness

The soundness of cement refers to the stability of the volume change in the process of setting and hardening. If the volume change is unstable after setting and hardening, the concrete structures will crack, which can affect the quality of buildings or even cause serious accidents, known as poor dimensional stability. The cement product whose dimensional stability is poor will be disposed as spoiled product, not used in projects.

The reasons for poor dimensional stability are: the free calcium oxide (f-CaO) in the clinker is too much, or the free magnesium oxide in the clinker (f-MgO) is quite a little, or the gypsum mixed in the clinker is excessive. f-CaO and f-MgO in the clinker are all sintered, so their ageing speed is very slow. They start ageing slowly after the setting and hardening.

$$CaO+H_2O=Ca(OH)_2$$

$$MgO+H_2O=Mg(OH)_2$$

In the ageing process, there is volume expansion which causes the cracking of cement. The excessive amount of gypsum will react with the solid calcium aluminate hydrate to generate crystals of calcium sulfoaluminate hydrate. Thus, the volume will expand 1.5 times, which leads to the cracking of cement paste matrix.

The national standards require: boiling method can be used to inspect the poor dimensional stability of the cement caused by the free CaO. The so-called boiling method includes Pat test and Le Chatelier test. Pat test is to make the cement paste of normal consistency into cement cake, boil it for 3h, and then observe it by naked eyes. If there is no crack and no bending by ruler inspection, it is called qualified soundness. Le Chatelier test is to measure the expansion value after the cement paste is boiled and get hardened on Le Chatelier needles. If the expansion value is within the required value, its stability is qualified. If there is contradictory between the results measured by Pat test and Le Chatelier test, Le Chaterlier test should prevail.

The hydration of free magnesium oxide is slower than that of free calcium oxide. Therefore, its harm can be inspected only by autoclave test. The harm of gypsum will be found by immersing in room-temperature water for a long time. Then the poor dimensional stability caused by magnesium dioxide and gypsum is inconvenient to be tested rapidly. Thus, they should be controlled strictly in the production of cement. The national standards require: the content of free magnesium oxide in cement should not be more than 5.0%, and the content of sulfur trioxide in slag cement should not be more than 4.0% and that in other kinds of cement should not exceed 3.5%.

4. Strength and Strength Grade

Strength is an important technical index to indicate the quality of cement and also is the basis for the division of strength grade.

Testing Methods of Cement Gel Sand Strength (ISO) (GB/T17671-1999), a national standard, claim to test cement strength by soft gel sand method. This method is to produce a set of plastic gel sand specimens of 40mm×40mm×160mm by mixing a portion of cement (by weight) and three portions of China's ISO standard sand with water in the ratio of 0.5, maintain the specimens with moulds in moisture for 24h, then put them in the water of normal temperature (20℃±1℃) for curing after removing moulds, and test the compressive strength and bending strength of 3d and 28d respectively. According to the test results, the strength grade of Portland cement can be determined in the light of the requirements in Table 4.2.

Portland Cement and Ordinary Portland Cement (GB175-1999) requires that every strength grade value should not be lower than the provisions in the Table 4.2.

Table 4.2 The Requirements of Portland Cement Strength Grade (GB175-1999)

Strength Grade	Compressive Strength		Bending Strength	
	3d	28d	3d	28d
42.5	17.0	42.5	3.5	6.5
42.5R	22.0	42.5	4.0	6.5
52.5	23.0	52.5	4.0	7.0
52.5R	27.0	52.5	5.0	7.0
62.5	28.0	62.5	5.0	8.0
62.5R	32.0	62.5	5.5	8.0

Note: R——rapid strengthening type.

5. Alkali Content

The alkali content refers to the content of Na_2O and K_2O in cement. The condition for concrete to conduct the alkali-aggregate reaction is that the cement must contain alkali. When the active aggregate material is used, the cement with low alkali content should be used. The national standard requires: the alkali content in cement (calculated by $Na_2O+0.658K_2O$) should not exceed 0.60% or can be determined by the two sides of supply and demand.

The national standard still prescribes that the product is waste as long as one of the four items, magnesium, sulfur trioxide, stability, and the initial time, does not meet the requirements. Any product whose fineness, final setting time, and strength are under the required indexes is unqualified. Off-grade cement is prohibited in engineering. If only the strength of cement is below the stipulated index, the use of cement can be demoted.

4.1.4 Corrosion and Prevention of Cement Paste

Cement products have good durability in general terms, but their strength will decrease or even damage structures with the role of some erosive media (such as soft water, acid water, or salt water), known as the erosion of cement paste.

The main reasons for corrosion are:

1. Soft-water Corrosion (Dissolution Corrosion)

Rain, snow, distilled water, industrial condensate water, and the river water and lake water with low bicarbonate content, all of them belong to soft water. When hardened cement paste has contacted with these kinds of water for a long time, calcium hydroxide in the cement paste dissolves first (per litre water can dissolve calcium hydroxide of 1.3g). Under the role of still water or zero-pressure water, the dissolution will stop because the surrounding water is easy to get saturated due to the dissolved calcium hydroxide, and dissolution only occur on the surface, little impact. But if the cement paste is in fluid water or pressure water, the dissolved calcium hydroxide is easy to be washed away, the density of gypsum keeps decreasing, and even other hydrates will dissolve. The corrosion gets to the inner part to enlarge the cement pores and lower the strength, which will destroy the structures of cement paste to totally collapse.

When the environmental water contains bicarbonate, bicarbonate will react with the calcium hydroxide in cement paste and generate the insoluble calcium carbonate:

$$Ca(OH)_2+Ca(HCO_3)_2=2CaCO_3+2H_2O$$

The generated calcium carbonate accumulates in the pores of hardened cement paste, forming dense protective layer to prevent the infiltration of water outside and the solution of calcium hydroxide, thus preventing the erosion.

In practical projects, the cement structures which will contact with soft water should get hardened in the air at first to form a layer of calcium carbonate, which may protect the structures from dissolution corrosion.

2. Acid Corrosion

(1) Carbonate Corrosion

There is quite a little carbon dioxide dissolving in industrial effluent and groundwater. The carbon dioxide in water reacts with calcium hydroxide in cement paste and generates calcium carbonate. If continuing to react with phenolated water, it will change into soluble calcium bicarbonate. The structure of cement paste will be destroyed because of the dissolution of calcium bicarbonate and the decomposition of the other products in cement paste. Its chemical reaction is as follows:

$$Ca(OH)_2+CO_2+H_2O=CaCO_3+2H_2O$$

$$CaCO_3+CO_2+H_2O \rightleftharpoons Ca(HCO_3)_2$$

Calcium carbonate reacts with phenolated water and transfers into calcium bicarbonate, known as reversible reaction. If there is too much carbonate in water which exceeds the equilibrium concentration, the above reactive mode should occur from right to left. In addition, the decreasing of calcium hydroxide concentration will lead to the dissolution of the other hydrates in cement paste, thus intensifying the corrosive effect.

(2) Normal Acid Corrosion

There are inorganic acids and organic acids in industrial effluent, groundwater and marsh water; there is sulphur dioxide in the gas from industrial furnaces which generates sulfurous acid by contacting with water. Various acids have different degrees of corrosive effect on cement paste. They react with calcium hydroxide in cement paste and generate chemical compounds which can dissolve in water or can expand in volume, leading to the damage of cement paste. Among all these acids, the ones with the fastest corrosive effect are hydrochloric acid, hydrofluoric acid, nitric acid, and sulfuric acid (which are inorganic acids) and acetic acid, formic acid and lactic acid (which are organic acids).

For example, hydrochloric acid reacts with calcium hydroxide in cement paste:

$$2HCl+Ca(OH)_2=CaCl_2+2H_2O$$

and generates the soluble calcium chloride of which the destruction mode is the soluble chemical corrosion.

Sulfuric acid reacts with calcium hydroxide:

$$H_2SO_4+Ca(OH)_2=CaSO_4 \cdot 2H_2O$$

and generates dihydrate gypsum or crystallizes in the pores of cement and expands, or reacts with calcium aluminate hydrate in cement paste and generates high-sparse calcium sulfoaluminate hydrate which has a greater destructive effect.

3. Salt Corrosion

(1) Sulfate Corrosion

When the environmental water contains sodium sulfate, potassium sulfate, ammonium sulfate and other kinds of sulfate, they can conduct substitution reaction with calcium hydroxide, generating calcium sulfate.

Calcium sulfate reacts with solid calcium aluminate hydrate in cement paste and generates the high-sparse calcium sulfoaluminate hydrate whose volume is 1.5 times more than the original one.

$$4CaO \cdot Al_2O_3 \cdot 12H_2O + 3CaSO_4 + 20H_2O = 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O + Ca(OH)_2$$

High-sparse calcium sulfoaluminate hydrate is a needle-like crystal, commonly called "cement bacilli" (as shown in Figure 4.4) which has a great devastating effect on cement.

Figure 4.4 The Needle-like Crystals in Cement Paste

If the concentration of sulfate in water is high, calcium sulfate will crystallize directly in the pores and enlarge the volume, leading to the destruction of cement paste.

To sum up, the nature of sulfate corrosion is expansible chemical corrosion.

(2) Magnesium Salts Corrosion

If the environmental water is sea water and groundwater which often contain a large quantity of magnesium salts, mainly magnesium sulfate and magnesium chloride, they will react with calcium hydroxide in cement paste as follows:

$$MgSO_4 + Ca(OH)_2 + 2H_2O = CaSO_4 \cdot 2H_2O + Mg(OH)_2$$

$$MgCl_2 + Ca(OH)_2 = CaCl_2 + Mg(OH)_2$$

The generated magnesium hydroxide is soft without cementing capacity. Calcium chloride is soluble in water. And dihydrate gypsum causes the damaging effects of sulfate. Therefore, magnesium sulfate plays double corrosive roles of magnesium salts and sulfate in cement paste.

4. Alkali Corrosion

Alkali solution is generally harmless if its concentration is low. But the Portland cement with high aluminate content will be destroyed by contacting with strong base. For example, sodium hydroxide can react with the unhydrated alumniate in cement paste and generate the soluble sodium aluminate:

$$3CaO{\bullet}Al_2O_3+6NaOH=3Na_2O{\bullet}Al_2O_3+3Ca(OH)_2$$

If cement paste is imbued by sodium hydroxide solution and then become dry in the air, it can generate sodium carbonate by reacting with carbon dioxide in the air.

$$2NaOH+CO_2=Na_2CO_3+H_2O$$

Sodium carbonate precipitates and crystallizes in the pores of cement paste and causes the crack of cement paste.

There is carbohydrate, animal fat and others except the above corrosive types.

In fact, cement paste corrosion is a very complex physical and chemical process. There is seldom one kind of corrosion existing in the environment where cement paste suffers corrosion and there are often several kinds of corrosion, co-existing and mutually impacting. The fundamental reason for the cement corrosion is: externally, the structure is placed in the environment with erosive media; internally, calcium hydroxide and calcium aluminate hydrate existing in cement paste are easy to erode, and the cement paste itself is not dense with many pores which are easy for erosive media to go through the inner part. The total process of corrosion is: the dissolve-loss of $Ca(OH)_2$ in hydrates of cement paste leads to the destruction and the decrease of cementing capacity; or there are expansible products to cause cracking.

The content of clinker in Portland cement and that of calcium hydroxide and calcium aluminate hydrate in hydrated products are high, so the anti-erosion of cement paste is bad, inappropriate to be used in the environment with erosive media.

5. The Prevention of Corrosion

According to the above analysis of corrosion reasons, the corrosion of cement paste occurs because chemical reaction can happen between its external environment and internal environment. The corrosive compound must be the solution with a certain concentration, such as high temperature, proper humidity, fast flow, and the corrosion of steel bar. Thus, the following measures can be adopted in the use of cement:

1) Select the cement varieties reasonably based on the features of the erosive environment. For example, the cement whose hydrates contains a little calcium hydroxide has high capacity to resist erosive effects of soft water and others; the anti-sulfate cement whose content of tri-calcium aluminate is less than 5% can resist the sulfate erosion.

2) Raise the Density of Cement Paste. The amount of mixing water for Portland cement should be strictly controlled in order to reduce the pore space. The water theoretically needed in hydration of Portland cement is only 23% but much more mixing water (accounting for about 40%~70% of the cement mass) is needed in practical projects, and the pores connect to each other after the excessive water evaporates, so the erosive media go through the inner part of cement easily to accelerate the corrosion of cement. The mix proportion should be designed reasonably in order to improve the compactness of cement concrete. Low water-cement ratio and the best construction method should be adopted as much as possible. In addition, the insoluble calcium carbonate shell or calcium fluoride and thin silica gel film generated by conducting carbonization or fluosilicic acid treatment on the surface of concrete and mortar can increase the compactness of the surface and decrease the infiltration of erosive media.

3) Add a Protective Layer. The resistant stone, ceramic, plastic, and waterproof material are covered on the surface of cement paste, forming a impermeable layer for protection, to prevent the corrosion media contacting with cement paste directly.

4.1.5 Applications and Storage of Portland Cement

Portland cement has some good properties, used widely (see Table 4.6 and Table 4.7).

The attention should be paid to water-resistance and moisture-resistance in transport and storage of cement. There should be a specific place for cement storage at the construction site and the storeroom should be dry. Cement should be stored separately according to different varieties, strength grades and date of production, and the cement in bulk should be stored in different rooms; and the cement in bags should be stored on the backing plate 30cm higher above the floor and 30cm away from the surrounding walls with a stacking height below 10 bags; in the storage of cement, the one which is stored first should be used first, and cement should not be stored for a long time. The storage period generally should be less than 3 months and the cement stored for over 6 months can be used only through test.

Agglomeration often appears in wet cement. And minor caking can be crumbed by fingers or ground in proper way. Then the activity of wet cement can be restored partly. It can be used in minor projects after re-determining its strength grade.

4.2 Blended Portland Cement

All the hydraulic binding materials ground by mixing a certain amount of blended materials and a limited amount of gypsum in the clinker of Portland cement belong to blended Portland cement. The mixture of blended materials can change the performance of cement, adjust the strength, diversify the varieties, increase yields, decrease costs, expand the application, and utilize industrial wastes and local materials comprehensively. According to different amounts and varieties of blended cement, they are: ordinary Portland cement, Portland blast furnace cement, Portland pozzolana cement, Portland fly-ash cement, and composite Portland cement.

4.2.1 Blended Materials

The blended materials used in cement can be divided into active blended materials and inactive blended materials.

1. Active Blended Materials

The Portland cement mixed with active blended material can react with calcium hydroxide, the hydrated product of cement, and generate hydraulic binding material which can possess certain strength and change some properties of Portland cement after setting and hardening. The commonly used materials are blast furnace granular slag, pozzolana blended material, and fly ash.

(1) Granular Blast Furnace Slag

Granular blast furnace slag is the soft granule produced by rapidly quenching the fused blast furnace slag.

The active components in granular blast furnace slag are mainly active aluminum oxide and active silicon oxide which can react with calcium hydroxide and produce strength at the room temperature. The fused blast furnace slag is quenched into granules by water, which prevents the fused mass transferring into crystalline structure. The fused mass changes into vitreous body with high potential chemical energy and high activity. The alkaline slag with a lot of calcium oxide has weak hydraulicity due to the content of dicalcium silicate.

(2) Pozzolana Blended Material

It is the natural or artificial mineral material with pozzolana which can be divided into the blended materials with hydrous silicic acid, alumina-silica glasses, and calcined clay and others based on its chemical components and mineral structures.

The blended materials with hydrous silicic acid are: diatomite, diatoms stone, opal and siliceous slag (such as artificial silica ash) of which the active ingredients are silicon oxide.

The Al-Si vitreous materials are: volcanic ash, tuff, pumice and some industrial wastes whose active ingredients are silicon oxide and aluminum oxide.

The blended materials with (artificial) calcined clay are: calcined clay, cinder and some burnt coal gangue of which the active ingredients are aluminum oxide.

(3) Fly Ash

It is the granular slag exhausted from the smoke that is generated from the power plant boiler where coal dust is used as the fuel. It contains a lot of SiO_2 and Al_2O_3 and a little CaO, of pozzolana.

2. Inactive Blended Materials

This kind of material includes: ground quartz sand, limestone, clay, slow cooling slag, and various kinds of waste slag. Inactive blended materials themselves are not (or slightly) of hydraulicity or pozzolana and cannot produce chemical reaction with mineral components in cement (that is, no chemical activity) or can produce small chemical effect. The addition of such materials in cement clinker can only improve the cement quality, decrease the strength grades, and reduce the heat of hydration.

The above active blended materials contain a lot of active SiO_2 and active Al_2O_3 which can conduct hydration in calcium hydroxide solution, even faster in the saturated calcium hydroxide solution, and generate calcium silicate hydrate and calcium aluminate hydrate.

$$X\mathrm{Ca(OH)_2}+\mathrm{SiO_2}+m\mathrm{H_2O} = X\mathrm{CaO{\bullet}SiO_2}{\bullet}n\mathrm{H_2O}$$

$$Y\mathrm{Ca(OH)_2}+\mathrm{Al_2O_3}+m\mathrm{H_2O} = Y\mathrm{CaO{\bullet}Al_2O_3}{\bullet}n\mathrm{H_2O}$$

If there is gypsum in the liquid, it will react with calcium aluminate hydrate and generate calcium aluminate. Ca $(OH)_2$, hydrate in cement clinker, and gypsum can trigger the activity of the active blended materials. In other words, calcium hydroxide and gypsum can agitate hydration and accelerate the hardening of cement, known as activator. The common activators include alkali activator and sulfate activator. The catalysis of sulfate activator can be brought into full play only under the condition of alkali activator.

4.2.2 Ordinary Portland Cement

Ordinary Portland cement (simply called ordinary cement) refers to the hydraulic binding material ground by mixing Portland cement clinker, 6%~15% blended materials, and appropriate amount of gypsum, code-named P• O.

The maximum amount of active blended materials mixed in cement should not exceed 15% of the total mass. They are allowed to be replaced by kiln ash and inactive blended materials which should be no more than 5% and 10% of the cement mass respectively.

The maximum amount of inactive blended materials mixed in cement should not exceed 10% of the total mass.

According to *Portland Cement, Ordinary Portland Cement* (GB175-1999), the national standard, the strength grades of ordinary cement can be divided into: 32.5, 32.5 R, 42.5, 42.5 R, 52.5, 52.5 R, and their ages should be no less than the numerical value in Table 4.3. The initial setting time of ordinary cement should not be earlier than 45min, and final setting time should not be later than 10h. The screenings left on the square-hole sieve of 0.08mm should not exceed 10%. And boiling stability must be qualified. The ignition loss of cement should be less than 5.0%.

Table 4.3 Requirements for the Strength of Ordinary Portland Cement at Various Ages (GB175-1999)

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)	
	3d	28d	3d	28d
32.5	11.0	32.5	2.5	5.5
32.5R	16.0	32.5	3.5	5.5
42.5	16.0	42.5	3.5	6.5
42.5R	21.0	42.5	4.0	6.5
52.5	22.0	52.5	4.0	7.0
52.5R	26.0	52.5	5.0	7.0

Note: R—rapid strengthening type.

The majority of ordinary Portland cement is Portland cement clinker whose performance is similar to Portland cement. Due to the mixture of a few blended materials, however, the early hardening rate of the Portland cement linker is slow, 3d compressive strength is low, and the frost-resistance and wear-resistance are relatively poor, compared with Portland cement. The application range is shown in Table 4.6.

4.2.3 Portland Blast Furnace Cement

Portland blast furnace cement (simply called slag cement) refers to the hydraulic binding material ground by mixing Portland cement clinker, granular blast furnace slag, and appropriate amount of gypsum, code-named P • S. The mixed amount of granular blast furnace slag in cement is 20%~70% by weight. One of the blended materials, limestone, kiln dust, fly ash and volcanic ash, is allowed to replace the slag. And the replaced amount should not exceed 8% of the total mass of cement, and the granular blast furnace slag in cement should not be less than 20% after replacement.

According to *Portland blast furnace slag Cement, Portland Pozzolana Cement, and Portland fly-ash Cement* (GB1344-1999), the national standard, the content of magnesium oxide in clinker should not exceed 5.0%. If the stability of cement tested by autoclave method is qualified, the content of magnesium oxide can be extended to 6.0%. The content of sulfur trioxide should not exceed 4.0%.

The strength grades of slag cement can be divided into 32.5, 32.5R, 42.5, 42.5R, 52.5, 52.5R, and their ages should be no less than the value in Table 4.4. The requirements for fineness, setting time and soundness of slag cement are the same to those of ordinary cement. The regulated density of slag cement is usually 2.8~3.1g/cm^3 and the bulk density is about 1000~1200kg/m^3.

Table 4.4 Requirements for the Strength of Slag Cement, Pozzolana Cement, and Fly-ash Cement at Various Ages (GB1344-1999)

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)	
	3d	28d	3d	28d
32.5	10.0	32.5	2.5	5.5
32.5R	15.0	32.5	3.5	5.5
42.5	15.0	42.5	3.5	6.5
42.5R	19.0	42.5	4.0	6.5
52.5	21.0	52.5	4.0	7.0
52.5R	23.0	52.5	4.5	7.0

Note: R—rapid strengthening type.

The content of clinker in slag cement is less than that in Portland cement but the content of granular blast furnace slag is more. Slag cement has the following characteristics compared with Portland cement (see Table 4.6).

1. Slow Setting and Hardening

The hydration process of slag cement is more complicated than Portland cement. At first, the minerals in cement clinker react with water and generate calcium silicate hydrate, calcium aluminate hydrate, calcium ferrite hydrate and calcium hydroxide. Calcium hydroxide and gypsum mixed in cement are the alkali activator and the sulfate activator for slag respectively which react with active silicon oxide and aluminum oxide again to generate calcium carbonate hydrate, calcium aluminate hydrate, and calcium sulphoaluminate. The setting and hardening is slow because the content of clinker minerals in slag cement is small and the hydration happens at two steps.

2. Low Early Strength, and Rapid Growth of Later Strength

Because the setting and hardening of slag cement is very slow, the early strength (3d and 7d) is low. The calcium silicate gel increases after the second hydration, so the later strength (28d) grows rapidly, which may keep pace with or even exceed Portland cement (see Figure 4.5).

3. Low Heat of Hydration

The decrease of slag cement in clinker can cause the reduction of C_3S content and C_3A content which will release much heat at the hydration of cement. Therefore, it has priority in the mass concrete projects due to the low heat of hydration.

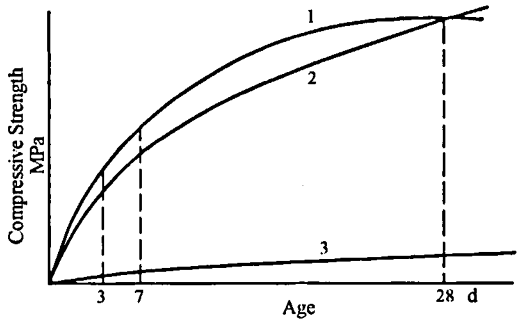

Figure 4.5 The Comparison between the Strength Growth of Slag Cement and that of Portland Cement

1. Portland Cement; 2. Slag Cement; 3. Granular Slag

4. Poor Carbonization Resistance

Among the hydrates of slag cement, the content of calcium hydroxide is small and alkalinity is low, so the carbonization resistance is poor. But the resistance to the dissolution corrosion and sulfate corrosion is strong.

5. Poor Water Retention and Good Water Segregation

The hydrophilicity of slag vitreous particles is low, so the water retention of slag cement is poor and its water segregation is good. It is easy to form capillary channels and water packets inside concrete. There are pores after water evaporates, which decreases the intensity and evenness of concrete. Thus, the dry shrinkage performance of slag cement is high, but its water resistance, frost resistance and the resistance to the alternation between wetness and dryness are poor. Slag cement should not be used in the concrete projects of which the impermeability is very important.

6. Good Heat Durability

Slag cement has good heat durability that can be used to prepare heat-resistant concrete because it contains a little calcium hydroxide after hardening and it is also the fire-resistant additive.

7. High Sensitiveness to Moist Heat at Hardening

The setting and hardening of slag cement is very slow at the low temperature, so insulation measures should be strengthened in the winter construction. But its strength develops very fast under the condition of heat, thus conserved with vapor.

4.2.4 Portland Pozzolana Cement

All the hydraulic hardening binding materials generated by grinding Portland cement clinker, pozzolana blended materials and appropriate amount of gypsum are called Portland pozzolana cement (simply called pozzolana cement), code-named P•P. The mixing amount of pozzolana blended materials accounts for 20%~50% of the total mass. The technical requirements for pozzolana cement are the same to those of blast-furnace slag cement.

Pozzolana cement and blast-furnace slag cement have many common grounds in performance (see Table 4.6), such slow hydration, setting and hardening process, low early strength, high growth of the later strength, low heat of hydration, high corrosion, poor frost-resistance, and easy carbonization.

The water demand of pozzolana cement is large. The dry shrinkage is more obvious than blast-furnace slag cement in the process of hardening. And under dry and heat conditions, dry shrinkage happens and the cement cracks. Thus, the conservation should be strengthened in use and it should be kept in the moist state for a long time.

The particles of pozzolana cement are very tiny, and the water segregation is low. Thus, its impermeability is good, favorable for the concrete projects.

4.2.5 Portland Fly-ash Cement

All the hydraulic hardening binding materials generated by grinding Portland cement clinker, blast furnace slag and appropriate amount of gypsum is known as Portland fly-ash cement (simply called fly-ash cement), code-named P•F. The mixing amount of fly-ash cement accounts for 20%~40% of the total mass.

The fineness, setting time, soundness and other technical requirements of fly-ash cement are the same to those of ordinary cement.

The hydration and hardening process of fly-ash cement is basically the same to that of pozzolana cement. And their performances have many similarities.

The main character of fly-ash cement is its little shrinkage, even less than Portland cement and ordinary cement. Therefore, its frost resistance is good. The water demand of fly-ash cement is little and the concrete mixed by it is workable because its particles are mostly spherical and the water absorption is low.

4.2.6 Composite Portland Cement

All the hydraulic hardening binding materials that are generated by grinding Portland cement clinker, two or more blended materials regulated above, and appropriate amount of gypsum is known as composite Portland cement (simply called composite cement), code-named P•C. The total mixing amount of blended materials in cement should be more than 15% but no more than 50%. Kiln dust under 8% is allowed to replace part of the blended materials; the mixing amount of blended materials should not overlap the Portland blast furnace slag cement when blended by slag.

In the light of *Composite Portland Cement* (GB12958-1999), the national standard, the content of magnesium oxide in cement clinker should be no more than 5.0%. If the cement is qualified through autoclave method for soundness, the content of magnesium oxide in clinker is allowed to reach 6.0%. The content of sulfur trioxide in cement should not exceed 3.5%.

The strength of composite Portland cement at each age in various strength grades should not be lower than the values in Table 4.5.

Table 4.5 Strength Values of Composite Cement at Various Ages (GB12958-1999)

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)	
	3d	28d	3d	28d
32.5	11.0	32.5	2.5	5.5
32.5R	16.0	32.5	3.5	5.5
42.5	16.0	42.5	3.5	6.5
42.5R	21.0	42.5	4.0	6.5
52.5	22.0	52.5	4.0	7.0
52.5R	26.0	52.5	5.0	7.0

Note: R——rapid strengthening type.

The properties of composite cement have different similarities with slag cement, pozzolana cement, and fly-ash cement, referring to Table 4.6. The selection of common cement can be seen in Table 4.7.

Table 4.6 Properties of Common Cement

Variety	Portland Cement	Ordinary Cement	Slag Cement	Pozzolana Cement	Fly-ash Cement	Composite Cement
Major Properties	① Very Fast Setting and Hardening ②Very High Early Strength ③Very High Heat of Hydration ④Very Good Frost Resistance ⑤Very Small Shrinkage ⑥Very Poor Corrosion Resistance ⑦Very Poor Heat Resistance	① Fast Setting and Hardening ②High Early Strength ③High Heat of Hydration ④Good Frost Resistance ⑤Little Shrinkage ⑥Poor Corrosion Resistance ⑦Poor Heat Resistance	① Slow Setting and Hardening ②Low Early Strength, High Later Strength ③Low Heat of Hydration ④Poor Frost Resistance ⑤Big Shrinkage ⑥Good Frost Resistance ⑦Good Heat Resistance ⑧High Water Segregation	① Slow Setting and Hardening ②Low Early Strength, Fast-growing Later Strength ③Low Heat of Hydration ④Poor Frost Resistance ⑤Big Shrinkage ⑥Good Frost Resistance ⑦Good Heat Resistance ⑧Good Impermeability	① Slow Setting and Hardening ②Low Early Strength, Fast-growing Later Strength ③Low Heat of Hydration ④Poor Frost Resistance ⑤Small Shrinkage, Good Crack Resistance ⑥Good Frost Resistance ⑦Good Heat Resistance	They are related to varieties and mixing amounts of the two or more blended materials. And its properties are basically the same to those of slag cement, pozzolana cement, and fly-ash cement.

Table 4.7 The Selection of Common Cement

Properties and Surrounding Conditions of Concrete Engineering			Priority	Available	Inadvisable
Ordinary Cement	1	The Concrete in General Climate	Ordinary Cement	Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement	
	2	The Concrete in Dry Conditions	Ordinary Cement	Slag Cement	Pozzolana Cement, Fly-ash Cement
	3	The Concrete in High Humidity or in Water for a Long Time	Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement	Ordinary Cement	
	4	The Concrete in Heavy Volume	Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement		Portland Cement

continued

Properties and Surrounding Conditions of Concrete Engineering			Priority	Available	Inadvisable
The Concrete with Special Requirements	1	The Concrete Requiring Fast Hardening Rate and High Strength (>C60)	Portland Cement	Ordinary Cement	Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement
	2	The Concrete in Cold and Open-air Area, or in the Changing Water Height in Cold Area	Ordinary Cement	Slag Cement (Strength Grade>32.5)	Pozzolana Cement, Fly-ash Cement
	3	The Concrete in the Changing Water Height in Cold Area	Ordinary Cement (Strength Grade>42.5)		Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement
	4	The Concrete Requiring Good Frost Resistance	Ordinary Cement, Pozzolana Cement		Slag Cement
	5	The Concrete Requiring Wear Resistance	Portland Cement, Ordinary Cement	Slag Cement (Strength Grade>32.5)	Pozzolana Cement, Fly-ash Cement
	6	The Concrete Affected by Corrosive Media	Slag Cement, Pozzolana Cement, Fly-ash Cement, Composite Cement		Portland Cement

4.3 Other Varieties of Cement

4.3.1 Aluminous Cement

Alumina bauxite and lime stone—the main raw materials—and the clinker whose main component is calcium aluminate after calcination are ground into hydraulic hardening material, belonging to aluminate cement, of which the code name is CA. A limited amount of α- Al_2O_3 powder can be added when the cement whose Al_2O_3 content is over 68% is ground based on the specific needs.

Aluminate cement can be divided into four categories by its Al_2O_3 content:

CA-50 $50\% \leqslant Al_2O_3 < 60\%$;

CA-60 $60\% \leqslant Al_2O_3 < 68\%$;

CA-70 68% $\leqslant$ Al_2O_3 <77%;

CA-80 77% $\leqslant$ Al_2O_3.

According to *Aluminate Cement* (GB201-2000), the national standard, the aluminate cement requirements are as follows:

1. Chemical Composition

The chemical composition of aluminate cement should be consistent with the requirements in Table 4.8, calculated by the mass percentage.

Table 4.8 The Chemical Composition of Aluminate Cement (%)

Type	Al_2O_3	SiO_2	Fe_2O_3	$R_2O(Na_2O+0.0658\ K_2O)$	S[1) (Total s)	Cl[1)
CA-50	≥50,<60	≤8.0	≤2.5	≤0.40	≤0.1	≤0.1
CA-60	≥60,<68	≤5.0	≤2.0			
CA-70	≥68,<77	≤1.0	≤0.7			
CA-80	≥77	≤0.5	≤0.5			

1) Producers should provide the results and test methods when users need.

2. Physical Properties

Fineness: specific surface area should not be less than $300m^2/kg$ or the screenings passing through the square-hole sieve of 0.045mm should not be more than 20%. The two methods can be negotiated by the parties of supply and demand. If there is disagreement, the specific surface area should prevail.

Setting time: the initial setting time of aluminate cement of type CA-50, CA-70, CA-80 should not be earlier than 30min, and the final setting time should not be later than 6h; the initial setting time of aluminate cement of type CA-60 should not be earlier than 60min, and the final setting time should not be later than 18h.

Strength: the strength of various aluminate cement types at each age should not be less than the values in Table 4.9.

Table 4.9 The Strength of Aluminate Cement Gel Sand (GB201-2000)

Cement Type	Compressive Strength (MPa)				Bending Strength (MPa)			
	6h	1d	3d	28d	6h	1d	3d	28d
CA-50	20[1)	40	50	—	3.0[1)	5.5	6.5	—
CA-60	—	20	45	85	—	2.5	5.0	10.0
CA-70	—	30	40	—	—	5.0	6.0	—
CA-80	—	25	30	—	—	4.0	5.0	—

1) Producers should provide results when users need.

GB201-2000 also provides that: if the content of R_2O in aluminate cement does not achieve the requirement, the cement is waste. If any of the other requirements can not be reached, the cement is unqualified.

The main characteristics and application of aluminate cement are as follows:

1) Fast setting and high early strength. The early strength is very high, and the later strength growth is not significant. Thus, aluminate cement is mainly used in the projects of which the construction period is urgent (such as roads, bridges) and salvaging (such as plugging); it still can be used for winter construction projects.

2) Large heat of hydration. It is more or less the same to high-grade Portland cement, but its heat release is very quick and concentrative. The total amount of the heat of hydration within 1d is 70%~80%. Aluminate cement would not be appropriate for mass concrete projects.

3) Its resistance to fossil water and surfate is very strong.

4) Its alkali-resistance is extremely poor, inappropriate for the projects that will contact with alkaline solution.

5) High heat resistance. When fire-resistant coarse-fine aggregate (such as chromite) is used, it can be made into the heat-resistant projects of 1300~1400℃ and its strength can be maintained around 53%.

6) It can be used as the chemical adding material for building materials to prepare expansive cement and self-stressing cement.

7) Under natural conditions, the long-term strength and other properties will decrease a bit. Therefore, aluminate cement would not be appropriate for the long-term load-bearing structure and the projects placed in hot and humid environment.

It should be also noted that aluminate cement products can not be conserved by steam curing; aluminate cement should not be mixed with Portland cement or lime so as not to cause flash condensation and the strength decline; the aluminate cement should not contact with the Portland cement which has not gotten hardened yet.

In addition, the moisture-proof protection of aluminate cement should be paid attention to in the course of transportation and storage, or the strength will drop rapidly after absorbing moisture.

4.3.2 Expansive cement

Expansive cement can generate volume expansion in the hydration process, and it does not shrink but also expand to some extent. The use of expansive cement can overcome and improve some shortcomings of ordinary cement concrete (commonly used cement will shrink in the hardening process, which causes the structures to crack and be permeable, inappropriate for some projects), and can enhance the density of cement concrete structures and the integrity of concrete.

The major components of expansive cement include: silicate-type, aluminate-type, sulphoaluminate-type and calcium aluminoferrite-type. The expansion mechanism is the expansion of ettringite generated in cement paste. And the setting and hardening of silicate expansive cement is relatively slow; but that of the aluminate one is fast.

1. Silicate Expansive Cement

It is the expansive cement made by mixing aluminate cement and gypsum based on Portland cement. The value of its expansion can be adjusted by changing the content of aluminate cement and gypsum.

If the aluminate cement in silicate expansive cement is replaced by alunite, it is known as alunite expansive cement. The composition of alunite is [K_2SO_4•$Al_2(SO_4)_3$•$4Al(OH)_3$], and it can generate ettringite, the best expansive cement at present.

The addition of alunite expansive agent and aluminate expansive agent into Portland cement will also lead to the expansion of cement.

2. Aluminate Expansive Cement

Aluminate expansive cement is generated by grinding aluminate cement clinker and dihydrate gypsum or mixing their ground particles. Its self-stressing and air tightness are good.

3. Aluminoferrite Expansive Cement

It is made by anhydrous calcium sulphoaluminate and dicalcium silicate as well as gypsum.

4. Sulphoaluminate Expansive Cement

It is made by iron phase, anhydrous calcium sulphoaluminate and dicalcium silicate as well as gypsum.

By adjusting the coordinate proportion of the above four types can generate the expansive cement with different expansion ratios. The expansive cement can be divided into expansive cement and self-stressing cement according to different expansion ratios. The linear expansion rate of expansive cement is generally under 1%, equivalent to or slightly larger than the shrinkage rate of ordinary cement, which can conduct shrinkage compensation. Thus it is also called shrinkage-compensating cement or the non-shrinkage cement. The linear expansion ratio of self-stressing cement is generally 1%~3%, with big expansion value. If it is the reinforced concrete, the concrete will bear compressive stress in order to achieve pre-stress. When self-stress is more than or equals to 2.0 MPa, it is called self-stressing cement; if self-stress is less than 2.0 MPa (normally 0.5MPa), it is called expansive cement.

The self-stressing cement can be used for pressure tubes and fittings in self-stressing reinforced concrete. The expansive cement can be used for shrinkage-compensating concrete, structure joints and pipe joints, the reinforcement and repair of concrete structures, anti-seepage and plugging projects, and the fix of machine base and foot screw.

4.3.3 White and Colorful Portland Cement

1. White Portland Cement

White Portland cement is simply called white cement. The main difference between it and the commonly used cement is that the content of ferric oxide is less, leading to white color. The production of white cement is basically the same to that of ordinary cement. The key is to strictly control the content of iron and ferric substance should be avoided in the production process. In addition, the manganese oxide and chromium oxide can also lead to the decrease of the whiteness, so the content must be controlled strictly.

The performance of white cement is basically the same to Portland cement. According to the national standard GB2015, the strength grades of white Portland cement include 3.5, 42.5, 52.5, and 62.5. And the cement strength of each grade in various ages should not be less than the values in Table 4.10.

Table 4.10 Strength Requirements of White Portland Cement

Strength Grade	Compressive Strength (MPa)			Bending Strength (MPa)		
	3d	7d	28d	3d	7d	28d
32.5	14.0	20.5	32.5	2.5	3.5	5.5
42.5	18.0	26.5	42.5	3.5	4.5	6.5
52.5	23.0	33.5	52.5	4.0	5.5	7.0
62.5	28.0	42.5	62.5	5.0	6.5	8.0

The reflectivity of the white cement surface to red, green, blue, the three primary colors is compared with that of the standard magnesium oxide white board, which is indicated by the percentage of relative reflect, known as whiteness. The whiteness of white cement can be divided into extra-grade, first-grade, second-grade, and third-grade, the four grades according to the values in Table 4.11. The whiteness grades should not be less than the values in the form.

Table 4.11 The Whiteness Requirements of White Cement

Grade	Extra-grade	First-grade	Second-grade	Third-grade
Whiteness (%)	86	84	80	75

The fineness of white Portland cement is regulated that the screenings pass through the square-hole sieve of 0.080mm is no more than 10%; its initial setting time should not be earlier than 45min, and the final setting time should not be later than 12h; soundness tested by boiling method must be qualified; meanwhile, the content of magnesium oxide in clinker should not be more than 4.5% and the content of sulfur trioxide should not exceed 3.5%.

2. Colorful Portland Cement

Based on different coloring method, there are three producing modes of colorful Portland cement: the first is direct sintering method, that is, to add colorful raw material into raw cement, to directly sinter them into colorful cement clinker, and then to grind it with a limited amount of gypsum; the second is staining method, namely, to grind white Portland cement clinker or Portland cement clinker with appropriate amount of gypsum and alkali substance into colorful cement; the third method is to add dry color substance directly into white cement or Portland cement. The third method is often adopted when the amount used in projects is not large.

The colorful Portland cement includes red, yellow, blue, green, brown, black and other colors. According to *Colorful Portland Cement*

(JC/T870-2000), the industrial standard, its strength grades can be divided into 27.5, 32.5, and 42.5. The color cement strength in various ages should not be less than the values in Table 4.12.

Table 4.12 Requirements for the Strength Grades of Colorful Portland Cement (JC/T870-2000)

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)	
	3d	28d	3d	28d
27.5	7.5	27.5	2.0	5.0
32.5	10.0	32.5	2.5	5.5
42.5	15.0	42.5	3.5	6.5

The fineness of colorful Portland cement is required that the screenings left on the square-hole sieve of 0.080mm should not exceed 6.0%; its initial setting time should not be earlier than 1h and final setting time should not be later than 10h; the soundness tested by boiling method be qualified, and its content of sulfur trioxide should not be more than 4.0%.

According to the standard JC/T870-2000, the cement is waste if any of its sulfur trioxide content, initial setting time, and soundness does not reach the requirement. The cement is unqualified if any of its fineness, final setting time, color difference, and color durability cannot achieve the standard. It is also unqualified if the package marks of cement are not complete, including variety, strength grade, color, the name of producer, and the ex-factory change.

Colorful and white Portland cement is mainly used for the decoration of buildings, commonly for the preparation of various types of colorful cement mortar and cement mortar for swabbing or pointing joints. It can be made into decorative concrete, colorful washed finish, artificial marble and terrazzo. And it is also used for sculpture and various decorative components due to its unique colors.

Questions

4.1 Why should a limited amount of gypsum be added into Portland cement clinker?

4.2 What are the main mineral components in Portland cement clinker? What kind of influence do they bring to cement? And what about their hydrated products?

4.3 What is the setting and hardening of Portland cement? What is the structure of the cement paste after hardening?

4.4 What is the main reason affecting the setting and hardening of Portland cement?

4.5 How are the initial setting time and final setting time of Portland cement regulated in the national standard?

4.6 What is the soundness of cement? What kind of factors can cause poor dimensional stability?

4.7 What kind of methods can be adopted to test the strength grades of cement, according to the national standards (GB/T17671-1999), *Testing Methods of Cement Gel Sand Strength* (ISO)?

4.8 Why to use low-alkali cement in the construction?

4.9 After inspection, what is qualified product? What is substandard product? What is waste?

4.10 What kind of corrosion does the cement have? Analyze the impacts of various kind of corrosion to cement paste.

4.11 What is the reason that causes the corrosion of cement? And what are the anti-corrosion measures?

4.12 What should be noted in the use of expired cement?

4.13 What are the mixed materials of cement? What kinds of changes will they cause to the Portland cement? And what about the practical significance?

4.14 Narrate the composition, properties and application of the six kinds of commonly used cement.

4.15 There are three kinds of white binding materials in warehouse: quicklime powder, building gypsum and white cement. They cannot be used due to the misplaced labels. Is there a simple way to identify them?

4.16 There are concrete structures and projects in the following. Try to select the proper cement and explain the reason.

①cast-in-place beam, plate, and column; ②the prefabricate parts conserved by autoclave method; ③urgent salvaging projects or urgent military engineering; ④mass concrete dam and the foundation for large-scale equipment; ⑤the underground engineering that can be corroded by sulfate; ⑥the basis for blast furnace; ⑦harbor projects.

4.17 There are several concrete structures made of cement in the following, which should not be used for the autoclave conservation?

① Slag Cement; ② Pozzolana Cement; ③ Fly-ash Cement; ④ Aluminate Cement.

4.18 Summary the characteristics of cement and the proper use.

Exercises

The Portland cement in a certain strength grade has been stored for more than three months. Now it is tested that the compressive loading value and bending strength value of 3d are as follows, how to evaluate its strength grade?

The compressive loading of 3d/ kN: 29.0, 28.0, 29.0, 27.5, 28.0, 29.0.

The bending strength of 3d/ MPa: 3.4, 3.2, 3.6.

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5

Concrete

This chapter mainly introduces the composing materials, the major technical functions and the factors influencing the performance of ordinary concrete, specifically discusses the methods to design the mix proportion of ordinary concrete, reveals the quality control and strength evaluation of concrete, and simply exhibits other kinds of concrete.

5.1 Overview

Concrete is a kind of man-made stone which is made by mixing gel materials, granular coarse-fine aggregate and water (if necessary, a certain amount of additive and mineral materials are added) in a proper ratio evenly, and then getting solidified and hardened. It is one of the main building materials in projects. The one mostly used in construction projects is the cement concrete made by mixing gel materials, aggregate (sand and stone), and water, which should get through hardening process. Cement concrete is also called ordinary concrete, which is the focus of this chapter.

Concrete is widely used in industry, national defense and civil buildings. With the rapid development of China's construction projects, the concrete with different kinds of functions has come into being.

1. Classification of Concrete

1) By cementing materials, there are: cement concrete, gypsum concrete, asphalt concrete and polymer concrete.

2) By apparent density, there are: heavy concrete ($\rho_0 > 2500\text{kg/m}^3$), ordinary concrete ($\rho_0$ from $1900\,\text{kg/m}^3$ to $2500\,\text{kg/m}^3$), light concrete (ρ_0 from $600\,\text{kg/m}^3$ to $1900\,\text{kg/m}^3$), and super-light concrete ($\rho_0 < 600\text{kg/m}^3$). The apparent density of concrete depends on the aggregate varieties and its own density. Many properties of concrete are connected with apparent density.

3) By performance and application, there are: structural concrete, hydraulic concrete, ornamental concrete, and special concrete (heat-resistant, acid-resistant, alkali-resistant, and anti-radiation concrete and so on).

4) By construction methods, there are: pump concrete, sprayed concrete, vibrating-compacting concrete, centrifugal concrete and so on.

5) By mixtures, there are: fly ash concrete, silica fume concrete, fine blast furnace slag concrete, fiber concrete, and others.

2. Characteristics of Concrete

1) Convenient for use: the new mixtures have good plasticity that can be cast into components and structures in various shapes and sizes.

2) Cheap: raw materials are abundant and available. More than 80% of them are sand and stone whose resources are rich, energy consumption is low, according with the economic principle.

3) High-strength and durable: the strength of ordinary concrete is 20 ~ 55MPa with good durability.

4) Easy to be adjusted: the concrete with different functions can be made just by changing the varieties and quantities of composing materials to meet various demands of projects; steel bar can be added to concrete to improve its strength, and this kind of concrete is a composite material (reinforced concrete) which can improve its low tensile and bending strength in order to meet the needs of various structural engineering.

5) Environment-friendly: concrete can make full use of industrial wastes, such as slag, fly ash and others to reduce environmental pollution.

Its major shortcomings are high dead weight, low tensile strength, brittle and easy to crack.

5.2 Components of Ordinary Concrete

The basic components of ordinary concrete are cement, water, sand, and stones. Generally, the amount of sand and stone accounts for above 80% of the total volume, functioning as frame, so they are respectively called as fine aggregate and coarse aggregate. Mixed with water, cement becomes cement paste, and cement mortar not only wraps the surface of particles and fills their gaps, but also wraps stones and fills their gaps, then concrete coming into being (see Figure 5.1). Cement paste can function as greasing before hardening, which renders concrete mixture with good mobility; after hardening, aggregates stick together and form a hard entity, known as man-made stone—concrete.

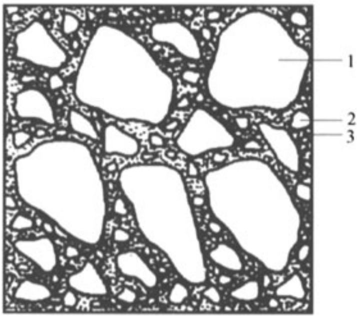

Figure 5.1 The Ordinary Cement Structure

1. coarse aggregate; 2. fine aggregate; 3. cement paste

5.2.1 Cement

Cement is the most important component for concrete and relatively expensive. In the preparation of concrete, the choice of cement varieties and strength grades are directly related with the durability and economy of concrete.

1. The Choice of Cement Varieties

When concrete is prepared, the rational choice should be made in light of the properties of cement varieties, according to the properties of the project, parts, construction conditions, environment and so on. The selection principles for the six common kinds of cement can be referred to in Chapter Four.

2. The Choice of Cement Strength Grades

The cement strength grades are corresponding to the design strength grades of concrete. The standard strength grade of ordinary cement should be 1.5~2.0 times as big as that of concrete. If the cement strength is too high or too low, the cement content in concrete will be too small or too large that will have a negative impact on the technical performance and the economic effect of concrete.

5.2.2 Aggregate

The aggregates used for ordinary concrete can be divided into two types by their sizes. The one whose diameter is more than 4.75mm is called coarse aggregate, and the one whose diameter is less than 4.75mm is called fine aggregate. The fine aggregates used in ordinary concrete generally are the natural sand which comes into being when the natural rock (excluding soft rock and weathered rock) has experienced natural weathering, water transportation, sorting, and stacking and other kinds of natural conditions; the machine-made sand (is made by grinding and sorting by machine, and the diameter of the rock particles is less than 4.75mm, except the particles of soft rock and weathered rock.) through de-dust treatment and the mixed sand (made by mixing machine-made sand and natural sand) are collectively call manufactured sand. According to different sources, natural sand can be divided into river sand, sea sand, mountain sand and desalted sea sand. The coarse aggregates used in ordinary concrete are gravel and pebble. In China's *Sand for Building* (GB/T14684-2001) and *Gravel and Pebble for Building* (GB/T14685-2001), it is regulated that the sand for building can be classified into category I, category II, and category III based on the technical quality requirements. Category I is properly used in the concrete whose strength grade is bigger than C60; category II is suitable for the frost-resistant and seepage-resistant concrete whose strength grade is within C30~C60; category III is good for the concrete whose grade is lower than C30. The specific technical quality requirements can be summarized as follows:

1. Mud and Clod Content

The mud content refers to the total amount of the dust, silt and clay whose diameters are smaller than 0.075mm in aggregates.

The clod content refers to the content of particles whose diameters are more than 1.18mm and become less than 0.60mm after being washed by water and pinched by hand in the fine aggregates; or the content of the particles whose diameters are more than 4.75mm and become less than 2.36mm after being washed by water and pinched by hand in coarse aggregates. The stone dust content means the content of the particles with diameters less than 0.075mm.

The mud particles in aggregates are very fine that can adhere to the surface of aggregates, which will impact the bond force between cement paste and aggregates. And clays will become the vulnerable parts in concrete, which will have a big impact on the quality of concrete. Thus, the mud and clod content in aggregates must be restricted strictly. See Table 5.1.

Table 5.1 The Restrictions of Mud and Clay Content in Sand and Stone

Terms		Index		
		I	II	III
Mud content (by weight) (%)	Sand	<1.0	<3.0	<5.0
	Stone	<0.5	<1.0	<1.5
Clay content (by weight) (%)	Sand	0	<1.0	<2.0
	Stone	0	<0.5	<0.7

2. Harmful Substances Content

GB/T14684-2001 and GB/T14685-2001 stress that the building sand and stone should not content grass roots, leaves, resins, coal, slag, and other miscellaneous items.

The harmful substances in aggregate mainly refer to sulfides, sulfate, organic matter, mica, chloride, clay, light substances, and so on. Clay and light substances (coal and slag, etc.) will adhere to the surface of aggregate, which impacts the cohesiveness between aggregate and cement and reduces the frost-resistance and impermeability; sulfides, sulfate and organic matter will be corrosive to cement, which will decreases the strength and durability of cement; chloride will corrode steel, which accelerates the damage of reinforced concrete. The limited quantity of harmful substances is shown in Table 5.2.

Table 5.2 The Limited Quantity of Harmful Substances in Aggregate

Items		Indexes		
		I	II	III
Sulfides and sulfate content (convert to SO_3, by weight) (%)	Sand	<0.5	<0.5	<0.5
	Stone	<0.5	<1.0	<1.0
Organic matter content (by colorimetric method)	Sand and stone	Qualified	Qualified	Qualified
Mica content (by weight) (%)	Sand	<1.0	<2.0	<2.0
Light substance (by weight) (%)	Sand	<1.0	<1.0	<1.0
Chloride content (by the weight of chloride ion) (%)	Sand	<0.01	<0.02	<0.06

3. Sturdiness

The sturdiness of aggregate refers to the ability to resist fracture under the role of natural weathering and other physical and chemical factors. According to the provisions, sodium sulfate solution is often used for the test. After 5 times cycle soakage, the mass loss of samples should accord with the regulations in Table 5.3.

The artificial sand is tested by crushing method, and the crushing indexes should be less than those regulated in Table 5.8.

Table 5.3 The Sturdines Index of Aggregate

Item		Indexes		
		I	II	III
Mass loss (%)	Sand	<8	<8	<10
	Stone	<5	<8	<12

4. Gradation and Coarseness

The aggregate gradation refers to the collocation distribution of particles with different diameters. Good gradation will not only reduce the amount of cement but also improve density, intensity and other properties of concrete. The aggregate coarseness refers to the average coarseness of the particle mixtures in different diameters.

(1) Grain Gradation and Coarseness of Sand

The grain gradation and coarseness of sand are determined by screen residue analysis. Grading region and fineness modulus can be used to express the gradation and the coarseness of sand particles respectively. A set of square-hole sieves whose diameters are 4.75mm, 2.36mm, 1.18mm, 0.60m, 0.30mm and 0.150mm are adopted specifically. Screen 500g dry sand obtained by sample splitting device from coarseness to fineness, then weigh their screen residue, and calculate their percentage a_1, a_2, a_3, a_4, a_5, a_6 (which means the mass of screen residue to the mass of the total sample sand) and the percentage of cumulative screen residue A_1, A_2, A_3, A_4, A_5, A_6 (which refers to the screen residue of one sieve to the sum of all the unit screen residue percentages whose sieves are thicker than it). The relationship between the cumulative screen residue and the unit screen residue is shown is Table 5.4. The cumulative screen residue in each group represents a gradation.

According to GB/T14684-2001, there are three grading regions of sand when it is calculated by the percentage of the cumulative screen residue of 0.60mm square-hole sieve, shown in Table 5.5. Compared with the standard indexes in Table 5.5, the real gradations of sand particles are allowed to exceed the limits slightly (except 4.75mm and 0.60 sieves), but the total percentage should not be more than 5%. Taken the cumulative screen residue percentage and the size of sieve holes respectively as the ordinate and the abscissa, the numbers regulated in Table 5.5 can be drown into sieve-analysis curves of the upper and the lower limits of three grading regions, shown in Figure 5.2. The sand of zone II is proper for the preparation of concrete; if the sand of zone I is selected, the sand ratio should be improved and the amount of cement should be enough to satisfy the workability of concrete; if the sand of zone III is used, the sand ratio should be lowered properly to guarantee the strength of concrete.

Table 5.4 The Relationship between Cumulative Screen residue and Unit Screen residue

Sieve hole(mm)	Unit screen residue(%)	Cumulative screen residue(%)
4.75	a_1	$A_1=a_1$
2.36	a_2	$A_2=a_1+a_2$
1.18	a_3	$A_3=a_1+a_2+a_3$
0.60	a_4	$A_4=a_1+a_2+a_3+a_4$
0.30	a_5	$A_5=a_1+\cdots+a_5$
0.15	a_6	$A_6=a_1+\cdots+a_6$

Table 5.5 Grading Zones of Sand Particles (GB/T 14684-2001)

Cumulative Screen residue(%) / Grading zones / Hole Size (mm)	I	II	III
9.50	0	0	0
4.75	10~0	10~0	10~0
2.36	35~5	25~0	15~0
1.18	65~35	50~10	25~0
0.60	85~71	70~41	40~16
0.30	95~80	92~70	85~55
0.15	100~90	100~90	100~90

Note: When the cumulative screen residue of artificial sand of 0.15mm sieve belongs zone I, the arrange can be relaxed to 100~85; when the sand is of zone II, the arrange can be widened to 100~80; and when of zone III, it can be relaxed to 100~75.

The coarseness of sand is expressed by fineness modulus (M_x), defined as follows:

$$M_x = \frac{(A_2 + A_3 + A_4 + A_5 + A_6) - 5A_1}{100 - A_1} \tag{5.1}$$

The bigger the fineness modulus is, the more coarse the sand is. The fineness modulus of the sand used in ordinary concrete is within 3.7~1.6. And if M_x is within 3.7~3.1, it is coarse sand; if M_x is within 3.0~2.3, it is medium sand; if M_x is within 2.2~1.6, it is fine sand; and if M_x is within 1.5~0.7, it is superfine sand which should be considered specifically when concrete is prepared. It should be reminded that the fineness modulus can not reflect the quality of their grading regions. The sand with the same fineness modulus can have very different grading regions. Therefore, the particle gradation and the fineness modulus should be considered in the preparation of concrete.

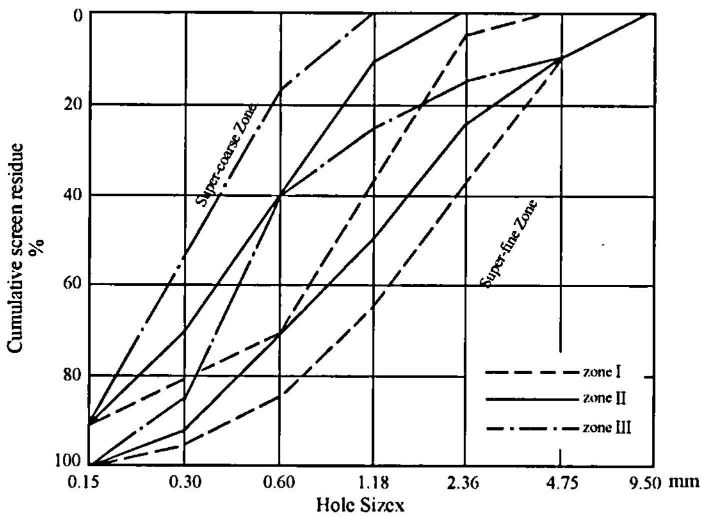

Figure 5.2 The Grading-zone Curve of Sand

(2) The Grain Composition of Stone and the Maximum Particle Diameter

The grain composition of stone includes continuous size fraction and single size fraction which are also determined by sieve analysis. There are 12 square-hole sieves used in tests: 2.36mm, 4.75mm, 9.50mm, 16.0mm, 19.0mm, 26.5mm, 31.5mm, 37.5mm, 53.0mm, 63.0mm, 75.0mm and 90mm. These sieves are selected according to demands, and the determination method is the same with that of fine aggregate. The grain composition of gravel and scree particles should be in line with the regulation in Table 5.6.

Continuous size fraction has priority in the design of concrete mixture ratio. Single size fraction can be used in the composition of required continuous size fraction and also used with continuous size fraction to improve the grading or to prepare the continuous size fraction of larger-sized particles. The single size fraction should not be used "singly" in the preparation of concrete. If it must be used lonely, the technical and economical analysis should be made and the experiment should be conducted to prove that there will be no segregation or any impact on the quality of concrete.

Table 5.6 The Grain Composition

Cumulative screen residue (%) / Nominal particle diameter (mm) \ Square-hole (mm)		2.36	4.75	9.50	16.0	19.0	26.5	31.5	37.5	53.0	63.0	75.0	90
Continuous size fraction	5~10	95~100	80~100	0~15	0								
	5~16	95~100	85~100	30~60	0~10	0							
	5~20	95~100	90~100	40~80	—	0~10	0						
	5~25	95~100	90~100	—	30~70	—	0~5	0					
	5~31.5	95~100	90~100	70~90	—	15~45	—	0~5	0				
	5~40	—	95~100	70~90	—	30~65	—	—	0~5	0			
Single size fraction	10~20		95~100	85~100		0~15	0						
	16~31.5		95~100		85~100			0~10	0				
	20~40			95~100		80~100			0~10	0			
	31.5~63				95~100			75~100	45~75		0~10	0	
	40~80					95~100			70~100		30~60	0~10	0

The maximum nominal size of stone particle is the maximum particle diameter of this size fraction. If the maximum diameter increases, its total area decreases when quality remains the same. Thus, from the economic perspective, cement can be saved by increasing the maximum diameter. Therefore, the bigger maximum size should be chosen if the circumstance allows. The selection of the maximum size should be considered from the following three aspects: first, from structure: the cross-section size of building component and the reinforcement should be considered when the maximum size of stone is selected. According to *The Construction and Examining Norms of the Concrete Structure* (GB50204-2002), the maximum size should not be more than 1/4 of the minimum cross-section size of the structure and 3/4 of the minimum net distance between steel bars. As to concrete solid plate, the maximum size should not be more than 1/3 of the board thickness and not exceed 40mm. Second, from construction: for the pumping concrete, the ratio between the maximum diameter and the delivery pipe should be as follows: the ratio of gravel should not be more than 1 : 3 and that of crushed stone should not be more than 1 : 2.5 when the pumping length is below 50m; the ratio of crushed stone should not be more than 1 : 4 and that of gravel should not be more than 1 : 3 when the pumping distance is within 50~100m; the ratio of crushed stone should not be more than 1 : 5 and that of gravel should not be more than 1:4 when the pumping distance is beyond 100m. Continuous size fraction should be adopted in aggregate. If the particle diameter is too big, it is inconvenient for both transportation and stirring. Third, from the economic perspective: it is proved that the using amount of cement will increase with the decrease of the maximum diameter if it is less than 80mm; the reduction effect is not that obvious if the maximum diameter is more than 150mm (shown in Figure 5.3). As a result, for the economic sake, the maximum diameter should not be more than 150mm. In general, the maximum diameter is usually 120mm or 150mm in the large-scale projects such as water conservation and harbor; it is usually 20mm, 31.5mm or 40mm in the building construction.

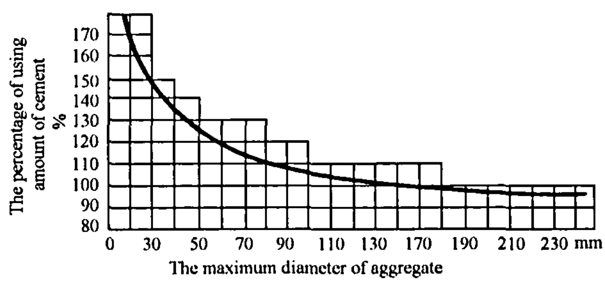

Figure 5.3 The Curve of the Relation between Maximum Diameter of Aggregate and Using Amount of Cement

5. Shape and Appearance Characteristics of Aggregate

The particles of fine aggregate—sand are small, and their appearances are rarely considered. Shapes and appearances of coarse aggregate—stone should be considered. The surface of gravel is smooth with less angulars. Meanwhile, its voidage and surface area are small. Thus, its workability is good in the preparation of concrete, which is good for the mobility of concrete and the reduction of the using amount of cement. But its bonding power with cement is bad and the strength of concrete is low. The surface of crushed stone is rough and its bonding power with cement is high, and thus the strength of cement is high. But its voidage and total surface area are large, and the using amount of cement is much. Meanwhile, its workability is bad in the preparation of concrete mixture. Coarse aggregate should not contain too many needle-like particles (the particle length should be more than 2.4 times of the average diameter of its size fraction) and the flake particles (whose thickness should be less than 0.4 times of the average diameter). The needle and flake particles are not only easy to break themselves, but also have influence on the strength of concrete and will enlarge the voidage of aggregate, which will impact the workability of mixture. Thus, the content of needle and flake particles regulated in JGJ53-92 should be in line with the limits in Table 5.7.

Table 5.7 Limits of Permissible Content of Needle and Flake Particles in Coarse Aggregate

Items	Index		
	I	II	III
Needle and flake particles content (by weight) (%)	<5	<15	<25

6. Strength

The strength of aggregate refers to that of coarse aggregates. The Coarse aggregate functions as the skeleton in concrete. Thus, it must have enough strength. The strength of crushed stone can be expressed by compressive strength and crushing index. The strength of gravel is expressed only by crushing index.

(1) The determination of compressive strength of rock

Make rock into a cube with the side length of 50mm (or a cylinder with both the diameter and the height of 50mm) and test its maximum compressive strength in the state of saturation. Generally, the ratio between its compressive strength and strength grade should not be less than 1.5; the strength of igneous rock should not be less than 80MPa, that of metamorphic rock should not be less than 60MPa, and that of hydrogenic rock should not be less than 30MPa. The compressive strength of crushed stone should be determined generally when the strength of concrete is equal to or more than C60. And it can also be tested in case of doubt.

(2) The determination of the crushing index of crushed stone and gravel

Put a certain amount of 10~20mm stone in air-dry state into the standard tube (which is a cylinder with the inner diameter of 152mm). On the basis of the regulated loading speed, add loads to 200kN, stable for 5s. Weigh the mass of the specimen m_0 after unloading. Screen it with the sieve of 2.5mm (pore size) and weigh the screen residue of the specimen m_1. Calculate the crushing index by the following formula:

$$\delta_0 = \frac{m_0 - m_1}{m_0} \times 100(\%) \tag{5.2}$$

The smaller the crushing index is, the stronger the ability to resist crushing pressure is. The crushing indexes of crushed stone and gravel are shown in Table 5.8.

Table 5.8 The Crushing Indexes of Sand and Stone
(GB/T14684-2001)(GB/T14685-2001)(%)

Items	Index		
	I	II	III
The single maximum crushing index of artificial sand	<20	<25	<30
The crushing index of crushed stone	<10	<20	<30
The crushing index of gravel	<12	<16	<16

7. Apparent Density, Bulk Density, Voidage

The apparent density of aggregate should be more than 2500kg/m^3; its bulk density should be more than 1350kg/m^3; and its voidage should be less than 47%.

8. Reaction of Alkali Aggregate

The reaction of alkali aggregate refers to the expanding reaction that cement, admixture and other concrete components and the alkali in the environment slowly react with alkali reactive minerals in the humid environment, leading to crack and break of concrete. After alkali-aggregate reaction test, the specimen made of sand and crushed stone should not have cracks, crisp fracture, and colloidal spillover. And the expansion rate in the required test age should be less than 0.10%.

5.2.3 Water for Concrete

The basic quality requirements for the water used in concrete should: not contain any harmful impurities impacting the normal setting and hardening of cement; not destroy the development of strength and durability of concrete; not speed up steel corrosion; not cause brittle fracture of pre-stressed steel bars;

and assure that the surface of concrete cannot be polluted. The substance content in water for concrete should accord with the limits of JGJ63-89 in Table 5.9.

Table 5.9 Limits of Substance content in Water for Concrete

Item	Pre-stressed Concrete	Reinforced Concrete	Plain Concrete
pH	>4	>4	>4
Soluble matter (mg/L)	<2000	<2000	<5000
Insoluble matter (mg/L)	<2000	<5000	<10,000
Chloride (by Cl^-)	<500 [1]	<1200	<3500
Sulphate (by SO_4^{2-}) (mg/L)	<600	<2700	<2700
Sulphide (by S^{2-}) (mg/L)	<100	—	—

1) The chloride content of pre-stressed concrete with steel wire or heat treatment steel should not exceed 350mg/L.

All of drinking water and clean natural water can be used for mixing and conserving concrete.

5.2.4 Concrete Admixture

Concrete admixture refers to the substance mixed in concrete according to different requirements to improve the performance of concrete. The mixing amount is generally no more than 5% of the cement mass (except special cases). Based on the main functions, admixtures mainly contain water-reducing agent, air-entraining agent, hardening accelerator, set retarder, flash setting agent, expanding agent, antifreeze agent, rust-resistant agent and others.

1. Water-reducing Agent

Water-reducing agent refers to the admixture used for reducing water consumption and strengthening functions when the slump degrees of mixtures are basically the same. By raw materials and chemical components, water-reducing admixtures can be divided into: lignosulfonate, alkyl aryl sulfonates (commonly known as coal tar water-reducing admixture), sulfonated melamine-formaldehyde resin sulfonate (commonly known as melamine water-reducer), molasses and humic aid water-reducer and others. Based on performances and functions, water-reducing admixtures can be divided into: ordinary water-reducer, effective water-reducer, hardening water-reducer, retarder water-reducer, and air entraining water-reducer. It is a kind of surfactant whose molecules are composed by hydrophilic group and hydrophobic group (see Figure 5.4).

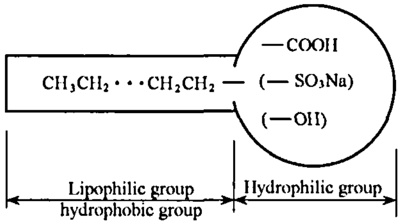

Figure 5.4 The Composition Diagram of Surfactant Molecules

When concrete is mixed, cement paste turns into flocculated structure due to the cohesion among cement particles without water-reducing admixtures [see Figure 5.5 (a)], and part of the mixing water is packed in flocculated structure of cement particles to reduce the mobility of concrete mixtures; if water-reducing admixture is added into cement paste, its hydrophobic group will stick to the surface of cement particles so that their surface take the same charges which can distract cement particles because of electrical repulsion [such as Figure 5.5 (b)], and then free water are released from floc and the mobility increases without adding water. In addition, water-reducing admixture can form a layer of solvent water film [see Figure 5.5 (c)] which functions as a good lubricant among cement particles.

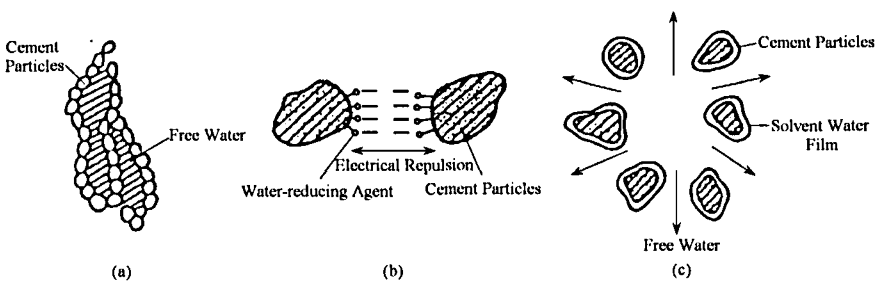

Figure 5.5 The Action between Flocculated Structure of Cement Particles and Water-reducing Agent

2. Air Entraining Admixture

Air entraining admixture refers to the admixture that entrains a large number of uniform, stable and closed tiny bubbles in the process of mixing concrete to reduce the segregation of concrete mixture, improve the workability, and also enhance anti-freeze ability and durability of concrete. It is a kind of surfactant, too. It has influences on concrete as follows:

1) It can improve the workability of concrete mixtures. The closed bubbles are like balls that can reduce the friction among cement particles to improve the mobility. Meanwhile, the bubble film can play a role of water conservation.

2) It can enhance impermeability and frost resistance. The closed stomata entrained by air entraining admixture can effectively cut off the capillary porosity ducts and reduce pores caused by segregation to enhance impermeability. Meanwhile, the closed pores entrained can be an effective buffer for the expansion caused by water freeze to improve frost resistance.

3) It can reduce strength. If the air content in concrete increases by 1%, its compressive strength will decrease by 4%~6%. Thus, the adding amount of air entraining admixture should be appropriate.

Air entraining admixture usually contains rosin resin, alkyl sulfonate, aliphatic alcohol sulfonate, protein salt and petroleum sulfonate, among which rosin resin is widely used.

3. Hardening accelerator

Hardening accelerator refers to the admixture that can accelerate the development of early strength of concrete. Generally, hardening accelerator can be divided into inorganic (chloride, sulfate, etc.), organic (triethanolamine, tri-isopropanolamine, and sodium acetate, etc.) and inorganic-organic compound, the three categories. It can accelerate the hydration and the hardening of cement, improve early strength, and shorten conservation cycle so as to enhance the turnover rate of templates and sites and speed up the construction process. It is especially used in winter construction (whose minimum temperature is not less than −5℃) and emergency repair works.

4. Set Retarder

Set retarder refers to the admixture that can delay the setting time of concrete mixing materials, and have no bad impact on the development of concrete's latter strength. It often contains lignosulfonate, carbohydrate, inorganic salts and organic acids. The most common ones are calcium lignosulfonate and molasses. And the retardant effect of molasses is better. Set redarder is appropriately used in the projects that need to delay time, such as high temperature or long transport distance, to prevent the lose caused by the early slump of concrete mixtures; and also for the layer pouring concrete, set retarder is often added to prevent cold joint. In addition, set retarder can be added into mass concrete to extend the heat-releasing time.

5. Flash Setting Admixture

Flash setting admixture refers to the admixture that can promote the rapid hardening of concrete. The concrete added by flash setting admixture can let the gypsum mixed in cement lose its retardant function to make concrete harden quickly. For example, 711 and Red Star I, the flash setting admixture produced by China, are compounded of several coagulants.

Generally, the adding of 2.5%~4% flash setting admixture can make the initial setting of concrete finish within 3 minutes and final setting within 7~10min; after 1d, the strength can be improved by 2~3 times; and after 28d, the strength will decrease by 20%~30%. Flash setting admixture is mainly used for shotcrete.

6. Expansion Agent

Expansion agent is the admixture that can make concrete produce shrinkage compensating or micro-expansion. The common expansion agent is alunite expansion agent. Its mixing amount is 10%~15% of the mass of cement. More mixing amount can produce self-stress in reinforced concrete. The mixture of expansion agent has little influence on the mechanical properties of concrete and can raise the frost resistance of concrete above P30, enhancing the crack resistance significantly.

7. Anti-freeze

Anti-freeze refers to the admixture that can reduce the liquid freezing point of water and the concrete mixtures to protect concrete against freeze under the corresponding negative temperature and achieve the expected effect under the regulated conditions. Anti-freeze admixtures usually include the following several ones:

1) Sodium nitrite and calcium nitrite, which can reduce freezing point, accelerate hardening, and resist corrosion, with the general mixing amount of 1%~8%.

2) Sodium chloride and calcium chloride, which can reduce freezing point but will corrode steel bars, with the general mixing amount of 0.5%~1.0%.

3) Potassium carbonate, urea and others. In practical projects, the anti-freezers are usually complex, and meanwhile they can resist freeze, accelerate hardening, and reduce water. Sometimes the anti-freezing effect can be enhanced greatly by adding air entraining agents.

8. Rust-resistant Agent

Rust-resistant agent is the admixture that can retard the corrosion to steel bars in concrete or other embedded metal, also called corrosion inhibitor. The common agent is sodium nitrite. Some admixtures contain chloride salt which will corrode steel bars (thus, it is necessary to control the content of chloride ions), so the adding of rust-resistant agent can retard corrosion to steel bars for the sake of protection.

5.3 The Main Technical Properties of Ordinary Concrete

5.3.1 Workability of Fresh Concrete

Fresh concrete refers to the mixtures made by cement, sand, stone and water in a certain proportion that has not yet hardened.

1. The Concept of Workability

The hardening of concrete must experience the processes like mixing, transport, casting and vibration. The workability should be considered to ensure that no stratification, segregation, bleeding and other phenomena happen to fresh concrete and its quality and moulding are stable and dense respectively. The main feature of concrete mixture is workability which refers to the operation difficulties of projects and the degrees to resist segregation. The workability of concrete mixture is an integrated technical property, including mobility, viscidity, and water retention, the three aspects. Mobility is the property that fresh concrete can move and fill every corner of the moulding evenly and densely under the role of deadweight and mechanical vibration. Viscidity refers to the property that there exists a certain bonding power among the components of concrete mixture to avoid stratification and segregation and maintain the entire uniformity. Water retention is the property to prevent moisture from precipitating during the construction process of fresh concrete.

2. The Determination Method of Workability

There is no a simple, rapid and accurate determination method to completely reflect the indexes of workability because the connotation of concrete workability is complex. Mobility has great impact on the properties of mixture through actual analysis. Thus, mobility is often used to test concrete mixture assisted by observation of viscidity and water retention to judge whether fresh concrete can satisfy the demand of projects. The mobility of fresh concrete is expressed by slump and vebe consistometer.

(1) The Determination of Slump

Install the concrete mixture into the standard conical tube (slump cone) in a certain way, tamp it evenly, fill it fully and shave it smoothly; lift the cone vertically and the mixture slumps downwards under the role of deadweight; measure the height difference (mm) between the cone and the peak of concrete specimen after slump, namely the slump (see Figure 5.6) which is usually expressed by *T*.

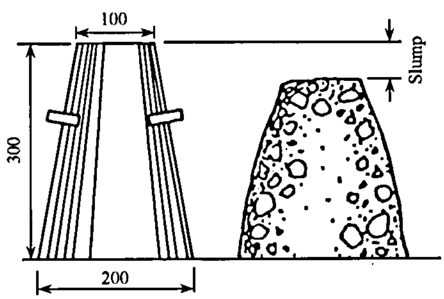

Figure 5.6 The Determination of Slump (unit:mm)

The higher the slump is, the better the mobility will be. The cohesion and water retention can be also inspected when slump is determined. The inspection method of cohesion is: to tap the side of the cone full of slumped concrete with tamper slightly, and if the cone can fall down gradually after slight tapping, it means that the cohesion is good. If the cone collapses or cracks partly, it indicates that the cohesion is not good. The inspection of water retention is: that if the concrete mixture loses pulp and the aggregates appear, or more slurries flow out from the bottom of the cone, it means that the water retention is bad.

According to different slumps, concrete mixtures can be divided into four grades: great mobile ($T \geqslant 160$mm); mobile (T for 100~150mm); plastic (T for 50 ~ 90mm); and low plastic (T for 10 ~ 40mm). The determination of slump is only limited to the concrete mixture of which the aggregate's biggest particle diameter is no more than 40mm and the slump is no less than 10mm.

In the plastic concrete projects, the slump should be tested in terms of the cross-section size of specimen, the density of steel bars and the tamping method. Slump should be in line with Table 5.10, *Code for Construction and Acceptance of Concrete Structure Works* (GB50204).

Table 5.10 The Slump of Concrete in Casting (mm)

Structure Categories	Slump
Cushion layer for foundation or ground, massive structure without steel bars (retaining walls, foundations, etc.) or reinforced sparse structure	10~30
Plates, beams and cross-section pillars of medium and large size	30~50
Reinforced dense structure (thin walls, bins, silos, and pigtail post)	50~70
Reinforced extreme-dense structure	70~90

(2) The Determination of Vebe Consistometer

The mobility of the concrete mixture whose slump is less than 10mm should be denoted by vebe consistometer. The determination method is: to put concrete mixture into the slump cone in a certain way, tamp the mixture, shave it smoothly after filling the cone fully, and lift the cone vertically. Put a transparent disc on the top of the specimen, start the shaking table, meanwhile measure the time with a stopwatch, and stop the table and the watch till the disc bottom full of slurry. And the passing time is vebe consistometer value. The larger the value is, the drier and denser the concrete mixture is. The method is proper for the determination of the mixture whose aggregate's biggest particle diameter is no more than 40mm and vebe consistometer is between 5~30s.

Concrete can be divided into four grades by its vebe consistometer: super hard and dry (≥31s); special hard and dry (30~21s); hard and dry (20~11s); half hard and dry (10~5s).

3. The Major Factors Influencing Workability

(1) The Quantity of Cement and Water-cement Ratio

The mobility of concrete mixture depends on cement paste. In unit volume, the more the cement paste, the greater the mobility, if the water-cement ratio is the same. However, if cement paste is too much, pulp fluid will occur; and if cement paste is too little, the cohesion among aggregate particles will be small, which may lead to segregation and collapse.

If the using amounts of cement and aggregate are the same, increasing the water-cement ratio can strengthen the mobility; on the contrary, the mobility will be lowered. Still, if the water-cement ratio is too big, the cohesion and water retention of the mixture will decrease; if the ratio is too small, the mobility will decrease, which may impact projects. Thus, the ratio should be chosen reasonably according to the strength and durability of concrete. It should be noted that both the impact of cement paste and that of water-cement ration are basically the impact of water consumption. Therefore, the key factor to affect the workability of concrete mixture is the water consumption per unit volume. In the light of experiments, with fixed amount of aggregate, if the unit water consumption is certain and the amount of cement is within 50~100kg, the slump remains unchanged, which is usually known as the fixed water consumption law. It is very convenient to adopt this law to design mix proportion of concrete. Through the fixed water consumption, it can not only meet the requirements of workability by changing water-cement ratio, but also satisfy the requirements of design.

(2) Sand Percentage

Sand percentage refers to how large the quality of sand within concrete is relative to the total mass of sand and stone. Sand percentage has great influence on mixture. Figure 5.7 is the impact of sand percentage on slump. On one hand, sand slurry can function as a lubricant among aggregates, and within a certain sand percentage, .the bigger the percentage is, the more obvious the lubricating effect will be, and thus the mobility can increase; on the other hand, the increase of sand percentage can lead to the increase of the total surface area of aggregates, and more water is needed. If the water consumption is fixed, the mobility of mixture will decrease. Thus,.if the percentage is beyond a certain range, the mobility will decrease with the increase of sand percentage. Otherwise, if the percentage is too small, the quantity of sand slurry will be small, which can reduce the cohesion and water retention of mixture. Then, segregation and pulp fluid will happen. Therefore, reasonable sand percentage should be chosen to ensure mobility, cohesion and water retention under the fixed quantity of water and cement.

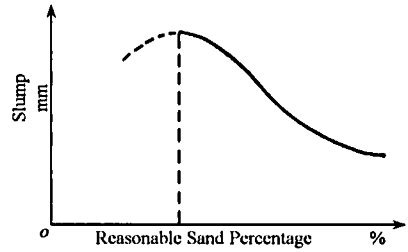

Figure 5.7 The Impact of Sand Percentage on Slump

(3) Properties of Components

It is the categories and fineness of cement that mainly influence the workability of mixture. If Portland cement and ordinary cement are used, the mobility will be big and the water retention will be good; if slag cement and pozzolana cement are used, the mobility will be small and water retention will be bad; the mobility of fly-ash cement is better than that of ordinary cement, and the water retention and cohesion are good. In addition, the fineness of cement also has influence on the workability of mixture. The finer the cement is ground, the smaller the mobility is, but the cohesion and water retention will be good.

Aggregate can affect the workability of mixtures, mainly including: gradation, particle shape, surface characteristics, and particle diameter. Generally, the aggregate with good gradation has big mobility and good cohesion and water retention; the aggregate (river sand, gravel, etc.) whose surface is smooth has big mobility; the increase of the diameter and decrease of the total surface area will increase the mobility.

Admixture has a great influence on the workability of mixtures, as well. The adding of water-reduce agent and air entraining agent can apparently enhance the mobility of mixtures; and air entraining agent can effectively improve the cohesion and water retention of mixtures.

(4) Time and Temperature

The mobility of concrete mixtures decreases with the increase of temperature (see Figure 5.8). In summer constructions, the water consumption for mixtures should be enhanced to guarantee the mobility because the increase of temperature accelerates the hydration of cement and speeds up the evaporation of moisture.

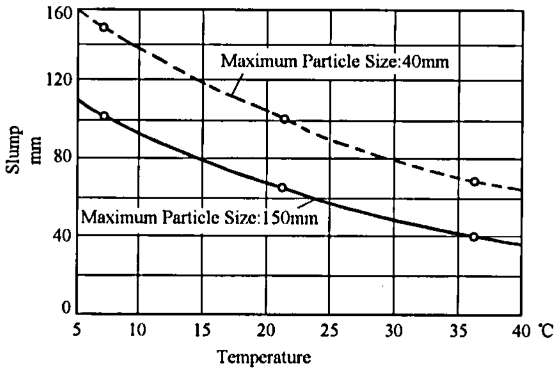

Figure 5.8 The Impact of Slump on Temperature

With the extension of time, concrete mixtures can become dry and dense and their mobility will decrease, because part of the moisture in mixtures is absorbed by aggregates, part of it evaporates, and part of it reacts with cement and turns into bound water of hydration product. Figure 5.9 is the relationship between slump and time.

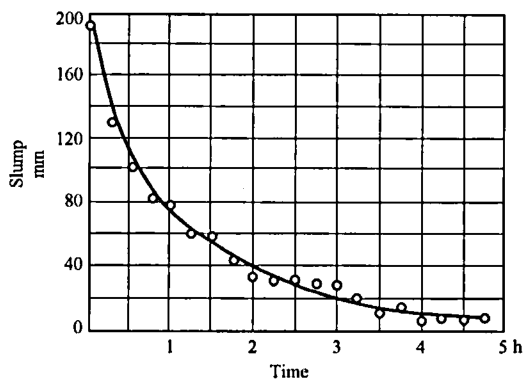

Figure 5.9 The Relation between Slump and Time

5.3.2 The Strength of Hardened Concrete

Ordinary concrete is the major building material and strength is its main technical property.

1. Compressive strength and Intensity Grade of Concrete

The strength of concrete includes compressive strength, tensile strength, bending strength, and shear strength, among which the compressive strength is the biggest one. Thus, concrete is mainly used to bear pressure. There is certain relevance between the compressive strength of concrete and various kinds of strength and other properties. Therefore, the compressive strength is the major parameter for the structure design and the indicator for the quality assessment of concrete.

Based on *Test Method of Mechanical Properties on Ordinary Concrete* (GBJ81), the national standard, the compressive strength of concrete cube (simply called compressive strength of concrete) is the compressive strength value obtained as follows: conserve the cube specimen with side length of 150mm made througn the standard method under standard conservation conditions [temperature of (20 ± 3)℃, and relative humidity above 90% or in water], and test and calculate it by standard method to get the compressive strength value which is called the compressive strength of concrete cube (expressed by f_{cu}). For the cube specimens with non-standard sizes (with the side length of 100mm or 200mm), the result should be multiplied by conversion coefficient and be conversed into the strength value of standard specimen. The reason is that: the bigger the size of the specimen is, the smaller the compressive strength value tested is, and thus the cube specimen with side length of 100mm should be multiplied by 0.95; and that with 200mm length should be multiplied by 1.05.

In order to facilitate the design selection and construction, concrete is divided into several grades, namely strength grades. They are divided in accordance with the compressive strength values of cubes ($f_{cu,k}$). Ordinary concrete is usually divided into 9 grades: C15, C20, C25, C30, C35, C40, C45, C50, and C55 (the concrete whose strength grade is ≥ C60 is called high-strength cement). The compressive strength value of cubes is one value of the overall distribution of cube compressive strength tested by standard method, and the percentage how strength is less than the value should not be more than 5% (namely guarantee rate of strength should be more than 95%). "C" is the symbol for strength grade, and the numerical value after "C" is the standard value of compressive strength. For example, strength grade C40 means that the compressive strength of the cube $f_{cu,k}$ is 40MPa.

In the structural design, the adoption of prism specimen can better reveal the actual pressure burdened by concrete than the cube one, taking into account that the compression members are usually prism (or cylinder). The compressive strength obtained by testing prism specimen is called prism compressive strength (or axial compressive strength). Recently in China, the prism specimen of 150mm × 150mm × 300mm is taken as the standard specimen to test axial compressive strength. Test shows that the ratio of the compressive strength of prism specimen to that of cube specimen is 0.7~0.8.

2. The Major Factors Influencing the Compressive Strength

There many factors influencing the compressive strength of concrete, such as the strength of cement, the bond strength between aggregate and cement, the quality of materials, the mixing ratio of materials, and the construction conditions. But the major factors are listed in the following:

(1) The Influence of Cement Strength Grades and Water-cement Ratio

Cement strength grades and water-cement ratio are the main factors impacting concrete strength. The chemically combined water needed in cement hydration generally account for 23% of the mass of cement. But in the actual mixture of concrete, more water is needed to obtain greater mobility. The space occupied by excessive water will turn into pores after hardening which will lower the density and strength of concrete (see Figure 5.10).

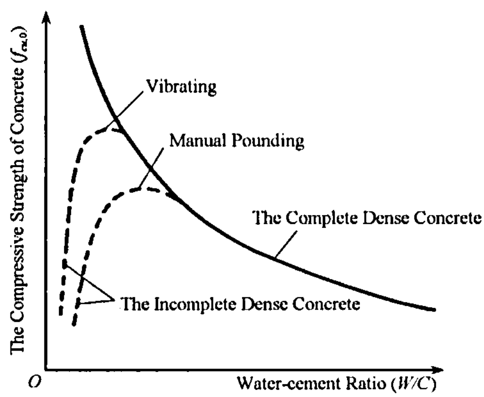

Figure 5.10 The Relationship between Concrete Strength and Water-cement Ratio

It is proved that the smaller the water-cement ratio is, the higher the strength of cement will be, the higher the cohesive power will be, and the strength of concrete will be, under the same condition.

A large number of tests have proved that: at the age of 28d, the relationship between the concrete strength ($f_{cu,0}$), the actual strength of cement (f_{ce}) and the water-cement ratio (W/C) is in line with the following formula:

$$f_{cu,0} = \alpha_a \cdot f_{ce}\left(C/W - \alpha_b\right) \tag{5.3}$$

In the formula: α_a and α_b are the regression coefficients. If crushed stones are used, α_a =0.46 and α_b =0.07; if gravels are used, α_a =0.48 and α_b =0.33.

In formula (5.3), if the actual strength of cement can be obtained, it can be calculated by the following formula:

$$f_{ce} = \gamma_c \cdot f_{ce.g} \tag{5.4}$$

In the formula: $f_{ce.g}$ is the strength grade of cement (MPa);

γ_c is the safe coefficient of cement strength grade which should be determined by the actual statistics of various regions.

(2) The Influence of Aggregate

The strength of aggregate itself is generally higher than that of cement paste and the bonding strength between cement and aggregate (except lightweight aggregate), so it will not directly impact the strength of concrete. But if the strength of aggregate is lowered by weathering effect, it can reduce the concrete strength. The surface of aggregate is coarse so that its bonding strength with cement paste is huge. But more water is needed to achieve the same mobility, which will increase the water-cement ratio and reduce the strength. Thus, if the water-cement ratio is under 0.4, the strength of the concrete mixed with crushed stones is 38% higher than that of the concrete mixed with gravels. With the increase of the water-cement ratio, however, their difference will not be that obvious.

(3) The Relationship between Age and Strength

Under normal curing conditions, the strength of concrete increases with its age, shown in Figure 5.11. During the initial 3~7d, it grows fast and it can reach the numerical value of the regulated design strength. Afterwards, it grows gradually slowly, even unchangeable ever after.

Figure 5.11 shows that the growth of concrete strength is in direct proportion to the logarithm of age (which is more than 3d) under standard curing conditions, calculated as follows:

$$f_n = f_{28} \frac{\lg n}{\lg 28} \tag{5.5}$$

In the formula: f_{28} is the concrete compressive strength of 28d;

f_n is the concrete compressive strength of nd ($n \geqslant 3$).

The above formula applies to the concrete made of cement in media grades under standard curing conditions. The real situation, however, is complicated, so it is generally only taken as reference.

Figure 5.11 The Growth Curve of Concrete's Strength

(4) The Influence of Curing Temperature and Humidity

After casting and moulding of concrete, proper temperature and sufficient humidity should be maintained for the full hydration of cement to guarantee a better quality.

Under the guarantee of sufficient humidity, different curing temperature has great influence on the growth of concrete strength. If the temperature decreases, the hydration of cement will become slow and the increase of concrete strength will be slow, as well (see Figure 5.12). When the temperature falls below freezing point, most of the water in concrete freezes, and the concrete strength not only stop growing but also expand because the water in pores freezes, which will lead to the structural damage inside concrete and reduce the strength greatly. Thus, it is regulated that: if the average outdoor temperature is under 5℃ for 5 days, the concrete construction should obey winter construction regulations. Generally, concrete after pouring and tamping can melt with the increase of temperature if it freezes, so its strength can keep growing. The earlier it freezes, the greater the loss will be; on the contrary, the loss will be smaller (see Figure 5.13). Therefore, the basic principle for the winter construction is to make concrete achieve certain strength (namely critical strength) before freeze, specifically referring to *Code for Construction and Acceptance of Concrete Structures* (GB50204-2002).

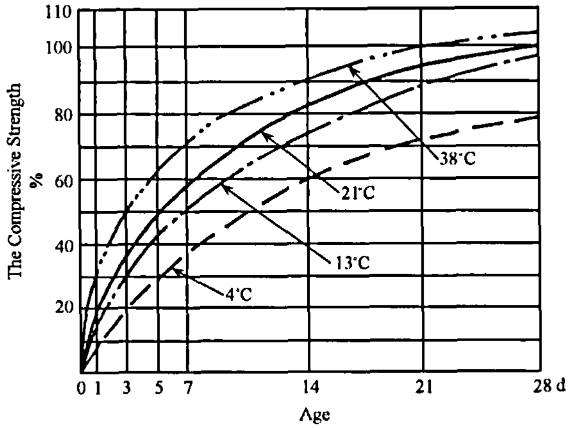

Figure 5.12 The Influence of Curing Temperature on Concrete Strength

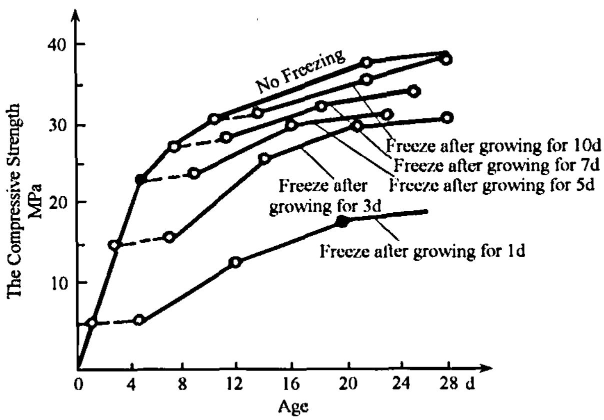

Figure 5.13 The Relationship between the Growth of Concrete Relative Strength and the Freeze Date

Environmental humidity has a significant impact on cement hydration. Because the hydration can only happen in pores, the strength will stop growing with the evaporation of water in the dry environment. Thus sufficient humidity must be guaranteed during the maintenance period. Figure 5.14 is the relationship between humid curing and concrete strength. Generally, the watering maintenance time should not be less than 7d for Portland cement, ordinary cement and slag cement; the time should not be less than 14d for pozzolana cement and fly ash cement. In the hot season, watering should be paid attention to due to rapid evaporation.

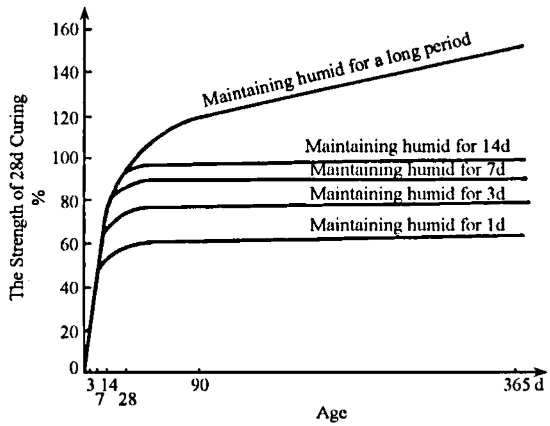

Figure 5.14 The Relationship between Concrete Strength and Humid Curing Time

5.3.3 The Deformability of Hardened Concrete

In addition to the external loads, hardened concrete can deform because of other factors, such as chemical shrinkage, temperature deformation, and dry shrinkage and wet swelling.

1. Chemical Shrinkage

In the hardening process, the size of hydrated cement product is smaller than that of cement before hydration, which results in shrinkage of concrete, called chemical shrinkage. Such chemical shrinkage can not recover. The shrinkage quantity increases with the extension of concrete's age, but the shrinkage rate is very little and becomes stable after 40d. Researches show that: although the shrinkage rate is small and can not damage structures under limited stress, there are still tiny cracks inside concrete. Thus, it may affect the load-bearing capacity and the durability.

2. Temperature Deformation

Concrete, like common solid materials, usually expands with heat and contracts with cold. General room temperature changes only have a little impact, but the impact will be serious if temperature changes greatly. The deformation of concrete depends on not only temperature changes but also the thermal expansion coefficient.

When the difference between the volume of aggregate particles and that of cement paste caused by temperature changes or the difference between the expansion coefficients of aggregate particles is huge, destructive internal stress will come into being. Cracks and spalling in many projects have explained this problem.

The temperature expansion coefficient of concrete varies with different aggregate types and mixture ratios, but not big. When temperature falls, cold shrinkage of the volume will have great impact on the concrete with low tensile strength. For instance, the common thermal expansion coefficient of concrete is $(6\sim12)\times10^{-6}/℃$; and take $10\times10^{-6}/℃$ for example, if the temperature drops about 15 ℃, the amount of cold shrinkage will be 150×10^{-6}.

Temperature deformation is extremely unfavorable for mass concrete. At the stage of initial hardening of concrete, much hydration heat is released. And if the concrete is very thick, heat dissipation will be slow so that the internal temperature will greatly differ from the external temperature, which will lead to deformation difference between inside and outside. In this case, there will be cracks caused by internal and external stress.

In order to reduce cracks caused by the deformation of mass concrete, the common methods used recently are as follows:

1) Use the cement with low heat hydration and try to minimize the amount of cement.

2) Try to minimize water consumption and increase the strength of concrete.

3) Adopt the aggregate with low thermal expansion coefficient and reduce heat deformation.

4) Pre-cool raw materials.

5) Reasonably divide joints and blocks, and reduce constrain.

6) Bury cooling pipes in concrete.

7) Insulate the surface, and regulate the decline rate of the surface temperature.

3. Dry Shrinkage and Wet Swelling of Concrete

When concrete in the air loses water, its volume will shrink, known as dry shrinkage, simply called shrinkage. And when it absorbs water, its volume will expand, known as wet swelling.

When the hardening of concrete conducts in water, there will be minor wet swelling because the water film absorbed by colloidal particles in gel become thick and the distance between particles enlarges. When concrete hardens in the air, there will be dry shrinkage because the evaporation of water absorbed inside concrete lead to the shrinkage of gel and the evaporation of free water increases the negative pressure in pores. If the contracted concrete is moistened again, part of deformation caused by dry shrinkage can recover (see Figure 5.15).

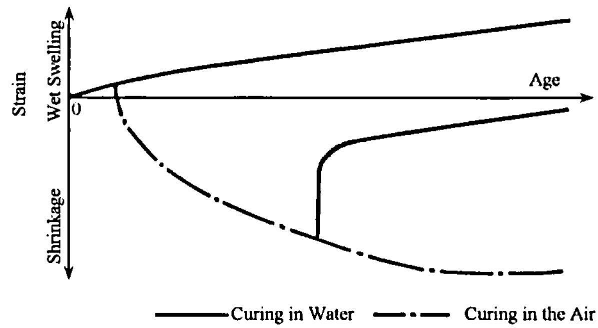

Figure 5.15 Shrinkage and Wet Swelling of Concrete

The excessive shrinkage of concrete can lead to cracks so that its performance will decrease, which thus should be considered in design. It is determined that the shrinkage rate of concrete can reach $(3\sim5)\times10^{-4}$, but the real structure is large, so its shrinkage rate will be much smaller than the value determined in tests. The common shrinkage rate adopted in design is $(1.5\sim2.0)\times10^{-4}$ which means that the shrinkage of 1m concrete is 0.15~0.2mm.

The dry shrinkage of concrete is mainly generated by cement. Thus, the key to reduce shrinkage is to decrease the amount of cement and the water-cement ratio. The factors influencing shrinkage also include water consumption, varieties and fineness of cement, aggregate types and conservation conditions, described as follows:

1) Water consumption: with certain water-cement ratio, the more the water, the more the cement content and the greater the dry shrinkage. If the average water consumption increases every 1%, the dry shrinkage will increase about 2%~3%.

2) Water-cement ratio: the bigger the water-cement ratio, the more the pores in cement paste and the bigger the shrinkage.

3) Varieties and fineness of cement: the shrinkage of pozzolana cement is the largest and that of fly-ash cement is smaller. The finer the cement is, the bigger the shrinkage rate will be.

4) Aggregate types: the bigger the elastic modulus of cement is, the smaller the dry shrinkage is. The aggregate with large water-absorption and big mud-content has great shrinkage rate.

5) Curing condition: the extension of curing time can postpone the occurrence and development of shrinkage but has no obvious impact on the final shrinkage. The adoption of wet-moisture treatment can reduce the shrinkage of concrete.

4. Deformation under Loads

(1) The deformation under short-term loads——elastic-plastic deformation and elastic modulus

Concrete is a kind of heterogeneous material, an elastic-plastic substance. Under the external force, it can generate renewable elastic deformation δ and non-renewable plastic deformation r. And the relationship between stress and strain is not a straight line but a curve (See Figure 5.16).

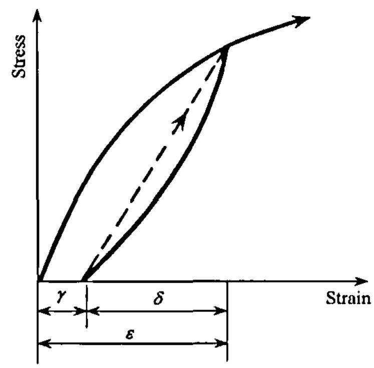

Figure 5.16 The Stress-strain Curve of Concrete under Loading and Unloading

The elastic modulus of concrete is indispensable in the structural design and the calculation of deformation and cracks of reinforced concrete. Because the stress-strain relationship of concrete is not a straight line but a curve, the elastic modulus decreases with the increase of stress. There are three methods to express elastic modulus (see Figure 5.17): ①the initial tangent modulus $E_i = \tan\alpha_0$; ②the tangent modulus $E_t = \tan\alpha_2$; ③the secant modulus $E_n = \sigma_1 / \varepsilon_1$. Because the initial tangent modulus E_i is difficult to measure accurately and this modulus only applies to small stress and strain, its practical use in the structural design of projects is small; tangent modulus E_i is the tangent slope of any point on the curve, only available for observing the strain response caused by smaller additional stress on some specific loads. Secant modulus E_n is the slope of the line connecting the origin point of the curve and the point of 40% ultimate stress on the curve. This modulus includes the nonlinear part and is easy to measure accurately, proper for projects.

When the strength grade of concrete is C10~C60, its elastic modulus is about (1.75~3.60)×10^4MPa.

There are many factors affecting the elastic modulus of concrete, for example, the higher the strength, the bigger the elastic modulus; the higher the elastic modulus of aggregate, the higher the elastic modulus of concrete; the elastic modulus of concrete in wet state is higher than that in dry state; the smaller the cement content in concrete (such as hard and dry concrete) is, the bigger the elastic modulus is; the elastic modulus of the concrete conserved by steam is 10% lower than that of the concrete conserved by moisture.

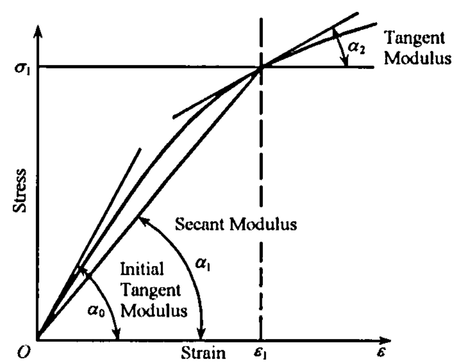

Figure 5.17 The Classification of Elastic Modulus of Cement Concrete

(2) Deformation under Long-term Loads —— Creep

Creep is the deformation increases with time under the role of long-tern loads.

The creep deformation of concrete grows fast in the early period of loading, then gradually slows down, and becomes stable generally after 2~3 years. After unloading, a part of concrete resumes immediately, and another part resumes gradually within a certain number of days, called creep recovery. The remaining unrecoverable part is residual deformation (see Figure 5.18).

The creep of concrete has great influence on the stress and strain state of concrete and reinforced concrete structures. Creep is likely to exceed and even be 2~4 times of elastic deformation. In some cases, creep will help weaken the constrained deformation caused by temperature, dry shrinkage and others to prevent cracks. In pre-stressed structure, however, creep will generate stress relaxation, lead to pre-stress loss, and result in adverse effects. Therefore, in the design of concrete structure, the favorable and unfavorable effects of creep should be fully considered.

The major factors impacting the creep of concrete are the using amount of cement and the water-cement ratio. The higher the amount of cement is, the bigger the water-cement ratio is and the greater the creep is.

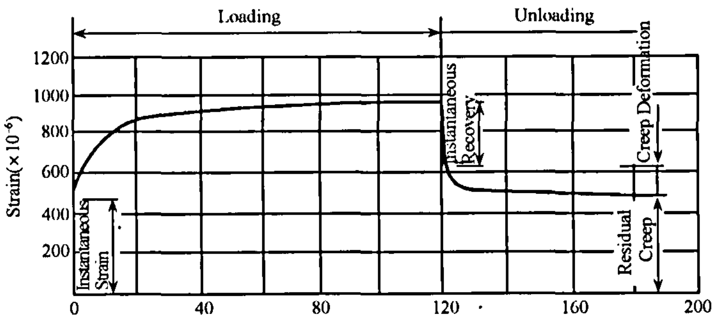

Figure 5.18 The Creep of Concrete

5.3.4 Durability of Hardened Concrete

Concrete structures require not only the design strength to guarantee buildings to bare safe loads, but also durability to insure that concrete can maintain its properties in the natural environment and using conditions for a long term. Here are some common issues concerning durability.

1. Impermeability of Concrete

The impermeability of concrete refers to the property of concrete that cannot be pervaded by water, oil and other liquids with pressures. It plays an important role in the durability of concrete. Moreover, it also directly affects the frost-resistance and anti-corrosion of concrete.

Impermeability is expressed by the anti-permeability level, P, which is determined by the maximum water pressure (MPa) borne by standard specimen at 28d age through required tests when it is impermeable. The impermeability levels include P6, P8, P10, P12..., which means that concrete can resist the water pressure of 0.6MPa, 0.8MPa, 1.0MPa..., not permeable.

The key to improve the impermeability of concrete is to enhance density and improve the inner pores structures of concrete. There are specific measures to reduce the water-cement ratio, adopt water-reducing agent, add air-entraining agent, select dense, clean and good aggregates, and strengthen curing.

2. Frost Resistance of Concrete

The frost resistance of concrete is the property that concrete resist the role of freeze-thaw cycles without damage when it suffers frost in the saturated state. The reason for freeze-thaw damage is that: the volume of water inside concrete expands after freezing, and fine cracks will appear when the expansive force is beyond its tensile strength, and the repeated freeze-thaw enlarges cracks, which finally results in the decreasing of concrete strength, even damaged.

Frost resistance is indicated by frost-resistance level. It is determined by the maximum cycle number of the 28d-age specimen whose mass loss and the strength loss do not exceed 5% and 25% respectively, when it stays in repeated freeze-thaw cycle of -15~-20℃ and 15~20℃ in the saturated state. The frost-resistance levels can be divided into F50, F100, F150 and above F150, which respectively indicate that the cycle numbers borne by concrete are not less than 50, 100, 150 and above.

The main factors affecting the frost resistance of concrete are varieties of cement, water-cement ratio and the sturdiness of aggregates. The measures to improve frost resistance are to enhance density, reduce water-cement ratio and mix air-entraining agent or air-entraining and water-reducing admixture.

3. Anti-corrosion of Concrete

If the water surrounding concrete is corrosive, corrosion must be attached importance to. Environmental erosion mainly refers to the corrosion of cement paste, specifically see Chapter Four in this book, namely the corrosion of fresh water, sulfate, acid, and alkali to cement paste. The chloride ions in sea water can also corrode steel bars to accelerate the damage of concrete. The anti-corrosion of concrete is improved by selecting appropriate cement varieties and enhancing the density of concrete. It is difficult for surrounding water to permeate the concrete with good density and closed pores, namely good anti-corrosion. The selection of cement varieties can be found in Chapter Four.

4. Carbonization of Concrete

The carbonization of concrete is the process that carbon dioxide in the air penetrates concrete, chemically reacts with calcium hydroxide in cement paste and generates calcium carbonate and water to reduce the alkalinity of concrete, also known as neutralization. It is known that cement generates a lot of calcium hydroxide in the process of hydration, which fills the pores in concrete with saturated calcium hydroxide solution, pH value of 12~13. In such alkaline environment, there will be a layer of iron-oxide passive film on the surface of steel bars in concrete members and it has a good protective effect. However, the protective passive film has been already neutralized when steel bars contract with carbonization deeply, and with the role of air and water, steel bars then begin to corrode and make the volume expand a little, which causes the protective film to crack and peel and reduces the strength of concrete. In addition, carbonization can also lead to contraction of concrete so that there will be tiny cracks on its surface. The advantage of carbonization is that the calcium carbonate generated by carbonization of concrete can fully fill the pores in cement paste to improve the density and prevent the intrusion of harmful substances.

The factors affecting carbonization are: first, the varieties of cement. The carbonization of Portland cement is faster than that of early-strength Portland cement, and that of the cement mixed with blending materials is faster than that of ordinary Portland cement. Second, the water-cement ratio: the bigger the ratio is, the faster the carbonization rate will be, while slower. Third, the external factors, mainly refer to the concentration of carbon dioxide and humidity in the air. The increasing of the concentration of calcium dioxide can accelerate carbonization. The fastest carbonization rate will be reached in the relative humidity of 50%~70%. Carbonization will stop when the relative humidity reaches to 100% (or in water) or be less than 25% (or in the dry environment).

The measures to improve the anti-carbonization of concrete are to reduce water-cement ratio and mix water-reducing agent or air-entraining agent, both of which can enhance the density of concrete and its impermeability and slow down the carbonization rate.

5. Alkali-aggregate Reaction of Concrete

The alkali-aggregate reaction of concrete is that alkalis (Na_2O and K_2O) in cement react with active silicon dioxide in aggregate to generate alkali-silicic acid gel on the surface of aggregate. This gel has the property of wet swelling. When it swells, the cement paste surrounding aggregate expands and cracks. Such phenomenon that damages concrete is called alkali-aggregate reaction.

The reasons for the occurrence of alkali-aggregate reaction are: first, the alkali content (the Na_2O content is over 0.6%) in cement is too high; second, there is active silica in aggregate; third, there is water in cement paste.

The measures to avoid alkali-aggregate reaction are mainly: to adopt low-alkali cement, mix active blending materials, reduce swelling reaction, and mix with air-entraining agent and the aggregate without active SiO_2.

Though the above factors affecting the durability of concrete are totally different, there are two common points that they all depend on the quality of component materials and the density of concrete.

6. Measures to Improve Durability of Concrete

The major measures to improve the durability of concrete are listed in the following:

1) To select appropriate varieties of cement.

2) To strictly control the water-cement ratio and guarantee enough using amount of cement.

3) To adopt good sand stone and the aggregate with high gradation to improve the density of concrete.

4) To mix with water-reducing agent and air-entraining agent to improve the density.

5) To fully stir, water, vibrate, and pound, and strengthen curing to improve the quality and density of concrete.

5.4 The Quality Control and the Strength Evaluation of Concrete

The guarantee rates of quality and strength of concrete directly impact the reliability and security of concrete structures and are the important aspects of modern scientific management.

5.4.1 Quality Control

The quality of concrete should be indicated by the result of testing its properties. In the actual projects, raw materials, construction and test conditions and other factors will affect the quality of concrete.

The influencing factors of raw materials and construction conditions are:

1) The fluctuation of the quality and measuring of cement, aggregates, additives, and other raw materials.

2) The fluctuation of water-cement ratio caused by the change of water consumption and the water content of aggregates.

3) The fluctuation of stirring, transport, pouring, vibration, and curing conditions and temperature changes.

The influencing factors of test conditions include: differences in sampling methods, specimen moulding, and curing conditions, errors of testing machines, and the proficiency of laboratory personnel.

In the normal continuous production of concrete, mathematical statistical method can be adopted to inspect whether the strength of concrete or other technical indexes meet the quality requirements. The statistical methods include arithmetic mean, standard deviation, coefficient of variation, and the guarantee rate of strength which can comprehensively evaluate the quality of concrete. In the management of concrete production, the compressive strength of concrete is relevant to other properties well, so the compressive strength is usually employed to assess the quality of concrete in actual works.

5.4.2 Strength Evaluation of Concrete

1. The Probability Distribution of Concrete Strength——Normal Distribution

(1) The Average Strength ($\overline{f}_{cu}$)

Randomly sample the concrete with the same strength grade at the pouring spot to conduct the compressive strength test. When construction conditions are basically the same, test results show that the fluctuation of strength is subject to the law of normal distribution (see Figure 5.19). Normal distribution takes the average strength as the vertical axis of symmetry and has a curve split symmetrically by the axis. The farther the distance between the value and the axis is, the smaller the probability to appear is, approaching zero. The area between the curve and the abscissa is the sum of probability, equal to 100%. The average strength can be calculated by:

$$\bar{f}_{cu}=\frac{1}{n}\sum_{i=1}^{n}f_{cu,i} \tag{5.6}$$

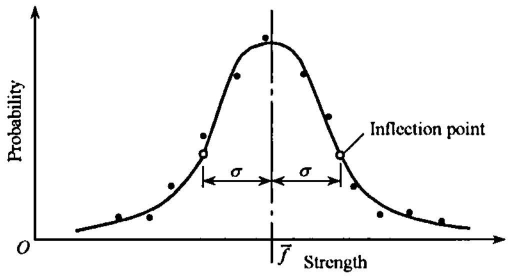

Figure 5.19 The Normal Distribution Curve of Concrete Strength

(2) Standard Deviation (σ)

The strength average value of concrete reflects whole average level of concrete. The fluctuation of concrete strength is indicated by strength standard deviation. It is calculated by the following formula:

$$\sigma=\sqrt{\frac{\sum_{i=1}^{n}(f_{cu,i}-\bar{f}_{cu})^2}{n-1}}=\sqrt{\frac{\sum_{i=1}^{n}f_{cu,i}{}^2-n\bar{f}_{cu}^2}{n-1}} \tag{5.7}$$

In this equation: n is the experimental group number ($n\geqslant 25$);

$f_{cu,i}$ is the compressive strength of the specimen in group No. i (MPa);

$\bar{f}_{cu}$ is the arithmetic mean of compressive strength values of n groups (MPa);

σ is the standard deviation of compressive strength values of n groups (MPa).

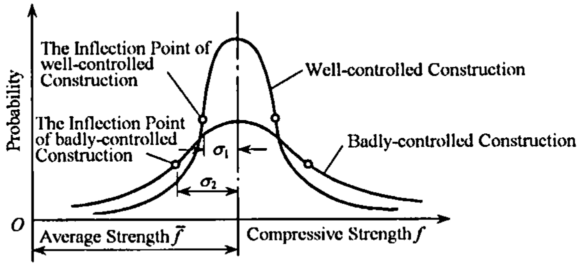

Figure 5.20 Two Strength Distribution Curves of Different Discrete Degrees

Standard deviation is also called root-mean-square deviation which shows the distance between the inflection point on the curve and the strength average (see Figure 5.20). The bigger σ is, the wider and lower the strength distribution curve will be, which indicates that the discrete degree is bigger and the evenness of concrete is poorer. It reflects that the management of production is not good, and the quality of concrete strength is not stable. On the contrary, the smaller σ is, the narrower and higher the curve will be, which exhibits that the measurements are concentrative, fluctuation is smaller, the evenness is better, and the construction level is higher.

(3) Coefficient of Variation (C_v)

The coefficient of variation is also called coefficient of deviation or coefficient of standard deviation. The smaller the variation is, the more stable the concrete quality is and the higher the level of concrete production is

$$C_v = \sigma / \overline{f}_{cu} \tag{5.8}$$

(4) Guarantee Rate of Strength (P)

The strength value of concrete must be in line with the design requirements of structures and reach a certain qualified rate, namely guarantee rate of strength. It refers to the probability that the overall strength of concrete is bigger than the grades of design strength, shown by the shadow part on the normal distribution curve (see Figure 5.21).

The guarantee rate of concrete strength P (%) is defined as follows: first, calculate the degree of probability t,

$$\begin{gathered} t = \frac{\overline{f}_{cu} - f_{cu,k}}{\sigma} \\ t = \frac{\overline{f}_{cu} - f_{cu,k}}{C_v \cdot \overline{f}_{cu}} \end{gathered} \tag{5.9}$$

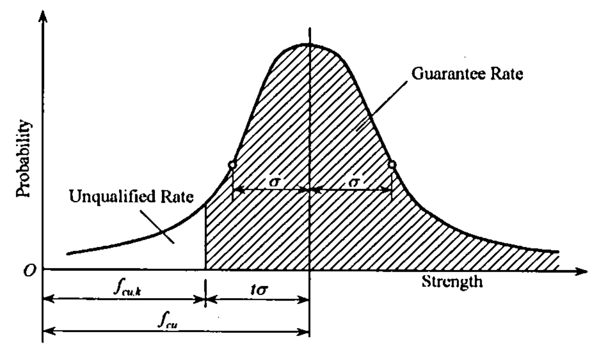

Figure 5.21 The Guarantee Rate of Concrete Strength

According to t values, the values of guarantee rate of strength P (%) can be found in Table 5.11.

Table 5.11 The Guarantee Rates of Different t Values.

t	0.00	0.50	0.84	1.00	1.20	1.28	1.40	1.60	1.645	1.70	1.81	1.88	2.00	2.05	2.33	3.00
P(%)	50.0	69.2	80.0	84.1	88.5	90.0	91.9	94.5	95.0	95.5	96.5	97.0	97.7	99.0	99.4	99.87

According to *Standard for Testing and Evaluating Concrete Compressive Strength* (GBJ107-87), the national standard, the σ value and guarantee rate P (%) of concrete strength within statistical period can classify the production management levels of concrete producers into good, normal, and bad, the three levels (see Table 5.12).

Table 5.12 The Production Management Levels of Concrete

Production Management Levels / Strength Grades / Producers / Evaluation Indexes		Good		Normal		Bad	
		<C20	≥C20	<C20	≥C20	<C20	≥C20
Strength Standard Deviation (MPa)	Pre-mixed Concrete and Pre-cast Concrete Members Producers	≤3.0	≤3.5	≤4.0	≤5.0	>4.0	>5.0
	Construction Sites for Concrete Mixing	≤3.5	≤4.0	≤4.5	≤5.5	>4.5	>5.5
The Percentage that the strength is equal to and more than the required strength grade, P (%)	Pre-mixed Concrete Producers and Pre-cast Concrete Producers and Construction Sites for Concrete Mixing	≥95		>85		≤85	

2. Confected Strength of Concrete

When the average strength of confected concrete equals the standard value of strength grades required by designs, its guarantee rate is only 50%, as shown in Table 5.11. Thus, in order to meet the qualified rate required by designs, the confected strength of concrete must be more than the value of the designed strength grade.

Supposed that the confected strength is equal to the average strength, that is, $f_{cu,0} = \overline{f}_{cu}$, there will be:

$$f_{cu,0} \geqslant f_{cu,k} + t\sigma \tag{5.10}$$

From the above formula, the greater the guarantee rate of the concrete strength required by designs is, the bigger the confected strength will be; and the poorer the stability of concrete strength, the more the confected strength will increase.

Based on China's present regulations, the guarantee rate of concrete strength required by designs should be 95%. And it is found from Table 5.11 that t=1.645, so the confected strength is:

$$f_{cu,0} \geqslant f_{cu,k} + 1.645\sigma \tag{5.11}$$

In this formula, value σ can be obtained by referring to the historical statistical data of the confected strength. Without information, the following data can be referred to:

If the grade of design strength is lower than C20, σ=4.0;

If the grade of design strength is equal to C20~C30, σ=5.0;

If the grade of design strength is higher than C35, σ=6.0.

5.5 The Design of the Mix Proportion of Ordinary Concrete

The mix proportion of ordinary concrete refers to the proportion among the numbers of all the composed materials of concrete.

5.5.1 The Basic Points for the Mix Proportion Design

1. The Basic Requirements

1) To meet the strength grades required by the design of concrete structures.

2) To meet the workability of concrete mixtures required by construction.

3) To meet the durability suitable to the operation environment.

4) On the condition of meeting the above three technical properties, try to save the amount of cement and reduce the cost of concrete, in line with the economic principle.

2. Three Major Parameters for the Mix Proportion Design

To design the mix proportion of concrete, in fact, is to confirm the consumption of cement, water, sand and stone, the four basic components.

There are three major parameters: water-cement ratio, unit water consumption, and sand percentage.

Water-cement ratio: the ratio of water to cement.

Unit water consumption: the water consumption of $1m^3$ concrete, which reflects the proportion between cement paste and aggregate.

Sand percentage: the percentage how sand accounts for the total mass of sand and stone, which impacts the cohesion and water retention of concrete.

To correctly confirm these three parameters in the design of mix proportion can make concrete meet the above design requirements.

3. Representation of the Mix Proportion Design

1) It is represented by the masses of all the materials in each $1m^3$ concrete. For example, if there is 300kg cement, 180kg water, 720kg sand, and 1200kg stone, the total mass of each $1m^3$ concrete is 2400kg.

2) It is also represented by the mass proportion between all the materials. If the mass of cement counts 1, the above example can be converted into mass ratio: cement: sand: stone = 1: 2.4: 4, and water-cement ratio = 0.60.

4. Preparation before the Mix Proportion Design

Before the mix proportion design, the following basic information should be mastered:

1) The strength grade required by designs and the strength standard deviation reflecting the stability of concrete strength, for the confirmation of the confected strength.

2) The conditions of the application environment and the durability requirements, for the confirmation of the maximum water-cement ratio and the minimum consumption of cement.

3) The section size of structures and the compounding of steel bars, for the confirmation of the maximum particle diameter of aggregate.

4) The mobility of concrete mixtures and the varieties, types, physical and mechanical properties of all the raw materials required by construction technologies.

5.5.2 The Methods and Steps of the Mix Proportion Design

The design of mix proportion should be conducted in three steps, namely, calculation of the preliminary mix proportion, the design of the proportion in labs, and the confirmation of the proportion in construction.

1. Calculation of the Preliminary Mix Proportion

According to the properties of raw materials and technical requirements for concrete, the consumptions of all the raw materials can be calculated preliminarily by formulas and tables to get the mix proportion for trail mixture.

(1) Determination of the Confected Strength ($f_{cu,0}$)

Based on the standard value of designed strength ($f_{cu,k}$) and the guarantee rate of 95%, the confected strength of concrete can be defined by the formula (5.11):

$$f_{cu,0} \geqslant f_{cu,k} + 1.645\sigma$$

(2) Preliminary Determination of the water-cement Ratio $\left(\frac{W}{C}\right)$

According to the actual strength of cement that has been tested f_{ce} (or the strength grade of cement f_{ce}^{b}), the aggregate types and the required confected strength of concrete $f_{cu,0}$, the water-cement ratio can be defined by the empirical formula of concrete strength (5.3):

$$f_{cu,0} = \alpha_a f_{ce}\left(\frac{C}{W} - \alpha_b\right)$$

Converted into:

$$\frac{W}{C} = \frac{\alpha_a f_{ce}}{f_{cu,0} + \alpha_a \alpha_b f_{ce}} \tag{5.12}$$

And also based on the using conditions of concrete, the maximum water-cement ratio can be found out in Table 5.13. If the calculated ratio is bigger than the regulated maximum ratio, the prescribed one prevails.

Table 5.13 The Limits of Maximum Water-cement Ratio and Minimum Cement Consumption

Environmental Conditions		Structure Types	Maximum Water-Cement Ratio			Minimum Cement Consumption (kg/m^3)		
			Plain Concrete	Reinforced Concrete	Prestressed Concrete	Plain Concrete	Reinforced Concrete	Prestressed Concrete
Dry Condition		Components for normal residential or official rooms	No Regulations	0.65	0.60	200	260	300
Humid Condition	Without freezing injury	① High humid indoor components ② Outdoor components ③ The components in non-corrosive soil and/or water	0.70	0.60	0.60	225	280	300
	With freezing injury	① Outdoor components suffering freezing injury ② The components in non-corrosive soil and/or water suffering freezing injury ③ High humid indoor components suffering freezing injury	0.55	0.55	0.55	250	280	300
Humid Condition with Freezing Injury and Deicer		Indoor and Outdoor components suffering freezing injury and deicer	0.50	0.50	0.50	300	300	300

Note: 1) When part of cement is replaced by active admixtures, the maximum water-cement ratio and minimum cement consumption in this table are the ratio and the consumption before being replaced.

2) The preparation of concrete of C15 or below cannot be limited by this table.

(3) Determination of Water Consumption of 1m^3 Concrete (m_{w0})

The water consumption can be selected from Table 5.14, according to the slump, the known aggregate types and the maximum particle diameter required by construction.

Table 5.14 The Selection Table of Unit Water Consumption of Concrete (kg/m^3) (JGJ55-2000)

Items	Indexes	Maximum Gravel Particle Size (mm)				Maximum Crushed Stone Particle Size (mm)			
		10	20	31.5	40	16	20	31.5	40
Slump (mm)	10~30	190	170	160	150	200	185	175	165
	35~50	200	180	170	160	210	195	185	175
	55~70	210	190	180	170	220	205	195	185
	75~90	215	195	185	175	230	215	205	195
Vebe Consistency (s)	16~20	175	160		145	180	170		155
	11~15	180	165		150	185	175		160
	5~10	185	170		155	190	180		165

Note: 1) The water consumptions in this table are the average values of medium sand; if fine sand is used, the water consumption of 1m^3 concrete can be added by 5~10kg; as for coarse sand, it can be reduced by 5~10kg.

2) Water consumption should be adjusted accordingly when concrete is mixed with various additives or admixtures.

3) This table does not apply to the concrete whose water-cement ratio is less than 0.4 or more than 0.8 and the concrete formed by special moulding process.

(4) Calculation of Unit Cement Consumption of Concrete (m_{c0})

According to the cement quantity of 1m^3 concrete and identified water-cement ratio $\left(\frac{C}{W}\right)$, the cement consumption can be calculated by the following equation:

$$m_{c0} = \frac{C}{W} \times m_{w0} \text{ or } m_{c0} = \frac{m_{w0}}{W/C} \tag{5.13}$$

Based on the application conditions of structures and requirements of durability, the minimum cement consumption of 1m^3 concrete can be found out in Table 5.13. Finally, the bigger value of the two results can be determined as the cement quantity of 1m^3 concrete.

(5) Determination of Sand Percentage (β_s)

The reasonable sand percentage should be determined by slump, cohesion and water retention of concrete mixtures. Generally, the reasonable rate should be found out through experiments or based on the selection experiences of makers. In the absence of experience, the value can be selected from Table 5.15 on the basis of aggregate types and water-cement ratios.

Table 5.15 Selection Table of Sand Percentage of Concrete (%) (JGJ/T55-2000)

Water-Cement Ratio (W/C)	Maximum Gravel Particle Size (mm)			Maximum Crushed Stone Particle Size (mm)		
	10	20	40	16	20	40
0.40	26~32	25~31	24~30	30~35	29~34	27~32
0.50	30~35	29~34	28~33	33~38	32~37	30~35
0.60	33~38	32~37	31~36	36~41	35~40	33~38
0.70	36~41	35~40	34~39	39~44	38~43	36~41

Note: 1) The sand percentages selected in this table are those of medium sand; as for fine sand or coarse sand, those values can be reduced or increased accordingly.

2) This table is suitable for the concrete with slump of 10~60mm. For the concrete whose slump is over 60mm, the value should be adjusted by the rule: based on this table, the percentage increases 1% when the slump increases 20mm. The sand ratio of the concrete whose slump is less than 10mm should be determined by experiment.

3) The sand percentage should be raised accordingly when the aggregates with only one gradation are used in concrete.

4) Larger sand percentage should be selected for thin-walled members.

(6) Calculation of Sand and Stone Consumption of 1m³ Concrete

The consumption of sand and stone can be obtained by mass method or volume method. In actual projects, the mass method often prevails.

1) Mass Method. Based on experience, if the state of raw materials is stable, the apparent density of prepared concrete mixtures should be approximate to a fixed value. Then an apparent density can be assumed at first, m_{s0} and m_{g0} can be calculated as follows:

$$\begin{cases} m_{c0} + m_{g0} + m_{s0} + m_{w0} = m_{cp} \\ \dfrac{m_{s0}}{m_{s0} + m_{g0}} \times 100\% = \beta_s \end{cases} \tag{5.14}$$

In this equation: m_{cp} is the assumed apparent density of concrete mixtures (kg/m³); m_{cp} value can be selected within2350~2450kg/m³ in accordance with the apparent density and particle size of aggregates and the strength grades of concrete.

2) Volume Method. Assumed that the volume of concrete mixtures equals to the sum of the absolute volume of all the components and the volume of the air contained in mixtures, the consumption of all the mixing materials can be identified as follows:

$$\begin{cases} \dfrac{m_{s0}}{m_{s0}+m_{g0}}\times 100\% = \beta_s \\ \dfrac{m_{c0}}{\rho_c}+\dfrac{m_{w0}}{\rho_w}+\dfrac{m_{s0}}{\rho_s}+\dfrac{m_{g0}}{\rho_g}+0.01\alpha = 1 \end{cases} \tag{5.15}$$

In this formula: ρ_c and ρ_w are the densities of cement and water respectively (g/cm^3);

ρ_s and ρ_g are the apparent densities of sand and stone respectively (kg/m^3);

α is the percentage of air content in concrete; $\alpha = 1$ if air-entraining agent is not used.

Solve the above equation (5.14) and can get m_{s0} and m_{g0}.

Through the above six-step calculation, the total consumptions of water, cement, sand and stone can be calculated to get the preliminary mix proportion. However, most of the above calculations are obtained by empirical formulas or resources. And the concrete prepared by those data may not meet the actual demands. Thus, the mix proportion should be tested, adjusted and identified.

2. Determination of the Lab Mix proportion

When the lab mix proportion of concrete is tested, the minimum stirring amount of concrete per tray should be: if the maximum particle size of aggregate is no more than 31.5mm, the amount of mixtures should be 15L; if the size is 40mm, the amount of mixtures should be 25L. When a mixer is used, the stirring capacity should be no less than 1/4 of the fixed stirring capacity of the mixer.

(1) Adjustment of Workability

Based on the preliminary mix proportion, calculate the amount required by 15L mixtures to prepare concrete mixtures. At first, determine the slump through test and observe cohesion and water retention at the same time. It should be adjusted if inconsistent with the requirement. The principles of adjustment are as follows: if the mobility is too big, increase sand and stone appropriately, with the same sand ratio; if the mobility is too small, increase water and cement, water-cement ratio unchangeable; if cohesion and water retention are not good, sand ratio can be raised or reduced to adjust the workability in order to satisfy the required mix proportion, namely, the standard mix proportion for the test of concrete strength. When trial mix and adjusting work have been done, the actual apparent density of concrete mixtures should be tested ($\rho_{c,t}$).

(2) Rechecking of Strength

The water-cement ratio of the tested standard mix proportion may be not appropriate and the strength of concrete may not accord with requirements, so the concrete strength should be rechecked. Three different mixture ratios will be adopted in rechecking. One is the standard ratio, and the other two are the ratios whose water-cement ratios are increased and reduced by 0.05 respectively. The water consumptions of the other two ratios are the same with the one of the standard ratios, but their sand percentages are respectively increased and reduced by 1%. By each mix proportion, a group (three pieces) of specimens is made (when they are made, the workability and apparent density of mixtures with the corresponding mix proportion should be tested and determined; and the result represents the properties of concrete mixtures of this mix proportion; conduct pressure test to the specimens after 28d standard curing for reserve). Construct or calculate the strength and its corresponding water-cement ratio to obtain the confected strength ($f_{cu,0}$) and its water-cement ratio. Finally determine the consumptions of all the materials in $1m^3$ concrete by the following rules:

Water consumption (m_{wo})——hould be determined based on the slump or vebe consistency measured in the production of specimens and the water consumption of the standard mix proportion.

Cement consumption (m_{co})——should be determined through multiplying water consumption by selected water-cement ratio.

Contents of fine and coarse aggregates (m_{g0} and m_{s0})——should be adjusted based on water-cement ratios and the content of fine and coarse aggregate of the standard mix proportion.

(3) Correction of the Apparent Density of Concrete

The mix proportion rechecked by strength should be corrected by the actually tested apparent density of concrete mixtures ($\rho_{c,t}$) to determine the consumptions of all the materials in $1m^3$ concrete. The steps are as follows:

First, calculate the apparent density of concrete mixtures ($\rho_{c,c}$)

$$\rho_{c,c} = m_c + m_g + m_s + m_w \tag{5.16}$$

Second, calculate the correction coefficient (δ):

$$\delta = \frac{\rho_{c,t}}{\rho_{c,c}} \tag{5.17}$$

Finally, calculate the lab mix proportion (the consumption of all the materials in 1m^3 concrete) by the following formulas:

$$\begin{cases} m_c = m_{cb} \cdot \delta \\ m_s = m_{sb} \cdot \delta \\ m_g = m_{gb} \cdot \delta \\ m_w = m_{wb} \cdot \delta \end{cases} \tag{5.18}$$

Specification for Mix Proportion Design of Ordinary Concrete (JGJ55-2000) regulates: if the absolute value of the difference between apparent density's actual tested value and calculated value is no more than 2% of the calculated value, apparent density cannot be corrected.

Through the adjustment of every index, the corrected lab mix proportion is the designed proportion of concrete.

3. The Determination of Construction Mix Proportion of Concrete

In the lab mix proportion of concrete, sand and stone are calculated in their dry state (the water content of sand is less than 0.5%, and that of stone is less than 0.2%). In fact, however, sand and stone stored on the building site contain a certain amount of water, according to which, the weights of site materials are calculated and the water consumption should also be amended at the same time. The amended consumptions of all the materials in 1m^3 concrete are known as the construction mix proportion.

Now, it is assumed that water ratio of sand on the building site is a% and that of stone is b%, and the consumptions of all the materials in 1m^3 concrete are respectively m_c', m_s', m_g', m_w'(kg). Then the weights of all the materials should be:

$$\begin{cases} m_c' = m_c \\ m_s' = m_s(1 + a\%) \\ m_g' = m_g(1 + b\%) \\ m_w' = m_w - m_s \cdot a\% - m_g \cdot b\% \end{cases} \tag{5.19}$$

5.5.3 Examples of the Mix Proportion Design of Ordinary Concrete

[Example] Reinforced concrete beams are cast in a room. The grade of design strength of concrete is C25, and the slump required by the project is 35~50mm (concrete is stirred and vibrated by machine). There is no historical material concerning the builder. The raw materials used are as follows:

Cement: is the ordinary cement with strength grade of 42.5, measured strength of 45MPa, and density $\rho_c = 3.00\text{g}/\text{cm}^3$;

Sand: is the medium sand in zone II whose fineness modulus M_x=2.7, apparent density $\rho_s = 2650\text{kg}/\text{m}^3$, and bulk density $\rho_s' = 1450\text{kg}/\text{m}^3$;

Crushed stone: of which the maximum particle diameter $D_{\max}$=40mm, apparent density $\rho_g = 2700\text{kg}/\text{m}^3$, and bulk density $\rho_g' = 1520\text{kg}/\text{m}^3$;

And tap water.

Try to solve: ① the preliminary mix proportion of concrete; ② if adjust the trial mixture by adding 5% cement paste, then the concrete meets the demand of workability, and at the moment, the volume density of the mixture is 2432kg/m^3. Calculate the standard mix proportion of the concrete; ③the lab mix proportion; ④ if it is known that the water ratios of sand and stone are respectively 4% and 1%, calculate the construction mix proportion of the concrete.

[Solution] 1. Determine the Preliminary Mix Proportion of Concrete

(1) Determine the Confected Strength ($f_{cu,0}$)

$$f_{cu,0} \geqslant f_{cu,k} + 1.645\sigma = 25 + 1.645 \times 5.0 = 33.2(\text{MPa})$$

(2) Determine the Water-cement Ratio (*W/C*)

Substitute the relevant parameters into equation (5.12), then:

$$\frac{m_{w0}}{m_{c0}} = \frac{\alpha_a f_{ce}}{f_{cu,0} + \alpha_a \alpha_b f_{ce}} = \frac{0.46 \times 45.0}{33.2 + 0.46 \times 0.07 \times 45} = 0.60$$

From Table 5.13, it is found that $W/C \leqslant 0.65$ in the dry state, so the water-cement ratio can be equal to 0.60.

(3) Determine the Water Consumption (m_{w0})

From Table 5.14, if the slump is 35~50mm and the maximum particle diameter is 40mm, then the water consumption of 1m^3 concrete can be 175kg, namely, $m_{w0} = 175\text{kg}$.

(4) Determine the Cement Consumption (m_{c0})

$$m_{c0}=\frac{m_{w0}}{\frac{m_{w0}}{m_{c0}}}=\frac{175}{0.60}=292(\text{kg})$$

From Table 5.13, it can be found that the minimum cement quantity should be more than 260kg/m^3, so the value of cement quantity should be $m_{c0}=292\text{kg}$.

(5) Determine the Sand Percentage (β_s)

By $\frac{W}{C}=0.60$ and maximum particle diameter of 40mm, it is found that the reasonable value of sand percentage β_s =35% from Table 5.15.

(6) Calculate Sand and Stone Consumptions (m_{s0}, m_{g0}) and the Preliminary Mix Proportion

1) Mass Method.

Assumed that the density of 1m^3 concrete is 2400kg, then:

$$\begin{aligned} m_{g0}+m_{s0}&=m_{cp}-m_{c0}-m_{w0}\\ &=2400-292-175\\ &=1933(\text{kg})\\ m_{s0}&=(m_{cp}-m_{c0}-m_{w0})\times\beta_s\\ &=1933\times35\%\\ &=677(\text{kg})\\ m_{g0}&=m_{cp}-m_{c0}-m_{w0}-m_{s0}\\ &=1933-677\\ &=1256(\text{kg})\end{aligned}$$

Solution: $m_{s0}=677\text{kg}; m_{g0}=1256\text{kg}$

2) Volume Method.

$$\begin{cases}\dfrac{292}{3000}+\dfrac{m_{s0}}{2650}+\dfrac{m_{g0}}{2700}+\dfrac{175}{1000}+0.01\times1=1\\[2ex] \dfrac{m_s}{m_s+m_g}=0.35\end{cases}$$

Solution: $m_{s0}=680\text{kg}, m_{g0}=1260\text{kg}$

Mass method is often adopted in actual projects, then the preliminary mix proportion are: cement, $m_{c0}=292\text{kg}$; sand, $m_{s0}=677\text{kg}$; crushed stone,

$m_{g0}=1256\text{kg}$; water, $m_{w0}=175\text{kg}$ .Or it can be expressed as $m_{c0}:m_{w0}:m_{s0}:m_{g0}$=1 : 0.60 : 2.32 : 4.30. $m_{c0}=292\text{kg/m}^3$

2. Adjust Workability and Determine the Standard Mix Proportion of Concrete

(1) Adjust Workability

Take sample of 25L by the calculated mix proportion, and the consumptions of all the materials:

Cement: 0.025×292 = 7.3 (kg);

Water: 0.025×175 = 4.38 (kg);

Sand: 0.025×677 = 16.92 (kg);

Stone: 0.025×1256 = 31.4 (kg).

Through trial mixing and workability test, the result shows that both cohesion and water retention are good but the slump is 10mm which is lower than the required value 35~50mm. It means that the sand percentage is proper but the slump needs to be adjusted. By testing, add 5% cement paste (cement and water need to be increased respectively by 0.37kg and 0.22kg), and then the slump is 35mm, in line with the construction requirements. And the bulk density of the mixture is 2432kg/m^3. After trial mixing, the actual consumptions of various materials are as follows:

Cement: 7.3 +0.37 = 7.67kg;

Sand: 16.92kg;

Stone: 31.4kg;

Water: 4.38 +0.22 = 4.6kg.

The total mass is: 60.59kg. Assumed that the actual volume of the mixtures is V_0 (m^3), then the apparent density is 60.59/V_0 (kg/m^3).

(2) The standard mix proportion

The standard mix proportion is:

Cement : sand : stone : water 7.67 : 16.92 : 31.4 : 4.6 = = 1 : 2.21 : 4.09 : 0.60

3. Determine the Lab Mix Proportion of Concrete

(1) Strength Check

By three water-cement ratios: 0.55, 0.60 and 0.65, three samples (of which the water-cement ratios of 0.55 and 0.65 are adjusted to meet requirements) are mixed. It is measured that their apparent densities are 2442, 2432 and 2422 (the unit is kg/m^3). Make them into sample blocks, and measure their compressive strength of 28d, as follows:

	W/C	C/W	f_{cu}, (MPa)
I	0.55	1.82	39.8
II	0.60	1.67	33.4
III	0.65	1.54	30.2

According to the requirements of confected strength, $f_{cu,t} = 33.2$MPa which meets the requirement of group II.

(2) Calculate the Lab Mix Proportion of Concrete

Because the measured apparent density of the mixtures in group II is $\rho_{c,t} = 2432$kg/m^3 and the calculated apparent density is $\rho_{c,c} = 60.47/V_0$kg/m^3, the correction coefficient of the mix proportion is:

$$\delta = \frac{2432}{60.59/V_0} = \frac{2432}{60.59}V_0$$

And the consumptions of various materials in 1m^3 concrete are:

Cement: $m_c = \frac{7.67}{V_0} \times \frac{2432}{60.59}V_0 = 308(\text{kg})$

Sand: $m_s = \frac{16.92}{V_0} \times \frac{2432}{60.59}V_0 = 679(\text{kg})$

Stone: $m_g = \frac{31.4}{V_0} \times \frac{2432}{60.59}V_0 = 1260(\text{kg})$

Water: $m_w = \frac{4.6}{V_0} \times \frac{2432}{60.59}V_0 = 185(\text{kg})$

4. Determine the Construction Mix Proportion of Concrete

The consumptions of various materials in 1m^3 concrete are:

Cement: $m_c' = m_c = 308(\text{kg})$

Sand: $m_s' = m_s(1 + a\%) = 679 \times (1 + 4\%) = 706(\text{kg})$

Stone: $m_g' = m_g(1 + b\%) = 1260 \times (1 + 1\%) = 1273(\text{kg})$

Water: $m_w' = m_w - m_s \cdot a\% - m_g \cdot b\%$

$= 185 - 679 \times 4\% - 1260 \times 1\% = 145(\text{kg})$

5.6 Other Varieties of Concrete

5.6.1 High-strength Concrete

The concrete of which the strength grade is up to C60 or more than C60 is usually called high-strength concrete. The concrete whose strength grade is more than C100 is called ultra-strength concrete.

The high-strength concrete has the following properties:

1) It has high compressive strength, small deformation, and can be applied to long-span structures, components under high loads and high-level structures.

2) Under the same stress, it can reduce the volume of components and the consumption of steel bars.

3) It is dense and hard and has good durability.

4) Its brittleness is higher than ordinary concrete.

5) With the rise of compressive strength, its tensile strength and shearing strength increase but tension-compression ratio and shear-compression ratio decrease.

There are many ways to improve concrete strength. Usually, several technical measures are adopted simultaneously to strengthen the effects. At present, the general preparation principles and measures are:

1) To improve the density of the concrete itself. For example, use high-strength cement; add efficient water-reducing agent; mix high-quality mixtures (such as silica fume, ultra-fine fly ash, and so on) and polymers; greatly reduce water-cement ratio; strengthen vibration.

2) To improve the strength of aggregates. Select dense, hard, and well-graded aggregate of which the maximum particle diameter should be no more than 31.5mm, the content needle-like particles should be no more than 5.0%, the mud content (in quality ratio) should not be greater than 0.5%, and the content of mud clods (in quality ratio) should not exceed 0.2%. Medium sand tends to be adopted as fine aggregate. And the fineness modulus of the aggregate should be more than 2.6, mud content should be no more than 2.0%, and the content of mud clods should not exceed 0.5%. In addition, various short fibers can be used to replace part of the aggregate to improve the toughness of cementing material.

3) To optimize the mix proportion. For the concrete of which the strength grade is above C60, the water-cement ratio is selected from the standard mix proportion by experience; the consumption of cement should not be more than 550kg/m^3; the total mass of sand percentage, admixtures, and mixtures should not exceed 600kg/m^3. In the trial mixing and determination of mix proportions, one of them is the standard mix proportions, and the water-cement ratios of the other two proportions are respectively increased or decreased by 0.02~0.03. And repeat such tests more than 6 times. Finally among the results, the mix proportion that is just a little more than the preparation strength should be determined as the deigned mix proportion.

4) To strengthen production and quality management and strictly control every part of the production.

Recently in China, the grades of the high-strength concrete practically applied in projects are C60~C100. It is mainly used for concrete pile foundation, prestressed sleeper, poles, long-span shells, bridges and pipes.

5.6.2 Lightweight Concrete

Lightweight concrete refers to the concrete of which the density is less than 1950kg/m^3, including lightweight aggregate concrete, porous concrete and macroporous concrete.

1. Lightweight Aggregate Concrete

All kinds of light concrete that are made by light coarse aggregates, light fine aggregates (or ordinary sand), cement and water are known as lightweight aggregate concrete. According to the types of aggregates, lightweight aggregate concrete can also be divided into full lightweight concrete (both the coarse and the fine aggregates are light aggregates) and sand lightweight concrete (all or part of the fine aggregate is the ordinary sand).

The lightweight aggregate used in this kind of concrete has high porosity, small apparent density, big water absorption, and low strength. Lightweight aggregates can be divided into three types by their sources:

1) Industrial waste lightweight aggregate——which is processed by industrial wastes, such as fly ash ceramisite, expanded slag ball, cinder and light sand, etc..

2) Natural aggregate——which is processed by natural porous stone, such as pumice, volcanic cinder, and light sand, etc..

3) Artificial lightweight aggregate——which is made by local materials, such as clay ceramisite, and expanded perlite, etc..

Based on the size of particle diameters, lightweight aggregates can be divided into lightweight coarse aggregate and lightweight fine aggregate (or called sand lightweight). The particle diameter of lightweight coarse aggregate is more than 5mm, and its bulk density is less than 1000kg/m^3; the particle diameter and the bulk density of lightweight fine aggregate are respectively less than 5mm and 1200kg/m^3.

Compared with ordinary concrete, lightweight aggregate concrete has following characteristics: apparent density is low; strength grades are CL5.0, CL7.5, CL10, CL15, CL20, CL25, CL30, CL35, CL40, CL45 and CL50. The elastic modulus is low so that aseismic performance is good; thermal expansion coefficient is small; impermeability, frost resistance, and durability are good; and thermal conductivity is low and insulation is good.

Lightweight aggregate concrete can be used in industrial and civil construction for insulation, structural insulation and structural load-bearing, the three aspects. It is particularly applicable to high-level and long-span structures because its structural deadweight is small (see Table 5.16).

Table 5.16 The Application of Lightweight Aggregate Concrete

Names	Reasonable Ranges of Strength Grades	Reasonable Ranges of Density Grades	Purposes
Insulated Lightweight Aggregate Concrete	CL5.0	800	Insulated Enclosure Structures or Thermal Structures
Structural Insulated Lightweight Aggregate Concrete	CL5.0~CL15	800~1400	Load-bearing and Insulated Enclosure Structures
Structural Lightweight Concrete	CL15~CL50	1400~1900	Load-bearing Components or Structures

2. Porous Concrete

Porous concrete is a kind of concrete containing uniformly distributed pores and no aggregate. Because the formation modes of pores are different, it can be divided into aerated concrete and foamed concrete.

Aerated concrete is generated by making calcareous materials (lime and cement), silicon materials (quartz sand and fly ash), and blowing agent (aluminum) through several processes, like grinding, proportioning, mixing, casting, foaming, standing, cutting and steam curing (under 0.8~1.5MPa and 175~203℃ for 6~28h). Generally, it is pre-cast into slats or blocks.

The apparent density of aerated concrete is about 300~1200kg/m^3, the compressive strength is about 0.5~7.5MPa, and the thermal conductivity coefficient is about 0.081~0.29W/(m•K).

The aerated concrete has big porosity, small water absorption, low strength, good insulation, and bad frost resistance, often used for roof boards and walls.

Foam concrete is a kind of porous concrete made by mixing cement paste with foam agent after hardening. Its apparent density and compressive strength are 300~500kg/m^3 and 0.5~0.7MPa respectively. It can be cast on the site directly, mainly used for the insulating layers of roof boards.

When produced, foam concrete is usually conserved by steam or autoclave. If it is conserved under the natural condition, the strength grade of cement should not be lower than 32.5, otherwise, the strength is too low.

3. Macroporous Concrete

Macroporous concrete is the concrete made of cement, water, and coarse aggregates whose particle diameters are similar, sometimes added by admixtures. Because this kind of concrete does not contain fine aggregates, there are a lot of macropores in it. Based on various aggregate types, there is ordinary macroporous concrete and lightweight macroporous concrete.

The apparent density of ordinary macroporous concrete is 1500~1950kg/m^3 and the compressive strength is 3.5~10MPa, used for load-bearing and insulating walls. The apparent density of lightweight aggregate is 500~1500kg/m^3 and the compressive strength is 1.5~7.5MPa, used for non-load-bearing walls. Macroporous concrete has small thermal conductivity coefficient, good insulation, low moisture absorption. Its shrinkage is 20%~50% smaller than ordinary concrete and its frost resistance can reach 15~20 times, used for walls.

5.6.3 Waterproof Concrete (Impermeable Concrete)

Waterproof concrete is the concrete whose impermeability is improved by a variety of ways, and thus its impermeability grades is equal to or more than P6. The impermeability grades of concrete are determined by the ratio of the maximum water head (that is, the vertical depth of this part under free water surface) to the minimum thickness of building walls, shown in Table 5.17.

When the mix proportion of waterproof concrete is designed, the impermeability test should be strengthened, in accordance with the following provisions:

1) The value of the water-resistant pressure should be increased by 0.2MPa higher than the designed value.

2) In trial mixing, the mix proportion with the highest water-cement ratio should be adopted in impermeability test. And the test result should be in line with the following requirements:

$$P_t \geqslant P/10+0.2 \tag{5.20}$$

In this formula: P_t is the maximum water pressure value when 4 of the 6 specimens are impermeable (MPa);

P is the value of the impermeability value required by design.

Table 5.17 The Selection of the Impermeability Grades of Waterproof Concrete

The Ratio of the Maximum Water Head to the Minimum Thickness of Building Walls	Designed Impermeability Grades
<5	P4
5~10	P6
11~15	P8
16~20	P10
>20	P12

According to the preparation methods, waterproof concrete can be generally divided into four categories: rich cement-slurry waterproof concrete, air-entraining agent waterproof concrete, compacting agent waterproof concrete, and expansive cement waterproof concrete.

1. Rich Cement-slurry Waterproof Concrete

This method is to improve the impermeability of concrete by adjusting mix proportion. The specific methods are: ①using small permeable aggregates; ② minimizing water-cement ratio; ③ properly increasing cement consumption, sand percentage, and cement-sand ratio to ensure that there will be quite thick sand layer around coarse aggregates and avoid that coarse aggregates directly contact with each other to form a mutual connected permeable network.

This kind of impermeable concrete should be in line with the following regulations: ①the limits of the maximum water-cement ratio is shown in Table 5.18; ②the strength grade of cement should not be less than 42.5 and the cement quantity should be not below 325kg; ③the biggest particle diameter of coarse aggregates should not be more than 40mm, and the sand percentage should be 35%~40%.

Table 5.18 Limits of the Maximum Water-cement Ratio of Impermeable Concrete

Impermeable Grades	The Largest Water-cement Ratio	
	Concrete of C20 ~C30	Concrete above C30
P6	0.60	0.55
P8~P12	0.55	0.50
>P12	0.50	0.45

2. Air-entraining Agent Waterproof Concrete

The commonly used air-entraining agent is rosin pyrolytic polymer. And the compound additive with rosin soap and calcium chloride is also available. The addition of air-entraining agent can produce tiny closed bubbles inside concrete, and they fully fill the pores of concrete and cut off water channels to improve the density and impermeability of concrete. Calcium chloride can stabilize bubbles and improve the early strength of concrete. The air content of the impermeable concrete mixed with air-entraining agent should be controlled at 3%~5%.

3. Compacting Agent Waterproof Concrete

Compacting agent is usually the ferric hydroxide solution or the aluminum hydroxide solution. All these solutions are insoluble gel substance which can block the capillary pipes and pores inside concrete to improve the density and impermeability of concrete.

The commonly used compacting waterproof agent is ferric chloride solution, and ferric chloride reacts with calcium hydroxide precipitating in the hydration process of cement and generates ferric hydroxide colloid.

$$2FeCl_3 + 3Ca(OH)_2 = 2Fe(OH)_3 + 3CaCl_2$$

The waterproof concrete mixed with compacting agent is often used for the concrete with higher impermeability, such as high pressure vessels or containers. The shortage is its high cost, and its steel corrosion and dry shrinkage will be great if the mixing amount is more than 3%.

4. Expansive Cement Waterproof Concrete

The waterproof concrete prepared by mixing with expansive cement can expand because the expansive cement generates a lot of ettringite in the process of hydration. Bound by the conditions, it can improve the pore structure of concrete and reduce pores and porosity to improve the density and impermeability of concrete.

The methods to improve the impermeability of concrete also include the mix of water-reducing agent and triethanolamine and the improvement of the density of ordinary concrete itself.

Waterproof cement is mainly used in impermeable hydraulic construction, water supply and drainage structures (such as pool ands water towers) and underground structures, and waterproof roofs.

5.6.4 Polymer Concrete

All kinds of concrete mixed with polymers is called polymer concrete.

It can be divided into three types.

1. Polymer Cement Concrete

It uses soluble polymer and cement as binders and is mixed with sand or other aggregates. Such concrete polymers can evenly distribute inside concrete to fill the pores between cement hydrates and aggregates and combine with cement hydrates as a whole to improve the density of concrete. Compared with the ordinary concrete, the polymer concrete has good durability, wear resistance, corrosion resistance, and impact endurance. Recently, it is mainly used for on-site perfused seamless ground, corrosion-resistance grounds, bridges and repairing projects.

2. Polymer Concrete

Polymer concrete, also called resin concrete, is a kind of concrete that uses synthetic resin as binder and sand and stone as aggregates.

Compared with ordinary concrete, resin concrete has high strength and good corrosion resistance, wear resistance, and frost resistance. The shortages are the bad durability and the great shrinkage during the hardening process. Due to its high cost, however, it can be only used in special projects (such as corrosion-resistant projects, concrete structures repairing, and joint sealing materials). In addition, rosin concrete is also called artificial marble due to its aesthetic appearance, used for desktop, tile bathtub, and other decorative materials.

3. Polymer Impregnated Concrete

Polymer impregnated concrete is made by taking concrete as the substrate, mixing organic monomers into concrete, and converging them with heat or radiation, in which way concrete and polymers can be formed into a whole.

The commonly used monomers are methyl methacrylate, styrene, cyanide propylene. Moreover, catalyst and cross-linking agent should be added.

In polymer impregnated concrete, polymers fully fill the inner pores of concrete to improve its density and its frost-resistance, impermeability, corrosion-resistance, wear-resistance, and impact endurance property greatly. In addition, its compressive strength and tensile strength can be more than 150MPa and 24.0MPa respectively.

Recently, the cost of polymer impregnated concrete is very high, so it can be only used to produce some special components, such as liquefied natural gas tank, marine structures and atomic reactors due to its high strength and durability.

5.6.5 Frost-resistance Concrete

The concrete whose frost-resistance grade is equal to or greater than F50 is known as frost-resistance concrete.

The raw materials of frost-resistance concrete should meet the following requirements: select Portland cement or ordinary Portland cement, but not Portland pozzlana cement; choose continuous size fraction coarse aggregates whose mud content should be no more than 1.0% and clod content should be no more than 0.5%; the mud content of fine aggregates should not be more than 3.0% and clod content should not be more than 1.0%; the coarse and fine aggregates used in the concrete whose frost resistance level is equal to or more than F100 should experience the sturdiness test and accord with *Building Sand* (GB/T14684-2001) and *Building Gravel and Pebble* (GB/T14685-2001); frost-resistance concrete should adopt water-reducing agent; and the concrete whose frost-resistance level is equal to or more than F100 should be mixed with air-entraining agent, and then its gas content should be in line with Table 5.19.

Table 5.19 Minimum Gas Content of the Concrete in Humid and Cold Environment for a Long Term

Maximum Particle Diameter of Coarse Aggregate (mm)	Minimum Gas Content (%)
40	4.5
25	5.0
20	5.5

Note: The percentage gas content is volume ratio.

The calculation methods and trial mixing steps of the mix proportion of frost-resistance concrete should accord with the regulations relevant to ordinary concrete, and the maximum water-cement ratio used in formula should be in line with Table 5.20. Moreover, freeze-thaw-resistance test should be added in the design of the mix proportion of the frost-resistance concrete.

Table 5.20 Maximum Water-cement Ratios of Frost-resistance Concrete

Frost-resistance Level	Without Air-entraining Agent	With Air-entraining Agent
F50	0.55	0.60
F100	—	0.55
F150 and above	—	0.50

5.6.6 Pumping Concrete

The mixtures slump of this concrete is no less than 100mm and it is also constructed by pumping, known as pumping concrete.

The raw materials of pumping concrete should meet the following requirements: select Portland cement, ordinary Portland cement, furnace-slag cement, Portland fly-ash cement but not Portland pozzolana cement; choose continuous size fraction coarse aggregates whose needle-like particles content should be no more than 10%; the ratio of the maximum particle diameter of coarse aggregates to the diameter of delivery pipes should be in line with the regulations in section 5.2; choose medium sand whose content of particles passing through 0.315mm sieve should be no less than 15%; pumping concrete should be mixed with pumping agent or water-reducing agent; it is appropriate to mix fly-ash or other active mineral mixtures whose quality should be consistent with the existing relevant national standards.

In trial mixture, the slump value of pumping concrete should be calculated as follows:

$$T_t = T_p + \Delta T \tag{5.21}$$

In the equation: T_t is the slump required in trial mixture;

T_p is the slump required when concrete enters pump;

ΔT is the measured gradual slump loss within estimated time.

The calculation and trial mixing steps of the mix proportion of pumping concrete should be consistent with not only the regulations of ordinary concrete, but also the following requirements:

1) The ratio of water consumption to the total amount of cement and mineral mixtures should not be more than 0.60.

2) The total amount of cement and mineral mixtures should not be less than 300kg/m^3.

3) The sand percentage should be 35%~45%.

4) The gas content of concrete should not be more than 4% when air-entraining agent is added.

5.6.7 Mass Concrete

The minimum size of the concrete structure entity is equal to or more than 1m, or it is estimated that the hydration heat of cement will lead to high internal and external temperature difference which result in the cracks of concrete, known as mass concrete.

The raw materials of mass concrete should meet the following requirements: select the cement with low hydration heat and long setting time, such as low heat Portland furnace-slag cement, medium heat Portland cement, Portland furnace-slag cement, Portland fly-ash cement, Portland pozzolana cement; adopt relevant measures to delay the release of hydration heat when use Portland cement or ordinary Portland cement; coarse aggregate should have continuous size fraction, and fine aggregate should be medium sand; mass concrete should be mixed with retardant, water-reducing agent and the mixtures that can lower the hydration heat of cement.

Based on the assurance of concrete strength and slump, the contents of mixtures and aggregates in mass concrete should be increased to reduce the cement quantity of concrete per cube meter. The calculation and trial mixing steps of the mix proportion of mass concrete should be consistent with related provisions. And checking and determination of hydration heat should be conducted after the mix proportion is determined.

5.6.8 Fiber Reinforced Concrete

Based on ordinary concrete, fiber reinforced concrete is made by evenly scattering the short and fine dispersed fibers into ordinary concrete. The purpose for the addition of short fibers is to improve the tensile strength and impact-resistance and reduce the brittleness of concrete.

There are two kinds of common short-cut fibers: one is the fiber with high elastic modulus, such as steel fiber, glass fiber, and carbon fiber; the other one is the fiber with low elastic modulus, such as nylon fiber, polyethylene fiber and polypropylene fiber. The low modulus fiber can improve toughness but rarely affects the tensile strength; the high modulus fiber can significantly increase the tensile strength.

In fiber reinforced concrete, fibers' mixing amount, aspect ratio, distribution and alkali resistance greatly influence its properties. Take steel fiber for example, theoretically, both the bending strength and the tensile strength will rise with the increase of fiber-content ratio. The better aspect ratio of steel fiber is 60~100. It is usually in straight shape, wave shape, and with hooks on the two ends. In application, it would be better to choose the shape easy to bond the basal body. The steel fiber used in concrete can generally increase the tensile strength by about 2 times, the bending strength by 1.5~2.5 times, the impact strength by more than 5 times or even 20 times, the ductility by 4 times, and durability by 100 times above.

Recently, fiber reinforced concrete has already been used for roads, bridges, aircraft runways, pipes, roofs, wall panels, and other elevations.

5.6.9 Shotcrete

Shotcrete is the concrete formed by installing the prepared cement, sand, stone and a certain amount of flash-setting agent into injection machine and conveying them through a hose and pneumatically projecting at high velocity onto stone or the concrete surface.

Flash-setting admixture needs to be added to shotcrete in order to condense the concrete in few minutes, improve its early strength, and reduce the rebound amount. But the late strength will decrease. Thus, the mixing amount of flash-setting admixture should be controlled and determined through trial mixture. At present, the common flash-setting agent includes Red Star I and 711 type.

The quality of shotcrete is closely related with the cement varieties. Ordinary Portland cement can be compatible with flash-setting agent well, to be preferred. Portland blast-furnace-slag cement and Portland pozzlana cement have good impermeability and can resist sulphat erosion, but they have long initial setting time, low early strength and big dry shrinkage, not appropriate.

Aggregate is required to have certain water-content ratio (that of sand should be 5%~7%, and that of stone should be 1%~2%) in order to prevent mixed materials generating dust in stirring and cement flying and losing when mixed with dry materials. It should be noted that the water-content ratio should not be too big in order to avoid condensation and blocking. The particle diameter of coarse aggregate should be less than 15mm to avoid blocking and reduce the kinetic energy as well as rebound loss when stone is shot. Crushed stone will seriously wear pipeline, but its rebound amount is small. Gravel is just opposite. It is better not to use fine sand, because fine sand will increase the shrinkage deformation of concrete which also affect the health of the operators.

The mix proportion of shotcrete (cement : sand : stone) is usually tested by empirical method and modified by real measurement. The common mix proportions include: 1 : 2 : 2.5, 1 : 2.5 : 2, 1 : 2 : 2, and 1 : 2.5 : 1.5 (mass ratio). If the cement quantity is 300~450kg/m^3, the water-cement ratio should be 0.4~0.5. If the sand percentage is below 45%, it is easy to block and the rebound amount is high; if the sand percentage is above 55%, the strength of concrete will decease and the shrinkage of cement will increase; and thus, the sand percentage should be 45%~55%.

Dry mixed materials are usually adopted in shotcrete. If it has been stored for a long time, the water in sand and stone will react with cement and affect the quality after injection. Therefore, mixed materials should be mixed when used.

The determination of the compressive strength of shotcrete can refer to *Specifications for Bolt-shotcrete Support* (GBJ50086-2001), the national standard. The compressive strength of shotcrete is 25~40MPa, the tensile strength is 2.0~2.5MPa, and its bonding power with stone is 1.0~1.5MPa, which can meet the requirements of underground structures completely. Shotcrete is widely used in bolt-shotcrete tunnel projects, underground rock engineering and mine support projects.

Questions

5.1 What is concrete and ordinary concrete? Why concrete can be widely used in projects?

5.2 What is ordinary concrete composed of? How do they function before and after the hardening of concrete?

5.3 How to select varieties and strength grades of cement in the preparation of concrete?

5.4 If the mud content in sand is too high, what kinds of impacts will it have on the properties of concrete?

5.5 Why are there requirements for the gradation and the fineness of sand used in concrete? Do the two kinds of sand have the same gradation if they have the same fineness modulus? On the contrary, do they have the same fineness modulus if they have the same gradation?

5.6 What characteristics of sand do its fineness modulus and the particle gradation imply?

5.7 What are the harmful substances in aggregates? Why they should be controlled?

5.8 What is the maximum particle diameter of stone? Why to choose the maximum particle diameter?

5.9 What is water-reducing agent? What are the common types? Simply narrate its water-reducing mechanism.

5.10 What is air-entraining agent? What are the common types? What properties of concrete will be affected if air-entraining agent is added?

5.11 What are hardening accelerating, set retarder, and anti-freezing admixture? What are their common types? What are their real significances when used in concrete projects?

5.12 What is the workability of concrete mixtures? How to evaluate it?

5.13 What is slump? What is vebe consistency? Where can they be used?

5.14 There will be the following four situations when the workability of concrete mixtures is measured:

① the mobility is smaller than the required one;

② the mobility is bigger than the required one;

③ the mobility is smaller than the required one, and the cohesion is bad;

④ the mobility is bigger than the required one, and both the cohesion and water retention are bad.

5.15 What are the factors affecting the workability of concrete?

5.16 How to determine the strength grades of concrete? What is the relationship between the compressive strength of prism specimen and that of cube specimen?

5.17 What are the factors affecting the strength of concrete? What are the main measures to improve the concrete strength?

5.18 What are dry shrinkage deformation and creep of concrete? And the affecting factors?

5.19 What kinds of properties does the durability of concrete refer to? What are the main factors influencing the durability of concrete?

5.20 What is the carbonization of concrete? And the influencing factors?

5.21 How does the carbonization of concrete influence the properties of concrete? What kinds of methods and measures can be used to improve the carbonization of concrete?

5.22 What is alkali-aggregate reaction of concrete? And why can it happen? What are the factors to avoid alkali-aggregate reaction?

5.23 How to improve the durability of concrete?

5.24 How to control the quality of concrete in actual projects?

5.25 What is the relationship between concrete design strength and concrete confected strength?

5.26 What are the three key parameters and the four basic requirements for the concrete mix proportion in design?

5.27 Why should the maximum water-cement ratio and minimum cement consumption be controlled when the mix proportion of concrete is designed?

5.28 How to determine the water consumption for concrete mixtures?

5.29 What is reasonable sand percentage? What kinds of factors is it related to?

5.30 What are the characteristics of high strength concrete? Which aspects will high strength concrete be used?

5.31 What are the characteristics of lightweight aggregate concrete compared with ordinary concrete?

5.32 What is waterproof concrete? And its types? Which aspects of construction engineering does it apply to?

5.33 What is polymer concrete, frost-resistance concrete, and pumping concrete?

Exercises

5.1 A and B, two kinds of sand, are 500g respectively. After the screening, the residual screening of each sieve is listed in the following table:

The Size of Sieve Hole(mm)	Unit Screening(g)	
	A	B
9.50	0	0
4.75	15	50
2.36	60	150
1.18	105	150
0.60	120	65
0.30	90	50
0.15	85	35
<0.15	15	0

Separately calculate the fineness modulus of these two samples and evaluate their gradation. If take 50% of each kind of sand and mix them together, try to calculate the fineness modulus of the mixed sand sample and evaluate its gradation.

5.2 There is a group of concrete specimens of 100mm × 100mm × 100mm, at the age of 28d. It is measured that their failure loads are 392kN, 379kN, 384kN. Try to calculate the compressive strength of this group of concrete cubes. If it is known that this concrete is confected by ordinary cement with strength grade of 42.5 (extra-coefficient is 1.10) and crushed stone. Try to estimate the water-cement ratio.

5.3 After the adjustment of the trial mixing of some concrete sample, it is known that the amounts of various materials are cement of 3.1kg, water of 1.86kg, sand of 6.20kg, and gravel of 12.85kg. The measured apparent density is 2450kg/m^3. Try to calculate the actual amounts of various materials in 1m^3 concrete.

5.4 The lab mix proportion of some concrete is 1 : 2.1 : 4.2 (cement : sand : stone), and W / C = 0.54. It is known that the density of cement is 3.1g/cm^3, the apparent density of sand is 2.6g/cm^3, and the apparent density of stone is 2.65g/cm^3. Try to calculate the consumptions of all the materials in 1m^3 concrete (the gas content α is 1%).

5.5 On a site, ordinary cement of 32.5 and gravel are used to prepare concrete. Its construction mix proportion is: cement of 330kg, sand of 680kg, gravel of 1270kg, and water of 130kg. If the water-content ratio of the sand on the site is 3% and that of gravel is 0.5%, whether can this concrete meet the strength requirement of C30 or not?

5.6 It is known that the concrete prepared by ordinary cement of 42.5 and crushed stone of 20~40mm is used to make the panels, beams, and stairs of a framework structure. The design strength grade of this concrete is C25, and the slump is required to be 30~50mm (the concrete is stirred and vibrated by machine). And there is no historical materials concerning this project. It is assumed that the apparent density of the concrete mixtures is 2440kg/m^3. Try to determine the preliminary mix proportion of the concrete by mass method.

5.7 The design strength grade of reinforced concrete beams of a project (not suffer from snow) is C25, and the slump is required to be 30~50mm (the concrete is stirred and vibrated by machine), and there is no historical materials concerning this project. All the raw materials used are as follows:

Cement: ordinary cement, the strength grade of 42.5 (the measured strength of 48.0MPa), density $\rho_c = 3.10$g/cm^3;

Crushed stone: continuous gradation of 5 ~ 20mm, $\rho_g = 2700$kg/m^3, and the water content is1.5%;

Sand: medium sand M_x=2.6, $\rho_s = 2650$kg/m^3, and the water content is 3%;

Water: tap water.

Try to calculate:

① The consumptions of all the materials used in 1m^3 concrete;

② The construction mix proportion of concrete;

③ If two bags are needed by mixer for each mixing, what are the consumptions of the other materials?

5.8 It is known that there are panels and beams of the main structure of a project. The mix proportion of 1m^3 concrete is: cement of 303kg, sand of 707kg, crushed stone of 1250kg, and water of 182kg. If the capacity of the mixer is 450L,

① calculate the consumptions of all the materials used in concrete per tray;

② if the cement used in each tray are two bags, what about the other materials?

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6

Building Mortar

This chapter mainly introduces the technical requirements for building mortar and the methods to design the mix proportion of masonry mortar, and simply presents other kinds of mortar.

It is required to master the major technical properties of mortar and the mix proportion design of masonry mortar.

Building mortar is a building material formed by mixing cementing materials, fine aggregates, mixtures and water in an appropriate proportion. The main difference between mortar and concrete is that there is no coarse aggregate in the composition of mortar. Thus, building mortar is also called fine aggregate concrete.

Building mortar is usually used in the following areas: in structural engineering, it binds stone, brick, blocks together and fills the gaps in brick walls and the joints in large wall panels and various components; in decorative projects, it is used to plaster brick walls, floors, and structural beams and columns; and it is also used to inlay natural stone, artificial stone, ceramic tiles and mosaic tiles.

According to different purposes, the building mortar can be classified into masonry mortar, surface mortar (ordinary surface mortar, waterproof mortar, decorative mortar), and special mortar (such as heat-insulated mortar, corrosion-resistant mortar, and sound-absorbing mortar).

Based on different cementing materials, building mortar can be divided into cement mortar, lime mortar, gypsum mortar, mixed mortar and polymer cement mortar. The commonly used mixed mortar includes cement lime mortar, cement clay mortar and lime clay mortar.

6.1 The Composition of Mortar

To ensure the quality of building mortar, various materials in the composition of mortar should meet certain technical requirements.

1. Cementing Materials

The major cementing material in building mortar is cement, including ordinary cement, furnace-slag cement, masonry cement and fly-ash cement. Proper cement varieties should be chosen according to the projects' environmental conditions. The strength grades should be selected in line with those of mortar. Generally, the strength grades of cement (the compressive strength value of 28d, in MPa) should be 4~5 times of the strength grades of mortar. Because the strength grades of mortar are not high, the cement in medium and low strength grades can satisfy the requirements. If the strength grade of cement is too high, appropriate amount of mixed materials (like fly ash) can be added in order to save the cement consumption. As to the mortar for special use, especial mortar and organic binding materials can be used. For example, expanding cement can be used for component joints, seams, structure strengthening or crack repairing; and white and color cement can be used to prepare decorative mortar.

Lime, gypsum and clay can also be used as the cementing materials for mortar and they can be mixed with cement to prepare mixed mortar to save cement and improve the workability of mortar.

The strength grades of cement used in masonry cement should be chosen according to the requirements of design. The strength grades of the cement used in cement mortar should not be more than 32.5; and that of the cement used in cement mix mortar should be no more than 42.5.

2. Fine Aggregate

Sand is the find aggregate for building mortar. It should be in line with the technical requirements of sand used in concrete. In addition, the maximum particle diameter of sand should be limited due to the thin layer of mortar. The layer of mortar used in rubble masonry is just 1/4~1/5 of mortar's maximum particle diameter; medium sand whose maximum particle diameter is not more than 2.5mm is appropriate for the mortar used in brickwork; fine sand can be applied to surface and jointing mortar, with the maximum diameter no more than 1.2mm. For the sake of mortar quality, clean sand should be selected. And the impurity content in sand should not be too much. It is regulated in *Specification for Mix Proportion Design of Masonry Mortar* (JCJ98-2000), the building industry standard, that the mud content of sand should not be more than 5%; and in the cement mix mortar of M2.5 (strength grade), the mud content of sand should not be more than 10%. And the sulfide content (equivalent in SO_3) in sand should be less than 2%.

3. Water

The Clean water without harmful impurities should be adopted to mix mortar, generally the same as the water requirement for concrete.

4. Mixtures and Additives

In order to improve the workability of mortar and save cement, some inorganic fine mixtures, such as lime paste, clay paste, and fly ash, can be added to mortar. Lime should precipitate, and fly ash should be ground, for a better effect. The provisions on mixtures regulated in *Specification for Mix Proportion Design of Masonry Mortar* (JCJ98-2000), the building industry standard, include:

1) When quick lime ages to lime paste, it should be screened by the sieve with the aperture no more than 3mm×3mm, and the aging time should be no less than 7d; the aging time of the ground quick lime should be no less than 2d. The lime paste stocked in sedimentation tank should be protected from drying, freezing and polluting. Dehydrated lime paste is forbidden.

2) When clay or mild clay is used for clay puddle, it should be mixed by mixer with water and be screened by the sieve with the aperture no more than 3mm×3mm. When the organic compounds in the clay are checked by colorimetry, the color should be paler than the standard color.

3) The carbide slag used for carbide plaster should be screened by the sieve with the aperture no more than 3mm×3mm, and when checked, it should be heated to 70℃ and maintained for 20min. It can only be used without the odor of acetylene.

4) Hydrated lime powder can not be used in masonry mortar directly.

5) The consistency of lime paste, clay plaster and carbide plaster in preparation should be 120mm±5mm.

6) The quality of fly ash should accord with *Fly Ash Used in Cement and Concrete* (GB1596-91), the national standard; and that of ground quick lime should be in line with *Building Quick Lime Powder* (JC/T480-92).

Sometimes, micro foam agent can be added to improve the workability of mortar. The common micro foam agent is rosin pyrolytic polymer and its mixing amount is 0.005%~0.01% of the mass of cement.

Additives can be mixed in mortar to improve the workability and other construction properties of mortar. The types, mixing amount, and physical properties of additives should be determined by test.

6.2 The Main Technical Properties of Mortar

For the sake of projects, the newly mixed mortar should have good workability, and the hardened mortar should have the required strength, the bending power to the bottom face, little deformation and durability.

6.2.1 Workability of Fresh Mortar

The workability of fresh mortar refers to the comprehensive properties of mortar easy for construction and good for quality, including mobility and water retention. The mortar with good mobility is easy to be paved thinly and evenly on bricks and bonded with floors well.

1. Mobility (Consistency)

The mobility of mortar is the property that mortar can flow under the role of dead weight and exterior force. Fluidity is expressed by "sinking degree", usually determined by the consistency of mortar. The bigger the sinking degree is, the better the mobility will be.

The selection of mortar mobility should be determined by masonry types, construction conditions, and weather. The consistency of masonry mortar should be selected according to *Code for Acceptance of Construction Quality of Masonry Engineering* (GB50203-98), the national standard, shown in Table 6.1.

Table 6.1 Consistency of Masonry Mortar

Masonry Types	Consistency of Mortar (mm)
Ordinary Sintered Masonry	70~90
Small-size Fine-aggregate Hollow Blocks and Masonry	60~90
Sintered Porous Bricks, Hollow Brick Masonry	60~80
Ordinary-sintered-brick Flat-arched Lintels Rowlock Walls, Barrel Arches Small-size Ordinary-concrete Hollow Blocks and Masonry Aerated Concrete Blocks and Masonry	50~70
Stone Masonry	30~50

2. Water Retention

The water retention of mortar refers to the property of mortar to maintain moisture. When the mortar with good water retention is used in transportation, standing and pavement, water will not escape from mortar soon and the necessary consistency can be maintained. To keep a certain amount of water in mortar is easy to manipulate and also guarantees the normal hydration of cement to maintain the strength of masonry.

The water retention of mortar is expressed by layering degree, measured by mortar layering degree instrument. The mortar with good water retention has the layering degree of 10~30mm, and if it is more than 30mm, the water retention will be bad and easy to segregate; the mortar whose layering degree is less than 10mm is not good for construction. Based on many experiments, the layering degree of cement mortar should be no more than 30mm, and the layering degree of cement mix mortar should be no more than 20mm.

6.2.2 Strength and Strength Grades of Hardened Mortar

The hardened mortar should have big strength which is expressed by strength grade. Compressive strength is the main basis for mortar strength.

The strength grade of mortar, expressed by $f_{m,0}$, is determined by compressive strength average (MPa) measured through curing a group of six cube specimens with side length of 70.7mm for 28d, the standard test method.

The strength grades of mortar include: M20, M15, M10, M7.5, M5 and M2.5, the six grades.

The strength of mortar is connected with its surface material. For the ordinary cement mortar, the following equation can be used to calculate its compressive strength.

1. Imhygrophanous Beds

The strength of the mortar used in imhygrophanous beds (such as dense stone), similar as concrete, mainly depends on the cement strength and water-cement ratio, defined as follows:

$$f_{m,0} = 0.29 f_{ce}\left(\frac{C}{W} - 0.4\right) \tag{6.1}$$

In this formula: $f_{m,0}$ is the compressive strength of 28d (MPa);

f_{ce} is the measured strength of cement (MPa);

$\frac{C}{W}$ is water-cement ratio.

2. Hygrophanous Beds

When mortar is used in the hygrophanous beds (bricks and other porous materials), some of the water will be absorbed by base materials. Because mortar has a certain property of water retention, no matter how much water is added, the remaining amount is the more or less the same. In this case, the strength of mortar is determined by cement grade and dosage and has nothing to do with water-cement ratio, defined as follows:

$$f_{m,0} = (\alpha f_{ce} Q_c / 1000) + \beta \tag{6.2}$$

In this formula: $f_{m,0}$ is the compressive strength of mortar for 28d (MPa);

Q_c is the cement consumption of mortar per cubic meter, (kg);

α, β is the characteristic coefficients, and $\alpha = 3.03$, $\beta = -15.09$;

f_{ce} is the measured cement strength, accurate to 0.1MPa.

6.2.3 Adhesion Stress of Mortar

Brick and stone masonry is a solid entity composed of many blocks that are bonded by mortar as a whole. Thus, it is required that mortar must have a certain adhesion stress over bricks and stones. Generally, the more the compressive strength of mortar is, the bigger its adhesion stress will be. In addition, its adhesion stress is related to the surface, cleanness, and humidity of bricks and stones, as well as the construction and curing conditions. For example, bricklaying needs watering, and the surface without clay will improve the adhesion stress and ensure the quality of masonry.

6.2.4 Deformability of Mortar

It is easy for mortar to get deformed when it bears loads or the temperature changes. If it deforms greatly or unevenly, the quality of masonry and surface will decrease and cause sinkage and crack. When fine aggregates are used to mix the mortar, its deformation is bigger than the ordinary mortar. In order to prevent the cracks caused by uneven shrinkage deformation, hemp cut, paper strip and others fabric materials can be mixed in the surface mortar.

6.2.5 Durability of Hardened Mortar

The durability of mortar refers to the property to withstand wear and tear in the long-term use. The hydraulic masonry that usually contacts with water should be impermeable and frost-resistant, so the impermeability and frost resistance of hydraulic masonry should be considered.

1. Frost Resistance

The frost resistance of mortar refers to the property to resist freeze-thaw cycle. Mortar is frozen and damaged because the water in its pores expands due to freeze and breaks the pores. Thus, dense mortar and the mortar with closed pores have good frost resistance. In addition, the factors influencing the frost resistance of mortar also include cement types, strength grades, and water-cement ratio.

2. Impermeability

The frost resistance of mortar is the property to resist the infiltration of pressure water. It is mainly related to density and size and structure of the inner pores. The connecting pores inside mortar and the cellular structures and pores formed when it is moulded, all of which can lead to water seepage of mortar.

6.3 Masonry Mortar

The mortar that binds bricks, stone, and construction blocks together into a whole masonry is called masonry mortar. The load-bearing ability of masonry depends on not only the strength of bricks and stones, but also the strength of mortar. Therefore, mortar is the most important part of masonry.

6.3.1 The Mix Proportion of Masonry Design of Mortar (JGJ98-2000)

The mix proportion of masonry mortar should be determined by the strength grade of masonry mortar selected according to the design requirements of project types and parts of masonry. Generally, it can be determined by adjusting through trial mixture after referring to the relevant manuals and information. The steps to design the mix proportion of mortar used for water-absorbing layers are as follows:

1. Determine the trial strength of mortar

The trial strength of mortar is calculated by the following equation:

$$f_{m,0} = f_2 + 0.645\sigma \tag{6.3}$$

In this equation: $f_{m,0}$ is the trial strength of mortar, accurate to 0.1MPa;

f_2 is the designed strength of mortar (namely, the compressive strength average of mortar) (MPa);

σ is the standard difference of on-the-site strength of mortar, accurate to 0.1MPa.

The standard difference of on-the-site strength of masonry mortar should be calculated by the following equation or selected according to Table 6.2.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} f_{m,i}^2 - N\mu_{f_m}^2}{N-1}} \tag{6.4}$$

In the equation: $f_{m,i}$ is the strength of the same-type specimens in Group i within the statistic cycle (MPa);

μ_{f_m} is the strength average of the same-type specimens in Group N within the statistic cycle (MPa);

N is the total numbers of the same-type mortar specimens within the statistic cycle, $N \geqslant 25$.

If there is no recent statistics, the standard difference of the on-the-site strength of mortar can be selected from Table 6.2.

Table 6.2 Values of the Standard Difference of Strength σ (MPa)

Strength / Construction Level	M2.5	M5.0	M7.5	M10.0	M15.0	M 20
Excellent	0.50	1.00	1.50	2.00	3.00	4.00
Normal	0.62	1.25	1.88	2.50	3.75	5.00
Bad	0.75	1.50	2.25	3.00	4.50	6.00

2. Calculate Cement Consumption

The cement consumption in every cubic meter should be calculated as follows:

$$Q_c = \frac{1000(f_{m,0} - \beta)}{\alpha \cdot f_{ce}} \tag{6.5}$$

In the equation: Q_c is the cement consumption in mortar per cubic meter (kg/m^3);

$f_{m,0}$ is the trial strength of mortar (MPa);

f_{ce} is the measured strength of cement, accurate to 0.1MPa;

α, β are the specificity coefficients, and $\alpha = 3.03$, $\beta = -15.09$.

If the measured strength of cement can be obtained, it can be calculated as follows:

$$f_{ce} = r_c \cdot f_{ce,k} \tag{6.6}$$

In the equation: $f_{ce,k}$ is the strength value of the level of cement varieties;

r_c is the extro-coefficient of cement strength, and it should be determined by the actual statistics; if there is no statistics, r_c is 1.0.

If the calculated cement consumption in cement mortar is less than 200kg/m^3, 200kg/m^3 should be adopted.

3. Determine the Quantity of Mixtures Q_d

The quantity of mixtures used in cement mixed mortar should be defined as follows:

$$Q_d = Q_a - Q_c \tag{6.7}$$

In the equation: Q_d is the quantity of the mixtures in mortar per cubic meter, (kg/m^3);

Q_c is the quantity of cement in mortar per cubic meter, (kg/m^3);

Q_a is the total quantity of the cementing materials and mixtures in mortar per cubic meter (kg/m^3), appropriate between 300~350kg/m^3.

If the consistencies of lime paste are different, the conversion factors can be selected from Table 6.3.

Table 6.3 The Conversion Factors of Lime Paste with Different Consistencies

Consistency of Lime Paste (mm)	120	110	100	90	80	70	60	50	40	30
Conversion Factor	1.00	0.99	0.97	0.95	0.93	0.92	0.90	0.88	0.87	0.86

4. Quantity of Sand Q_s

The water, cementing materials and mixtures in mortar are used to fill the pores in sand. Thus, mortar of $1m^3$ contains sand of $1m^3$ cumulative volume. The quantity of sand in mortar per cubic meter should be calculated by the bulk density in the dry state (the water ratio is less than 0.5%), in the unit of kg/m^3.

5. Quantity of Water Q_w

The quantity of water in mortar per cubic meter should be 240~310kg according to the consistency of mortar.

In order to solve the problem that the calculated quantity of cement is small, the mix proportion of cement mortar can be determined by table-checking method: the quantity of the materials used in cement mortar can be selected from Table 6.4.

Table 6.4 Water Quantity in Mortar Per Cubic Meter

Strength Grades	Cement Quantity in Mortar Per Cubic Meter (kg)	Sand Quantity in Mortar Per Cubic Meter (kg)	Water Quantity in Mortar Per Cubic Meter (kg)
M2.5~M5	200~230	Bulk Density Value of $1m^3$ Sand	270~330
M7.5~M10	220~280		
M15	280~340		
M20	340~400		

Note: 1) The strength grade of cement in this table is 32.5; if the strength grade is more than 32.5, it is appropriate to choose the minimum.

2) Select the cement quantity reasonably according to projects.

3) When fine sand or coarse sand is used, the water quantity should be the maximum and minimum respectively.

4) If the consistency is lower than 70mm, the water quantity can be lower than the minimum.

5) If the building site is hot or in dry seasons, more water can be used accordingly.

6. Trial Mixing, Adjustment and Determination of the Mix Proportion

The actual materials used in projects should be adopted in preparation, and as for the mechanical mixing, the stirring time should be calculated from the end of feeding, in line with the following regulations:

1) For the cement mortar and cement mix mortar, the time should be no less than 120s.

2) For the mortar mixed with fly ash and admixtures, the time should be no less than 180s.

There are two steps of trial mixing:

(1) Adjusting Trial Mixing

When mix the calculated proportion or that checked from table, the layering degree and the consistency of the mixtures should be determined. If it cannot meet the requirements, the quantity of materials should be adjusted until it meets the demand. This mix proportion is the basic mix proportion.

(2) Checking Strength

There are at least three mix proportions in trial mixing. One of them is the basic mix proportion obtained from the above adjustment of trial stirring. Moreover, the cement quantities of the other two mix proportions should be increased and decreased by 10% of the basic one respectively. The water quantity or mixtures quantity can be adjusted accordingly under the conditions that the consistency and layering degree are qualified. After adjustment, the shaping of specimen and the determination of the strength grades of mortar should be conducted according to the existing *Experimental Method of the Basic Properties of Building Mortar* (JGJ70), the national standard; and the mix proportion of mortar selected is the one in which the cement quantity is small, in line with the requirements.

Though the mix proportion of mortar has been determined, it must be tested and determined again if the raw materials are changed.

6.3.2 Examples for the Mortar Mix Proportion Design

[Example] It is required to design the mix proportion of the mortar for brick walls whose level is M10 and the consistency of cement lime mortar is 70~90mm. The main parameters of the raw materials are: cement: ordinary Portland cement of 42.5; sand: medium sand with bulk density of 1450kg/m^3 and water content of 2%; lime paste: consistency of 100mm; building level: normal.

[Solve] (1) Calculate trial strength $f_{m,0}$

$$f_{m,0} = f_{m,k} + 0.645\sigma = 10 + 0.645 \times 2.5 = 11.6(\text{MPa})$$

(2) Calculate cement quantity Q_c

$$Q_c = \frac{1000 \times (f_{m,o} - \beta)}{\alpha \cdot f_{ce}} = \frac{1000 \times (11.6 + 15.09)}{3.03 \times 42.5} = 207(\text{kg/m}^3)$$

(3) Calculate the quantity of lime paste Q_d

$$Q_d = Q_a - Q_c = 350 - 207 = 143(\text{kg/m}^3)$$

Convert the lime paste consistency of 100mm to 120mm (referred to table 6.3)

$$143\times0.97=139(\mathrm{kg/m^3})$$

(4) Calculated sand quantity based on its bulk density and water content, Q_s

$$Q_s=1450\times(1+0.02)=1479(\mathrm{kg/m^3})$$

(5) Select water quantity Q_w

According to Table 6.4, the water quantity $Q_w=300\mathrm{kg/m^3}$. The ratio of various materials used in mortar is:

Cement : lime paste : sand : water = 207 : 139 : 1479 : 300 = 1 : 0.69 : 7.14 : 1.45

6.4 Other Kinds of Building Mortar

6.4.1 Surface Mortar

Surface mortar is also called plaster mortar that is plastered on the surface of buildings in a thin layer to protect them, increase their durability, and also smooth their surfaces and make them clean and artistic. Based on its different functions, surface mortar can be classified into ordinary surface mortar, waterproof mortar, decorative mortar and special surface mortar.

1. Ordinary Surface Mortar

Ordinary surface mortar is mainly used to protect buildings and also smooth their surfaces and make them clean and artistic. Different from masonry mortar, the technical requirement for surface mortar is not compressive strength but workability and bonding power with substrate. Thus, it needs more cementing materials.

In order to ensure the smooth surface and avoid cracking, plaster mortar is usually plastered on bottom, middle-level, and cover coat, the three layers. And different layers need different kinds of mortar.

The mortar on the bottom layer mainly need to bond with the base. Mortar plastered on the bottom of brick wall is lime mortar; cement mortar is used for waterproof and moisture-proof; cement mortar or mixed mortar are often used on the bottom layer of concrete; mixed mortar or lime mortar are used on strapped walls and ceilings.

The mortar on the middle-level layer is used for leveling, mostly mixed mortar or lime mortar.

The mortar on the cover coat mainly functions as protection and decoration. Thus, it is appropriate to use fine sand. The mortar plastered on surface is often mixed mortar, hemp cut lime mortar, and paper strip mixed lime mortar. Cement mortar should be used in the parts easy to get bumped or wet, such as dado, washboard, pool, windowsill and others.

The mobility of surface mortar and the maximum particle diameter of aggregate should be referred to in Table 6.5, and its mix proportions in Table 6.6.

Table 6.5 Mobility of Surface Mortar and the Maximum Particle Diameter of Aggregate

Names of Plaster Layer	Sinking Degree(cm)Artificial Plastering	Maximum Particle Diameter of Sand(mm)
Bottom Layer	10~12	2.6
Middle-level Layer	7 ~ 9	2.6
Cover Coat	7 ~ 8	1.2

Table 6.6 The Reference List of the Mix Proportions of Various Surface Mortar

Materials	Mix Proportion(Volume Ratio)	Application
Lime : Sand	1 : 2~1 : 4	The surfaces of brick walls (except cornice, plinth, parapet, and walls of wet rooms)
Lime : Clay : Sand	1 : 1 : 4~1 : 1 : 8	The surfaces of walls in dry environment
Lime : Gypsum : Sand	1 : 0.4 : 2~1 : 1 : 3	Walls and ceilings of dry rooms
Lime : Gypsum : Sand	1 : 0.6 : 2~1 : 1.5 : 3	Walls and ceilings of dry rooms
Lime : Gypsum : Sand	1 : 2 : 2~1 : 2 : 4	Architraves and other decorative projects of dry rooms
Lime : Cement : Sand	1 : 0.5 : 4.5~1 : 1 : 5	Cornices, plinths, parapets, and wet parts
Cement : Sand	1 : 3~1 : 2.5	Dados, plinths or ground bases of bathrooms and wet workshops
Cement : Sand	1 : 2~1 : 1.5	Floors, canopies, or the surfaces of walls
Cement : Sand	1 : 0.5~1 : 1	Press polish for concrete floors
Cement : Gypsum : Sand : Sawdust	1 : 1 : 3 : 5	Sound absorption paint
Cement : White Pebble	1 : 2~1 : 1	Terrazzo concrete (1 : 2.5 cement mortar used for priming)
Cement : Dolomitic lime : White Pebbel	1 : (0.5~1) : (1.5~2)	Granitic plaster(1 : 0.5 : 3.5 for priming)
Cement : White Peddle	1 : 1.5	Chopped stone [1 : (2~2.5) cement mortar for priming]
White lime : Hemp cut	100 : 2.5 (Mass Ratio)	Bottom layer of batten canopy
White lime paste : Hemp cut	100 : 1.3 (Mass Ratio)	Cover coat of batten canopy(or 100 kg lime paste mixed with 3.8 kg paper strips)
Paper Strip : White lime mortar	Emplaster of 0.1cm^3, paper strip of 0.36kg	Advanced walls and canopies

2. Waterproof Mortar

The mortar used to make waterproof layer is called waterproof mortar, or rigid waterproof layer. This kind of layer is only used for concrete or brick and stone masonry that has certain stiffness but does not suffer from vibrating. Rigid waterproof layer is inappropriately used in the buildings that deform greatly or may sink unevenly.

Waterproof mortar can be made by ordinary cement mortar. Or, water-repellent admixture can be added to cement mortar to improve the impermeability of mortar.

The commonly used water-repellent admixtures include chloride metallic salt water-repellent admixture, sodium silicate water-repellent agent, and metallic soap water-repellent admixture. Chloride metallic salt water-repellent admixture is the colored liquid mixed with calcium chloride, aluminum chloride, and water in a certain ratio. And its mix proportion is: aluminum chloride : calcium chloride : water= 1 : 10 : 11. The mixing amount is 3%~5% of the cement mass. If this water-repellent agent is mixed in cement mortar, it can generate impermeable double salt in the process of setting and hardening to densify structures and improve the impermeability of mortar, generally used for pools or other underground buildings.

Sodium silicate water-repellent agent mainly contains sodium silicate to which four alums are often added, thus also known as quadric-alum water-glass water-repellent agent. The four alums are blue copperas (sodium sulfate), alums (potash alum), hemalum (chromic alum), and dichromate (potassium dichromate). Take one-share sample separately from each of the four alums to make them dissolve in 60-share water of 100℃, then cool them down to 50℃, put them into 400-share water-glass and fully stir them. Such water-repellent agent can generate many colloid that will jam capillary tubes and pores, thus to improve the waterproof property of mortar. Potassium dichromate is highly toxic, so it should be used very carefully.

Metal soap waterproof agent is made by mixing stearic acid, ammonia, potassium hydroxide (or sodium carbonate) and water together in a certain ratio and then heating and saponifying them. This kind of waterproof agent also can fill pores and jam capillary tubes. The mixing quantity should be about 3% of the cement mass.

The mix proportion of waterproof mortar is usually: cement: sand= 1 : (2~3), and water-cement ratio is often controlled between 0.5~0.55. The appropriate cement is the ordinary Portland cement of 32.5 strength grade above, and the proper sand is medium sand.

The construction of waterproof mortar requires high techniques. To prepare waterproof mortar, first mix cement and sand fully, add measured waterproof agent to mixing water and cement as well as sand, and fully stir them. When plaster it, the thickness of each layer should be about 5mm. There are totally 4~5 layers about 20~30mm. First plaster a pure cement paste on wet and clean bottom and then plaster waterproof mortar about 5mm. Use a wooden float to press it for one time before initial setting. The techniques used in the second, third, and forth layers are the same. Press polish is conducted on the last layer. Curing should be strengthened after plastering. In short, the density of the mortar and the construction techniques should be required strictly in plastering the rigid waterproof layer; otherwise, it is difficult to reach the desired waterproof effect.

3. Decorative Mortar

The mortar plastered on the surface of interior and exterior walls of constructions to increase their aesthetic effects is called decorative mortar. The main difference between the decorative mortar and the plastering mortar lies on the surface layer. The colorful cementing materials and dyes should be used in surface layer and they can make the surface reveal various colorful lines and patterns through special processing methods.

The cementing materials used in decorative mortar include ordinary cement, fly ash cement, pozzolana cement, white cement and colorful cement, or the colorful cement, lime, and gypsum made by mixing alkali-resistant mineral dyes into the commonly-used cement. The dyes are often marbles, granites and other kinds of colorful rock ballasts, glass, and ceramic particles.

The processing methods of the decorative mortar include:

Scuffing: use the cement mortar as the bottom layer and the cement lime mortar as the surface layer; before the mortar coagulates, scuff the surface into rugged shapes with a spatula.

Granitic plaster: use the mortar confected by the rock ballasts of about 5mm as the bottom layer; then spray water to the surface before the initial setting of the cement to make the ballasts show out but not fall off, looked like granite in distance.

Terrazzo: use the common cement, white cement or colorful cement and various colorful marble ballasts as the surface layer, and scrape and polish the surface after they get hardened. There is pre-cast terrazzo and present-cast terrazzo. It is aesthetic and also water-proof and wear-resistant, used for flooring and decoration, such as dado, baseboard, sill board, partition board, pool and sink.

Pebble dash: bond colorful ballasts and glass particles below 5mm on the whole surface of the cement plaster. It can be bonded manually or mechanically. The bonding should be firm. The decorative effect of pebble dash is the same with that of terrazzo. It avoids wet work and also can be built efficiently and save materials.

Artificial stone: also called chopped false stone, is a kind of false stone facing. Its raw materials and processing methods are the same with those of terrazzo. Chop the surface with the edge of axe after the cement mortar hardens. It has the same effect as the coarse granite.

6.4.2 Special Mortar

1. Insulating Mortar

Insulating mortar is made by mixing cement, lime, gypsum and other cementing materials with expanded perlite sand, expanded vermiculite, or ceramic particles and other lightweight porous materials together in a certain mix proportion. The insulating mortar is lightweight and has good thermal insulation. Its thermal conductivity is 0.07~0.10W/ (m • K). It can be used for the insulating layers of roofs and pipelines, insulating walls, and others.

The common insulating mortars include:

(1) Modified Lime Insulating Mortar (simply called CL insulating mortar)

The modified lime insulating mortar (simply called CL insulating mortar) is the dry material of the insulating mortar made by: calcining calcium sulfate dihydrate and anhydrous calcium sulfate at a high temperature (more than 1180 ℃), mixing the resultants type Ⅰ—$CaSO_4$,CaO and $\beta CaSO_4 \cdot 1/2 H_2O$—with admixtures into cementing materials, adding the lightweight sand with the density no less than 180 kg/m^3 (the lightweight sand made by the high temperature puffing of obsidian) and polyphenylene particles, and precasting them all.

The high-temperature calcined modified anhydrite should be taken as the base for the cementing materials of the insulating material, and the semi-hydrated gypsum is forbidden.

The added insulating material should not be broken in the plastering process. The loose density of the lightweight sand should be within 180~250kg, and the particle size of polyphenylene particles should be no more than 3mm.

The technical indexes of the modified insulating mortar should accord with *Technical Specification for Application of the Insulating Mortar* [DB13/T(J)25-2000], the local standard of Hebei province: the thermal conductivity ≤0.07W/(m•K); the compressive strength ≥ 0.6MPa; the bending strength ≥0.4MPa; the loose density is 480kg/m^3 and the density after plastering is 600 kg/m^3; the bond strength ≥0.4MPa; the initial time ≥60min and the final time ≥24h.

The preparation of the modified lime insulating mortar: the insulating mortar (dry material) should be confected into slurry manually on the plastering floor indoor or by the portable mixer in half of a barrel; the consistency (used for walls and roofs) is: dry material of mortar ∶ water = 1 ∶ 1; the consistency can also be controlled according to the real needs, with the thickness of 20~50mm; if the slurry is used for walls or roofs, it should be confected into semi-hard mortar, and its thickness is calculated in thermal unit.

The modified insulating mortar can be used for the thermal insulation of solid sintered bricks, porous sintered bricks, hollow ceramic blocks, hollow furnace-slag blocks, aerated concrete blocks, concrete and other masonries.

(2) ZNJ-I Silicate Insulating Material

ZNJ-I silicate insulating material is a kind of powder made by mixing aluminum silicate fibers, expanded perlite powder and other kinds of good insulating materials. It is non-toxic, pollution-free, light, insulating, deafening, flame retardant, and fire-proof. It has high strength, quick setting, no cracks, no hollow beds, convenience and durableness. The compressive strength is 5~8 times than that of the traditional materials.

The technical indexes of ZNJ- I silicate insulating material are: dry density ≤230kg/m^3; thermal conductivity ≤0.058W/(m•K); volume shrinkage ≤20%; bonding strength ≥50kPa.

The process features of ZNJ- I silicate insulating material are: paint a layer of interfacial agent on the concrete wall and scuff it; add appropriate amount of water into the dry powder and stir them into slurry; when the slurry has a certain strength and moisture at the first time, repeat the above movements for the second time. It is required that the product should be scraped smoothly and pressed solidly; there should be no hollow beds; the material should be mixed when used; it will become the waste material for over 3h, and no new material is allowed to mix into the waste one; and outside decoration process should be done until it becomes dry, with the temperature ≥3℃.

ZNJ- I silicate insulating material can be used for the thermal insulation of residential buildings, office buildings, and public constructions. It should be packed in the woven bag with plastic bag inside. In transport, it should be protected from moisture and water; in storage, it should be put in dry place to avoid moisture and insolation.

(3) ZNR-III Silicone Insulating Material

ZNR-III Silicone Insulating Material is a kind of powder made by lignocellulose, organic coagulant, compound perlite, heat insulation powder and other insulating materials. When used, it should be stirred with water. It can be a good insulating layer when painted on walls, proper for the thermal insulation. Its other features are almost the same with those of ZNJ- I silicate insulating material.

2. Sound-absorbing Mortar

Similar with the insulating mortar, sound-absorbing mortar is consisted of lightweight porous aggregates. It has good sound absorption. The sound-absorbing mortar can be made by mixing cement, gypsum, sand, and sawdust (whose volume rate is 6 : 1 : 3 : 5) together, or adding glass fibers, mineral wools into lime and gypsum mortar. This mortar can be used for the sound absorption of inner walls and roofs.

3. Corrosion-resistant Mortar

Corrosion-resistant mortar is made by water glass (sodium silicate) and sodium fluosilicate. And sometimes, quartzite, granite, cast stone, and other kinds of fine aggregates can be added into it. The hardened water glass has good corrosion resistance. This mortar can be used for lining materials, corrosion-resistant floors, and the protective layers inside the corrosion-resistant containers.

4. Polymer Mortar

The polymer mortar is made by adding organic polymer emulsion into the cement mortar. The common polymer emulsions include styrene butadiene rubber emulsion, chloroprene rubber emulsion and acrylic resin emulsion. The polymer mortar has high bonding power, little shrinkage, low brittleness, good corrosion resistance, used for repair and protection engineering.

5. Radiation-proof Mortar

Radiation-proof mortar is made by mixing barite powder and barite sand into cement mortar. Its mix proportion is: cement : barite powder : barite sand = 1 : 0.25 : (4~5). It can resist X-ray. If borax and boric acid are mixed into the cement mortar, it will be the radiation-proof mortar which is often used in the radiation protective engineering.

Questions

6.1 Briefly describe the application and classification of mortar in projects.

6.2 What's the difference between the composition of mortar and that of concrete?

6.3 How to select cement when preparing mortar?

6.4 What's the requirement for the sand used in masonry mortar? Why should the mud content in sand be controlled?

6.5 What's the regulation about mixtures in *Specification for Mix Proportion Design of Masonry Mortar* (JGJ98-2000), the building industry standard?

6.6 What kinds of contents does the workability of mortar include? And how to express them?

6.7 Why should mortar have water retention? How to improve the water retention of mortar?

6.8 What are the types of surface mortar based on the functions?

6.9 What are the requirements for ordinary surface mortar?

6.10 What are the requirements for the techniques of waterproof mortar?

6.11 What are the types of decorative mortar?

6.12 What are the types of thermal mortar?

Exercises

The cement lime mortar used for brick walls is prepared on a building site. The required design strength is M7.5, required consistency is 70~90mm, and the construction level is normal. The main parameters of raw materials are: cement: the ordinary Portland cement of 42.5; sand: medium sand with bulk density of 1450kg/m^3 and water content of 2%; lime paste: consistency of 110mm. Try to calculate the mix proportion.

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7

Wall and Roof Materials

This chapter mainly reveals three kinds of masonry wall materials: wall bricks, wall blocks, and plywood. It introduces various tiles and plates used for roofs. It focuses on the major technical requirements of the fired common bricks. It is required to master the varieties of all the materials, their technical requirements, and applications.

In constructions, walls function as load bearing, enclosure protection, and partition; and roofs are the protective structure on the top layer, weather-proof and heat-insulating. The reasonable selection of materials is very important for function, safety and cost of buildings.

At present, many materials can be used as wall materials, including wall bricks, blocks, and plywood, the three major varieties. The roof materials include various kinds of tiles, plates, coiled materials, and coating. This chapter mainly introduces various tiles and plates.

7.1 Wall Bricks

According to different manufacturing techniques, wall bricks include fired bricks and non-fired bricks. Fired bricks are fired common bricks, fired porous bricks, fired hollow bricks and hollow blocks (simply called hollow bricks); and non-fired bricks are autoclaved lime-sand bricks, fly ash bricks, slag bricks, and carbonated lime bricks.

7.1.1 Fired Bricks

A fired brick is made by preheating, roasting, insulating and cooling a raw brick in a kiln.

1. Fired Common Bricks

A fired common brick is a common solid brick made by roasting clay, shale, coal gangue or fly ash. The fired common brick is rectangular, and its standard dimension is 240mm×115mm×53mm. If the thickness of masonry mortar joint (10mm) is added, all the length of four bricks, the breadth of eight bricks, and the thickness of sixteen bricks are just 1m respectively. Then, the theoretical brick numbers needed by one cube meter are 512, show in Figure 7.1. Based on different raw materials, the fired bricks include fired clay bricks (symbol is N), fired shale bricks (Y), fired coal gangue bricks (M) and fired fly ash bricks (F).

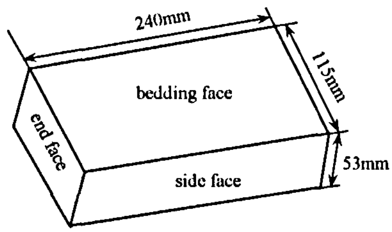


Figure 7.1 Dimensions and Face Names of Brick

(1) The Roast Theory of Fired Common Bricks

The fired common brick is made by material proportioning, mixing, homogenizing, forming, drying, preheating, and roasting the above mentioned materials with a little amount of admixtures.

The fired clay brick is made of arenaceous clay whose mineral component is kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), and the clay contains a little amount of Fe_2O_3 and CaO, besides Al_2O_3 and SiO_2. When the clay is stirred into slurry, it has good plasticity and can be shaped into various products. Shrinkage, sintering, and fusing will happen during roasting. In the initial roasting period, there is free water evaporating from clay and the body becomes dry; when the temperature reaches 450~850 ℃, the organic impurities in clay will burn off, crystal water will emerge from minerals and gradually disassemble, and the body will become porous and low-strength; when the temperature rises to 1000℃, the minerals disassemble and new molten mineral appears which will wrap the un-molten particles and fill the voids between particles to bond them together, so the voidage of the brick body decreases, the volume shrinks, the strength increases, which is called sintering; the sintered product has good strength and water-resistance, so the sintering temperature for fired clay bricks should be controlled at 950~1050℃ that is the sintering state. If the temperature continues rising, the body will get soft or even molten.

Roasting is the key process for brick making. When a brick is roasted, the duration of heating should be proper and even to avoid place brick or crozzle. The place brick is light-colored and has broken bread crumb (black or white), hoarse knocking noise, big voidage, low strength, and poor durability. Thus, the national standards regulate that the place bricks are unqualified product. The crozzle is dark-colored and has crisp knocking noise, high density, high strength and good durability but easy to deform, called deformed brick (also crisp brick or screw brick). The deformed brick is also unqualified.

When a brick is fired, the oxygen in kiln should be sufficient so that the brick can be roasted in an oxidized environment, and the iron element in clay can be oxidized into high valent iron oxide Fe_2O_3 and then it becomes a red brick. If there lacks oxygen in kiln during the last stage of roasting, the combustion atmosphere in kiln turns into the reducing atmosphere and the high valent Fe_2O_3 will be reduced into grey low valent iron oxide and then it becomes a grey brick. The grey brick is more solid and durable than the red brick, but more expensive.

The fired shale brick is made by grinding, proportioning, blank-forming, drying and roasting the shale. Because the fineness of shale is not as good as that of clay, less water is needed in material proportioning. The green brick becomes dry quickly and its shrinkage is little. The color of the finished brick is similar with that of the fired clay brick, and it can replace the fired clay brick in constructions.

The fired coal gangue brick is made by grinding, proportioning, blank-forming, drying and roasting the coal gangue rejected from the coal mine. No more coal is needed in roasting. It is a kind of internal burned brick.

The fired fly ash brick uses the fly ash and some clay as the raw materials. The fly ash is the slag of coal powder exhausted from thermal power plant. Because of its bad plasticity, some clay should be added into the fly ash when bricks are formed. The processing technique of this kind of bricks is the same with that of fired clay bricks, belonging to semi-internal-burned bricks.

Shale is a sort of local material. Coal gangue and fly ash are industrial wastes and combustible materials, and they are burning inside the brick in roasting, which can save fuel and make the brick body burn evenly, thus improving the brick quality. The fired coal gangue brick and fired fly ash brick can replace the fired clay brick in constructions.

(2) Technical Requirements for Fired Common Bricks

According to the *Fired Common Bricks* (GB/T5101-2003), the technical requirements include size deviation, appearance quality, strength grade, weathering resistance, efforescence, and lime burst. If the weathering resistance of bricks is qualified, they can be divided into excellent class(A), first class(B), qualified class(C), the three quality scale, based on the size deviation, appearance quality, efforescence, and lime burst.

1) Size Deviation.

In order to guarantee the masonry quality, the size deviation of bricks should accord with the regulation (GB5101-2003).

2) Appearance Quality.

The appearance quality of bricks include the height difference between the two side faces, bending degree, the convex height of impurities, arris defect, cracks, finished face, and others, in line with Table 7.1. In addition, the color of the excellent class should be almost the same.

Table 7.1 Appearance Quality of Fired Common Bricks(GB5101-2003)

Items	Excellent Class	First Class	Qualified Class
The height difference between the two side faces (≤) (mm)	2	3	4
The bending degree (≤) (mm)	2	3	4
The convex height (≤) (mm)	2	3	4
The three damaged dimensions of the arris defect should not be more than (mm) at the same time	5	20	30
The length of cracks (≤) (mm)			
① the length in the breadth direction on the bedding face and the length extending to the side faces	30	60	80
② the length in the length direction on the bedding face and the length extending to the end faces or the length of the horizontal crack on the side face	50	80	100
Finished face (≥)	Two side faces and two end faces	One side face and one end face	—
Color	Almost the same	—	—

Note: 1) All the decorative color difference, raised grain, scuffing, and embossing are not defects.

2) It should not be called finished face, if it has one of the following defects:

(a) the damaged dimensions of the defect on the side face or the end face are more than 10mm×10mm at the same time;

(b) the breadth and the length of the crack on the side face or the end face are more than 1mm and 30mm respectively;

(c) the concave and the convex heights of the compressed mark, adhesive backing and burnt flower on the side face or the end face are more than 2mm, and the dimensions are more than 10mm×10mm at the same time.

3) Strength Grade.

The strength grades of fired common bricks can be divided into MU30, MU25, MU20, MU15 and MU10, the five grades, in line with Table 7.2.

Table 7.2 Strength Grades of Fired Common Bricks (GB/T5101-2003)

Strength Grade	Average Compressive Strength $\overline{f}$ (MPa) (≥)	Variation Coefficient $\delta \leqslant 0.21$	Variation Coefficient $\delta > 0.21$
		Standard Strength Value f_k (MPa) (≥)	Minimum Compressive Strength of One Brick f_{min} (MPa) (≥)
MU30	30.0	22.0	25.0
MU25	25.0	18.0	22.0
MU20	20.0	14.0	16.0
MU15	15.0	10.0	12.0
MU10	10.0	6.5	7.5

The standard strength values in the above table are the basis for the strength value of bricks in the design of brick structure. They can guarantee the strength of the brick structure, defined as follows:

$$f_k = \overline{f} - 1.8s$$

$$\delta = \frac{s}{\overline{f}}$$

$$s = \sqrt{\frac{1}{9}\sum_{i=1}^{10}\left(f_i - \overline{f}\right)^2}$$

In this formula: f_k is the standard strength value (MPa), accurate to 0.1MPa;

$\overline{f}$ is the arithmetic mean of the compressive strength of 10 brick samples (MPa), accurate to 0.1MPa;

δ is the variation coefficient of strength, accurate to 0.01;

s is the standard deviation of the compressive strength of 10 brick samples (MPa), accurate to 0.01MPa;

f_i is the measured value of the compressive strength of one brick sample (MPa), accurate to 0.01MPa.

4) Weathering Resistance.

Weathering resistance is the property to resist dry and wet change, temperature change, freeze-thaw change and other kinds of climate. GB5101-2003 regulates that the antifreeze test should be conducted to the bricks in Northeast China, Inner Mongolia, Sinkiang, and other regions heavily influenced by weathering; if the 5h water absorption rate and saturation indexes of the bricks in other regions accord with the standard values, freeze-thaw test can not be conducted, or the test must be done; after the freeze-thaw test, every brick sample should not have cracks, layers, arris defects and other frozen symbols; and the weight loss should not be more than 2%.

In addition, efflorescence, and lime burst of bricks should be in line with GB5101-2003, and there should be no place bricks, crisp bricks and screw bricks in products.

The fired common brick products are coded by name, specification, variety, strength grade, quality degree and standard numbers. For example, the fired common bricks with the strength grade of MU10 which is qualified clay brick should be marked as: fired common bricks N-MU10-C-GB 5101.

(3) The Application of Fired Common Bricks

The fired common brick, a kind of traditional material, has a certain strength, durability and also good heat-insulation. They can be used to build the interior and exterior walls of buildings as well as columns, arches and chimneys. GB5101-2003 regulates: the excellent bricks can be used for dry walls and decorative walls; the first-class and qualified bricks can be used for furred walls; the medium frost bricks can not be used in humid parts.

2. Fired Porous Bricks, Hollow Bricks and Hollow Blocks

In modern constructions, the development of high-rise buildings requires producers to reduce the dead weight of fired bricks and improve their insulation and sound absorption, and thus fired porous bricks, hollow bricks and hollow blocks come into being. Compared with fired common bricks, they have a series of advantages when used: the dead weight of walls can decrease by 30%~35%; the efficiency can be improved by 40%; the cost of mortar can be saved by about 20%; the insulation and sound absorption of walls can be improved. In addition, the clay raw materials and fuels can be saved, the quality and the yield can be increased, and the cost can be reduced in production.

(1) Fired Porous Bricks

A fired porous brick is a porous brick with bedding surfaces (240mm×115mm). The size of pores is small [the round hole diameter ≤22mm; the incircle diameter of non-round hole≤15mm; the hole made by hand (30~40)mm×(75~85)mm], with the hole ratio equal to or more than 15%.

The pores are perpendicular to the load face when used. Because the strength is high, the fired porous bricks are often used in the load-bearing parts of buildings.

According to *Fired Porous Brick* (GB13544-2000), its appearance is a right-angled hexahedron, and its length, breadth, and height should be in line with the following requirements: 290mm, 240mm, 190mm, 180mm; 175mm, 140mm, 115mm; and 90mm respectively. And 190mm×190mm×90mm (Type M) and 240mm×115mm×90mm (Type P) are the two common specifications, shown in Figure 7.2. Other dimensions should be negotiated by the supply and the demand parts. The bricks whose strength and weathering resistance are qualified can be divided into three quality levels: the excellent (A), the first-class (B) and the qualified (C), according to the size deviation, appearance quality, and physical property.

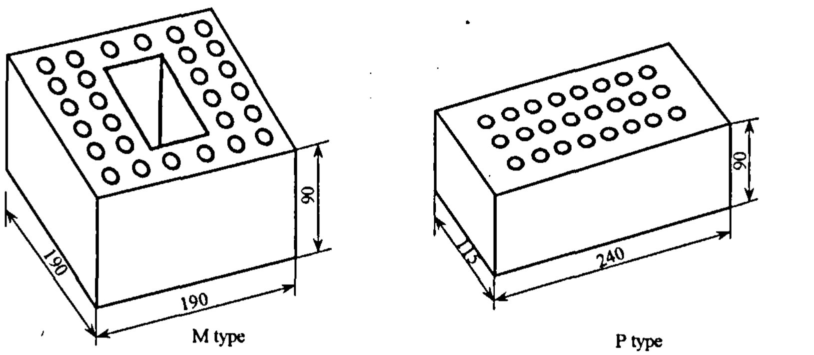


Figure 7.2 A Fired Porous Brick (Unit: mm)

1) Size Deviation.

The size deviation of porous bricks should accord with GB13544-2000 for the sake of the masonry quality.

2) Appearance Quality.

The appearance quality of porous bricks should be in line with Table 7.3.

Table 7.3 Appearance Quality of Fired Porous Bricks (GB13544-2000)

Item	Excellent Class	First Class	Qualified Class
① Color(a side face and a end face)	The same	Almost the same	—
② Finished face (≥) (mm)	A side face and a end face	A side face and a end face	

continued

Item	Excellent Class	First Class	Qualified Class
③The three damaged dimensions of the arris defect should not be more than at the same time (mm)	15	20	30
④The length of cracks (≤) (mm) (a) the length, above 15mm deep in the hole wall, in the breadth direction on the bedding face and the length extending to the side faces (b) the length, above 15mm deep in the hole wall, in the breadth direction on the bedding face and the length extending to the end faces (c) the horizontal crack on the side and the end faces	60 60 80	80 100 100	100 120 120
⑤The convex height (≤) (mm)	3	4	5

Note: 1) All the decorative color difference, raised grain, scuffing, and embossing are not defects.
2) It should not be called finished face, if it has one of the following defects:
(a) the damaged dimensions of the defect on the side face or the end face are more than 20mm, 30mm at the same time;
(b) the breadth and the length of the crack on the side face or the end face are more than 1mm and 70mm respectively;
(c) the concave and the convex heights of the compressed mark, adhesive backing and burnt flower on the side face or the end face are more than 2mm, and the dimensions are more than 20mm, 30mm at the same time.

3) Strength Grade.

The strength grades can be divided into MU30, MU25, MU20, MU15, and MU10, the five grades. The determination of the strength grades of fired porous bricks is the same with that of fired common bricks. And all the grades should be in line with Table 7.2.

In addition, the weathering resistance, efforescence and lime burst of fired porous bricks should accord with GB13544-2000. And there should be no place bricks, crisp bricks and screw bricks.

The fired porous brick products are coded by name, variety, specification, strength grade, quality degree and standard numbers. For example, the excellent fired clay bricks with the specification of 290mm×140mm×90mm and the strength grade of MU25 should be marked as: fired porous brick N 290×140×90 25A GB13544.

(2) Fired Hollow Bricks

The fired hollow bricks and hollow blocks (simply called hollow bricks) are the bricks or blocks with pores on the end faces. The pores are large and not many, with the hole ratio more than 30%. Because pores are big, the dead weight is light, and the strength is low, the bricks are usually used in the non-bearing parts.

According to *Fired Hollow Brick and Block* (GB13545-2003), the fired hollow brick and block is a right-angled hexahedron, shown in Figure 7.3. And its length, breadth and depth should be in line with the following requirements: 390mm, 290mm, 240mm, 190mm, 180 (175)mm, 140mm, 115mm, and 90mm; because the raw materials are different, there are clay brick and block (Y), coal gangue brick and block (M), and fly ash brick and block (F); the compressive strength of fired hollow brick and block has five grades: MU10.0, MU7.5, MU5.0, MU3.5, and MU2.5, and the fired bricks and blocks in each grade should be in line with Table 7.4; there are three bulk density grades: 800, 900 and 1100, in line with Table 7.5. The bricks and blocks qualified in strength, density, weathering resistance and radioactive substance can be divided into three classes: the excellent (A), the first-class (B) and the qualified (C), based on the size deviation, appearance quality (the appearance quality should be in line with Table 7.6), the arrangement and structure of pores, efflorescence and lime burst, as well as water absorption.

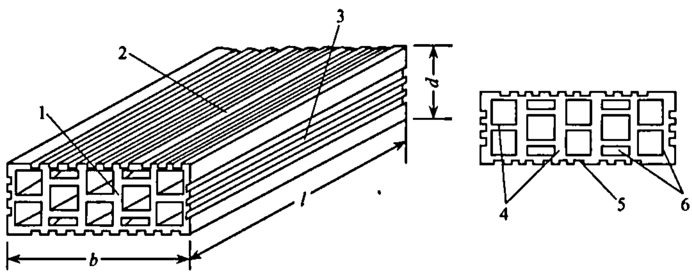


Figure 7.3 The Appearance of Fired Hollow Brick

1. end face; 2. bedding face; 3. side face; 4. rib; 5. concave groove; 6. shell; *l*. length; *b*. breadth; *d*. depth

The fired hollow brick and block products are coded by name, variety, specification, density grade, strength grade, quality degree and standard numbers. For example, the excellent shale hollow bricks with the specification of 290mm×190mm×90mm, the density grade of 800 and the strength grade of MU7.5 should be marked as: fired hollow brick Y (290×190×90) 800 MU7.5 GB13545; and the first-class clay hollow bricks and blocks with the specification of 290mm×290mm×190mm, the density grade of 1000 and the strength grade of MU3.5 should be marked as: fired hollow brick N (290×290×190) 1000 MU3.5 GB13545.

Table 7.4 Strength Grades of Fired Hollow Bricks and Blocks (GB13545-2003)

Strength Grade	Compressive strength (MPa)			Density grades (kg/m^3)
	Average Compressive Strength $\bar{f}$ (≥)	Coefficient of Variation ≤0.21 Standard strength f_k (≥)	Coefficient of Variation >0.21 Minimum strength of a brick f_{min} (≥)	
MU10.0	10.0	7.5	8.0	≤1100
MU7.5	7.5	5.0	5.8	
MU5.0	5.0	3.5	4.0	
MU3.5	3.2	2.5	2.8	
MU2.5	2.5	1.5	1.8	≤800

Table 7.5 Density Grades of Fired Hollow Bricks and Blocks (GB13545-2003) (kg/m^3)

Density grades	Density average of five bricks
800	≤800
900	801~900
1000	901~1000
1100	1001~1100

Table 7.6 The Appearance Quality of Fired Hollow Bricks and Blocks (GB13545-2003) (mm)

Items	Excellent Class	First Class	Qualified Class
①The bending degree (≤)	3	4	5
②The three damaged dimensions of the arris defect at the same time (>)	15	30	40
③ Error of perpendicularity (≤)	3	4	5
④ Un-through-wall cracks (≤)			
(a) the length in the breadth direction of the bedding face and the length extending to the side faces	Inadmissible	100	120
(b) the length in the length direction on the bedding face or the length in the horizontal direction on the side face	Inadmissible	120	140
⑤ Through-wall cracks			
(a) the length in the breadth direction of the bedding face and the length extending to the side faces	Inadmissible	40	60
(b) the length along the length direction on walls or ribs, the breadth direction and the horizontal direction	Inadmissible	40	60
⑥ The damaged length of ribs and inside walls (≤)	Inadmissible	40	60
⑦ Finished face (≥)	A side face and a bedding face	A side face or a bedding face	—

Note: It should not be called finished face, if it has one of the following defects:

1) the damaged dimensions of the defect on the bedding face and the side face are more than 20mm × 30mm at the same time;

2) the breadth and the length of the crack on the bedding face and the side face are more than 1mm and 70mm respectively;

3) the concave and the convex heights of the compressed mark, adhesive backing and burnt flower on the side face or the bedding face are more than 2mm, and the dimensions are more than 20mm×30mm at the same time.

7.1.2 Non-Fired Bricks

The bricks made not by roasting are called non-fired bricks.

1. Autoclaved Lime-sand Bricks (Lime-sand Bricks)

An autoclaved lime-sand brick is made by mixing ground quicklime or slaked lime power, natural sand and water in a certain proportion, then storing, pressure molding, autoclaving (by the saturated steam with the temperature of 175~203℃ and the pressure of 0.8~1.6 MPa) and curing them.

The dimensions of the solid lime-sand brick is the same with the fired common brick, and its apparent density is 1800~1900kg/m^3 and its thermal conductivity is about 0.61W/(m • K). According to *Autoclaved Lime-sand Brick* (GB11945-1999), the national standard: the bricks can be divided into the excellent (A), the first-class (B) and the qualified (C), based on the appearance quality, size deviation, strength and frost resistance. The compressive strength and bending strength after the bricks being immersed for 24h include MU25, MU20, MU15, and MU10, the four grades. The strength grade of excellent bricks should not be less than MU15. And the compressive strength, bending strength and frost resistance of bricks in every grade should be in line with Table 7.7.

Table 7.7 Strength and Frost Resistance Indexes of Autoclaved Lime-sand Bricks (GB11945-1999)

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)		Frost Resistance	
	Average (≥)	Single one (≥)	Average (≥)	Single one (≥)	Compressive strength after frost (MPa) Average (≥)	Dry weight loss of a brick (%) (≤)
MU25	25.0	20.0	5.0	4.0	20.0	2.0
MU20	20.0	16.0	4.0	3.2	16.0	2.0
MU15	15.0	12.0	3.3	2.6	12.0	2.0
MU10	10.0	8.0	2.5	2.0	8.0	2.0

Lime-sand bricks have colors (Co) and natural color (N). Lime-sand bricks are coded by name (LSB), color, strength grade, and standard number. For example, the excellent colorful lime-sand bricks with strength grade of MU20 can be marked as: LSB Co 20A GB11945.

Some of the components in a lime-sand brick (such as calcium silicate hydrate, calcium hydroxide, and calcium carbonate) cannot resist acid and heat, and if they are heated for a long time, those components will resolve, dehydrate and even lead to the crystal transfer of quartz, so lime-sand bricks should not be used in the building parts that are often staying in the heat above 200℃, or influenced by the nasty cold and nasty hot alternation, or corroded by acid substance. In addition, the calcium hydroxide and others in lime-sand bricks can be washed out by running water, so the bricks cannot be used in the places that are often washed by flowing water. Lime-sand bricks should be stored for about a month after being taken out from autoclaves. The water content of lime-sand bricks will affect the bonding power between sand and mortar. Thus, the water content should be controlled at 7%~12%. Mixed mortar is the best choice.

2. Autoclaved Fly Ash Bricks (Fly Ash Bricks)

An autoclaved fly ash brick is a solid brick made by mixing appropriate amount of gypsum and aggregates into fly ash and lime, the raw materials, and then blank producing, pressure forming, and normal or high pressure autoclaving or conserving them.

The autoclaved fly ash brick is charcoal grey and its apparent density is 1500 kg/m^3. The autoclaved fly ash brick has the same dimensions with the fired common brick. According to *Fly Ash Brick* (JC239-2001), the national standard: the bricks can be divided into the excellent (A), the first-class (B) and the qualified (C), based on the appearance quality, size deviation, strength, frost resistance and dry shrinkage. The compressive strength and bending strength include MU20, MU15, MU10, and MU7.5, the four grades. The strength grade of the excellent brick should not be less than MU10, and its dry shrinkage should not more than 0.60mm/m; the strength grade of the first-class brick should not be less than MU10, and its dry shrinkage should not more than 0.75mm/m; and the dry shrinkage of the qualified brick should be no more than 0.85mm/m. And the compressive strength, bending strength and frost resistance of bricks in every grade should be in line with Table 7.8.

Table 7.8 Strength and Frost Resistance Indexes of Fly Ash Bricks

Strength Grades	Compressive Strength (MPa)		Bending Strength (MPa)		Frost Resistance	
	Average of 10 bricks (≥)	Single one (≥)	Average of 10 bricks (≥)	Single one (≥)	Compressive strength (MPa) Average (≥)	Dry weight loss of a brick (%) (≤)
MU20	25.0	15.0	4.0	3.0	16.0	2.0
MU15	20.0	11.0	3.2	2.4	12.0	2.0
MU10	15.0	7.5	2.5	1.9	8.0	2.0
MU7.5	10.0	5.6	2.0	1.5	6.0	2.0

Fly ash bricks can be used in walls and bases of industrial and civil buildings. But if they are used in bases or the parts easily influenced by freeze-thaw or dry-wet alternation, the bricks should be the first class and the excellent class. Fly ash bricks should not be used in the building parts that are often staying in the heat above 200℃, or influenced by the nasty cold and nasty hot alternation, or corroded by acid substance. The buildings built by fly ash bricks should be added with ring beams and expansion joints to reduce or avoid contraction cracks. Fly ash bricks should be stored for about one week after being taken out from autoclaves. When used in masonry, they can be wetted by water until the water content exceeds 10% or just dry. Masonry mortar can be the mixed mortar with appropriate amount of fly ash.

3. Slag Bricks

The slag brick, also called cinder brick, is a solid brick made by mixing cinder, lime, gypsum (or carbide slag and fly ash) and water evenly, and then storing, rolling, forming, autoclaved curing them.

The slag brick is black grey, its apparent density is 1500~2000 kg/m^3 and its water absorption ratio is 6%~19%. The slag brick has the same dimensions with the fired common brick. According to *Fly Ash Brick* (JC525-1993), the industrial standard, the bricks are divided into the excellent class(A), the first class(B), the qualified class(C), based on appearance quality, size deviation, and strength grades. The compressive strength and the bending strength of slag bricks include MU20, MU15, MU10, the three grades. And all the strength indexes of bricks should be in line with Table 7.9.

The slag bricks can be used in the inner walls and non-bearing outer walls of the normal buildings. The other using points are similar with those of lime-sand bricks and fly ash bricks.

Table 7.9 Strength Indexes of Slag Bricks

Strength Grade	Compressive Strength (MPa)		Bending Strength (MPa)	
	Average of a group of sample bricks (≥)	Minimum value of a brick (≥)	Average of a group of sample bricks (≥)	Minimum value of a brick (≥)
MU20	20	15	9.1	2.0
MU15	15	11	2.3	1.3
MU10	10	7.5	1.8	1.1

Note:1) Every group of sample bricks contain 5 bricks; and there should not be more than 2 of the 5 bricks that are lower than their own strength grade average.

2) If it is suspected that the samples are not representative, re-test can be conducted once. But the new samples should double the old ones, like 10 bricks. And there should not be more than 5 of the 10 bricks that are lower than their own strength grade average.

7.2 Wall Blocks

Blocks are the artificial materials used for masonry, bigger than wall bricks. And they are often the right-angled hexahedron. Based on the dimensions, blocks can be divided into large-sized blocks (higher than 980mm), middle-sized blocks (380~980mm high) and small-sized blocks (higher than 115mm and lower than 380mm). The height of a block is usually not more than its length or 6 times of its breadth, and the length is no more than 3 times of its breadth. There will be blocks in various shapes to meet the actual demands.

Blocks are a kind of new wall material that can make full use of the local materials and industrial wastes, save clay resource and improve the environment. Their production process is simple, their raw materials are rich, they are practical and easy to be used, and also they can improve the function of walls, so blocks develop very fast.

There are various classification methods for blocks: by purposes, there are load-bearing blocks and non-load-bearing blocks; by pores, there are solid blocks (with no pores or voidage less than 25%) and hollow blocks (voidage $\geqslant$ 25%); by materials, there are silicate blocks, light-weight aggregate concrete blocks, aerated concrete blocks, and concrete blocks. This chapter mainly introduces several common blocks.

7.2.1 Autoclaved Aerated Concrete Blocks

Autoclaved aerated concrete blocks are the lightweight block materials made by proportioning calcareous materials (cement and lime), siliceous materials (sand, slag and fly ash) and air entraining admixture (aluminum powder), and then mixing, casting, gas-developing, cutting and autoclaving them.

1. Specifications of Blocks

There are A and B, the two series of blocks, and their nominal sizes are shown in Table 7.10.

Table 7.10 Specifications of Autoclaved Aerated Concrete Blocks
(GB/T11968-1997)

Item	Series A	Series B
Length L (mm)	600	600
Height H (mm)	200, 250, 300	200, 250, 300
Breadth B (mm)	100, 125, 150, 200, 250, 300	120, 180, 240

Note: The manufacture size: length= $L-10$; breath=B; and height= $H-10$

2. Indexes of Main Technical Properties of Autoclaved Aerated Concrete Blocks

According to *Autoclaved Aerated Concrete Block* (GB/T11968-1997), the blocks can be divided into the excellent (A), the first-class (B) and the qualified (C), the three grades, based on appearance quality, size deviation, bulk density, and compressive strength. The compressive strength includes A1.0, A2.0, A2.5, A3.5, A5.0, A7.5, and A10, the seven grades. The apparent density includes B03, B04, B05, B06, B07, and B08, the six grades, shown in Table 7.11. Table 7.12 shows the indexes of strength grades, dry shrinkage and frost resistance of the autoclaved aerated concrete blocks.

Table 7.11 Bulk Density of Autoclaved Aerated Concrete Blocks

Apparent Density Grade		03	04	05	06	07	08
Bulk Density (kg/m³)	Excellent (A) (≤)	300	400	500	600	700	800
	First-class (B) (≤)	330	430	530	630	730	830
	Qualified (C) (≤)	350	450	550	650	750	850

Table 7.12 Indexes of Strength Grades, Dry Shrinkage and Frost Resistance of the Autoclaved Aerated Concrete Blocks

Strength Grade		A1.0	A2.0	A2.5	A3.5	A5.0	A7.5	A10.0
Compressive Strength of Cube[1] (MPa)	Average	≥1.0	≥2.0	≥2.5	≥3.5	≥5.0	≥7.5	≥10.0
	Minimum Value	≥0.8	≥1.6	≥2.0	≥2.8	≥4.0	≥6.0	≥8.0
Apparent Density Grade		B03	B04	B05	B06	B07	B08	
Dry Shrinkage	Standard Method[2] (≤)	mm/m	0.50					
	Rapid Method (≤)		0.80					
Frost Resistance	Weight loss (%) (≤)	5.0						
	Strength after frost MPa (≥)	0.8	1.6	2.0	2.8	4.0	6.0	
Thermal Conductivity (exclude)[W/(m•K)] (≤)		0.10	0.12	0.14	0.16			

1) The compressive strength of cube is the compressive strength measured by 100mm×100mm×100mm cube with water content of 25%~45%.

2) It is used for special requirements.

Autoclaved aerated concrete block products are coded by name (code name ACB), strength grade, bulk density grade, specification, product class, and standard number. For example, the excellent autoclaved aerated concrete blocks with strength grade of A3.5, bulk density of B05, and specifications of 600mm×200mm×250mm can be marked as: ACB A35 B05 600×200×250A GB1968.

7.2.2 Fly Ash Block

Fly ash blocks are the dense blocks made by mixing fly ash, lime, gypsum, and aggregates (slag) with water, and then vibrating, shaping, and autoclaving them. The major specifications are 880mm×380mm×240mm and 880mm×420mm×240mm, the two kinds.

1. Major Technical Indexes of Fly Ash Blocks

According to Fly Ash Block (JC238-91), the strength grades of blocks include MU10 and MU 13, based on the compressive strength of their cube specimens; there are first class (B) and qualified class (C) by appearance quality, size deviation, and dry shrinkage. The compressive strength, the strength after carbonization, frost resistance and density of the cube fly ash blocks should accord with Table 7.13. The dry shrinkage of fly ash blocks should be in line with Table 7.14.

Table 7.13 Compressive Strength, Strength after Carbonization, Frost Resistance and Density of Cube Fly Ash blocks

Item	Index	
	MU10	MU13
Compressive Strength (MPa)	The average of 3 blocks is no less than 10.0; and the minimum value of a block is 8.0	The average of 3 blocks is no less than 13.0; and the minimum value of a block is 10.5
Strength after Carbonization (MPa)	No less than 6.0	No less than 7.5
Frost Resistance	When the freeze-thaw cycle ends, there is no apparently loose and spalling signs, or cracks, and the strength loss is no more than 20%	
Density (kg/m^3)	No more than 10% of designed density	

Table 7.14 Dry Shrinkage Values of Blocks (mm/m)

First Class (B)	Qualified Class (C)
≤0.75	≤0.90

2. Application of Fly Ash Blocks

The autoclaved fly ash blocks are silicate products whose dry shrinkage is higher than cement concrete and elastic modulus lower than the cement concrete with the same strength grade. The fly ash blocks with slag as the aggregate has the apparent density of 1300~1550 kg/m^3, and thermal conductivity of 0.465~0.582W/ (m • K). The blocks can be used in walls and foundations of normal industrial and civil buildings but not in load-bearing walls that stay in high temperature for a long time (such as steelmaking workshop) and in moisture environment or the parts corroded by acid substance.

7.2.3 Small-sized Concrete Hollow Blocks

They are the hollow blocks made by mixing, forming, and conserving common concrete mixtures. There are load-bearing blocks and non-load-bearing blocks. In order to reduce the dead weight, non-load-bearing blocks can be made by slag or other lightweight aggregates. There are excellent class (A), first class (B) and qualified class (C), based on the appearance quality. The shapes of common concrete blocks are shown in Figure 7.4.

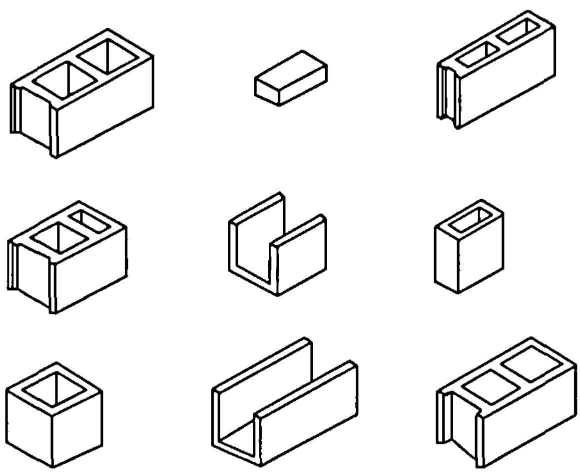


Figure 7.4 Shapes of Several Concrete Hollow Blocks

1. Indexes of Major Technical Properties

The specification of small-sized concrete hollow blocks: the major one is 390mm×190mm×190mm, and the other ones should be negotiated by the supply and the demand. The compressive strength of blocks is obtained by the gross area of the compressed face dividing broken loads. *Small-sized Concrete*

Hollow Block (GB8239-97) regulates that the compressive strength can be divided into MU3.5~MU20.0, the six grades, shown in Table 7.15.

Table 7.15 Compressive Strength of Blocks

Strength Grades	Compressive Strength (MPa) (≥)	
	Average of 5 Blocks	Minimum Value of a Block
MU3.5	3.5	2.8
MU5.0	5.0	4.0
MU7.5	7.5	6.0
MU10.0	10.0	8.0
MU15.0	15.0	12.0
MU20.0	20.0	16.0

Note: the strength of non-load-bearing blocks should be in line with GB15229-94.

2. Applications of Small-sized Concrete Hollow Block

This kind of small-sized blocks can be used in the normal civil and industrial buildings with seismic design intensity of the eighth Richer Scale or below. For the blocks used in the load-bearing and outer walls, their dry shrinkage should be less than 0.5mm/m; and for the blocks used in non-load-bearing and inner walls, their dry shrinkage should be less than 0.6mm/m. The impermeability of blocks should be tested according to GB4111-1997 and it has S and Q, the two grades. The blocks of Q grade can only be used in the parts without impermeability requirement. The insulation properties of blocks are different due to their raw materials and hollow ratio. The thermal conductivity of common small-sized concrete blocks with the hollow ratio of 50% is 0.26W/(m•K).

7.2.4 Middle-sized Concrete Hollow Blocks

The middle-sized concrete hollow block is the product made by mixing cement or cement without clinker with a certain amount of aggregates, with the hollow ratio ≥25%. The specification includes: length is 500mm, 600mm, 800mm and 1000mm; breadth is 200mm and 240mm; and height is 400mm, 450mm, 800mm, and 900mm. The shape of blocks is shown in Figure 7.5.

The blocks made by cement without clinkers or cement with a few clinkers are silicate products. In production, their quality should be improved by autoclaved curing or the relevant techniques. The dry shrinkage of the blocks ≤0.8mm/m; and the strength loss after 15 times freeze-thaw cycles ≤15%, and there is no apparent loose and spalling signs, or cracks; the natural carbonation coefficient (1.15×artificial carbonation coefficient)≥0.85.

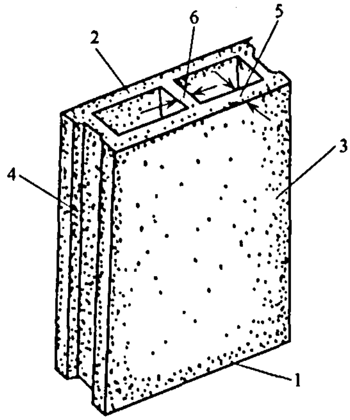


Figure 7.5 The Shape of Middle-sized Hollow Block

1. top face; 2. bedding face, 3. side face; 4. end face; 5. shell; 6. rib

The compressive strength of the middle-sized concrete hollow blocks should accord with Table 7.16.

Table 7.16 Technical Properties of Middle-sized Cement Concrete Hollow Blocks

Strength Grade	MU35	MU50	MU75	MU100	MU150
Compressive Strength(MPa) (≥)	3.5	5.0	7.5	10.0	15.0

The middle-sized blocks have small apparent density, high strength as well as simple production process, and are easy to be used, applying for walls of normal civil and industrial buildings.

7.3 Wall Plates

Various lightweight and composite wall plates and lightweight roof boards are flourishing, with the reform of architectural structure system and the development of multi-functional large-bay structures. There are many kinds of wall and roof plywood in China, recently. This chapter just introduces several representative products (for reference).

7.3.1 Cement Wall Plates

The cement wall plate has good mechanical property and durability. The production technique is mature and the products are reliable. They can be used for the external layers in bearing walls, outer walls and composite walls. The disadvantages are the large apparent density and low tensile strength (large panel is easy to damage in the lifting process). In production, the pre-stressed hollow plate can be made to reduce the dead weight and improve the sound-proof and heat-insulating properties; or the thin boards can be reinforced by fibers; and decorative effect can be made on the top layers of cement boards (to press patterns, lines, to reveal aggregates, or to color them).

1. Pre-stressed Concrete Hollow Wallboards

The pre-stressed concrete hollow wallboard is shown in Figure 7.6. In use, it can be required to add insulating layer, decorative layer and waterproof layer. The length of wallboards is 1000~1900mm; the width is 600~1200mm; and the total thickness is 200~480mm. They can be used as the load-bearing or non-load-bearing external wallboards, internal wall boards, roof boards and balcony boards.

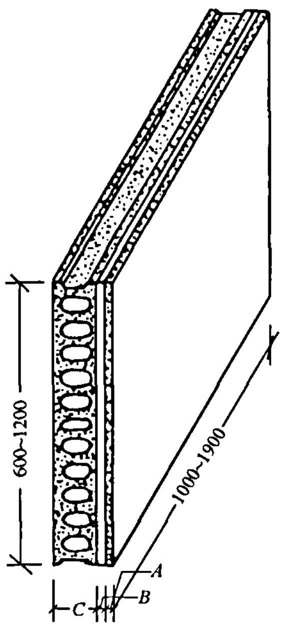


Figure 7.6 A Pre-stressed Concrete Hollow Board

A: external decorative layer; B: insulating layer; C: pre-stressed concrete hollow board

2. GRC Hollow Lightweight Wallboards

This kind of boards is made by mixing low alkali cement (the cementing material), alkali-resistant glass fiber or mesh cloth (the reinforcing material) and expanded perlite (or slag or fly ash) with foaming agent and waterproof agent, and then stirring, casting, vibrating, forming, dehydrating, and conserving them. The length is 3000mm, the breadth is 600mm, and the thickness is 60mm, 90mm and 120mm.

GRC hollow lightweight wallboard has: light weight (the board of 60mm thick, 35kg/m^2), high strength (bending load of the board of 60mm thick is over 1400N; that of the board of 120mm thick is over 2500N), good insulation [thermal conductivity $\leqslant$0.2W /(m•K)], soundproof property [soundproof index >(30~45)dB], non-combustibility (the fire-resistant limit is 1.3~3h), and convenient processing. They can be used in the inner partitions and the outer layers of composite walls of civil and industrial buildings.

3. Fiber-reinforced Cement Board (TK Board)

The board is a kind of thin board made by mixing low alkali cement and alkali-resistant glass fiber with water, dredging them with cylinder mould, and then forming, pressing, and conserving them. The length is 1200~3000mm, the width is 800~900mm, and the thickness is 4mm, 5mm, 6mm or 8mm.

The apparent density of TK boards is about 1750kg/m^3, their bending strength reaches 15MPa, and impact-resistant strength $\geqslant$0.25J/cm^2. The boards have light weight, high strength, moisture-proof and fire-proof properties, and are difficult to deform and easy to be processed (such as sawing, drilling, nailing, and surface decoration). They can be used in the composite outer walls and inner partitions of various buildings, especially the moisture-proof and fire-proof walls of high-rise buildings.

4. Cement Wood Boards

The board is a kind of building thin board made by slicing wood trash into uniform wood wool by machines, mixing them with cement and water glass, shaping, cold pressing, curing, and drying them. They have light dead weight, high strength, good fireproof, waterproof, mothproof, insulating, and soundproof properties, and are easy to be processed (like sawing, drilling, nailing, and decoration). They are mainly used as inner and outer wall boards, ceiling boards, and cupboards.

5. Cement Particleboards

The board is made by mixing cement and wood trash—shavings—with a certain amount of water and chemical additives, and then stirring, shaping, pressing, and conserving them. The apparent density is 1000~1400 kg/m^3. The properties and application are the same with cement wood boards.

7.3.2 Gypsum Wall Boards

Gypsum products have many advantages. And they take a big proportion of lightweight wall materials, including paper gypsum fiber boards, gypsum hollow boards, and gypsum particleboards.

1. Paper Gypsum Boards

This board is made by gypsum core materials and firmly bonded protective paper, including common type, waterproof type and fireproof type. The common paper gypsum board is made by bonding building gypsum, a certain amount of reinforcing fibers and addictives (the core materials) with the protective paper of a certain strength; if waterproof and moisture-proof agents are added into the core materials and waterproof paper is used, waterproof paper gypsum boards will come into being; if inorganic fireproof fibers and flame retardant are added into the materials, the fireproof paper gypsum board can be made.

The specifications of paper gypsum boards are:

Length: 1800mm, 2100mm, 2400mm, 2700mm, 3000mm, 3300mm and 3600mm;

Width: 900mm and 1200mm;

Thickness: the common boards: 9mm, 12mm, 15mm and 18mm;
the waterproof boards: 9mm, 12mm, 15mm;
the fireproof boards:9mm, 12mm, 15mm, 18mm, 21mm and 25mm.

The quality requirements and performance indexes of paper gypsum boards should be in line with GB9775-88, GB11978-89 and GB11979-89; the waterproof indexes of the waterproof paper gypsum boards should accord with Table 7.17; the fire-stability time of the fireproof paper gypsum boards should be no less than the times in Table 7.18.

Table 7.17 The Waterproof Property of Waterproof Paper Gypsum Boards

Item		Indexes					
		Excellent		First-class		Qualified	
		Average	Max.	Average	Max.	Average	Max.
Water absorption ratio (in water for 2h) (%) (≤)		5.0	6.0	8.0	9.0	10.0	11.0
Surface water absorption (g) (≤)		1.6		2.0		2.4	
Moisture deflection (mm) (≤)	Thickness 9mm	48		52		56	
	Thickness 12mm	32		36		40	
	Thickness 15mm	16		20		24	

Note: After the board has immerged in water for 2h, the protective paper should not split from gypsum core materials.

Table 7.18 The Fire-Stability Time of Fireproof Paper Gypsum Boards (min)

Excellent	First-class	Qualified
30	25	20

The apparent density of paper gypsum boards is 800~950 kg/m^3, the thermal conductivity is about [0.20W/(m•K)], soundproof coefficient is 35~50dB, and bending load is 400~800N, the surfaces are smooth, and the dimensions are stable. The boards have light weight, good insulating, soundproof, fireproof, and anti-seismic properties, and they can adjust the room temperature, easy to be processed and used. But the consumption of paper is huge, and the cost is high.

Common paper gypsum boards can be used for the inner partitions, the inner boards of the composite outer walls, and ceiling boards. Waterproof boards can be used in the environment with high humidity (≥75%), such as washroom and bathroom. Fireproof paper gypsum boards are mainly used in the buildings with fireproof requirements.

2. Gypsum Fiber Boards

The board is the paperless gypsum board taking fiber reinforced gypsum as the base. The inorganic fibers or organic fibers are often used as the reinforcing materials which are beat with building gypsum and retardant and then are paved, dehydrated, shaped, and dried into gypsum boards. The boards have light weight, high strength, fireproof and soundproof properties, as well as high toughness, and are easy to be processed. The specifications and application are the same with paper gypsum boards.

3. Gypsum Hollow Slabs

The appearance and production mode of the slabs are the similar with those of cement concrete hollow slabs. A gypsum hollow slab is made by mixing, stirring, vibrating, and forming gypsum (the cementing material) with various lightweight aggregates (such as expanded perlite or expanded vermiculite) and modified materials (like, slag, fly ash, lime, and addictives), and then drying them after taking out the core mould. The length is 2500~3000mm, the breadth is 500~600mm, and the thickness is 60~90mm. The production of these slabs needs no paper and no glue; and when they are installed, no keel is needed, the equipment is simple, and they are easy to be put into production.

The apparent density of gypsum hollow slabs is 600~900kg/m^3, the bending strength is 2~3MPa, thermal conductivity is 0.22W/ (m•K), the soundproof index is more than 30dB, and the fireproof limit is 1~2.25h. The slabs have light weight, high strength, as well as insulating, soundproof, and fireproof properties, and they are easy to be processed and installed. The slabs can be used for the non-load-bearing inner partition walls of various buildings; but if the relative humidity of the environment is more than 75%, the waterproof treatment should be conducted to the surface of these boards.

4. Gypsum Particleboard

The boards are made by mixing gypsum (the cementing material) and wood shavings (the reinforcing material) with addictives, and then stirring, paving, and pressing them. They possess the advantages of all the above gypsum boards, used as the non-load-bearing inner partition walls and decorative boards.

7.3.3 Plant Fiber Boards

With the development of agriculture, the agricultural wastes (such as straw, wheat straw, maize stalk and bagasse) are increasing, and the environment has been polluted. If the above-mentioned wastes can be treated properly, they can be made into various boards for use. Early in 1930, Swedes used 25kg straw to produce boards instead of 250 pieces of clay bricks, which saved a great deal of fields. Over the years, more than 20 countries have built about 30 production lines of straw boards. China, as a big agricultural country, has rich resources and should develop and promote these products.

1. Straw (Wheat) Board

The main raw materials of straw boards are straw or wheat straw, paper boards, and urea-formaldehyde resin. The production is to heat-press the dry straw into solid board core, bond paper on the two faces and the four sides of the core with glue, and then curing it with heat. There is no binder in the board core. The board is solid and has stiffness because the straw entwists inside. The production is easy, and the production line is only 80~90m long. From material feeding to product, it only needs 1h. The energy consumption of the straw boards production is low, only 1/3~1/4 of paper gypsum boards.

Straw boards are light (apparent density of 310~440kg/m^3), and have good insulation [thermal conductivity $<$0.14W/(m•K)]. The soundproof volume of a single plate is 30dB. If mineral wool of 30mm and air layer of 20mm are added between the two plates, the soundproof volume can reach 50dB. The fireproof limit is 0.5h. The disadvantages are the poor water resistance and the combustibility.

Straw boards have enough strength and rigidity that can be used singly without keel. They are easy to be sawed, nailed, drilled, bonded and painted. They can be used for the non-load-bearing inner partitions, ceiling boards, roof boarding, and the inner boards of composite out walls.

2. Rice Hull Board

Rice hull boards are made by mixing, paving, and heat-pressing rice hull and synthetic resin into plates with middle density. Urea-formaldehyde and polyvinyl acetate can be used for bonding, and bakelite lacquer can be painted on and veneer overlayering can be added to the surface for decoration. They can be used as the inner partitions and various partition boards and clapboards for closets and others.

3. Bagasse Board

Bagasse boards are made by processing, mixing, paving, and hot-pressing sugarcanes into boards. In production, the substance contained in sugarcanes themselves can be transferred into furan resin by heat-pressing for bonding, or synthetic resin adhesive can also be used. The bagasse boards are lightweight, soundproof, easy to be processed (such as sawing, nailing, planning, and drilling) and ornamental. They can be used as inner partitions, ceiling boards, door panels, and decorative boards.

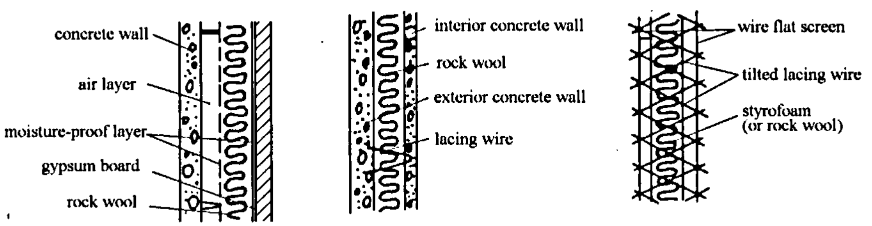
4. Hards Board

Hards boards are made by grounding flax stalks, then mixing them with synthetic resin, waterproof agent, and curing agent, and paving, heat-pressing, curing, trimming, and calendering them. The properties and application of hards boards are the same with those of bagasse boards.

7.3.4 Composite Wallboards

The use of the boards made of single material is often confined because of their own limitations. For example, the lightweight, insulating and soundproof gypsum boards, aerated concrete boards, and straw boards can usually be used in non-load-bearing partitions due to their poor water resistance and low strength. Although cement concrete boards have enough strength and durability, they also have heavy deadweight and poor soundproof and insulating properties. In order to conquer the above defects, different materials are combined into multi-functional composite walls for demand.

The common composite wallboards consist of load-bearing (or force-transferring) layer (often is common concrete or metal boards), insulating layer (such as mineral wool, foam plastic, and aerated concrete) and surface layer (various decorative lightweight boards), shown in Figure 7.7. The advantages are that all the properties of load-bearing materials and lightweight insulating materials can be reasonably and fully used to exploit resources.



(a) Assembly Composite Wall (b) Rock wool–concrete Pre-stressed Composite Wall (c) Taibai Board (or GY Board)

Figure 7.7 Several Composite Walls

1. Concrete Sandwich Panel

The reinforced concrete of 20~30mm thick is used in concrete sandwich panel as the interior and exterior surface layers and slag felt, rock wool felt, or foam concrete is added in the middle of panel for insulation. The thickness of sandwich depends on the thermal calculation. The inner and outer layers are connected by reinforced steel bars. They can be used for the interior and exterior walls.

2. Taibai Wallboard

Taibai wallboard is the core board made by welding the steel wire with diameter (φ) of 2.06mm±0.03mm and yield strength of 390~490MPa into three-dimensional steel-wire mesh skeleton, combining it with self-extinguishing polystyrene foam with high heat resistance, and then spraying (plastering) cement mortar on the two surfaces, shown in Figure 7.8.

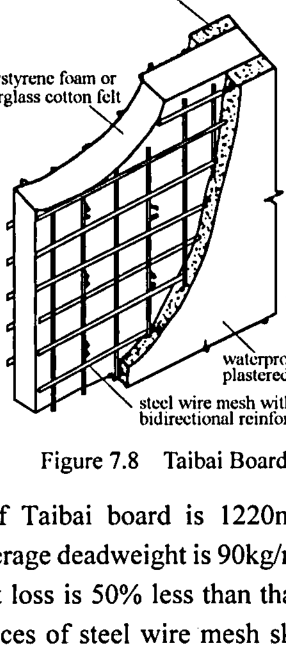


Figure 7.8 Taibai Board

The standard size of Taibai board is 1220mm×2440mm, the standard thickness is 100mm, average deadweight is 90kg/m^3, and thermal resistance is 0.64(m^2•K)/W (the heat loss is 50% less than that of brick-and-a-half wall). Because of the differences of steel wire mesh skeleton, sandwich materials and thickness, this kind of board has many names, such as GY board (the sandwich is rock wool felt), 3-dimensional board, 3D board, steel wire mesh board. They have the similar structures.

This kind of board is lightweight, high-strength, insulating, soundproof, fireproof, moisture-proof, anti-seismic, durable, and easy to be processed and used. They can be used for outer walls with heavy deadweight, inner partitions, roof boards, and floors of less than 3m stride.

3. Lightweight Sandwich Board

This board is a composite board made by using lightweight and high-strength thin plate as the outer layer and the lightweight insulating materials as the middle layer. The thin plate used as the outer layer on outer wall is stainless board, colorful galvanized steel board, aluminum alloy board, and fiber reinforced cement board. The sandwich materials include rock wool felt, glass cotton felt, flame-retardant polystyrene foam, and polyurethane foam. The outer layer on interior wall can be gypsum boards, plant fiber plates, or plastic boards. The properties of the boards are basically the same with Taibai boards.

4. ZNF-II Plastering Gypsum Polystyrene Board

ZNF-II Plastering Gypsum Polystyrene Board is made by bonding the self-extinguishing polystyrene board on the base surface of the outer wall with specific adhesive gypsum, plastering gypsum on the surface layer, and reinforcing it with middle-alkali glass fiber cloth (net diameter is 4mm×4mm or 5mm×5mm). The boards are easy to be used and can greatly save energy and create good integrity. They can be used for the insulation of various walls.

The technical indexes of self-extinguishing polystyrene boards: density is 12~16kg/m^3; thermal conductivity is 0.041W/(m•K); specification is 600mm×900mm; water absorption ratio is $\leqslant$6%; the thickness is 40mm, 50mm, 60mm or 80mm.

5. ZWD-III Polystyrene Board with Internal-large Framework

ZWD-III Polystyrene board with internal-large framework is made by installing polystyrene boards outside and linking with steel bars, erecting and casting them to integrate them together, plastering crack-resistant mortar on the surface, and pressing anti-alkali mesh cloth in it. There are the polystyrene boards with grooves and those with galvanized steel mesh on one side, the two sorts. The specification includes 1220mm×3000mm and so on. The other technical indexes are the same with those of self-extinguishing polystyrene boards. They can be used for the insulation layers inside the concrete casting outer walls.

In conclusion, the major components, properties and application ranges of common wall materials are listed in Table 7.19 for reference.

Table 7.19 Major Components, Properties, and Applications of Common Wall Materials

Varieties	Major Components	Main Properties	Applications
Fired Common Bricks (including clay bricks, fly ash bricks, shale bricks, and coal gangue bricks)	Made by sintering the clay materials	Compressive strength: 10~30MPa; apparent density: 1500~1800kg/m^3; thermal conductivity: 0.78W/(m•K); and frost resistance: 15times	Walls, bases, columns, brick arches, etc.
Fired Porous Bricks		Compressive strength: 7.5~30MPa; apparent density: 1100~1300kg/m^3; and frost resistance: 15times	Insulating load-bearing walls
Fired Hollow Bricks and Blocks		Compressive strength: 2.0~5.0MPa; apparent density: 800~1100kg/m^3; and frost resistance: 15times	Non-load-bearing walls, and insulating walls
Lime-sand Bricks	Made by autoclaving ground fine silicate sand, lime and water	Compressive strength: 10~25MPa; apparent density: 1800~1900kg/m^3; thermal conductivity: 0.6W/(m•K); the appearance is structured and white grey; they also can be made into colorful bricks; the bricks cannot resist flowing water for a long time and also acid corrosion	The application is almost the same with fired common bricks, but they cannot be used in the parts experiencing flowing water and heat above 200℃ for a long time
Autoclaved Fly Ash Bricks	Fly ash, lime, aggregates (slag, and mineral slag) and gypsum	Compressive strength: 7.5~20MPa; apparent density: 1500kg/m^3; the dry shrinkage of qualified products: ≤0.85mm/m	The same with lime-sand bricks
Aerated Concrete Blocks	The porous concrete made by gas-forming and autoclaving ground silicate materials, lime, aluminum powder and water	The compressive strength of 500(kg/m^3) grade: 2.2~3.0MPa; thermal conductivity: 0.10~0.16W/(m•K); frost resistance: 15 times; the compressive strength of 700 grade: 4.2~5.0MPa	Walls of buildings and insulation
Aerated Concrete Boards (exterior wallboards, or partitions)	Ditto, and with steel bars		Outer walls and partition walls

continued

Varieties	Major Components	Main Properties	Applications
Foam Concrete Blocks	The porous concrete made by gas-forming and autoclaving cement, foam agent and water	The common ones are 400 grade and 500 grade; the compressive strength of 500 grade is 2.0~3.0MPa; and the thermal conductivity is 0.12 W/(m•K)	The same with aerated concrete
Common Small-sized Concrete Hollow Blocks	Made by stirring and forming cement, sand, stone, and water; there are single-row pores, double-row pores and treble-row pores	Compressive strength: 3.5~15MPa; hole rate: 35%~50%; apparent density: 1300~1700kg/m^3 ; thermal conductivity: 0.26W/(m•K)	The inner walls and load-bearing walls of low-rise and middle-rise buildings
Small-sized Lightweight-aggregate Concrete Hollow Blocks	Made by stirring and forming cement, sand (lightweight sand or common sand) lightweight aggregates and water; there are single-row pores and multi-row pores	Compressive strength: 2.5~10MPa; apparent density: 500~1400kg/m^3	The insulating walls (<3.5 MPa) or non-load-bearing walls; load-bearing walls (≥3.5MPa)
Lightweight Concrete Wallboards	Cement, sand, lightweight, water and steel bars,	Apparent density: 1000~1500 kg/m^3; compressive strength: 10~20MPa; thermal conductivity: 0.35~0.5W/(m•K)	The wallboards with strength less than 15MPa can be used in non-load-bearing walls; and those with strength more than 15MPa can be used in load-bearing walls
Lightweight Sandwich Boards	The polystyrene boards with steel mesh plastered by cement mortar on two sides, or composite colorful thin steel plates, aluminum alloy boards and colorful galvanized steel boards	Weight: 10~110 kg/m^3; heat resistance: 0.6~1.1(m^2•K)/W; soundproof index: 40dB	Self-supporting outer walls, partitions, insulating walls (such as), ceilings, and roof boards
Concrete Sandwich Boards	Composed by reinforced concrete of 20~30 thick as the surface layers, rock wool felt, glass fiber felt, foam concrete and other insulating materials as the middle layer	Load-bearing board: 500~542 kg/m^3; thermal conductivity: 1.01W/(m^2•K) (thickness of 250mm); non-load-bearing: 260kg/m^3; thermal conductivity: 0.593W/(m^2•K) (thickness of 180mm)	Load-bearing outer walls or non-load-bearing outer walls

continued

Varieties	Major Components	Main Properties	Applications
Paper Gypsum Boards, Fiber Gypsum Boards, Hollow Gypsum Boards, and Decorative Gypsum Boards	Building gypsum, paper boards, glass fiber and water	Apparent density: 600~1000kg/m^3 ; bending load: 400~850N; thermal conductivity: 0.2~0.25W/(m•K); soundproof indexes: 30~50dB; lightweight, insulating, soundproof, easy to be processed and used, and poor water resistance	Inner partition walls, or the boards inside composite walls; the relative humidity of the environment $>$ 75%, and the temperature $>$60℃
Glass Fiber Reinforced Cement Boards (GRC Boards)	Low-alkali cement, anti-alkali glass fiber, lightweight aggregate, and water	Apparent density: 1880kg/m^3 ; bending strength:$>$25kJ/ m^2; thermal conductivity: $\leqslant$0.2W/(m•K); soundproof indexes: $>$30~45dB; fireproof limit: 1.3~3h; easy to be used	Inner partition walls, the protective boards on the exterior walls or combined with other core materials

7.4 Roof Materials

7.4.1 Roof Tiles

With the improvement of the function requirements of modern buildings and the development of material technologies, roof tiles have been changed from the traditional fired tiles into the large cement tiles of various materials and the polymer compound tiles.

1. Fired Tiles (JC709-1998)

The fired tiles are made by molding (or extruding), drying, and roasting the clay with little impurity and good plasticity, used as the waterproof roof material. By colors, they are divided into grey tiles and clay tiles; by shapes, they are classified into flat tiles, ridge tiles, tri-bend tiles, double pantiles, fish-scale tiles, ox-tongue tiles, plain tiles, pantiles, J-shaped tiles, and S-shaped tiles, groove-head tiles, and other kinds of tiles in abnormal shapes as well as the fittings; and by the surface states, there are glazed tiles and unglazed tiles.

According to *Clay Flat Tile* (JC709-1998), the standard dimension of the flat tiles is 400mm×240mm~360mm×220mm, and the thickness is 10~20mm; and the coverage area of 15 pieces of flat tiles is 1m^2; the water absorption of the glazed tiles should not be more than 12%, and that of the unglazed tiles should not be more than 21%; the bending load should be no less than 1020N; after 15times thaw-freeze cycles, if there isn't scaling, arris effected, chipping and increasing of cracks, the products are qualified; as to the impermeability of unglazed tiles, the products are qualified if the water level is no lower than 15mm after the tiles are immerged in water for 3h and there is no water drop on their backs.

According to JC709-1998, the standard size should be length≥300mm and width≥180mm, and thickness is 10~20mm; the resistance to bending load, water absorption, frost resistance, and impermeability are the same with the flat tiles.

According to JC709-1998, the size of tri-bend tiles, double pantiles, fish-scale tiles, ox-tongue tiles, J-shaped tiles, and S-shaped tiles should be 300mm×200mm~150mm×150mm, and their thickness is 8~12mm. The bending strength should be no less than 8.0 MPa. Water absorption, frost resistance, and impermeability are the same with the flat tiles.

According to JC709-1998, the size of plain tiles, pantiles, water-drop tiles, and groove-head tiles should be 430mm×350mm~110mm×50mm; and their thickness is 8~16mm. The bending load should be no less than 1070N. For grey tiles, the bending load should no less than 850N. Water absorption, frost resistance, and impermeability are the same with the flat tiles.

According to JC709-1998, the size of J-shaped tiles and S-shaped tiles should be 320mm×320mm~250mm×250mm; and the thickness is 12~20mm. The bending load should be no less than 1600N. Water absorption, frost resistance, and impermeability are the same with the flat tiles.

The experimental methods of all the above tiles are regulated in *The Fired Tile* (JC709-1998).

2. Cement Tiles

(1) Concrete Tile

According to *Concrete Tile* (GB8001), the standard size of concrete flat tile includes 400mm×240mm and 385mm×235mm. The bending load of single tile should be more than 600N. And frost resistance and impermeability should accord with the requirements.

The concrete flat tiles have good durability, low cost, but bigger dead weight than clay tiles. If alkali-resistant pigments are added into the ingredients, they can change into colorful tiles.

(2) Fiber Reinforced Cement Tile

Fiber reinforced cement tiles are the tiles made by mixing, beating, shaping, and curing the reinforced fibers and cement. The fibers are alkali-resistant glass fibers, organic fibers and asbestos fibers. The tiles made by stirring, filter pressing, forming, and curing the cement and chrysotile are called asbestos cement tiles which include large corrugated tiles, middle corrugated tiles, and small corrugated tiles and ridge tiles. This kind of tile is fireproof, waterproof, moisture-proof, and corrosion-proof, used as the roofs for work shed, storage, and temporary structure. But asbestos fiber is bad for people's health, and China is trying to use other kinds of fibers to replace asbestos fibers.

(3) Large Steel Mesh Cement Corrugated Tile

Large steel mesh cement corrugated tile is the large corrugated sandwich tile made by mixing cement and sand with water, injecting mold, adding a layer of cold-drawn low-carbon steel mesh, and forming and curing them. The size of this tile is 1700mm×830mm×14mm, the height of wave is 80mm, and each tile weighs 50kg, used as the roofs for heat-eliminating workshops, storages, and temporary structures, and sometimes as the protective structures for these structures.

3. Polymer Composite Tiles

(1) Fiberglass Corrugated Tile

Fiberglass corrugated tile is the corrugated tile made by pasting unsaturated polyester and fiberglass manually. Its length is 1800~3000mm, its width is 700~800mm, and its thickness is 0.5~1.5mm. This kind of corrugated tile is lightweight, high-strength, impact-resistant, heat-resistant, light-transmitting and colorful, used as roofs for constructive sun visors, stations, platforms, and pergolas.

(2) PVC Corrugated Tile

PVC corrugated tile is also called plastic corrugated board made by plasticizing, calendering, wave-pressing PVC with other addictives. The size is 2100mm×(1100~1300)mm×(1.5~2)mm. This kind of tile is lightweight, waterproof, corrosion-proof, light-transmitting, and colorful, used as roofs for sheds, pergolas, fruit sheds and other simple structures, and also sun visors.

(3) Fiberglass Asphalt Tile

Fiberglass asphalt tile (simply called asphalt shingle) is a kind of flake roof material made by fiberglass felt (body material) and modified asphalt (coating). The tile is lightweight, easy to be used and can reduce the deadweight of the roof, stick to each other, and resist weathering. Colorful mineral particles can be scattered on the surface to change it into colorful asphalt shingle. Asphalt shingle is normally used as the roofs for civil constructions, and colorful shingles can be used for decoration.

7.4.2 Roof Lightweight Plates

1. EPS Lightweight Board

This board is a super lightweight board made by heating and pressurizing 0.5~0.75mm thick colorful coated steel plate (the surface material) and self-extinguishing polystyrene (the core) with thermal curing glue in continuous forming machine. Its weight is 1/20~1/30 of the concrete roof, and it is a new kind of enclosure structure material which is insulating [thermal conductivity is 0.034W/(m•K)], easy to be used (no wet operation and no twice decoration), load-bearing, waterproof and decorative. It can be made into planar and curved shapes, used for various roofs, shown in Figure 7.9. The board can be used for large-span roof structures, such as gymnasium, exhibition hall, and cold storage.

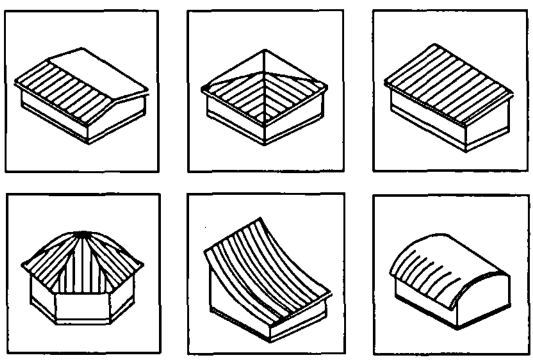


Figure 7.9 Shapes of the Roofs made by Coated Steel Sheet

2. Rigid Polyurethane Sandwich Board

This board is made by colorful galvanized profiled steel sheet (surface layer) and rigid polyurethane foam (core). The profiled steel sheet is 0.5mm, 0.75mm, and 1.0mm thick. The colorful coat is polyester, silicon modified polyester, or fluoride-chloroethylene plastic, and all of them have strong weatherability.

The thermal conductivity of the composite board is 0.022W/(m•K) and its apparent density is 40kg/m^3; if the board is 40mm thick, the average soundproof volume is 25dB. It is lightweight, high-strength, insulating, soundproof, colorful and easy to be used. It is a load-bearing, insulating, and waterproof roof board, used as the roof structures of large industrial factory buildings, storages, public constructions, and other kinds of large-span buildings and high-rise buildings.

3. Aluminum-alloy Corrugated Tile

The aluminum-alloy corrugated tile made by antirust aluminum (LF21) is lightweight, high-strength, anti-corrosion, aesthetic, and easy to reflect sunshine and be installed. It can be used as the 1/6~1/8 roofs. When paved, it should be done from up to down, upwind.

Questions

7.1 What are the common masonry bricks used in projects?

7.2 Which simple methods can be used to distinguish crozzle and place bricks?

7.3 What is red brick? What is grey brick? And what is internal burned brick?

7.4 Simply narrate how to determine the strength grades of fired common bricks.

7.5 By materials, how many kinds of wall blocks are there? What the advantages of blocks, compared with fired common clay bricks?

7.6 Which kinds of wall plates cannot stay in humid environment for a long time? And which cannot stay in heat (>200℃) for a long time?

7.7 What are the common compound wall boards? Talk about their significance in building.

7.8 What are the characteristics of lightweight composite roof materials, compared with traditional clay tiles?

Exercises

1. There are a few fired common bricks whose dimensions are standard, dry constant weight is 2500g, and saturated mass is 2900g. After the bricks are ground and dried, take 50g from it, and the volume measured by density bottle is 18.5cm^3. Try to calculate the water-absorption, density, apparent density and voidage of the bricks.

2. There is a batch of fired common bricks. The test results are listed in the following table, and what's the strength grade of the bricks?

Code	1	2	3	4	5	6	7	8	9	10
Failure Load	254	270	218	183	238	259	151	280	220	254

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8

Construction Steel

This chapter focuses on the mechanical properties of construction steel, the cold working and strengthening of steel, and the standards and selection of steel. It introduces the corrosion reasons of steel and the measures to prevent corrosion. It simply introduces the fire protection of steel.

Steel consists mostly of iron, with a carbon content under 2% and various other elements.

Construction steel refers to various steel materials used in construction projects, including various materials used for steel structures (such as round steel, angle steel, joint steel, and steel pipe), plates, and steel bars, steel wires, and strands used in concrete structure.

Steel is the material produced under strict technical conditions, and it has the following advantages: even materials, stable properties, high strength, certain plasticity and toughness, and the properties to bear impacts and vibration loads, and can be welded, riveted, or screwed; the disadvantages are: easy to be corroded and high cost of repairs.

These characteristics determine that steel is one of the important materials needed by economic construction departments. In construction, the steel structures consisted by steel in various shapes have high security and light deadweight, used for large-span and high-rise structures. However, because every department needs a large amount of steel, the wide use of steel structure is limited to some extent. But though concrete structures have heavy deadweight, the usage of steel is decreased greatly, and it can overcome the corrosion and high cost of repairs of steel. Thus, steel is widely used in concrete structures.

8.1 Classifications of Steel

8.1.1 By Smelting Processes

Smelting is to oxidize the molten pig iron to reduce its carbon content to the scheduled range and to remove the other impurities to allowable range. During smelting, the removal degrees of impurities by different smelting methods are not the same, so the steel qualities are different. Recently, there are three kinds of steel, including Bessemer steel (converter steel), Siemens-Martin steel, and electric steel.

1. Bessemer Steel

The smelting process of this steel is to use the molten pig iron as the raw material without any fuel and to make steel with air being blown through the molten iron (the raw material) from the bottom or the sides of the converter, called pneumatic converter steel; if pure oxygen is used to replace the air, it is called the oxygen converter steel. The disadvantage of pneumatic converter steel is that the nitrogen, hydrogen and other impurities in the air will interfuse easily, the smelting time is short, and the impurity content is difficult to control, so the quality is poor; the quality of oxygen converter steel is high, but the cost is a little higher.

2. Siemens-Martin Steel

The process of Siemens-Martin steel is to use solid or fluid pig iron, ore or waste steel as the raw materials and coal gas or heavy oil as the fuel and to remove the impurities from the iron by oxidation with the oxygen in ore or waste steel or the oxygen being blown through the iron. Because the smelting time is long (4~12h), the impurities are removed clearly and the quality of steel is good. But the cost is higher than that of Bessemer steel.

3. Electric Steel

The process of electric steel is to make steel by electric heating. The heat source is high-tension arc, and the smelting temperature is high and can be adjusted freely, so the impurities can be removed clearly and the steel quality is good.

8.1.2 By Deoxidation Methods

Unavoidably, there will be part of ferric oxide left in molten steel during the smelting process, which reduce the steel quality. Thus, deoxidation is needed during the ingot casting. The steel made by different deoxidation methods has various properties. Therefore, there is rimmed steel, fully-killed steel, and semi-killed (or semi-deoxidized) steel.

1. Rimmed Steel

It is the unkilled steel which is deoxidized only by ferromanganese, a weak deoxidizer. Because the remained FeO in the molten steel can generate CO with C, there are a lot of foams in the process of casting ingot, like boil, known as rimmed steel. Its organization is not dense enough and contains foams, so the quality is poor; but the rate of finished products is high and the cost is low.

2. Fully-killed Steel

This kind of steel is deoxidized thoroughly with a certain amount of silicon, manganese, and aluminum deoxidizers. Because deoxidation is thorough, the molten steel can solidify calmly in ingot casting, known as fully-killed steel. Its organization is dense, chemical elements are even, and properties are stable, so its quality is good. However, the productivity is low, so the cost is high. It can be employed in the steel structures used to bear impacts, vibration or important welding.

3. Semi-killed Steel

Its deoxidation degree and quality are between the above two.

8.1.3 By Press-working Modes

In the process of smelting and ingot-casting, there will be uneven structures, foams or other defects happening to the steel, so the steel used in industry should be processed by press to eliminate the defects. Meanwhile, there is requirement for shapes. The press-working modes include hot working and cold working.

1. Hot-working Steel

Hot working is to heat the steel ingot to a certain temperature and to conduct press-working to the steel ingot in the plastic state, such as hot rolling and hot forging.

2. Cold-working Steel

The steel is processed under the normal temperature.

8.1.4 By Chemical Elements

Steel Classifications (GB/T13304-91), the Chinese standard, recommends two classification methods: one is to classify by chemical elements, and the other is to classify by quality degrees. By chemical elements, there is non-alloy steel, lean-alloy steel and alloy steel.

1) Non-alloy Steel: that is carbon steel with few alloy elements.

2) Lean-alloy Steel: that is the steel with low alloy elements.

3) Alloy Steel: that is the steel added with more alloy elements to improve some properties of the steel.

8.1.5 By Quality Degrees

According to quality degrees, the steel can be classified into: common steel, quality steel and advanced quality steel.

8.1.6 By Purposes

The steel can be classified by purposes, such as construction steel, railway steel, and pressure vessel steel. The construction steel can be classified by purposes into the steel for steel structures and that for concrete structures. At present, the steel commonly used in constructions includes carbon structural steel and lean-alloy and high-strength structural steel.

8.2 Characteristics of Steel

8.2.1 Characteristics of Steel

The characteristics of steel include strength, elasticity, plasticity, toughness and rigidity.

1. Tensile Strength

The tensile strength of construction steel includes: yield strength, ultimate tensile strength, and fatigue strength.

(1) Yield Strength or Yield Limit

Subjected to the dead load, steel starts to lose the ability to resist deformation and generates a great deal of stress in plastic deformation. As shown in Figure 8.1, at the yield stage, the corresponding stress of the highest point on the hackle is called the upper yield point (B_{up}); the corresponding stress of the lowest point is called the lower yield point (B_{down}). Because the yield points are unstable, the Chinese Standard regulates that the stress of the lower yield point is the yield strength of the steel, expressed by σ_s. Medium carbon steel and high carbon steel have no obvious yield points, so 0.2% of the stress of the residual deformation is the yield strength, expressed by $\sigma_{0.2}$, shown in Figure 8.2.

Yield strength is very important to the use of steel. When the actual stress of a structure reaches the yield point, there will be irretrievable deformation which is not allowed in constructions. Thus, yield strength is the main base to determine the allowable stress of the steel.

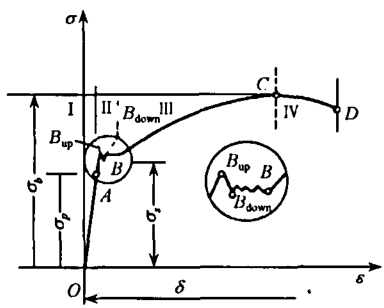


Figure 8.1 Stretching of Low Carbon Steel σ - ε

I The elastic stage, expressed by σ_p ; II The yield stage, expressed by σ_s
III The reinforcement stage, expressed by σ_b ;IV The necking stage.

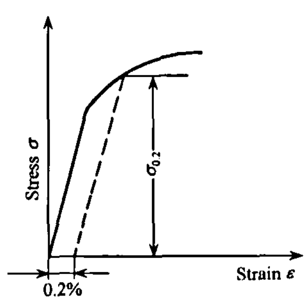


Figure 8.2 The Assigned Yield Point of Hard Steel

(2) Ultimate Tensile Strength (Simply Called Tensile Strength)

It is the ultimate tensile stress that the steel can bear under the role of tension, shown in Figure 8.1, the highest point of stage III. Tensile strength cannot be the calculated base directly, but the ratio of yield strength to tensile strength is the yield ratio, namely, $\frac{\sigma_s}{\sigma_b}$ which is very important in constructions. The smaller the yield ratio is, the more reliable the structure is, that is, the higher the potential to prevent the damage of the structure is; but if the ratio is too small, the available utilization ratio of the steel will be too low, and the reasonable yield ratio should lie between 0.6~0.75. Therefore, the yield strength and the tensile strength are the major test indexes of the mechanical properties of steel.

(3) Fatigue Strength

Under the role of alternating loads, steel will be damaged suddenly when the stress is far below the yield strength, and this damage is called fatigue failure. The value of stress at which failure occurs is called fatigue strength, or fatigue limit. The fatigue strength is the highest value of the stress at which the failure never occurs. Generally, the biggest stress that the steel bears alternating loads for 10^6~10^7 times and no failure occurs is called the fatigue strength.

2. Elasticity

Figure 8.1 shows that the steel is subjected to the dead load and the ratio of the stress to the strain at stage *OA* is the elastic stage. This deformation property is called elasticity. At this stage, the ratio of the stress to the strain is the modulus of elasticity, that is, $E=\frac{\sigma}{\varepsilon}$ with MPa as the unit.

The modulus of elasticity is the index to measure the ability of the steel to resist deformation. The bigger *E* is, the higher the stress that causes its deformation is; and under the certain stress, the smaller the elastic deformation will be. In projects, the modulus of elasticity reflects the rigidity of the steel which is an important value to calculate the deformation of a structure under stress. The elastic modulus of Q235, the carbon structural steel commonly used in constructions, is calculated as follows: E=(2.0~2.1) $\times 10^5$MPa.

3. Plasticity

The construction steel should have good plasticity. In projects, the plasticity of the steel is usually expressed by the elongation (or the reduction of cross-section area) and cold bending.

1) Elongation refers to the ratio of the increment of the gauge length to the original gauge length when the specimen is stretched off, expressed by δ (%), shown in Figure 8.3.

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

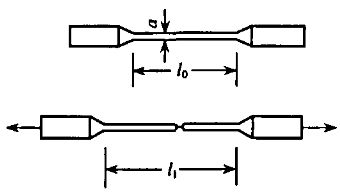


Figure 8.3 Elongation of Steel

2) Reduction of cross-section area is the percentage of the cross-section shrinkage quantity of the neck-shrinking part to the original cross-section area when the specimen is stretched off, expressed by ϕ (%).

For the sake of measurement, elongation is often used to express the plasticity of steel. Elongation is the important index to measure the plasticity of steel. The bigger the elongation is, the better the plasticity of steel is. The elongation is related to the gauge length, and usually δ_5 and δ_{10} are used to express the elongation when l_0=5a and l_0=10a respectively. For the same steel, $\delta_5 > \delta_{10}$.

3) Cold bending is the property that the steel bears the bending deformation under the normal conditions. The cold bending is tested by checking whether there are cracks, layers, squamous drops and ruptures on the bending part after the specimen goes through the regulated bending. Generally, it is expressed by the ratio of the bending angle α and the diameter of the bending heart d to the thickness of the steel or the diameter of the steel a. Figure 8.4 shows that the bigger the bending angle is, the smaller the ratio of d to a is, and the better the cold bending property is.

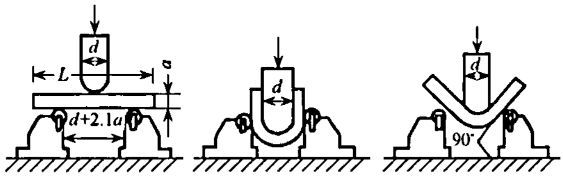


Figure 8.4 Cold Bending Test of Steel

d. diameter of the bending heart; *a*. the thickness or the diameter of the specimen; α . the cold bending angle (90°)

Cold bending is a method to check the plasticity of steel and is related to the elongation. The steel with bigger elongation has better cold bending property. But the cold bending test for the steel is more sensitive and strict than the tension test. Cold bending test is helpful to expose some defects of steel, such pores, impurities and cracks. In welding, the brittleness of parts and joints can be found by cold bending test, so the cold bending test is not only the index to check plasticity and processability, but also an important index to evaluate the welding quality. The cold bending test for the steel used in important structures or the bended steel should be qualified.

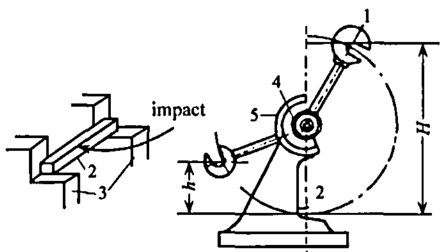
Plasticity is an important technical property for steel. Though the structures are used during the elastic stage, the part where the stress converges could be beyond the yield strength. And certain plasticity can guarantee the redistribution of the stress to avoid failure of structures.

4. Impact Durability

Impact durability refers to the property that the steel resist loads without being damaged. It is regulated that the impact durability is expressed by the work spent on the unit area of the damaged notch when the standard notched specimen is stricken by the pendulum of the impact test, with the sign α_K and the unit J, as shown in Figure 8.5. The bigger α_K is, the more work will be spent in damaging the specimen, or the more energy the steel will absorb before getting cracked, and the better the durability of the steel is.

The impact durability of the steel is related to its chemical elements, smelting, and processing. Generally, *P* and *S* contents in steel are high, and impurities and the tiny cracks forming in smelting will lower the impact durability.

In addition, the impact durability of the steel can be influenced by temperature and time. At the room temperature, the impact durability will decline little with the temperature falling, and the damaged steel structure reveals the ductile fracture; if the temperature falls into a range, α_K declines suddenly, as shown in Figure 8.6, the steel reveals the brittle fracture, and the temperature is very low when cold brittle fracture occurs. In north, especially the cold places, the brittle fracture of the steel should be tested when the steel is used. The critical temperature of its brittle fracture should be lower than the lowest temperature of the place. Because the measurement of the critical temperature is complicated, what is regulated in standards is the impact values at the negative temperature -20℃or -40℃.



(a) Test Device (b)Working Principle of Pendulum Tester

Figure 8.5 The Test Principle of Impact Durability

1. Pendulum; 2. Specimen; 3. Test-bed; 4. Dial; 5. Needle

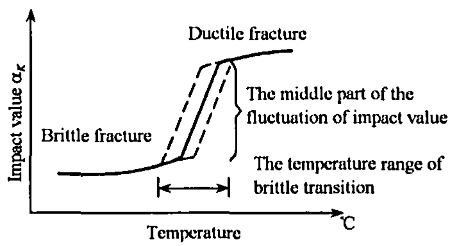


Figure 8.6 The Impact of Humidity on Impact Durability

5. Rigidity

Rigidity is the property to resist the plastic deformation when there is a hard object press into the steel within the partial volume of the surface, often related to the tensile strength. Recently, there are various methods to measure the rigidity of the steel, and the most common one is Brinell hardness, expressed by HB.

The yield strength, tensile strength, elongation, cold bending, and impact durability of the steel are usually used as the base for the evaluation mark.

8.2.2 Influences of the Steel Composition on Other Properties

1. Steel Composition

Steel is iron-carbon alloy. Besides iron and carbon, there are a large number of other elements left due to the raw materials, fuels, and smelting process, such as silicon, oxygen, sulfur, phosphor, nitrogen and others. Alloy steel is the modified steel added with some elements, like manganese, silicon, vanadium and titanium.

The combination of iron and carbon atoms in the steel has three basic modes: solid solution, compound, and mechanical mixture. Solid solution uses as the dissolvent and carbon as the solute, and the iron remains its original crystal lattice and carbon dissolves in it; compound is the chemical compound of Fe and C (that is, Fe_3C) whose crystal lattice is different from the original one; and mechanical mixture is the combination of the above solid solution and the compound. The so-called organization of the steel is composed by the above single combination mode or several combination modes. And it is a kind of polymer. The basic composition of the steel includes ferrite, cementite, and pearlite.

1) Ferrite is the solid solution of carbon in iron. Because the void between atoms is very small and C is hard to dissolve in the iron, it is just like pure iron, which renders the steel with good ductibility, plasticity and durability as well as low strength and rigidity.

2) Cementite is the compound of iron and carbon, Fe_3C, with the carbon content of 6.67%. It is hard and brittle and the major component of the strength of carbon steel.

3) Pearlite is the mixture of ferrite and cementite, with high strength and medium plasticity and durability (between the above two).

The mechanical properties of the three basic components are listed in Table 8.1.

Table 8.1 Elements and Mechanical Properties of the Basic Composition

Name	Element	Tensile Strength (MPa)	Elongation (%)	Brinell Hardness (HB)
Ferrite	A small amount of pure iron of carbon dissolving in the crystal texture of steel with	343	40	80
Pearlite	The mixture of ferrite and cementite in a certain proportion (carbon content is 0.80%)	833	10	200
Cementite	The grain of (Fe_3C) in the crystal texture of steel	Below 343	0	600

If C=0.8%, the steel with only pearlite is called eutectoid steel; if the carbon content is lower than 0.8%, the steel is called hypo-eutectoid steel; if the carbon content is higher than 0.8%, the steel is called hyper-eutectoid steel. The building steel is the hypo-eutectoid steel. The relations between the steel, carbon content and components are listed in Table 8.2.

Table 8.2 Relations between Steel, Carbon Content and Components

Name	Carbon Content	Components
Hypo-eutectoid Steel	<0.8	Pearlite + Ferrite
Eutectoid Steel	0.80	Pearlite
Hyper-eutectoid Steel	>0.80	Pearlite + Cementite

2. Influences of Chemical Elements on the Properties of Steel

(1) Carbon

Carbon is the major element that determines the properties of steel.

The influence of carbon on the mechanical properties of carbon is shown in Figure 8.7. With the increasing of carbon content, the rigidity and the trength of steel will increase, and its plasticity and toughness will decrease. If the carbon content is more than 1%, the ultimate strength of the steel begins to fall. In addition, if the carbon content is too high, the brittleness and aging sensitivity of the steel will rise, which reduce its ability to resist the corrosion of the atmosphere and weldability.

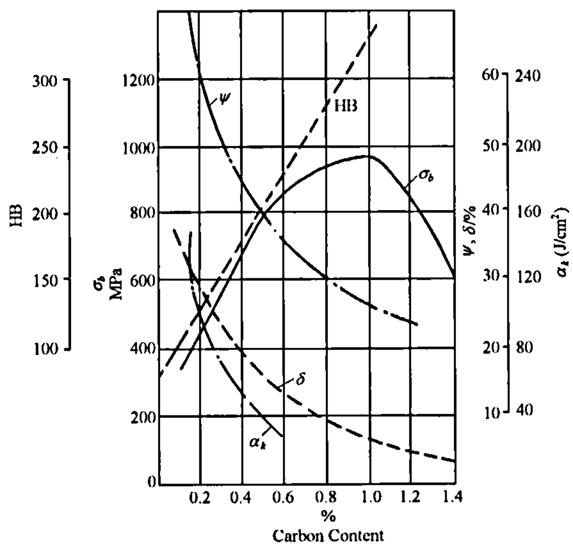


Figure 8.7 Influences of Carbon Content on Properties of Hot-rolled Carbon Steel

σ_b. Tensile Strength ; α_k .Impact Toughness; HB. Hardness; δ . Elongationl; φ . Shrinkage of Cross-section

(2) Phosphor and Sulfur

Phosphor is similar with carbon that can improve the yield point and bending strength of steel, lower its plasticity and toughness, and greatly increase its cold brittleness. But the segregation of phosphor is serious and there are cracks in welding, so phosphor is one of the elements that can lower the weldability of steel. Thus, in carbon steel, the phosphor content should be controlled strictly; but in alloy steel, it can improve the resistance to atmospheric corrosion of steel, and can also be the alloy element.

In steel, sulfur exists in the mode of FeS. FeS is a kind of low melting compound that has been melted when the steel is processed or welded in the state of glowing red and will lead to cracks inside the steel, called hot brittleness. The hot brittleness greatly reduces the processability and weldability of steel. In addition, the segregation of sulfur is serious that can reduce the impact-resistance, fatigue strength and anti-corrosion of steel. Thus, the sulfur content should also be controlled strictly.

(3) Oxygen and Nitrogen

Oxygen and nitrogen can partly dissolve in ferrite and most of them exist in the mode of compounds. These non-metals contain impurities that reduce the mechanical properties of steel, especially the toughness of steel, and can accelerate aging and lower weldability. Thus, the oxygen and nitrogen should be controlled strictly in steel.

(4) Silicon and Manganese

Silicon and manganese are the elements added purposely during steelmaking for deoxidation and desulphurization. Because silicon can combine with oxygen greatly, it can capture the oxygen in ferric oxide to generate silicon dioxide and stay in the steel slag. Most of the remaining silicon will dissolve in ferrite. And when the content is low (less than 1%), it can improve the strength of steel and has little influence on plasticity and toughness. Combining force of manganese with oxygen and sulfur is higher than that of iron, so manganese can change FeO and FeS into MnO and MnS respectively and stay in the steel slag. And the remaining manganese dissolves in ferrite and twists the crystal lattice to prevent slippage and deformation, greatly improving the strength of steel.

8.3 Cold Working, Ageing and Welding

8.3.1 Cold Working

Cold working is the process that steel is processed at the room temperature. The common cold working modes for construction steel include: cold stretching, cold drawing, cold rolling, cold twisting, notching.

At the room temperature, beyond the elastic range of the steel, the plastic deformation strength and rigidity of the steel have increased and its plasticity and toughness have decreased, which is called cold-working strengthening. As shown in Figure 8.8, the stress—strain curve of steel is $OBKCD$; if the steel is stretched to point K and release the tension, the steel will recover to point O'; and if it is stretched again, the stress—strain curve will be $O'KCD$, and the new yield point (K) is higher than the original yield point (B), but the elongation decreases. Within a certain range, the bigger the cold-working deformation is, the greater the yield strength increases, and the more the plasticity and the toughness decrease.

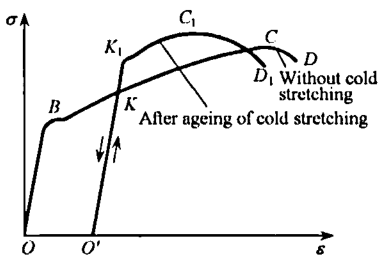


Figure 8.8 The Curve of Cold Stretching of Steel Bar

8.3.2 Ageing

With the extension of time, if the strength and the rigidity of steel increase and the plasticity and the rigidity of steel decrease, it is called ageing. The ageing process of steel under the natural state is very slow. If the steel often suffers vibrating and impact loads in cold working or use, the ageing will develop fast. After cold working, the yield strength, tensile strength and rigidity of steel will increase but the plasticity and the toughness keep decreasing, if the steel stay at room temperature for 15~20 days or is heated to 100~200℃ for 2h. The former is called natural ageing, and the latter is called artificial ageing. As shown in Figure 8.8, after cold working and ageing, the stress—strain curve is $O'K_1C_1D_1$; and the yield strength (K_1) and the tensile strength (C_1) are higher than those before ageing. Generally, the steel with lower strength adopts natural ageing, and the steel with higher strength adopts artificial ageing.

The degree to which the properties of steel have been changed by ageing is called ageing sensitivity. The bigger the sensitivity is, the greater the plasticity and the toughness have been changed. Thus, the important structures bearing vibrating and impact loads (such as crane beam and bridge) should use the steel with small ageing sensitivity.

Cold working and ageing are often used to improve the strength of building steel, increase the varieties and dimensions of steel and save steel.

8.3.3 Welding

Welding is the major mode for the combination of steel. The quality of welding depends on the welding techniques, welding materials and the weldability of steel.

Weldability refers to the property that under a certain welding condition, there is no crack or hard rupture in or around welding seams and the mechanical property after welding, especially the strength, should be not lower than the original one.

Weldabiltiy is often impacted by chemical components and the contents. The weldability will decrease, if the carbon content is more than 0.3%, or there is more sulfur, or the impurity content is high, and the alloy elements content is high.

Usually, the steel used for welding is the oxygen converter or the Siemens-Martin fully-killed steel with lower carbon content. For the high carbon steel and alloy steel, preheating and heat treatment should be adopted respectively before and after welding in order to improve the hard brittleness of the steel after welding.

8.4 Standards and Selection of Building Steel

8.4.1 The Steel Used for Steel Structures

Recently, the steel used for steel structures includes carbon structural steel and low-alloy high-strength structural steel.

1. Carbon Structural Steel

(1) Grade and Representation

Carbon Structural Steel (GB700-88), the national standard, regulates that grade consists of the letter of yield point, the value of yield point, the quality level, and the deoxidation method, the four parts in order. And, “Q” represents the yield point; the value of yield point includes 195MPa, 215MPa, 235MPa, 255MPa and 275 MPa; the quality level is expressed by the content of sulfur and phosphor: A, B, C, and D, in decreasing order; the deoxidation method is expressed as follows: F represents rimmed steel, b represents semi-killed steel, Z and TZ represents fully-killed steel and special fully-killed steel, and Z and TZ can be omitted in the grades of steel.

For example, Q235-A·F represents A-grade rimmed steel with the yield point of 235MPa.

(2) Technical Requirements

The chemical components of each steel grade should accord with Table 8.3. The mechanical properties and technological characteristics should be in line with Table 8.4 and Table 8.5.

Table 8.3 Chemical Components of Carbon Structural Steel (GB700-88)

Grade	Level	Chemical Component (%)					Deoxidation
		C	Mn	Si	S	P	
				≤			
Q195	—	0.06~0.12	0.25~0.50	0.30	0.050	0.045	F, b, Z
Q215	A	0.09~0.15	0.25~0.55	0.30	0.050	0.045	F, b, Z
	B				0.045		
Q235	A	0.14~0.22	0.30~0.65[1)]	0.30	0.050	0.045	F, b, Z
	B	0.12~0.20	0.30~0.70[1)]		0.045		
	C	≤0.18	0.35~0.80		0.040	0.040	Z
	D	≤0.17			0.035	0.035	TZ
Q255	A	0.18~0.28	0.40~0.70	0.30	0.050	0.045	F, b, Z
	B				0.045		
Q275	—	0.28~0.38	0.50~0.80	0.35	0.050	0.045	b, Z

1) The upper limit of manganese content of rimmed steel Q235 A and Q235B is 0.60%

Table 8.4 Mechanical Properties of Carbon Structural Steel (GB700-88)

Grade	level	Tensile Test														Impact Test	
		Yield Point σ_s (N/mm^2)						Tensile Strength σ_b (N/mm^2)	Elongation δ_5 (%)						Temperature (°C)	V Impact Work (Vertical) (J)
		Thickness of Steel (Diameter) (mm)							Thickness of Steel (Diameter) (mm)							
		≤16	>16~40	>40~60	>60~100	>100~140	>150		≤16	>16~40	>40~60	>60~100	>100~140	>150		
		≤							≤							≥
Q195	—	(195)	(185)	—	—	—	—	315~430	33	32	—	—	—	—	—	—
Q215	A	215	205	195	185	175	165	335~450	31	30	29	28	27	26	—	—
	B														20	27
Q235	A	235	225	215	205	195	185	375~00	26	25	24	23	22	21	—	—
	B														20	27
	C														0	
	D														-20	
Q275	A	255	245	235	225	215	205	410~550	24	23	22	21	20	19	—	—
	B														20	27
Q275	—	275	265	255	245	235	225	490~630	20	19	18	17	16	15	—	—

Table 8.5 Technological Characteristics of Carbon Structural Steel (GB700-88)

Grade	Direction of Samples	Cold Bending Test B=2a, 180°		
		Thickness of Steel(Diameter) (mm)		
		60	＞60~100	＞100~200
		Diameter of Bending Heart d		
Q195	Vertical	0	—	—
	Horizontal	0.5a		
Q215	Vertical	0.5a	1.5a	2a
	Horizontal	a	2a	2.5a
Q235	Vertical	a	2a	2.5a
	Horizontal	1.5a	2.5a	3a
Q255	—	2a	3a	3.5a
Q275a	—	3a	4a	4.5a

Note: B is the width of sample; a is the thickness of steel (diameter).

(3) Selection

The selection of steel depends on the quality, properties and the corresponding standards of steel on one side; on the other side, it depends on the requirements of the projects for the properties of steel.

In national standards, carbon structural steel includes five grades, and each grade has different quality levels. Generally, the bigger the grade is, the higher the carbon content is, and the higher the strength and the rigidity are, but the lower the plasticity and the toughness are. The martin steel and oxygen converter steel have good quality, and steel grade D and grade C with lower sulfur and phosphor contents are better than steel grade B and grade A. Special fully-killed steel and fully-killed steel are better than rimmed steel. And the better the steel, the higher the cost.

The load types, welding, and temperatures of the projects have different requirements for the properties of steel. And the demands should be met in the selection of steel. Usually, the rimmed steel is restricted under the following conditions: ①it is a welding structure directly bearing the dynamic loads; ②it is a non-welding structure and the calculating temperature is equal to or lower than –20℃; ③it is a welding structure bearing static loads and indirect dynamic loads and the calculating temperature is equal to or lower than –30℃.

In the construction steel structures, carbon steel Q235 is mainly used, namely, various profiles, steel boards and coffins made of Q235. Steel Q235 has good strength, toughness, plasticity, and processability, and is easy to be smelted and has lower cost. Because Q235-D has enough elements to form fine-particle structures and controls the contents of sulfur and phosphor strictly, it has better impact toughness to resist vibrating and impact loads than other grades, especially at negative temperature. Steel grade A is often used for the structures bearing static loads.

Steel Q215 has low strength and high plasticity, and deforms a lot under stress. It can replace Q235 after cold working.

Steel Q275 has high strength but low plasticity, and sometimes is rolled to ribbed bars used in concrete.

2. Low-alloy High-strength Structural Steel

(1) Representation of Grades

According to *Low-alloy High-strength Structural Steel* (GB1591-94), the national standard, there are five grades. The known elements are manganese, silicon, barium, titanium, niobium, chromium, nickel and lanthanon. The representation of grades consists of the letter of the yield point, the value of the yield point, and the quality level (including A, B, C, D, E, the five levels).

(2) Standards and Properties

Table 8.6 and Table 8.7 show the chemical elements and mechanical properties of the low-alloy high-strength structural steel.

Table 8.6 Chemical Components of Low-alloy High-strength Structural Steel (GB1591-94)

Grade	Quality Level	Chemical Components(%)										
		C (≤)	Mn	Si	P (≤)	S (≤)	V	Nb	Ti	Al (≥)	Cr ≤	Ni (≤)
Q295	A	0.16	0.80~1.50	0.55	0.045	0.045	0.02~0.15	0.015~0.060	0.02~0.20	—		
	B	0.16	0.80~1.50	0.55	0.040	0.040	0.02~0.15	0.015~0.060	0.02~0.20	—		
Q345	A	0.20	1.00~1.60	0.55	0.045	0.045	0.02~0.15	0.015~0.060	0.02~0.20	—		
	B	0.20	1.00~1.60	0.55	0.040	0.040	0.02~0.15	0.015~0.060	0.02~0.20	—		
	C	0.20	1.00~1.60	0.55	0.035	0.035	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
	D	0.18	1.00~1.60	0.55	0.030	0.030	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
	E	0.18	1.00~1.60	0.55	0.025	0.025	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
Q390	A	0.20	1.00~1.60	0.55	0.045	0.045	0.02~0.20	0.015~0.060	0.02~0.20	—	0.30	0.70
	B	0.20	1.00~1.60	0.55	0.040	0.040	0.02~0.20	0.015~0.060	0.02~0.20	—	0.30	0.70
	C	0.20	1.00~1.60	0.55	0.035	0.035	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.30	0.70
	D	0.20	1.00~1.60	0.55	0.030	0.030	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.30	0.70
	E	0.20	1.00~1.60	0.55	0.025	0.025	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.30	0.70
Q420	A	0.20	1.00~1.70	0.55	0.045	0.045	0.02~0.20	0.015~0.060	0.02~0.20	—	0.40	0.70
	B	0.20	1.00~1.70	0.55	0.040	0.040	0.02~0.20	0.015~0.060	0.02~0.20	—	0.40	0.70
	C	0.20	1.00~1.70	0.55	0.035	0.035	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.40	0.70
	D	0.20	1.00~1.70	0.55	0.030	0.030	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.40	0.70
	E	0.20	1.00~1.70	0.55	0.025	0.025	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.40	0.70
Q460	C	0.20	1.00~1.70	0.55	0.035	0.035	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.70	0.70
	D	0.20	1.00~1.70	0.55	0.030	0.030	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.70	0.70
	E	0.20	1.00~1.70	0.55	0.025	0.025	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.70	0.70

Note: Al in the table is the total aluminum content. If the acid-soluble aluminum is tested, the content should be no less than 0.010%.

Table 8.7 Mechanical Properties of Low-alloy High-strength Structural Steel (GB1591-94)

Grade	Level	Yield Point σ_s (MPa) Thickness(diameter、side length)(mm)				Tensile Strength σ_b (MPa)	Elongation δ_5 (%)	Impact work(A_{kv})(Vertical) (J)				180°Bending Test d— diameter of bending heart; a— thickness of specimen(diameter) Thickness of steel(diameter)(mm)	
		≤15	>16~35	>35~50	>50~100			+20℃	0℃	-20℃	-40℃	≤16	>16~100
		≥					≥						
Q295	A	295	275	255	235	390~570	23					d=2 a	d=3 a
	B	295	275	255	235	390~570	23	34				d=2a	d=3 a
Q345	A	345	325	295	275	470~630	21					d=2 a	d=3 a
	B	345	325	295	275	470~630	21					d=2 a	d=3 a
	C	345	325	295	275	470~630	22	34				d=2a	d=3 a
	D	345	325	295	275	470~630	22		34			d=2 a	d=3 a
	E	345	325	295	275	470~630	22			34	27	d=2 a	d=3 a
Q390	A	390	370	350	330	490~650	19					d=2 a	d=3 a
	B	390	370	350	330	490~650	19					d=2 a	d=3 a
	C	390	370	350	330	490~650	20	34				d=2 a	d=3 a
	D	390	370	350	330	490~650	20		34			d=2 a	d=3 a
	E	390	370	350	330	490~650	20			34	27	d=2 a	d=3 a
Q420	A	420	400	380	360	520~680	18					d=2 a	d=3 a
	B	420	400	380	360	520~680	18					d=2 a	d=3 a
	C	420	400	380	360	520~680	19	34				d=2 a	d=3 a
	D	420	400	380	360	520~680	19		34			d=2 a	d=3 a
	E	420	400	380	360	520~680	19			34	27	d=2 a	d=3 a
Q460	C	460	440	420	360	550~720	17					d=2 a	d=3 a
	D	460	440	420	360	550~720	17		34			d=2 a	d=3 a
	E	460	440	420	360	550~720	17			34	27	d=2 a	d=3 a

(3) Application

The addition of alloy elements into the steel can modify the organization and properties of steel. If 18Nb or 16Mn (the yield point is 345MPa) with the similar carbon content (0.14%~0.22%) is compared with Q235 (the yield point is 235MPa), the yield point is improved by 32%, and it has good plasticity, impact toughness and weldability and can resist low temperature and corrosion; and under the same conditions, it can make the carbon structural steel save steel consumption by 20%~30%.

The ore or the original alloy elements in steel waste, such as niobium and chromium, are often used for the alloying of steel; or some cheap alloy elements, such as silicon and manganese, are added; if there is special requirement, a little amount of alloy elements, such as titanium and vanadium, can be used. The smelting equipment is basically the same with the equipment to produce carbon steel, so the cost increases a little.

The adoption of low-alloy structural steel will reduce the weight of structures and extend the useful time, and the high-strength low-alloy structural steel is especially used in the large-span or large column-grid structures for better technical and economical effects.

8.4.2 Steel for Concrete Structures

Recently, the steel used for concrete structures mainly includes: hot-rolled reinforced bar, cold-drawn hot-rolled reinforced bar, cold-drawn low-carbon steel wire, cold-rolled ribbed bar, heat-tempering bar, steel wire and strand for pre-stressed concrete, and cold-rolled-twisted bar.

1. Hot-rolled Reinforced Bar

The hot-rolled reinforced bars used for concrete structures should have high strength, a certain plasticity, toughness, cold bending and weldability.

The hot-rolled reinforced bars mainly are the plain round bar rolled by Q235 and the ribbed steel made of alloy steel.

(1) Standard and Property of Hot-rolled Reinforced Bar

Based on *Hot-rolled Plain Round Steel Bars for the Reinforcement of Concrete* (GB13013), the national standard, the hot-rolled vertical round bars are level I, and the strength grade is HPB 235(see Table 8.8); the grades of the plain steel bars are represented by HRB and the minimum value of the yield point of the grade, and grades include HRB335, HRB400, and HRB500. H represents "hot-rolled", R represents "ribbed", and B represents "bar", the numbers afterwards represents the minimum value of the yield point (see Table 8.9).

Table 8.8 Technical Requirements for Hot-rolled Plain Round Bars

Surface Shape	Bar Level	Strength Grade	Nominal Diameter (mm)	Yield Point σ_s (MPa)	Tensile Strength σ_b (MPa)	Elongation δ (%)	Cold Bending d—diameter of bending heart a— nominal diameter of bar
				≥			
Plain Round	I	HPB235	8~20	235	370	25	180° d=a

Table 8.9 Grades and Technical Requirements for Hot-rolled Bars

Grade	Nominal Diameter (mm)	σ_s (或 $\sigma_{p0.2}$) (MPa)	σ_b (MPa)	δ_5 (%)
		≥		
HRB335	6~25 28~50	335	490	16
HRB400	6~25 28~50	400	570	14
HRB500	6~25 28~50	500	630	12

(2) Application

Steel bar grade I or HRB 335 and HRB 400 can be used as the non-prestressed bars in ordinary concrete based on the using conditions; the pre-stressed bars should be HRB400 or HRB 335. The hot-rolled bars grade I is the plain round bars, and others are the crescent ribbed bars whose coarse surface can improve the gripping power between concrete and steel bars.

2. Cold-drawn Hot-rolled Bar

Cold-drawn hot-rolled bar is made at the room temperature by drawing the hot-rolled steel bar with a kind of stress up to or beyond the yield point but less than the tensile strength and then unloading. The cold drawing can improve the yield point by 17%~27%, the material will become brittle, the yield stage becomes short, the elongation decreases, but the strength after cold-drawn ageing will increase a little. In practice, all the cold drawing, derusting, straightening, and cutting can be combined into one process, which simplifies the procedure and improves the efficiency; cold drawing can save steel and make pre-stressed bars, which increases the varieties of steel, and the equipment is simple and easy to operate, so it is one of the most common method for the cold working of steel. According to *Construction and Acceptance Codes for Concrete Structures* (GB50204-2002), the national standard, the technical requirements should be in line with Table 8.10.

Table 8.10 Properties of Cold-drawn Hot-rolled Bars (GB50204-2002)

Grade	Diameter (mm)	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation δ_{10} (%)	Cold Bending	
		≥			Bending Angle (°)	Bending Diameter (mm)
HPB235	≤12	280	370	11	180°	3d
HRB335	≤25	450	510	10	90°	3d
	28~40	430	490	10	90°	4d
HRB400	8~40	500	570	8	90°	5d
HRB500	10~28	700	835	6	90°	5d

Note: 1) *d* is the diameter of steel bar (mm);

2) The value of the yield strength of cold-drawn bars in the table is the standard strength value of cold-drawn bars regulated in *Design Specifications for Concrete Structure*, the existing national standard.

3) The cold bending diameter of the cold-drawn steel bars HRB400 and HRB500 with the diameter more than 25mm should increase 1*d*.

3. Cold-rolled Ribbed Bar

The cold-rolled ribbed bar is the bar made by cold drawing or cold rolling the ordinary low-carbon steel, the quality carbon steel or the low-alloy hot-rolled coiled bar to reduce the diameter and form crescent cross ribs on three faces or two faces of the bar. The base metal of the cold-rolled ribbed bar should be in line with the existing national standard *Cold-rolled Ribbed Bar* (GB13788). At present, most of the cold-rolled ribbed bars produced at home adopt passive cold rolling machine to reduce diameter and form crescent cross ribs on three faces of bars. The other one is the active rolling machine which can reduce diameter and form crescent cross ribs on two faces of bars.

Cold-rolled ribbed bar uses CRB as the grade code. According to JGJ95-2003 and J254-2003, the cold-rolled ribbed bar has five grades divided by tensile strength: CRB550, CRB650, CRB800, CRB970, and CRB1170. C represents "cold-rolled", R represents "ribbed", and B represents "bar". The value is the minimum value of tensile strength. The mechanical and technological properties of the cold-rolled ribbed bars should be in line with Table 8.11.

Table 8.11 Mechanical and Technological Properties of Cold-rolled Ribbed Bars (JGJ95-2003)

Grade	Tensile Strength σ_b (MPa) (≥)	Elongation (%)		Cold Bending180° Diameter of Bending Heart —d Nominal Diameter of Bar—a	Alternating bending frequency	Relaxation ratio (initial stress σ_{con} =0.7 σ_b)	
		δ_{10}	δ_{100}			1000h (≤) (%)	10h(≤) (%)
CRB550	550	8	—	d=3a	—	—	—
CRB650	650	—	4.0	—	3	8	5
CRB800	800	—	4.0	—	3	8	5
CRB970	970		4.0	—	3	8	5
CRB1170	1170	—	4.0	—	3	8	5

Note: 1) There should be no crack on the surface of the bending parts.

2) If the nominal diameters of the bars are 4mm, 5mm and 6mm, the bending diameter of the alternating bending should be 10mm, 15mm, and 15mm respectively.

3) For various bars supplied in coils, their tensile strength after straightening should be still in line with the table.

4) δ_{10} is the elongation of the bar whose standard measured distance is 10 times of its diameter; δ_{100} is the elongation of the bar whose standard measured distance is 100mm.

The cold-rolled ribbed steel bars have high strength, good plasticity, high cohesion force with concrete, and stable quality. Grade 550 steel bars are mainly used for reinforced concrete structures, especially the main load-bearing bars of slab members and the non-prestressed steel bars in pre-stressed concrete structures. Based on the need of projects and the actual conditions of materials, the cold-rolled ribbed steel bars with diameter of

4~12mm can be upgraded by 0.5mm. When grade 550 steel bars are used as the main load-bearing bars, their diameters should be 5~12mm. At present, the diameter of the steel bars used greatly in cast-in reinforced concrete slabs is 6mm above. Grade 650 bars are mainly used in the pre-stressed hollow slabs, with the diameter of 5mm or 6mm in several places. Grade 800 bars are the low-alloy coiled bars with diameter of 6.5mm and strength of 550MPa.

4. Heat-tempering Bar

Heat tempering is a technological process that the steel is heated, insulated, and cooled based on some rules to make its organization change and gain a required property. Heat-tempering bar is the bar made by quenching and high tempering the hot-rolled ribbed bar (middle-carbon low-alloy steel). Its plasticity decreases little, but its strength increases a lot, and the comprehensive property is ideal. Table 8.12 shows the mechanical indexes of the national standard GB4463-84.

Table 8.12 Mechanical Properties of Heat-tempering Bars (GB4463-84)

Nominal Diameter (mm)	Grade	Yield Point (MPa) (kgf/mm^2)	Tensile Strength (MPa) (kgf/mm^2)	Elongation δ_{10} (%)
		no less than		
6 8.2 10	$40Si_2Mn$ $48Si_2Mn$ $45Si_2Cr$	1325(135)	1470(150)	6

Heat-tempering bars are mainly used for the pre-stressed concrete sleepers in stead of carbon steel wires. Because they are easy to be made, have stable quality and good anchoring ability, and can save steel, they starts to be used in pre-stressed concrete projects.

5. Cold-drawn Low-carbon Steel Wire

The cold-drawn low-carbon steel wire is made by tungsten alloy wire-drawing model whose cross-section is less than Q235 (or Q215) coiled bars with diameter of 6.5~8mm. The cold-drawn steel wire undertakes not only tension but also extrusion, shown in Figure 8.9. The yield strength of the steel wire undertaking drawing once or more is improved by 40%~60%, and it has already lost the property of low-carbon steel and become hard and brittle, belonging to hard steel wire. The national standard (GB50204-92) regulates that the cold-drawn low-carbon steel wire has two grades of strength: the first grade is pre-stressed wire, and the second grade is non-prestressed wire. When a concrete plant conducts cold-drawing by itself, it should strictly control the quality of steel wires and check their appearances in batches randomly. There should be no rust, oil pollution, scratching, soap spot, and crack. The plant should check the coiled bars one by one to find whether their mechanical and technical properties are in line with Table 8.13. All the bars whose elongation is unqualified should not be used in the pre-stressed concrete members.

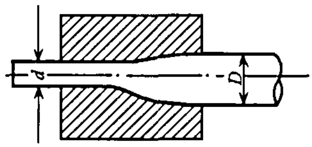


Figure 8.9 Cold Drawing

Table 8.13 Mechanical Properties of Cold-drawn Low-carbon Steel Wires (GB50204-92)

Grade	Diameter (mm)	Tensile Strength (MPa) ≥ Group 1	Tensile Strength (MPa) ≥ Group 2	Elongation δ_{10} (%)	180° Repeated Bending (number)
First Grade	5	650	600	3.0	4
	4	700	650	2.5	4
Second Grade	3~5	550		2.0	4

Note: After the pre-stressed cold-drawn low-carbon steel wire is adjusted by machine, the standard tensile strength should be decreased by 50MPa.

6. Pre-stressed Steel Wire for Concrete or Steel Strain

They are the special products made by cold working, re-backfiring, cold rolling or crossing the high-quality carbon structural steel, also called high-quality carbon steel wire or steel strain.

The national standard (GB5223-2002) regulates that the pre-stressed steel wire for concrete can be divided by processing way: cold-drawn steel wire (code of WCD) and stress-relieved wire, the two types. The stress-relieved wire can be divided into low loose plain round wire (code of P), spiral rib steel wire (code of H), and deformed steel wire (code of I), the three types. The mechanical properties of cold-drawn wire, stress-relieved wire, spiral rib steel wire, and stress-relieved deformed wire are shown in Table 8.14, Table 8.15, and Table 8.16.

Table 8.14 Mechanical Properties of Cold-drawn Steel Wires

<table>
<tr><th>Nominal Diameter d_n (mm)</th><th>Tensile Strength σ_b (MPa) (≥)</th><th>Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)</th><th>Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)</th><th>Bending Number (number/ 180°) (≥)</th><th>Bending Diameter R (mm)</th><th>Shrinkage Ratio of Section ϕ (%) (≥)</th><th>Twisting Number of Every 210mm Torque</th><th>Relaxation Ratio after 1000h, when the initial stress equals to 70% of nominal tensile strength r (%) (≤)</th></tr>
<tr><td>3.00</td><td>1470</td><td>1100</td><td rowspan="8">1.5</td><td>4</td><td>7.5</td><td>—</td><td>—</td><td rowspan="8">8</td></tr>
<tr><td>4.00</td><td>1570</td><td>1180</td><td>4</td><td>10</td><td rowspan="3">35</td><td>8</td></tr>
<tr><td rowspan="2">• 5.00</td><td>1670</td><td>1250</td><td rowspan="2">4</td><td rowspan="2">15</td><td rowspan="2">8</td></tr>
<tr><td>1770</td><td>1330</td></tr>
<tr><td>6.00</td><td>1470</td><td>1100</td><td>5</td><td>15</td><td rowspan="4">30</td><td>7</td></tr>
<tr><td>7.00</td><td>1570</td><td>1180</td><td>5</td><td>20</td><td>6</td></tr>
<tr><td rowspan="2">8.00</td><td>1670</td><td>1250</td><td rowspan="2">5</td><td rowspan="2">20</td><td rowspan="2">5</td></tr>
<tr><td>1770</td><td>1330</td></tr>
</table>

Table 8.15 Mechanical Properties of Stress-relieved Plain Round and Spiral Rib Steel Wires

<table>
<tr><th rowspan="4">Nominal Diameter d_n (mm)</th><th rowspan="4">Tensile Strength σ_b (MPa) (≥)</th><th colspan="2" rowspan="3">Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)</th><th rowspan="4">Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)</th><th rowspan="4">Bending Number (number/ 180°) (≥)</th><th rowspan="4">Bending Diameter R (mm)</th><th colspan="3">Stress Relaxation Property</th></tr>
<tr><th rowspan="2">Percentage of Initial Stress to Nominal Tensile Strength (%)</th><th colspan="2">Relaxation Ratio after 1000h r (%) (≤)</th></tr>
<tr><th>WLR</th><th>WNR</th></tr>
<tr><th>WLR</th><th>WNR</th><th colspan="3">For All Specifications</th></tr>
<tr><td>4.00</td><td>1470</td><td>1290</td><td>1250</td><td rowspan="14">3.5</td><td>3</td><td>10</td><td rowspan="14">60
70
80</td><td rowspan="14">1.0
2.0
4.5</td><td rowspan="14">4.5
8
12</td></tr>
<tr><td>4.80</td><td>1570</td><td>1380</td><td>1330</td><td rowspan="4">4</td><td rowspan="4">15</td></tr>
<tr><td rowspan="3">5.00</td><td>1670</td><td>1470</td><td>1410</td></tr>
<tr><td>1770</td><td>1560</td><td>1500</td></tr>
<tr><td>1860</td><td>1640</td><td>1580</td></tr>
<tr><td>6.00</td><td>1470</td><td>1290</td><td>1250</td><td>4</td><td>15</td></tr>
<tr><td>6.25</td><td>1570</td><td>1380</td><td>1330</td><td>4</td><td>20</td></tr>
<tr><td rowspan="2">7.00</td><td>1670</td><td>1470</td><td>1410</td><td rowspan="2">4</td><td rowspan="2">20</td></tr>
<tr><td>1770</td><td>1560</td><td>1500</td></tr>
<tr><td>8.00</td><td>1470</td><td>1290</td><td>1250</td><td>4</td><td>20</td></tr>
<tr><td>9.00</td><td>1570</td><td>1380</td><td>1330</td><td>4</td><td>25</td></tr>
<tr><td>10.00</td><td rowspan="2">1470</td><td rowspan="2">1290</td><td rowspan="2">1250</td><td>4</td><td>25</td></tr>
<tr><td>12.00</td><td>4</td><td>30</td></tr>
</table>

Table 8.16 Mechanical Properties of Stress-relieved Deformed Wires

Nominal Diameter d_n (mm)	Tensile Strength σ_b (MPa) (≥)	Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)		Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)	Bending Number (number/ 180°) (≥)	Bending Diameter R (mm)	Stress Relaxation Property: Percentage of Initial Stress to Nominal Tensile Strength (%)	Relaxation Ratio after 1000h r (%) (≤)	
		WLR	WNR				For All Specifications	WLR	WNR
≤5.0	1470	1290	1250	3.5	3	15	60	1.5	4.5
	1570	1380	1330						
	1670	1470	1410				70	2.5	8
	1770	1560	1500						
	1860	1640	1580						
>5.0	1470	1290	1250			20	80	4.5	12
	1570	1380	1330						
	1670	1470	1410						
	1770	1560	1500						

For the pre-stressed steel wires for concrete, the national standard GB5223-2002 regulates that the mark of the products should contain the following content: pre-stressed steel wire, nominal diameter, tensile strength grade; code of processing state, code of appearance, and standard code.

Example 1: The mark of the cold-drawn plain and round wire with diameter of 4.00mm and tensile strength of 1670MPa should be: pre-stressed steel wire 4.00-1670-WCD-P-GB/T5223-2002.

Example 2: The mark of the low loose spiral rib steel wire with diameter of 7.00mm and tensile strength of 1570MPa should be: pre-stressed steel wire 7.00-1570-WLD-H-GB/T5223-2002.

Steel strand is made by 7 steel wires undertaking crossing hot treatment. The national standard GB5224-85 regulates that the diameter of steel strand should be 9~15mm, failure load should be 220kN, and its yield strength should be 185kN.

7. Cold-rolled-twisted Bar

After the low-carbon hot-rolled coiled bar is formed once by getting straightened by specific cold-rolled-twisted machine, cold rolling and cold twisting, the continuous spiral bars with regulated shape of cross-section and pitch is the cold-rolled-twisted bar (shown in Figure 8.10). Pitch is the advancing distance that the cross-section of cold-rolled-twisted bar turns 1/2 circle (180°) along the axis of bar; the rolled thickness is the size of the smaller side of the rectangle cross-section or the shorter diagonal size of the diamond cross-section after the cold-rolled-twisted bar is formed; and the mark diameter is the nominal diameter (d) of the raw material (base metal) before getting rolled, with the mark of "ϕ' ".

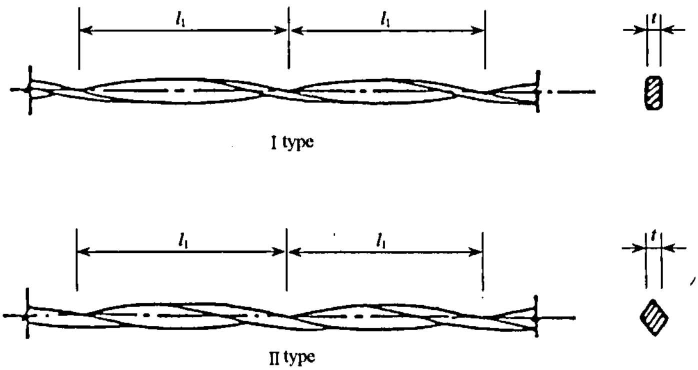


Figure 8.10 Shape and Cross-section of Cold-rolled-twisted Bar

t. rolled thickness; l_1. pitch

Cold-rolled-twisted bar has rectangle section I and diamond section II, based on the cross-section shapes. The mark of the product contains name code, characteristics code, main parameter code, and modification code, the four parts.

LZN □ Δ - □

- Modification Code: A, B, C
- Main Parameter Code: Type I , Type II
- Characteristics Code: symbol of the mark diameter Φ'
- Name Code: LZN

Example: the cold-rolled-twisted bar with the mark diameter of 10mm and rectangle section should be marked as: LZN ϕ' 10(I).

The low-carbon non-torsion-control cold hot-rolled wire rod (high speed wire rod) regulated in YB4027 is the best raw material for cold-rolled-twisted bar. The low-carbon hot-rolled wire rod in line with GB701 can also be used. The grade of raw material is Q235 and Q215. When Q215 is adopted, the carbon content should not be less than 0.12%.

The rolled thickness and pitch of cold-rolled-twisted bar should accord with Table 8.17. Its nominal cross-section area and nominal weight should accord with Table 8.18. Its mechanical properties should be in line with Table 8.19.

There should be no cracks, fold, scar, indentation, mechanical damage or other defects that affecting the normal use.

Table 8.17 The Rolled Thickness and Pitch (mm)

Type	Symbolic Diameter d	Rolled Thickness t ($\geqslant$)	Pitch l_1 ($\leqslant$)
I	6.5	3.7	75
	8	4.2	95
	10	5.3	110
	12	6.2	150
	14	8.0	170
II	12	8.0	145

Table 8.18 Nominal Section Area and Nominal Weight

Type	Mark Diameter d (mm)	Nominal Section Area A(mm^2)	Nominal Weight G (kg/m)
I	6.5	29.5	0.232
	8	45.3	0.356
	10	68.3	0.536
	12	93.3	0.733
	14	132.7	1.042
II	12	97.8	0.768

Table 8.19 Mechanical Properties

Tensile Strength σ_b (N/mm^2)	Elongation δ_{10} (%)	Cold Bending 180° (Bending Diameter = $3d$)
$\geqslant$ 580	$\geqslant$ 4.5	No Cracks on the Surface of Bending Part

Note: 1) d is the mark diameter or cold-rolled-twisted bar.

2) δ_{10} is the elongation at break of the sample whose standard distance is 10 times of mark diameter.

8.5 Fire Protection of Steel

8.5.1 Fire Protection of Steel Structures

Though steel does not burn with fire and does not supply fuels to fire, it will quickly become soft with fire. And when a steel structure stay in fire for about 15~20min, the roof truss and other member bars will collapse. With the damage of members, the whole structure will lose balance and be destroyed. Moreover, the steel structure cannot be repaired after damage. In order to conquer the poor fire-resistance of steel structures, the following protection methods can be adopted to guarantee the security of steel structures after encountering fire.

1) Protection methods should be chosen according to different requirements for fire-resistant limit. Fire-resistant limit refers to the period from the time that the building member starts to encounter fire to the time that it loses supporting ability, or the whole member is destroyed or lose the fire-insulated ability, when it is conducted fire-resistant test based on the standard curve of time and temperature, expressed by hour. If the fire-resistant limit is high, the thickness of the heat-insulating board should be increased accordingly.

2) Add box coat to the steel columns, and inject water into the box. In fire, the temperature of the steel columns rises slowly due to the protection of water.

3) Paint fire retardant coatings on the steel structures to improve their fire-resistant limit.

Recently, the last method is used commonly. The fire retardant coatings painted on the steel structures include LG fireproof and heat-insulating coatings (thick layer type), LB thin-layer fire retardant coating, JC-276 fire retardant coating and ST1-A fire retardant coating. The last two coatings can be used not only to prevent fire for steel structures but also for the fireproof treatment of the pre-stressed concrete structures.

8.5.2 Fire Protection of Steel Bars

The reinforced concrete structure refers to the members, such as beams, boards, columns, roof trusses, consisting of concrete and steel bars. In these structures, the steel bars are enwrapped by concrete, but their mechanical properties will still lose due to the fire to destroy the whole structure.

Because the thermal conductivity of concrete is big and the thermal expansion rate of steel bars is 1.5 times of that of concrete after being heated, their elongation strain is bigger than that of concrete. Thus, the thickness of protecting layer should be added accordingly within the allowable range of structure design, which will reduce or delay the elongation strain of steel bars and the losing of pre-stressed value. If the structure design does not allow the adding of thickness, fire retardant coatings can be painted on the surface of the tensile area of the concrete to protect the structure.

8.6 Corrosion and Prevention of Steel

When the surface of steel contacts with the surrounding environment under a certain condition, it will be corroded. The corrosion will reduce the load-bearing cross-section of steel, the uneven surface will lead to the convergence of stress, which will lower the load-bearing ability of steel; also, the corrosion will lower the fatigue strength greatly, especially the impact toughness of steel, which will result in the brittle fracture of steel. If the steel bars in concrete are corroded, there will be expansion of volume, which makes the concrete crack along bars. Thus, the measures to resist corrosion should be adopted in order to prevent the corrosion of steel in working.

8.6.1 Reasons for Corrosion of Steel

There are two kinds of corrosion based on different functions of the surface of steel and its surrounding media.

1. Chemical Corrosion

It is a pure chemical corrosion caused by the electrolyte solution or various dry gases (such as O_2, CO_2 and SO_2. etc.), without any electric current. Usually, this kind of corrosion will generate loose oxide on the surface of steel by oxidation, and it is very slow under the dry condition, but it will be very fast under high temperature and humidity.

2. Electrochemical Corrosion

When steel contacts with electrolyte solution and generates electric current, there will be the electrochemical corrosion caused by the role of primary battery. The steel contains ferrite, cementite, and non-metal impurities, and all of these components have different electrodes and potentials, which means their activity are diversified; if there is electrolyte, it will be easy to form two poles of primary battery. When the steel contacts with humid media, like air, water, and earth, a layer of water film will cover its surface and various ions coming from the air dissolves in water, which forms electrolyte. At first, the ferrite in steel lose its electron, that is, $Fe \rightarrow Fe^{2+}+2e$, to become anode, and cementite becomes cathode. In acidic electrolyte, H^+ obtains electron to become H_2 and runs away; in neutral media, water gets OH^- due to the deoxidation of oxygen and generates insoluble $Fe(OH)_2$; it can be oxidized into $Fe(OH)_3$ and its dehydration product $Fe_2(OH)_3$ which is the major component for bronze rust.

8.6.2 Corrosion Prevention of Steel

There are three methods to prevent the corrosion of steel.

1. Protective Film

This method is to isolate the steel from the surrounding media with the protective film to prevent or delay the damage caused by the corrosion of external corrosive media. For example, paint coatings, enamel or plastic on the surface of steel; or use the metal coating as the protective film, such as zinc, tin, and chrome.

2. Electrochemical Protection

Current-free protection is to connect a piece of metal, such as zinc and magnesium, more active than steel to the steel structure, and because zinc and magnesium have lower potentials than steel, the anodes of the corrosion cells coming from zinc and magnesium have be destroyed, but the steel structure will be protected. This method can be used for the places which are difficult or impossible to be covered with protective layer, such as steam boiler, shell of steamboat, underground pipe, maritime structure, and bridge.

Impressed current protection is to emplace some waste steel or other refractory metals around the steel structure, such as high silicon iron and silver-lead alloy, and to connect the cathode of the impressed direct current to the protected steel structure and the anode to the refractory metals, and the refractory metals become the anode to be corroded and the structure becomes the cathode to be protected.

3. Alloying

The addition of alloy elements into carbon steel to produce various alloy steel will improve its anti-corrosion, such as nickel, chrome, titanium, and copper.

The above method can be adopted to prevent the corrosion of the steel bars in concrete, but the most economic and effective way is to improve the density and the alkalinity of concrete and make sure that the steel bars are thick enough.

In the hydration products of the cement, there is about 1/5 $Ca(OH)_2$, and when the pH value of the media reaches to about 13, there is passive film on the surface of steel bars, so the bars in concrete are difficult to generate rust.

But when CO_2 in the air diffuses into the concrete and reacts with $Ca(OH)_2$ to neutralize the concrete. When pH value falls to 11.5 or below, the passive film will be destroyed and the steel surface reveals active state; and if there is humid and oxygen condition, the electrochemical corrosion will start on the surface of steel bars; because the volume of rust is 2~4 times than steel, it will lead to the cracking of concrete along bars. CO_2 diffuses into the concrete and carries the carbonization, so the improvement of the density of concrete will effectively delay the carbonization process.

Because CL^- will destroy the passive film, the consumption of chloride should be controlled in the preparation of reinforced concrete.

Questions

8.1 What is steel? What is construction steel? What are the properties of steel?

8.2 From what aspects is steel divided? How many subdivisions of each aspect? How is the construction steel divided?

8.3 How is steel produced? What kind of influence does each production modes have on the properties of steel?

8.4 What are the technical properties of construction steel? How to express each property? What is the actual significance? How to determine?

8.5 In the figure of stress-strain curve of low-carbon steel, how many stages are there? What are the characteristics and indexes of each stage?

8.6 What is yield ratio? What is the actual significance in projects?

8.7 What is the basic organization of steel? What are the characteristics? What kinds of impact do the chemical components of steel have on the properties?

8.8 What is cold working and aging? How does the property of steel change after cold working and aging?

8.9 What is the major element affecting the weldability of steel?

8.10 How to express the grade of carbon structural steel and low alloy structural steel?

8.11 In steel structures, why can Q235 and low alloy structural steel be commonly used?

8.12 How to divide the grades of hot-rolled steel? What is the application range of each level?

8.13 What are the common steel bars, steel wires, and steel strands used in concrete projects? How to select them?

8.14 What kinds of corrosions do construction steel have? How to resist corrosion?

8.15 What are the fire protection measures of steel bars?

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9

Wood

This chapter mainly states the structure and the physics characteristics of wood. Furthermore it also introduces the corruption and the insect pest caused and the preventive measures to them. This chapter also tells something about artificial plate and its usage.

In the ancient history of Chinese architectural history, the wood used to be combined with materials of construction and those of decoration. The architectures built of them amazes the whole world for the outstandingly perfect usage of wood. Take the world famous Beijing Qi'nian Palace for example, which was made up of completely wood. Nowadays wood is mainly used for interior decoration and ornament.

Wood is used as architectural and decoration material for its several advantages as follows: its specific strength is intense, and it is light-weight and high-strength; it has great elasticity and tenacity that it can bear certain grade of bow and shock wave; its thermal conductivity is low but thermal isolation is good; Being conserved properly, it can be very durable; it is also easy to process, and it can be made into products in various shapes; the wood is beautiful-grained, mild-toned, elegant-styled and well-effected in decoration; the combination of its elasticity, heat isolation and warm tone makes us comfortable; moreover it has high insulating ability without poison.

And for sure the wood also has following disadvantages: it is not even in structure, and it is of anisotropy; its quality and usage are affected by the numerous natural disadvantages; it expands with wetness and shrinks with dryness, so it is liable to crack or warp when being used incorrectly; if not properly conserved, it may be corrupted or mildew and rot or even eaten by worms; in addition its fireproof is poor and is liable to burn.

9.1 Classifications and Structures of Wood

9.1.1 Classifications

In architecture the wood are made of trees, which are many in species. But trees are mainly classified into two species. (As is shown in Table 9.1)

Table 9.1 Classifications and Characteristics of Trees

Classification	Characteristics	Usage	Examples
Conifer	The leaves are slime and long and needle-like, the trunks are straight and tall, and ligneous tissue is soft, liable to process. Of superior strength, apparent density is low, and shrinkage deformation is low.	The major trees used in architecture, mainly for load-carrying members, doors or windows etc.	Pine, juniper, cypress etc.
Broadleaf	Leaves are broad and shape in sheets, most of which are hardwood. The straight parts of the trunks are short, and ligneous tissue is hard, not easy to process. The apparent density is high, and the shrinkage deformation is high, easy to crack or warp	Used for minor load-carrying member in interior decoration or veneer, etc.	Elm, birch, Manchurian ash, etc.

The performance of wood derives from the structure of the wood, and the structure of the wood can be classified into macro structure and microstructure.

9.1.2 The Macro-structure of wood

The wood structures that can be seen by eyes or through magnifying glass are called the macro structure of wood. In order to observe closely, the trunks are cut into three different sections. As is shown in Figure 9.1:

Transverse section: the section that is vertical against the trunk axis;

Radial section: the section that passes the trunk axis;

Tangential section: the section that parallels with the trunk axis and tangent with the annual ring.

As it is shown in Figure 9.1, the wood is made up of bark, xylem and pith. Bark is mainly used for burning except certain species of trees (cork oak, and yellow pineapple tree) whose bark can be used to make heat-proof materials. Pith is in the central part of the trunk, whose texture is loose and fragile, and is liable to be corrupted or eaten by insect worms. So the best part for use is the xylem of trunk. In the xylem, the darker part near the pith is called duramen, while the light part outside is called alburnum. The duramen contains little water so that it is not liable to reshape, and it has high corrosion resistance. While the albumum contains more water that it is easy to deform and has worse corrosion resistance than duramen.

On the transverse section many centric circles can be seen, which are called annual rings. Of them the part in dark color and lie close are grown in summer, called summerwood. And the converse part is grown in spring, called springwood. The more summerwood wood has, the better the wood is. The more intense and evener annual rings the wood has, the better quality the wood has.

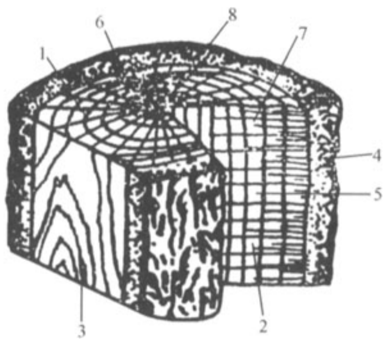

Figure 9.1 Three Sections of Trunk

1. transverse section; 2. radial section; 3. tangential section; 4. bark; 5. xylem; 6. annual ring; 7. pith ring; 8. pith

9.1.3 The Microstructure of Wood

The wood structures that can be seen through microscope are called microstructure of wood. There are differences between the structures of conifer and broadleaf, just as shown in Figure 9.2. Every cell can be classified into two parts: the cell wall and the lumen. The cell wall is composed of fibrils. The longitudinal combination is firmer than the transverse combination. So the cell wall is of high strength in lengthways, but of low strength in transverse. There are very little spaces among the fibrils composed of cell wall, which enables the material to absorb or leak water.

The structure of the cell determines the physical characteristics of wood. For example: the wood with thick cell wall and small lumen is intense and hard, and its bulk specific gravity is high and it is of high strength.

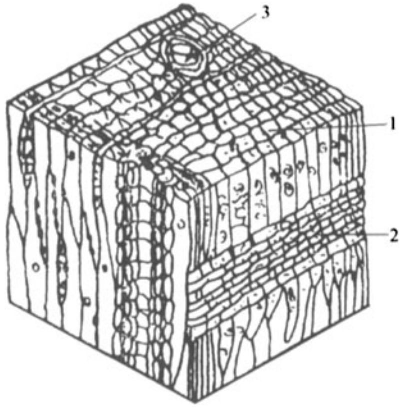

Figure 9.2 Microstructure of Masson Pine

1. tracheid; 2. pith ring; 3. resin canal

9.1.4 Disadvantages of Wood

During the process that wood are growing, cut down, stored and carried, processed and used, there may be such defects arise as knots, splits, bark pockets, disorder grains, curves, scars, decay rot and worm holes. Those defects not only reduce the mechanical property of wood, but also affect their appearance quality. Among them the knots, the splits and the decay rot play the most harmful part.

1. Knots

The branch grow in trunk is called knot. Intergrown knots are composed of branches alive, and they live closely together with wood neighborhood. They are hard in texture and normal in structure. Dead knots are composed of dead branches, and they are separate from the wood nearby. Their texture may be either hard or loose and soft. Sometimes they may also fall off and holes may arise. The knots with sound texture are called sound knots. And the knots with rotten texture are called rotten knots. The streaks are not only rotten themselves, but spread the rot into the interior part of wood, and the interior rot of wood may be caused. The knots' influences on the application of wood usage vary for their species, position, size and intensity, and the ways to use wood. Sound intergrown knots have little negative influences on the mechanical property of wood, while dead knot, rotten knot and streak do the worst harm to the mechanical properties and the outer appearance of wood.

2. Splits

The splits are caused by the separation among wooden fibers. The splits that split from the pith along with the direction of radius are called radius splits. The splits split along with the direction of annual rings are called ring splits. The splits split along with the direction of grains, from surface to interior are called longitudinal splits. The splits of wood are caused by the growing surroundings and factors of growing stress; moreover the reasons may also be the improper drying after cutting. Splits destroy the integrality of wood, influence the usage ratio and decorative value of wood, reduce the strength of wood, and meanwhile they are also access for fungus to invade the wood.

9.2 Physical and Mechanical Properties of Wood

9.2.1 Moisture

The moisture of wood is measured in the percentage of water content, which is the percentage of the mass of water to the mass of dry wood.

1. The Water in Wood

The water in the wood can be classified into the free water that lies in intercellular space and the absorbed water that lies inside the cell wall. The newly-cut wood is green wood. There is a plenty of free water and absorbed water in it. And the percentage of water content ranges from 70 % to 140%. When wood becomes dry, the free water is the first to evaporate, but at this time the size and mechanical property of wood are not influenced. When the free water finishes evaporating, the absorbed water begins to evaporate. The process of absorbed water evaporating is slow, and during it the bulk and the strength change regularly.

2. Fiber Saturation Point

The status when there is no free water in wood, but the cell walls are saturated with absorbed water, is called the fiber saturation point. In general the fiber saturation point of wood is from 25% to 35%.

3. Equilibrium Water Content

The status that the percentage of water content of wood keeps balance with the surrounding moisture is called equilibrium water content. In order to avoid deformation and splits of wooden products caused by the change of moisture of wood, the wood must be dried until the percentage of water content reaches the equilibrium water content. In the north area of China the equilibrium water content is about 12%, while in the south area the balanced percentage of water content is 15%~20%. The kiln-dried wood's percentage of water content is 4%~12%.

9.2.2 Wet Swelling and Dry Shrinking (Deformation)

When absorbed water content in cell walls changes, the deformation of wood may arises, which is wet swelling and dry shrinking.

During the process that wood are dried from damp status to the cellar saturation point, the size of wood remains still but the mass decreases. Only when the wood remains being dried until the absorbed water in cell wall begins to evaporate, do the wood begin to shrink. And when the absorbed water in wood begins to increase, the wood will start to expand, as shown in Figure 9.3.

Because the structure of wood is not even, so the shrinkage value also varies from direction to direction. The shrinkage value is the smallest in the direction of long grain, and bigger in the radial direction, and the most in the chordwise direction. So when the green wood becomes dry, the size and the shape of section may change a lot, as shown in Figure 9.4.

The shrinkage effect makes a great difference to the usage of wood. It may cause the wood split or warp, even make the structure of wood loosen or heave.

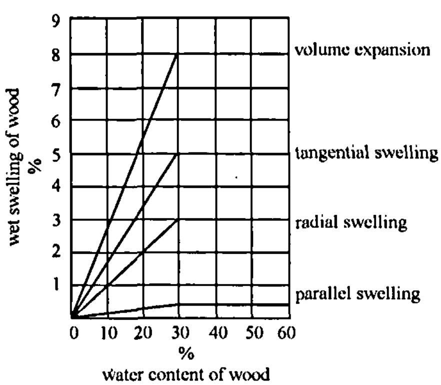

Figure 9.3 The Wet Swelling of Pine

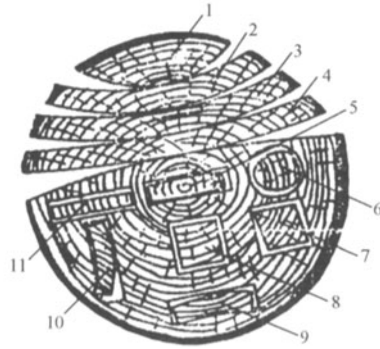

Figure 9.4 Deformation of Wood's Section Shape after Drying

1. arching like an olive nucleus; 2,3,4. springing; 5. shrinking like a spinning cone through pith; 6. round or oval; 7. square in a diagonal direction to the annual ring changing into diamond; 8. square with two sides paralleling with the annual ring changing into rectangle; 9,10. warping of the rectangle board; 11. the laburnum through saw plate is even

9.2.3 The Strength of Wood

1. All kinds of Strength

According to the ways that wood bears force, the strength of wood can be classified into tensile strength, compression strength, bending strength and sharing strength. And the tensile strength, compression strength and sharing strength also vary with the parallel grain (the direction of force parallels with the fiber direction) and transverse grain (the direction of force is vertical against the fiber direction). The parallel grain strength is quite different from the transverse grain strength. According to the Table 9.2, you can see how to make good use of all species of wood on the basis of their strengths separately.

Table 9.2 The Relationships between Strengths of wood

Compression strength		Tensile strength		Bending strength	Sharing strength	
Parallel grain	Transverse grain	Parallel grain	Transverse grain		Parallel grain	Transverse grain
1	1/10~1/3	2~3	1/20~1/3	1.5~2	1/7~1/3	1/2~1

The wood' strength grade are measured through tangential static bending strength of flawless standard specimens (see Table 9.3). The values of the strength grades of wood are the design strength values when wood structures are designed. They are several times lower than the actual strength, because the actual wood strength is determined by many factors.

Table 9.3 Measurement Standards of Wood Strength Grades

The species of wood	Conifer wood				Broadleaf wood				
Strength Grade	TC11	TC13	TC15	TC17	TB11	TB13	TB15	TB17	TB20
Minimum Value of Static Bending Strength (MPa)	48	54	60	74	58	68	81	92	104

2. Factors Affecting the Wood Strength

Besides its own structure, the strength of wood is also determined by such factors as the percentage of wood moisture, the defects (knots, irregular grain, splits, decay rot and worm rot), the duration of outside force and temperature.

(1) Water Content of Wood

When the wood contains less water than the saturation point, the percentage of moisture reduces, and the absorbed water becomes less and less, so that the strength of wood rises. To the contrary, the absorbed water increases and the cell walls expand, then the structure loosens and the strength of wood lowers. When the percentage of moisture exceeds the fiber saturation point, only free water is changing, and the strength of wood remains still. The influence of water content on the strength of wood see Figure 9.5.

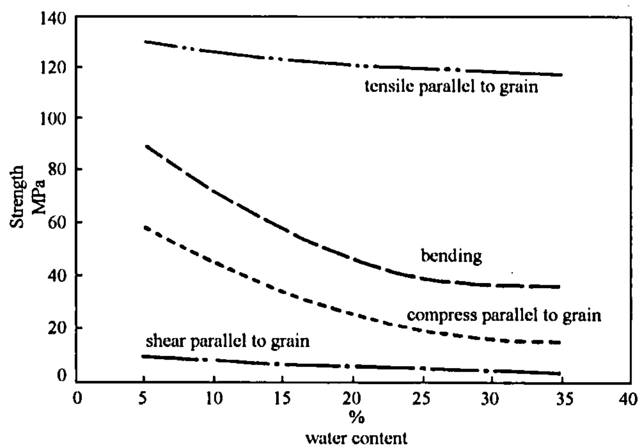

Figure 9.5 The Influence of Water Content on the Strength of Wood

In order to judge the wood strength and compare the results of experiment correctly, the wood strength should be calculated into the strength value in the state of standard water content (which is 12%) through following formula:

$$\sigma_{12} = \sigma_w[1+\alpha(W-12)]$$

In the formula, σ_{12} stands for the wood strength when the water content is 12% (MPa);

σ_w is the wood strength when moisture content is W% (MPa);

W stands for the moisture content in experiment (%);

α stands for the coefficient of moisture content, when the water content is 9%~15%, the numeral values are determined according to Table 9.4.

Table 9.4 Numeral Values of α

Strength type	Compression Strength		Tensile Strength parallel to grain		Bending Strength	Sharing Strength parallel to grain
	Parallel grain	Transverse grain	Broadleaf wood	Conifer wood		
α	0.05	0.045	0.015	0	0.04	0.03

(2) Environment Temperature

Temperature has direct influence on the wood strength. The experiment shows that when the temperature rises from 25 ℃ to 50 ℃, the wood compression strength will be reduced by 20%~40% and the wood sharing strength will be reduced by 12%~20% because the collide among wood fibers is softened. In addition, if the wood is in hot and dry surrounding, it may become fragile. During the processing of wood, boiling method is often employed to reduce its strength contemporarily to meet the needs of processing (such as the production of plywood).

(3) The Duration of Outer Force

The limit strength of wood stands for the capability of standing the outer force in a short time. The limit that the wood can stand in a long run is the rupture strength of wood. Because plastic-flow deformation will occur to wood, the strength of wood will be reduced with the lasting of loading time, and the rupture strength of wood may be only 50%~60% of the limit strength of wood (as shown in Figure 9.6).

(4) Defects

The wood strength is judged by the samples without defects. In fact, during the growing, cutting and processing process of wood, there may be such defects as knots, splits and worm rot. These defects make the wood uneven, and destroy wood structures; all these influences may reduce the strength of wood, especially the tensile strength and the bending strength.

Besides the factors above, the species of trees, growing surroundings, the age of trees, and different parts of trees all influence the wood strength.

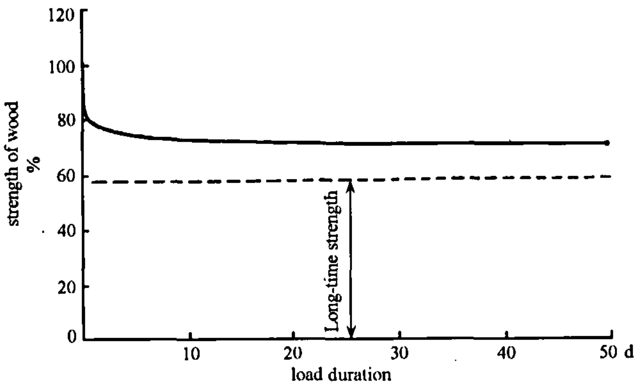

Figure 9.6 The Creep Rupture Strength of Wood

9.3 Wood Preservation

In order to increase the wood strength, keep the original size and shape of wood, improve the usage property and lengthen the useful time; the preservative treatment and the drying treatment must be made before wood is processed and used.

9.3.1 The Drying Treatment of Wood

The ways to dry the wood are natural drying and artificial drying:

1. Natural Drying

The natural drying is to store the plates and square timber that are just sawed off at the drafty place in a certain manner, and the direct sunlight and the rain should also be avoided, so that the water in the wood can evaporate naturally. This method is easy and no special equipment is required, and the quality of dried wood is good. But it takes up too much time and space to dry the wood, and the drying status can only reach the weathered status.

2. Artificial Drying

Artificial drying makes use of artificial ways to remove the water from wood. The usually used methods are heated stream drying and hot air drying.

9.3.2 Wood Preservation

The decay of wood is caused by fungi or insects. There are three factors needed by epiphyte to live. They are the water, oxygen and temperature. In proper circumstances with proper temperature (25~30℃) and proper moisture (the percentage of water content is 35%~50%), etc., fungi and insects will reproduce in wood and at the same time destroy the wood structure and influence the usage of wood.

In order to lengthen the useful life of wood, three wood preservative treatment methods can be used.

1. Drying Treatment

Reduce the percentage of water content as much as possible by air-drying or kiln drying. And during drying process all species of damp-proof and drafty measures should be adopted. Such as add the damp-proof pad between wood and other materials, seal no joint or wooden member into the wall, set the drafty hole under the wooden floor, adopt gable to keep drafty, and set the dormer window, etc..

2. Antiseptic Treatment

This method is making the wood poisonous through brushing or immerging into antiseptic to keep the wood from decaying or worm rotting. The common preservatives are water agents (sodium chloride, zinc chloride, copper sulfate, monohydrate, Na-CPC, etc.), oil agents (lindane five chlorophenol mixture), and emulsion agents. The methods to inject wood preservative are external coating, immersion at room temperature, immersion in hot and cold bath and pressure treatment, etc..

3. Paint Coating

There are many species of paints, but in wood preservative treatment the adopted paint should possess good waterproof property. The function of paint is to form a complete and hard protective coat on the surface of wood to separate the water and air from wood, and therefore, the fungi and insects can also be avoided.

9.3.3 Fire Protection of Wood

Flammability is the biggest disadvantage of wood, and the following methods are often adopted to protect wood from fire.

1) Put the wood into flameproof infusion and ensure a proper amount of infusion and the filtration depth to meet the demand of fireproofing.

2) Paint or spray the flameproof coating on to the surface of wood until the coating becomes dry. The flameproof effect depends on the thickness of coating or the amount used in every square meter.

With the passing of time and the influence of surrounding factors, the fireproof components in fireproof paints or infusion may decrease or decay that the fireproof ability of wood will decrease if the above two methods are adopted.

9.4 Applications of Wood in Architecture

During the construction process, the wood should be used rationally according to the species, the grade and the structure. And we should also try to avoid using the big ones for fraction and the good ones for trifles.

9.4.1 Species and Specifications of Wood

The wood used in architecture can be classified into primitive streak, log, sawn timber and crosstie according to its usage and status of processing.

Primitive streak means the wood without bark, root and treetop. And usually it is not processed into certain length or diameter by certain size. Primitive streak is often used as scaffold, architecture material and furniture.

Log means the wood without bark, root and treetop. And usually it is processed into certain length or diameter according to certain size. Log is often used as frame, purlin or rafter, etc.. Furthermore it can also be used as pile timber, pole, mine timber, etc.. When processed, it can also be made into plywood, ship model and machine model.

Sawn timber means timber, which has been processed and sawn. The timber whose width is three (or more than three) times of its thickness is called plate. While the timber whose width is less than three times of its thickness is called square log. Sawn timber is often used in architecture, bridge, furniture, ship, automobile or pocking box.

Crosstie means the timber processed according to the section and length of sleeper. Crosstie is often used in railway construction.

9.4.2 Artificial Wood

Artificial wood is made of various leftover materials, small scraps, wood shavings and timbering residues. All those materials are made into sorts of artificial wood to improve the usage of wood. The usual artificial woods are like follows:

1. Plywood

Plywood is made through following procedures, peel the log into laminas and dry them, then pile the laminas whose fibers are transverse to each other together, finally agglutinate and stress them in heat. Generally speaking plywood contains from 3 to 13 levels. 3-plywood and 5-plywood are usually used in architecture. Both conifer and broadleaf can be made into plywood.

Characteristics: It has even texture and high strength, without obvious fiber saturated point, warping or split; it contains seldom defect; usually it has wide surface and is convenient for using; and it makes a good decorative effect.

The glue species, characteristics and using range of normal plywood are shown in Table 9.5.

2. Fiberboard

Fiberboard is also a kind of artificial wood. The procedure is as follows. First break the bark, wood shavings branch and other waste materials into pieces, and then mill them into wood pulp, after that add the glue into it or make use of its own agglutination, through heated pressure and drying treatment, and finally the plywood is made.

Fiberboard makes use of 90% of wood, and its texture is even, the strengths in every direction are equal, especially the bending strength is intense. In addition fiberboard is not liable to warp and split, and it totally avoids the defects of wood.

Hard fiberboard can be used as wall slab, door board, floor, furniture and other decorations instead of wood. And the soft fiberboard whose apparent density is low($<400kg/m^3$) and porosity is high, often used as heatproof or acoustical materials.

Table 9.5 Species, Characteristics and Applications of Plywood

Kind	Species	Name	Glue Species	Characteristics	Applications
Normal Broadleaf Plywood	Species I	NQF(climate tolerant plywood)	phenolic resin	tolerant of age, boiling and steam, dry and heat, fungi tolerant	Outdoor engineering
	Species II	NS (water tolerant plywood)	urea-formaldehyde resin	Tolerant of cool water and hot water immersion, but not tolerant of boiling	Outdoor engineering
	Species III	NC(moisture tolerant plywood)	blood glue, urea-formaldehyde resin with many other ingredients and other glues of the similar capacity	tolerant of cool water immersion in a short period	Indoor engineering in normal circumstances
	Species IV	BNS (moisture intolerant plywood)	Soy-adhesive or other glues of the similar capacity	certain agglutinative strength, but intolerant of water	Indoor engineering in normal circumstances
Normal Pine Plywood	Species I	species I plywood	phenolic resin ak or other synthesis resin of the similar capacity	tolerant of age, heat, and fungi	Enduring outdoor engineering
	Species II	species II plywood	underhydrated or other synthesis resin of the similar capacity	tolerant of water and fungi	Engineering in damp circumstances
	Species III	speciesIII plywood	blood glue or urea-formaldehyde resin with a little ingredient	tolerant of damp	Indoor engineering
	Species IV	speciesIV plywood	Soy-adhesive and urea-formaldehyde resin with plenty of ingredient	intolerant of water and damp	Indoor engineering (in dry circumstances)

3. Particle board, fiberboard and oxychloride

Particle board, fiberboard and oxychloride are artificial wood made by damaging, dipping and grinding wood shavings, wood wool and timbering residue into wood pulp, mixing the pulp with glue, and then heat-pressing and drying the pulp. And the glues used in the procedure are plant or animal glue (soy-adhesive, blood glue), synthesis resin adhesive (phenolic resin, urea-formaldehyde resin), and inorganic gelling material (concrete, magnesite, etc.)

These kinds of wood are of low apparent density and strength. And they are mainly used as heat proof and acoustical material, and after facing treatment they can also be as ceiling board or partition board.

4. Block Board

Block board is made of all kinds of wood comprehensively. The core plate is made up of laths and the surfaces are made of wooden veneer.

The block board can be classified according to its structure into two kinds: block board whose core plate with or without glue.

The block board can be classified according to the status into three kinds: the block board with one sanded surface, the block board with both sanded surfaces and the block board without sanded surface.

The block board can be classified into three kinds according to the texture and the processing quality of the board: I , II and III. The standards and sizes of all kinds of block boards are shown in Table 9.6.

Table 9.6 Standards and Sizes of Block boards

length (mm)						width (mm)	thickness (mm)
915	1200	1520	1830	2135	2440		
915	—	—	1830	2135	—	915	16 19
—	1220	—	1830	2135	2440	1220	22 25

Notes: The crane direction of the core plate is the length of the blockb oard.

Performance and technological indexes of block board: the moisture content is 7% ~ 13%; when the thickness of block board is 16mm, the horizontal static bending strength is not less than 15MPa; and when the thickness of blockboard is over 16 mm, it is over 12MPa; and the sharing strength of the glue level is over 1MPa.

The block board is acoustic, heat-proof, hard in texture and easy to be processed. So that it is mainly used for furniture, carriage and indoor decoration.

Questions

9.1 How many kinds are wood classified, what are they? Please list the characteristics and usages of it.

9.2 What are the main components of wood according to its general structure?

9.3 What are the fiber saturation point, equilibrium water content and standard water content of the wood? What practical meanings do they have?

9.4 How can the change of wood moisture affect the capacities of wood?

9.5 What are the factors affecting the strength of wood? How to influence?

9.6 Briefly list the reason of wood rot and the preservative measures.

9.7 What are the common artificial woods? And what about their characteristics and usages?

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10

Waterproof Materials

This unit briefly introduces the composition, structure and technical properties of petroleum asphalt. It also tells about the methods to modify the petroleum asphalt, and focuses on various new waterproof materials.

Through studying this chapter, students should know the composition, structure and technical properties of petroleum asphalt and master the applications of various new waterproof materials and experimental methods of elastic-plastic modified asphalt waterproof membrane.

Waterproof materials are the materials that can prevent seepage of rain, ground water and other kinds of water. Waterproof materials are one of the necessarily important materials in construction. And they are also widely used in irrigation works, roads and bridge buildings.

Waterproof materials, according to their states, can be classified into waterproof paint (such as high polymer modified petroleum asphalt and Synthesis of polymers), sealing material used in architecture (such as asphalt jointing ointment and acrylic acidic jointing ointment), waterproof binding material and waterproof membrane (such as SBS waterproof modified asphalt waterproof membrane, APP modified petroleum waterproof membrane, EPDM waterproof membrane, PVC waterproof membrane, etc.); and waterproof materials according to their structures can also be classified into petroleum asphalt material, waterproof material of asphalt basis, modified waterproof asphalt material and synthetic polymer waterproof material.

10.1 Asphalt

Asphalt is a kind of water-repellent organic binding material, and at room temperature, it is a black or dark brown thick liquid, semisolid or solid. Asphalt is impermeable, bonding, plastic, strike-resistant, chemical etching resistant and electricity insulating. Moreover asphalt can also be used for waterproof membrane, waterproof paint, waterproof ointment, adhesive agent and rustproof and antiseptic paint, etc..

10.1.1 Petroleum Asphalt

Petroleum asphalt is the oil residue after all kinds of light oil (such as gasoline, kerosene and diesel, etc) and lube oil having been refined from petroleum through several procedures such as distillation and other ones. And the oil residue can be made into petroleum asphalt through reprocessing.

1. Components and Structure of Petroleum Asphalt

(1) The Components of Petroleum Asphalt

Petroleum asphalt is a complicated mixture composed of various polymer hydrocarbon and its derivatives. Asphalt is mainly made from carbon and hydrogen, and the carbon takes up 70%~85%, and the hydrogen takes up 10%~15%, and other fraction is made from oxygen, sulfur, and nitrogen which takes up about 5% of the asphalt. Because the asphalt takes the characteristics of isomerism, which means the chemical components of asphalt are the same while the physical mechanical states varies greatly. So that seldom chemical analysis is done on the asphalt. And the analysis on asphalt is done from the perspective of usage, the components with similar chemical structures and concerned with physical mechanical characteristics to certain extent are classified into several groups, and the groups are called components group or group clumps.

The components groups of asphalt are mainly oil composition, resin and ground asphaltene.

1) Oil.

Oil is a kind of brown viscous liquid, from yellow to reddish. Its molecular weight is 100~500, its density is 0.70~1.00 g/cm^3, and its content in asphalt is 40% ~ 60%. Oil composition can dissolve in most organic solvents, except alcohol. Oil determines the plasticity and the adhesive performance of asphalt.

2) Resin.

Resin is a kind of viscous semisolid, from yellow to dark brown. Its molecular weight is 600~1000, its density is 1.0~1.1g/cm^3, and its content in asphalt is 15%~30%. Most of the resins are neutral in nature, and neutral resins can dissolve in chloroform, gasoline, benzene and other organic solvents. In addition, there are also a few kinds of acidic resin, and the content in asphalt is below 10%. The acidic resin is produced after oil composition is oxidized, and it is acidic in nature. The acidic resin is liable to dissolve in alcohol and chloroform, and it is the surfactant of asphalt. The acidic resin improves the adhesive force between asphalt and mineral materials. Resin is the component that determines the adhesive performance of asphalt.

3) Ground Asphaltene.

The ground asphaltene is a kind of shapeless solid powder, from dark brown to pitchy. The molecular weight is 1000 ~ 6000, and the density is 1.1~1.5g/cm^3, and the content is 10% ~ 30%. The ground asphaltene can dissolve carbon disulfide, chloroform and benzene, but can not dissolve in gasoline or petroleum ether. The ground asphaltene is the substance that determines the bonding performance and the temperature stability of asphalt.

Besides the above three main components, there is also a fraction of pitch carbon and carboid, shapeless solid black powder. The molecular weight of this fraction is not high, and the content is also low, normally 2% ~ 3%. These components are produced during the procession because of overheat or deep oxidation dehydrogenation. The pitch carbon and carboid can reduce the bonding performance of asphalt.

Moreover, there is also paraffin in asphalt, which can reduce the bonding performance and plasticity of asphalt, while increase the temperature sensitivity of asphalt. Thus, the paraffin is the harmful substance of asphalt.

(2) The Structure of Petroleum Asphalt

In the colloidal structure of asphalt, oil composition and resin can dissolve each other, resin can infiltrate the ground asphaltene, and resin film may form on the ultrafine particle surface of asphalt. Therefore, the structure of petroleum asphalt is centered by ground asphalt, and around it there is oil composition and resin that forms the micelles. And thousands of micelles spread in the oil composition and the colloidal structure is formed.

The colloidal structure varies due to different content of each composition.

1) Sol Structure.

The content of oil and resin is relatively high, and the distances among the micelles are far, the attraction among the micelles is low, so the fluidity is good. In this case the formed asphalt structure is called sol structure. This kind of asphalt is characterized by the great fluidity, plasticity and temperature sensitivity, but inferior viscosity. The sol structure is liable to heal after cracking.

2) Gel Structure.

The asphalt of the gel structure contains more ground asphaltene and micelles. The distances among the micelles are small and the attraction among the micelles is high, and relatively speaking the fluidity is inferior. This kind of asphalt is characterized by the inferior fluidity, plasticity and temperature sensitivity, but of great viscosity. The gel structure is hard to heal after cracking. And the asphalt of this structure is usually used as architectural petroleum asphalt.

3) Sol-gel Structure.

The asphalt contains appropriate ground asphaltene and micelles, and the distances among micelles are relatively small, and there is certain attraction among them, and the structure between sol structure and gel structure is formed, called sol - gel structure. The characteristics of this structure are between sol structure and gel structure, and the asphalt of this structure is often used as road building.

The structure of petroleum asphalt depends not only on the content of the composition but also on the temperature.

2. Technical Properties of Petroleum Asphalt

(1) Waterproof Property

The asphalt is water-repellent material, and it has compact structure and can't dissolve in water, and meanwhile it has good plasticity, adhesion ability and bond force with mineral materials so that it is assumed to be well waterproof.

(2) Viscosity

Viscosity is a kind of ability reflecting that the materials inside asphalt hinder its fluidity. Viscosity also reflects the hardness and density of asphalt. At room temperature, asphalts in different states have different indexes of viscosity. For the semisolid or solid asphalt at room temperature, penetration is used to express the viscosity; for the liquid asphalt at room temperature, viscosity degree is used to express the viscosity.

Penetration means the depth that the standard needle of the regulated mass (100g) penetrate into the sample after the given time (5s) at the specified temperature (25℃), in the unit of 1/10mm. The deeper the penetration is, the smaller the viscosity will be. Penetration is an important technical index for petroleum asphalt.

Viscosity degree means the time that asphalt of 50cm^3 takes to flow through the pore of the specified diameter (3mm, 5mm or 10mm) at the specified temperature (25℃ or 60℃), expressed by " $C_t^d T$ ". d is the diameter of the pore, t is the temperature of the sample, T is the time that the asphalt of 50cm^3 takes to flow. The bigger the viscosity degree is, the greater the viscosity of asphalt will be.

Viscosity of asphalt is related with the relative content and the temperature of composition. Take it for example, when the content of ground asphaltene is high in the asphalt, then the viscosity increases; and when the temperature decreases the viscosity also increases; and vice versa.

(3) Plasticity

Plasticity means the asphalt deforms without being destroyed in the circumstance of external force, and when the external force is excluded, the asphalt remains the deformed shape, expressed by ductility.

Put the asphalt sample of "∞" standard mould (the minimum section area in the middle is 1cm^2) into the water of 25℃, and stretch it at the speed of 5cm/min, and the elongation when the sample is broken is used to express ductility, in the unit of cm. The bigger the elongation is, the better the plasticity is.

The plasticity of asphalt is related with the composition of asphalt, temperature, thickness, and the drawing speed. When the content of resin is high and the content of other compositions is appropriate, then the asphalt has great plasticity; the plasticity of asphalt increases with the temperature, the thickness of asphalt and the drawing speed.

(4) Temperature Sensitivity

Temperature sensitivity of asphalt means the property that the viscosity and the plasticity of asphalt change with the temperature change. The asphalt is polymer non-crystal material. And asphalt has not certain melting point, and its shape changes (solid→semisolid→liquid; liquid→semisolid→solid) with the temperature change. When the temperature changes at the same rate and the viscosity and the plasticity change little, then it means the temperature sensitivity of asphalt is low, and when the temperature changes at the same rate and the viscosity and the plasticity change much, then it means the temperature sensitivity of asphalt is high.

The property of temperature sensitivity is represented by softening point, which is determined by softening point determinator. First, melt the asphalt and inject it into the standard copper ring (whose diameter is 15.88mm, and height is 6mm). When it is cooled, put a standard steel ball (whose diameter is 9.53mm and weight 3.5g) onto the sample. And then put them into water or glycerol. Then heat the water or glycerol at the fixed heating ratio (5℃/min). And the temperature when the asphalt is softened to droop to a certain length (25.4mm) is the softening point. The higher the softening point is, the lower the temperature sensitivity of asphalt is.

The temperature sensitivity of asphalt is also related with the composition and the content of paraffin. When the content of ground asphaltene in asphalt is high, the temperature sensitivity of asphalt is low, and when the content of paraffin is high in asphalt, the temperature sensitivity of asphalt is high.

(5) The stability of asphalt in atmosphere

The stability of asphalt in atmosphere means the asphalt's property of resisting the aging in the comprehensive environment of heat, sunshine and atmosphere for a long run. In the comprehensive environment of atmosphere, the low molecular groups will be transformed into polymeric group, and the resin transforms into ground asphaltene in a much higher speed than the oil composition into the resin. The oil composition and the resin decrease and the ground asphaltene increases, which reduces the fluidity, plasticity and cohesion of asphalt and increases the hardness and brittleness of asphalt. This phenomenon is called the aging of asphalt. From the assumptions above, it can be seen that the stability of asphalt in atmosphere is the asphalt's property of resisting aging, also called the durability of asphalt.

The stability of asphalt in atmosphere is represented by evaporation loss percentage and needle penetration ratio. First determine the mass weight and the needle penetration of asphalt. And then heat and evaporate the sample for 5 hours in the 160℃, later cool it and determine its mass weight and needle penetration. The percentage of the lost weight during evaporation to the original mass weight is called the evaporation loss percentage, and the ratio of the needle penetration degree to the original needle penetration degree is the needle penetration degree ratio. The lower the evaporation loss percentage is, the higher the stability of asphalt in atmosphere is; the higher the needle penetration ratio is, the higher the stability of asphalt in atmosphere is; and the slower the aging is.

In addition, in order to judge the asphalt quality and ensure the security of engineering, the solubility, the flash point and the ignition point of asphalt should also be learnt.

The solubility of asphalt means the percentage that the asphalt can dissolve in the Trichloroethylene, Carbon Tetrachloride or benzene. It is a measure of active substance in asphalt, called purity of asphalt. The substance that cannot dissolve lowers the property of asphalt, so they are regarded as the harmful substances of asphalt.

The flash point of asphalt means the temperature at which the first flash (with blue light) appears when a mixture of burnable gas and atmosphere produced by asphalt that is heated to a certain temperature contacts with the flame in specific condition

The ignition point of asphalt means the temperature at which a mixture of burnable gas and the atmosphere produced when the asphalt is heated to a certain temperature keeps burning for more than 5 minutes.

The flash point and the ignition point represent the possibility of causing fire. They are closely concerned with the security of carrying, storing, heating and using of asphalt. For example, the flash point of architectural asphalt is normally about 230℃, so the temperature of heating during the process of decocting the asphalt should be controlled between 185～200℃. For the sake of security, the asphalt should be separated from flame during the decocting.

3. The Technical Standards of Petroleum Asphalt

The petroleum asphalt used in the civil engineering is classified into road petroleum asphalt, building petroleum asphalt, water and damp proof petroleum asphalt and normal petroleum asphalt.

The classification of asphalts is according to the penetration, elongation, softening point and other technical standards. The technical standards of various grades and types of asphalt are shown in Table 10.1.

Seen from the Table 10.1, the road asphalt is classified into 7 grades. The more the number of the grade is, the higher the penetration is (the less the viscosity is), the higher the elongation is (the better the plasticity is), the lower the softening point is (the higher the temperature sensitivity is), the better the stability in atmosphere is.

The grades of the water and damp-proof asphalt are classified according to the penetration index, penetration, softening point, breaking point and other technical indexes, and are represented by the value of penetration index. The technical demands of each grade are listed in Table 10.1.

Seen from the Table 10.1, the more the number of the grade is, the higher the penetration is (the less the temperature sensitivity is), the lower the breaking point is, the wider the temperature of using range is, and the better the stability in atmosphere is. The penetration of water and damp-proof asphalt is similar with those of No.30 building petroleum asphalt, but the softening point is 15 ~ 30℃ higher, so the quality of water and damp proof is higher than that of the building petroleum asphalt.

Table 10.1 Technical Indexes of Petroleum Asphalt

Quality index	Road petroleum asphalt (SH1661-92)							Building petroleum asphalt (GB494-85)		Water and damp proof asphalt (SH0002-90)				Normal petroleum asphalt (SH1665-77)		
	200	180	140	100 I	100 II	60 I	60 II	30	10	No.3	No.4	No.5	No.6	75	65	55
Penetration (25, 100g) (1/100 mm)	201 ~ 300	161 ~ 200	121 ~ 160	91 ~ 120	81 ~ 120	51 ~ 80	41 ~ 80	25 ~ 40	10 ~ 25	25 ~ 45	20 ~ 40	20 ~ 40	30 ~ 50	75	65	65
Elongation (25℃) not less than(cm)	—	100	100	90	60	70	40	3	1.5	—	—	—	—	2	1.5	1
Softening point (ring and ball method) (℃)	30 ~ 45	35 ~ 45	38 ~ 48	42 ~ 52	42 ~ 52	45 ~ 55	45 ~ 55	≮70	≮95	≮85	≮90	≮100	≮95	≮60	≮80	≮100
Penetration index[1)]	—		—	—	—	—	—	—	—	3	4	5	6	—	—	—
Solubility (trichloroethylene, chloroform or benzene) not less than (%)	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.5	99.5	98	98	95	92	98	98	98

continued

Quality index	Road petroleum asphalt (SH1661-92)							Building petroleum asphalt (GB494-85)		Water and damp proof asphalt (SH0002-90)				Normal petroleum asphalt (SH1665-77)		
	200	180	140	100 I	100 II	60 I	60 II	30	10	No.3	No.4	No.5	No.6	75	65	55
Evaporation loss	1	1	1	1	1	1	1	1	1	1	1	1	1	—	—	—
Penetration ratio after evaporation	50	60	60	65	65	70	70	65	65	—	—	—	—	—	—	—
Flash point (opening) not lower than(℃)	180	200	230	230	230	230	230	230	230	250	270	270	270	230	230	230
Breaking point not higher than(℃)	—		—	—	—	—	—	reported	reported	-5	-10	-15	-20	—	—	—

Note: *The penetration index is shown in GB4507-4509.*

4. The selection of the petroleum asphalt

The principle of asphalt selection is to select different types and grades of asphalt according to the engineering property (road, building, corrosion resistance), the operated parts and the climate environment. In the case that the selected asphalt meets the main demands of technical property, the asphalt of higher grade should be used to ensure its longer serving age.

Road petroleum asphalt has such properties as low viscosity, good plasticity, etc.. that it is often used to make asphalt concrete or asphalt mortar and often to make road pavement or mill floor. In addition, the road asphalt can also be used as sealing material, bonding agent and asphalt paint. Sometimes in the engineering No. 60 asphalt and building petroleum asphalt are mixed for using.

Building petroleum asphalt has such properties as high viscosity, poor plasticity, low temperature sensitivity, etc. The building petroleum asphalt is mainly used to make waterproof membrane, waterproof paint or asphalt iac that are often used in such engineering as roof or underground waterproofing, groove waterproofing, anticorrosion or pipeline anticorrosion. During the operation, the formed asphalt adhesive film is thick, which increases the temperature sensitivity.

For the roof waterproofing engineering, the asphalt flowing due to softening should be avoided. The temperature of roof waterproof layer is 25 ~ 30 ℃ higher than that in normal environment, especially in the summer. In order to avoid the asphalt flowing, the softening point of the selected asphalt should be 20℃ higher than the local highest roof temperature.

Waterproof asphalt has the property of low temperature sensitivity, so it is particularly fit for waterproof membrane paint or bonding agent of roof and underground waterproofing. Among the damp-proof asphalts, the temperature sensitivity of No. 3 is normal, and it is fit for the interior or underground waterproofing engineering in normal temperature; and the temperature sensitivity of No. 4 is low, and it is fit for the normal stepable flat slope roof waterproofing engineering; and the temperature sensitivity of No. 5 is lower, and it is fit for the waterproofing engineering of exposed roof in normal areas or roof in higher temperature areas; and the temperature sensitivity of No. 6 is the lowest, and it is fit for the roof waterproofing engineering or other waterproofing engineering, especially in cold areas.

Normal petroleum asphalt contains much paraffin (on average the content is more than 5%, and some of the asphalt contains even more than 20%), and has such properties as high temperature sensitivity, low viscosity, poor plasticity. As it is shown above, during the building operation, the asphalt is not used directly, and it can only be used together with other types of petroleum asphalt.

When one grade of asphalt can not meet the demands of technical index, two or three asphalt of the same resource can be used together, and the formula of the two mixing asphalt is as follows:

$$P_1 = \frac{T_2 - T}{T_2 - T_1} \times 100\% \tag{10.1}$$

$$P_2 = 100 - P_1 \tag{10.2}$$

In the formula: P_1 is the content of soft asphalt (%);
P_2 is the content of hard asphalt (%);
T_1 is the softening point of soft asphalt (℃);
T_2 is the softening point of hard asphalt (℃);

T is the demanded softening point (℃).

Take the calculated mixing ratio as the center, conduct more than three groups of experiments in the range of ±5% ~±10% neighborhood, then determine the softening point of the mixed asphalt. Draw the "mixing ratio-softening point" relationship curve on which fix the practical mixing ratio.

10.1.2 The Modified Asphalt

The asphalt used in civil engineering should have good comprehensive properties, such as sufficient strength and thermal stability, and good flexibility in low temperature, property of aging resistance during the circumstance of processing and using, and good cohesion with all kinds of mineral materials. But the asphalt can't meet all these demands itself, and the engineering of waterproof asphalt fails in preventing water seepage, and the service life is short. So the asphalt is often modified through the following methods to meet the demands of engineering.

1. Mineral Filler Modification

The viscosity and the heat resistance of asphalt can be improved by adding some mineral fillers, and by that way the temperature sensitivity of asphalt can also be decreased, and the amount of asphalt used in engineering can also be decreased.

The normally used mineral fillers are in the state of powder or fiber. The powder fillers include talc, limestone powder, dolomite powder, size reduction sand, fly ash and cement. The fiber fillers include asbestos powder and others.

After the mineral filler is added into asphalt, because of the infiltration and the adhesion of asphalt with the surface of mineral fillers, a great number of structural asphalt are formed and for which the stability of asphalt in atmosphere increases while the temperature sensitivity of asphalt decreases.

After the fiber asbestos powder is added into the asphalt, because the asbestos powder is elastic, acid resistant, alkali resistant and heat resistant. The asbestos powder is a poor conductor of heat and electricity, in which there are many microporous that enable the material to absorb oil (asphalt) on a great amount. It can be concluded that the asbestos powder can increase the tensile strength and the heat resistance of asphalt.

The mixing amount of normal mineral filler is 20%~40%.

2. Polymer Modification

The strength, plasticity, heat resistance, cohesiveness and aging resistance of asphalt can be increased through adding polymer to modify the asphalt. And such modified asphalt is often used as waterproof membrane, sealing material and waterproof paint. The normally used synthetic resins in modifying the asphalt mainly include SBS and APP, and sometimes PVC, PE and coumarone resins are also used.

(1) The Styrene-butadiene-styrene (SBS) Modified Asphalt

The styrene-butadiene-styrene (SBS) is a kind of thermoplastic elastomer which has the same elasticity with the rubber in normal temperature, and can be melt to flow at high temperature like plastics, called plastic material. Thus, the SBS modified asphalt is characterized as neither being viscous when being heated nor being fragile when cooled; of great plasticity and property of aging resistance. And the SBS modified asphalt is now the most successfully applied and widely used modified one. The amount of SBS added into the asphalt is normally between 5% ~10%. SBS is normally used in making not only waterproof membranes but also sealing material and waterproof paint.

(2) The Atactic Polypropylene (APP) Modified Asphalt

The atactic polypropylene (APP) is a kind of sticky white substance without obvious melting point. When the atactic polypropylene (APP) is added into asphalt, the property of asphalt can be improved. The atactic polypropylene (APP) modified asphalt is of good elasto-plasticity; good flexibility in low temperature; good abrasion resistance property and aging resistance. The atactic polypropylene (APP) modified asphalt is mainly used as waterproof membrane.

Preparation method: at first heat and melt the asphalt, and add APP into the asphalt, then stir it even with strength.

3. Other Kinds of Modification

(1) The Reclaimed Rubber Modified Asphalt

The reclaimed rubber modified asphalt has certain plasticity and elasticity, with good bonding force, air tightness, flexibility in low temperature and property of aging resistance. In addition, it is inexpensive. The reclaimed rubber modified asphalt can be used as waterproof membrane, waterproof sheet, sealing material, glue and paint.

Preparation method: process the waste rubber into particles whose diameter is 1.5mm or less. And then blend it with asphalt. Finally process the mixture through heating and desulfurization.

In addition, butyl rubber, styrene-butadiene rubber, chloroprene rubber and other rubber can also be used to modify the asphalt.

(2) The Rubber-resin Blending Modified Asphalt

The blending of rubber and resin can modify asphalt, and in that way asphalt can have the properties of rubber as well as resin. The blending of rubber and resin is of good miscibility, so the modification is of good effect.

The blending of rubber, resin and asphalt in the molten state, the polymers of asphalt invade and expand to each other, and the asphalt molecules fill into the gaps among polymer molecules, and meanwhile some connections of polymer molecules expand into the asphalt molecules. And by that way the condensed mixed network structure is formed, and the property of asphalt is greatly improved.

The property of the rubber-resin blending modified asphalt is different for the differences in material variety, ratio and fiberation process. If can be used as waterproof coiled materid, sheet materral, sealing material and wating.

10.2 Waterproof Asphalt Materials

10.2.1 Waterproof Asphalt Paint

The waterproof asphalt paint is the aqueous waterproof asphalt-based material, which uses asphalt as the basic material and the mineral colloid as emulsifier. And then the asphalt and the mineral colloid are blended together and processed through forced mixing. That is how the waterproof asphalt paint is made. The normally used waterproof asphalt-based paints include the lime emulsified asphaltum, the bentonite-asphaltum emulsion, the aqueous waterproof asbestos-asphalt paint, etc. They are used in industrial or civil architectures, especially in roof waterproofing, underground concrete waterproofing and toilet waterproofing. And the grade of waterproofing ranges from grade III to grade IV.

The aqueous waterproof asphalt paint is aqueous in nature, and mono-group in structure. It is characterized as non-poisonous, incombustible and can be used on damp structures. According to the *Waterproof Asphalt Paint* (JC408-91), its properties should meet the needs listed in Table 10.2.

Table 10.2 The Quality Indexes of Waterproof Asphalt Paint (JC408-91)

Index Name		Quality Index
The content of solid (%) (≥)		50
Extensibility (mm) (≥)	unmanaged	5.5
	managed	4.0
Heat resistance (℃)		No flowing, foaming or sliding
Cohesiveness (MPa) (≥)		0.20
Impermeability		No seepage
Frost resistance		Not crack after 20 times of experiments

10.2.2 Architectural Waterproof Asphalt Jointing Ointment

The architectural waterproof asphalt jointing ointment is an ointment material which is based on asphalt and blended with modifier (such as waste rubber powder and sulfide fish oil), diluents (such as pine tar, pine knot heavy oil and engine oil) and fillers (such as asbestos wool and talcum powder). The waterproof asphalt jointing ointment is has good heat resistance, cohesiveness, oil keeping, and flexibility at low temperature. Therefore, the architectural waterproof asphalt jointing ointment is widely used in waterproofing and sealing in various joints between roof boards, hollow slabs and wallboards. In addition, the architectural waterproof asphalt jointing ointment can also be used as the joint sealing material in the expansion joints between concrete running ways, roads, bridges and various architectures.

The architectural waterproof asphalt jointing ointment is classified into six grades. The properties of the architectural waterproof asphalt jointing ointment should meet the demands listed in the *The Architectural Waterproof Asphalt Jointing Ointment* (JC207-76), as is shown in Table 10.3.

Table 10.3 The Requirements for the Technical Properties of Architectural Waterproof Asphalt Jointing Ointment (JC207-76)

Index Name		Grade					
		701	702	703	801	802	803
Heat resistance property	Temperature (℃)	70			80		
	Drooping value (mm) (≥)	4					
Cohesiveness (mm) (≥)		15					
The property of oil keeping	Permeability amplitude (mm) (≥)	5					
	The pieces of permeability (piece) (≤)	4					
Volatilization rate (%) (≤)		2.8					
Construction grade (mm) (≥)		22					
Flexibility in low temperature	Temperature (℃)	-10	-20	-30	-10	-20	-30
	The property of cohesiveness	Qualified					
Cohesiveness after being damped (mm) (≥)		15					

10.3 New Waterproof Materials

10.3.1 New Waterproof Membrane

1. The Polymer Modified Asphalt Waterproof Membrane

The polymer modified asphalt waterproof membrane uses the polymer modified asphalt as overlay; and the fiber felt, fiber fabric and plastic lamina as matrix; and the powder-shaped material, particle-shaped material, piece-shaped material or lamina-shaped material as the surface materials. The materials are made into flaky-shaped waterproof materials, and this kind of materials is called the polymer modified asphalt waterproof membrane.

(1) SBS Modified Asphalt Waterproof Membrane

The SBS modified asphalt waterproof membrane is made through following procedures. First, impregnate the fetus basis into the asphalt or SBS modified asphalt, put the SBS modified asphalt (also named elastic asphalt) overlay onto the both sides, scatter the fine sand, mineral particles (pieces) or polyethylene film onto the upper surface, and cover the fine sand or polyethylene film onto the undersurface (as shown in Figure 10.1). It is a kind of elastic waterproof membrane.

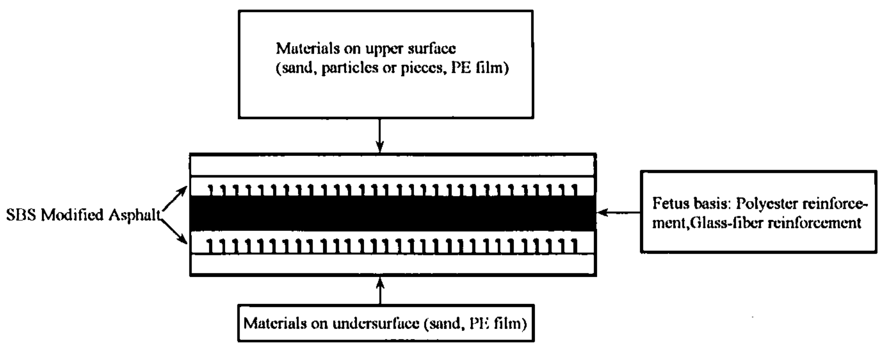

Figure 10.1 The Structure of SBS Modified Asphalt Waterproof Membrance

1) Classifications.

The SBS waterproof modified asphalt coiled materials are classified into two types according to the fetus basis: polyester reinforcement (PY) and glass-fiber reinforcement (G).

The properties of polyester reinforcement: it is the combination of high-qualified fetus basis and modified asphalt, of great comprehensive properties; it can form waterproof layer that is high-strength, tearing-resistant, piercing-resistant, water pressure resistant, antifatigue and self-healing;

meanwhile it has good anti-deformation, elasticity and plasticity and can be used in both high temperature and low temperature (bended in −15~−25℃ without cracking, still waterproof in −50℃); and it is also aging resistant, and can serve for a long period.

The properties of glass-fiber reinforcement: it is usually 3~4mm thick and can form waterproof layer of high strength; it has good comprehensive properties and similar properties as those of SBS modified waterproof asphalt material, such as good elasticity, extensibility, plasticity; meanwhile, it can be used in both high temperature and low temperature (bended in −15~−25℃ without cracking, still waterproof in −50℃); and it is also aging resistant, and can serve for a long period.

According to the material of upper surface the waterproof materials are classified into Polyethylene (PE) film, fine sand (S), and mineral partial (sheet) material (M). And according to the physical properties the waterproof materials can be classified into type Ⅰ and type Ⅱ. The coiled materials are classified into six types, as is shown in Table 10.4.

Table 10.4 Types of Elastic (Plastic) Modified Asphalt Coiled Material (GB18242-2000)(GB18243-2000)

Fetus basis / Upper surface material	Polyester reinforcement	Glass-fiber reinforcement
Polyethylene (PE) film	PY-PE	G-PE
fine sand (S)	PY-S	G-S
mineral partial (sheet) material (M)	PY-M	G-M

2) Specifications and Grades.

SBS modified asphalt coiled material is 1000 mm wide; the coiled materials of polyester reinforcement are 3 mm and 4 mm thick; and the coiled materials of glass-fiber reinforcement are 2 mm, 3 mm and 4 mm thick; and the area of the coiled materials are 15m^2, 10 m^2 and 7.5 m^2.

The coiled materials are labeled in the following order: elastic modified asphalt waterproof membrane, type, fetus basis, upper surface material, thickness and standard text order. For example 3 mm thick sand surface polyester reinforcement type Ⅰ elastic modified asphalt waterproof membrane is labeled as: SBS Ⅰ PY S3 GB 18242.

3) Technical Requirements.

The roll weight, area and thickness should meet the demands listed in Table 10.5; the coiled material should be coiled tightly and regularly. The end face should be flat, and the inlet and outgoing should not be more than 10 mm. There should not be crack or bonding 1000 mm from the center of the coiled rolls in any coiled material at the temperature 4 ~ 50 ℃. The fetus basis should be soaked completely, and there should not be the grains that are not soaked. The surface of the coiled material should be flat, and there should not be holes, defected edge or cracks. The mineral particles should be even and coherent and attached tightly on the surface of the coiled material. The splice on the coiled material should not be more than one, and the shorter part should not be shorter than 1000 mm. The joint should be cut regularly and lengthen by 150 mm; the physical properties should meet the demands listed in Table 10.6.

Table 10.5 Roll Weight, Area and Thickness (GB 18242-2000)(GB18243-2000)

<table>
<tr><td colspan="2">The specification (normal thickness) (mm)</td><td colspan="2">2</td><td colspan="3">3</td><td colspan="6">4</td></tr>
<tr><td colspan="2">Upper surface material</td><td>PE</td><td>S</td><td>PE</td><td>S</td><td>M</td><td>PE</td><td>S</td><td>M</td><td>PE</td><td>S</td><td>M</td></tr>
<tr><td rowspan="2">Area (m^2/roll)</td><td>Normal area</td><td colspan="2">15</td><td colspan="3">10</td><td colspan="3">10</td><td colspan="3">7.5</td></tr>
<tr><td>Deviation</td><td colspan="2">±0.15</td><td colspan="3">±0.10</td><td colspan="3">±0.10</td><td colspan="3">±0.10</td></tr>
<tr><td colspan="2">The minimum roll weight (kg / roll)</td><td>33.0</td><td>37.5</td><td>32.0</td><td>35.0</td><td>40.0</td><td>42.0</td><td>45.0</td><td>50.0</td><td>31.5</td><td>33.0</td><td>37.5</td></tr>
<tr><td rowspan="2">Thickness</td><td>Average value (≥)</td><td colspan="2">2.0</td><td colspan="2">3.0</td><td>3.2</td><td colspan="2">4.0</td><td>4.2</td><td colspan="2">4.0</td><td>4.2</td></tr>
<tr><td>The minimum single value</td><td colspan="2">1.7</td><td colspan="2">2.7</td><td>2.9</td><td colspan="2">3.7</td><td>3.9</td><td colspan="2">3.7</td><td>3.9</td></tr>
</table>

Table 10.6 Physical Properties of Elastic Modified Asphalt Waterproof Membrane

<table>
<tr><td rowspan="2">Serial number</td><td colspan="3">Fetus basis</td><td colspan="2">PY</td><td colspan="2">G</td></tr>
<tr><td colspan="3">Type</td><td>I</td><td>II</td><td>I</td><td>II</td></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Solvable substance content (g/m^2)</td><td colspan="2">2 mm</td><td colspan="2">—</td><td colspan="2">1300</td></tr>
<tr><td colspan="2">3 mm</td><td colspan="4">2100</td></tr>
<tr><td colspan="2">4 mm</td><td colspan="4">2900</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Impermeability</td><td colspan="2">Pressure (MPa) (≥)</td><td colspan="2">0.3</td><td>0.2</td><td>0.3</td></tr>
<tr><td colspan="2">Lasting time (min) (≥)</td><td colspan="4">30</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2" colspan="3">Heat resistance (℃)</td><td>90</td><td>105</td><td>90</td><td>105</td></tr>
<tr><td colspan="4">No fluidity, flowing or drooping</td></tr>
<tr><td rowspan="2">4</td><td rowspan="2">Pull strength (N/50mm)(≥)</td><td colspan="2">Vertical</td><td rowspan="2">450</td><td rowspan="2">800</td><td>350</td><td>500</td></tr>
<tr><td colspan="2">Transverse</td><td>250</td><td>300</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Elongation under the maximum pull strength (%) (≥)</td><td colspan="2">Vertical</td><td rowspan="2">30</td><td rowspan="2">40</td><td rowspan="2" colspan="2">—</td></tr>
<tr><td colspan="2">Transverse</td></tr>
<tr><td rowspan="2">6</td><td rowspan="2" colspan="3">Flexibility in low temperature (℃)</td><td>-18</td><td>-25</td><td>-18</td><td>-25</td></tr>
<tr><td colspan="4">No crack</td></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Breaking strength (N) (≥)</td><td colspan="2">Vertical</td><td rowspan="2">250</td><td rowspan="2">350</td><td>250</td><td>350</td></tr>
<tr><td colspan="2">Transverse</td><td>170</td><td>200</td></tr>
<tr><td rowspan="5">8</td><td rowspan="5">Artificial weathering accelerate aging</td><td rowspan="2" colspan="2">Out looking</td><td colspan="4">Grade one</td></tr>
<tr><td colspan="4">No fluidity, flowing or drooping</td></tr>
<tr><td>Lasting rate of pulling strength (%)(≥)</td><td>vertical</td><td colspan="4">80</td></tr>
<tr><td rowspan="2" colspan="2">Flexibility in low temperature</td><td>-10</td><td>-20</td><td>-10</td><td>-20</td></tr>
<tr><td colspan="4">No crack</td></tr>
</table>

Note: volume 1 ~ 6 of the table are compulsory.

4) Applications.

The SBS modified waterproof asphalt coiled material is used in waterproof engineering in industrial or civil roof, underground or toilet. And it is also widely used in swimming pool, tunnel or reservoir, especially fit for the waterproofing engineering in cold areas or the buildings that transforms frequently. Among them, No.25 and No.35 coiled material can be used in multiple layered waterproofing, and No.45 and No.55 can be used as the surface course of multiple-layered waterproofing or single ply waterproofing. The construction can be done through hot melt method, self-adhered method or cold sticking method with adhesive agent.

(2) APP Modified Waterproof Asphalt Membranes

APP modified waterproof asphalt coiled material is made through following procedures. First, impregnate the fetus basis into the asphalt or APP modified asphalt, scatter the fine sand, mineral particles (pieces) or polyethylene film onto the upper surface, and scatter the fine sand or polyethylene film onto the undersurface. APP modified waterproof asphalt membrane is a kind of plastic waterproof asphalt coiled material, whose fetus basis can be classified into polyester reinforcement and glass-fiber reinforcement. The technical properties of plastic waterproof asphalt coiled material are almost the same as those of elastic waterproof asphalt coiled material, except that the plastic waterproof asphalt coiled material has better property of heat-resistance, but inferior flexibility at low temperature. The specification of APP modified asphalt waterproof membranes are shown in Table 10.4, the roll weight, area and thickness of APP modified asphalt waterproof membrane are shown in Table 10.5. APP modified asphalt waterproof membrane is labeled in the following order: plastic modified asphalt waterproof membrane, type, fetus basis, material of upper level, thickness and standard text order. For example 3mm thick sand surface polyester reinforcement type Ⅰ plastic modified asphalt waterproof membrane is labeled as: APP Ⅰ PY S3 GB 18243.

The technical properties of plastic asphalt waterproof coiled materials are almost the same as those of the elastic asphalt waterproof coiled materials. While the plastic asphalt waterproof coiled materials have the properties such as good heat proof but poor flexibility at low temperature. The plastic asphalt waterproof coiled materials' usage range are also similar with those of the elastic asphalt waterproof coiled materials, while the plastic asphalt waterproof coiled materials are especially fit for the waterproofing engineering in such environment as high temperature, intense sunshine radiation. Plastic asphalt waterproof coiled materials can be managed through hot-melt method, self-adhering method, and they can also be managed through cold sticking method with glues.

The physical and mechanical properties of plastic asphalt waterproof membranes should meet the demands of *plastic asphalt waterproof membranes* (GB18243-2000), as shown in Table 10.7.

Table 10.7 Physical and Mechanical Properties of Plastic Modified Asphalt Waterproof Membrane (GB 18243-2000)

Serial number	Fetus basis			PY		G	
	Type			I	II	I	II
1	Solvable substance content (g/m^2)	2 mm		—		1300	
		3 mm		2100			
		4 mm		2900			
2	impermeability	Pressure (MPa) (≥)		0.3		0.2	0.3
		Lasting time (min) (≥)		30			
3	Heat resistance① (℃)			110	130	110	130
				No fluidity, flowing or drooping			
4	Pull strength (N/50mm) (≥)	Vertical		450	800	350	500
		transverse				250	300
5	Elongation under the maximum pull strength (%)(≥)	Vertical		25	40	—	
		Transverse					
6	Flexibility in low temperature (℃)			-5	-15	-5	-15
				No crack			
7	Breaking strength (N)(≥)	Vertical		250	350	250	350
		Transverse				170	200
8	Artificial weathering accelerate aging	Out looking		Grade one			
				No sliding, flowing or drooping			
		Lasting rate of pulling strength (%)(≥)	Vertical	80			
		Flexibility in low temperature		3	-10	3	-10
				No crack			

Note: Item 1~6 are compulsory.

①If the coiled material with the heat resistance higher than 130℃ is needed, the indexes can be negotiated by suppliers and buyers.

2. Synthetic Polymer Waterproof Membranes

(1) The EPDM rubber waterproof membrane

The EPDM rubber waterproof membrane is a kind of coiled waterproof material with high elasticity, and the procedure of making is as follows. The EPTM rubber is the main precursor, and curing agent, accelerator, softener and filler, etc.. And they are processed through internal mixing, calendaring and extrusion modeling. Then the substance is sulfurized and packed into coiled materials.

The EPTM rubber waterproof membrane has great property of anti-aging, ozone resistance and heat resistance. In addition, it is aging-resistant (usually the service age is over 20 years), lightweight (1.2～2.0kg/m^2),of high tensile strength, high breaking elongation, good flexibility at low temperature and acid and alkali resistance. The EPDM rubber waterproof membrane is a kind of high-grade waterproof material. And its technical properties should meet the needs listed in *The EPTM Rubber Waterproof Membrane* (HG2402-92), shown in Table 10.8.

Table10.8 Requirements for Technical Properties of the EPTM Rubber Waterproof Membrane (HG2402-92)

Index Name	Excellent	Qualified
Tensile strength(MPa) (≥)	8.0	7.0
Breaking elongation (%) (≥)	450	450
Brittleness temperature (℃) (≤)	-45	-40
Impermeability, remains 30min (MPa) (≥)	0.3	0.1

The EPDM rubber waterproof membrane is widely used. It can be used in waterproofing engineering in industrial or civil roof or toilet, whose demands are high and the serving age is long. And it can also be used in the waterproofing engineering in bridge, tunnel, basement, reservoir and other engineering.

The disadvantages of the EPDM rubber waterproof membrane: the EPDM rubber waterproof membrane is nonpolar material, difficult to be bonded. So when seamed, special bonding adhesive made of special material must be chosen, otherwise it may be degummed and leakage may be caused.

(2) PVC Waterproof Plastic Coiled Material

The main material of the PVC waterproof plastic coiled material is PVC resin, and the procedure of making it is like the follows: add fillers and certain modifiers, plasticizer and other promoters, process them through mixing milling, calendaring, extruding and then forming, and finally pack it into coiled materials.

The waterproof PVC coiled materials are classified into P-type and S-type according to their base material and properties. P-type is a kind of plastic coiled material whose base material is plasticized PVC; while the S-type is a kind of flexible coiled material whose base material is the soluble material mixed by coal tar oil and PVC. The waterproof PVC coiled material has such properties as high tensile strength, high breaking elongation, good flexibility at low temperature and long serving age. At the same time, it also has the properties of dimensional stability, heat resistance, corrosion resistance and bacteria resistance. The technical properties of the waterproof PVC coiled material should be in line with *The PVC Waterproof Coiled Material* (GB12952-91), shown in Table 10.9.

Table 10.9 Requirements for Technical Properties of PVC Waterproof Coiled Material (GB12952-91)

Index Name	P-type			S-type	
	Excellent	First-class	Qualified	First-class	Qualified
Tensile strength(MPa) (≥)	15.0	10.0	7.0	5.0	2.0
Breaking elongation (%)(≥)	250	200	150	200	120
Kink resistance in low temperature	−20℃ without cracking				
Leakage resistance (0.2MPa, lasting 24h)	impermeable				

The waterproof PVC material is mainly used in roof waterproofing of construction engineering. And it can also be used in pool or dam and other waterproofing engineering. The construction methods of the waterproof PVC material are bonding method, aerial paving method and mechanical fixing method. And it is accompanied with unique welding technology. And special related matching fits are used in complicated construction parts.

(3) Chlorinated Polyethylene-rubber waterproof coiled material (the regulation of JC/T684 − 97 standard S-type)

The base material of the waterproof chlorinated polyethylene-rubber coiled material, a kind of high elastic waterproof material, is the blended material of chlorinated polyethylene resin and synthetic rubber. It is made as follows: add some curing agent, promoter, stabilizer, softener and filler, etc., and process it through mixing milling, filtering, calendaring or extruding forming, and sulfuration.

The chlorinated polyethylene-rubber waterproof coiled material has the properties of plastics, as well as those of rubber. The properties are as follows: high strength (the tensile strength is over 7.5MPa), ozone resistance, water resistance, corrosion resistance, good aging resistance (the serving age is over 20 years), high breaking elongation (the elongation reaches 450%), and good flexibility at low temperature (brittleness temperature is below −40℃). Thus it is particularly fit for the engineering in low temperature or the engineering whose shape transforms quite a lot. And the chlorinated polyethylene-rubber waterproof coiled material can also be used in the waterproofing engineering of roof, basement or tank with preservative levels. The construction is through cold bonding method with adhesions.

The synthetic polymer waterproof coiled material include chloroprene rubber, EPT/IIR, butyl rubber, chlorinated polyethylene (CPE), Polyethylene (PE), chlorosulfonated polyethylene, Polyethylene — Ethylene propylene terpolymer (EPDM), etc.. besides the three types isted above. Their properties are very different because of the different base materials of which they are made.

10.3.2 New Waterproof Paint

1. Polymer Modified Asphalt Waterproof Paint

The polymer waterproof modified asphalt paint is a kind of waterproof paint whose shape is water emulsion type or solvent type. The base material of the polymer waterproof modified asphalt paint is asphalt, which is modified by high polymer. And the varieties include the regenerated rubber modified asphalt waterproof paint, the water emulsion type chloroprene rubber asphalt waterproof paint and the SBS rubber asphalt waterproof paint.

This kind of paints are modified by the rubber, so that such properties of the paint as the flexibility, crack resistance, tensile strength, high and low temperature resistance and serving age improve quite a lot. And the polymer waterproof modified asphalt paint has the following advantages: quick film forming, high strength, good anti-aging and crack resistance, fire retarding and non-toxic. It can be concluded that the polymer modified asphalt waterproof paint is fit for the roof, floor, basement, toilet and other parts' waterproofing engineering of grade two or inferior waterproof grade.

2. Waterproof Synthetic Polymer Paint

The waterproof synthetic polymer paint is a kind of one-component or multi-component waterproof paint whose main film-forming component is synthetic resin or synthetic rubber. The varieties of the waterproof synthetic polymer paint include the polyurethane waterproof paint, the petroleum asphalt polyurethane waterproof paint, the silicon rubber waterproof paint and the acrylic ester waterproof paint. Compared with the pitch-based modified waterproof material, this kind of waterproof material has better plasticity, elasticity, aging resistance and high temperature resistance.

(1) Polyurethane Waterproof Paint

The polyurethane waterproof paint is two-component reactive paint. Prepolymer containing the isocyanic acid groups composes component Ⅰ, and component Ⅱ is composed by curing agent and plasticizer containing Polyhydroxy, filler and diluent. After component Ⅰ is mixed with component Ⅱ, and after the curing reaction, the even and elastic waterproof film is formed.

This kind of paint transforms from liquid to solid directly by the chemical reaction among components. When curing, the volume almost has no shrinkage, and the thick film is easy to form. The operation is very simple, and the Polyurethane waterproof paint has good properties of elasticity, elongation, anti-aging, oil resistance, wear resistance, ozone resistance, resistance to sea water, non-combustion. The construction thickness is 1.5～2.0mm(when painted for 3～4 times). The serving age is over 10 years. Thus the Polyurethane waterproof paint is widely used in waterproofing engineering, such as mid or high-level toilet, kitchen, water pool, and basement waterproofing engineering or roof with preservative level.

The technical properties of the polyurethane waterproof paint should meet *The Polyurethane Waterproof Paint* (JC500-92), shown in Table 10.10.

Table 10.10 The Main Technical Properties of Polyurethane Waterproof Paint

Grade / The demands of technical index / The name of index		First-class	Qualified
Tensile strength (MPa)		>2.45	>1.65
Breaking elongation(%)		>450	>300
Tensile aging	Aging for heated	No crack or transformation	
	Aging for ultraviolet	No crack or transformation	
Flexibility in low temperature (℃)		-35℃, no crack	-30℃, no crack
Impermeability		0.3MPa, 30min	
Solid content (%)		≥94	
Duration of fit for use (min)		≥20	
Drying time (h)		Surface drying ≤4	Fully drying ≤12

(2) The Petroleum Asphalt Polyurethane Waterproof Paint

The petroleum asphalt polyurethane waterproof paint is a kind of two-component reaction cured type waterproof material with high elasticity and elongation. Component one is composed of carbamate prepolymer, which is made from esserbetol and diisocyanate through hydrogen Transfer and addition polymerization, and the carbamate prepolymer contains isocyanate-group through the procedures above. And the component two is made from curing agent, catalyst (also named accelerator), arranged petroleum asphalt and cosolvent through Vacuum dehydration, mixture stirring, grind dispersing and other procedures. Two components are mixed together by certain ratio, painted onto the surface needing processing, after crossing and curing in normal temperature, and then the film waterproof paint which is non-toxic, non peculiar smell, cohesive, elastic, seamless and whole can be formed.

The scope of application and the technical properties of the petroleum asphalt polyurethane waterproof paint are shown in Table 10.11.

Table 10.11 The Main Properties of Petroleum Asphalt polyurethane Waterproof Paint

Test items		JC500-92standard index		Measured value
		First-class	Qualified	
Solid content (%)		≥94	≥94	94.3
Tensile strength (MPa)	Untreated	≥2.45	≥1.65	3.16
	Heating treated	value Without treatment 80%~150%	Not less than the value Without treatment 80%	128
	Ultraviolet treated	value Without treatment 80%~150%	Not less than the value Without treatment 80%	91
	Alkali treated	value Without treatment 60%~150%	Not less than the value Without treatment 60%	78
	Acid treated	value Without treatment 80%~150%	Not less than the value Without treatment 80%	86
Breaking elongation (%)	Untreated	≥450	≥350	545
	Heating treated	≥300	≥200	578
	Ultraviolet treated	≥300	≥200	512
	Alkali treated	≥300	≥200	543
	Acid treated	≥300	≥200	563
Flexibility in low temperature (℃)	Untreated	-35 no crack	-30 no crack	-35 qualified
	Heating treated	-30 no crack	-25 no crack	-30 qualified
	Ultraviolet treated	-30 no crack	-25 no crack	-30 qualified
	Alkali treated	-30 no crack	-25 no crack	-30 qualified
	Acid treated	-30 no crack	-25 no crack	-30 qualified
impermeability		0.3MPa,30min, impermeable		qualified

1) Compared with coal tar polyurethane waterproof paint, the petroleum asphalt polyurethane waterproof paint has following advantages: low toxicity, little irrigating peculiar smell, little environment pollution, steady properties, aging resistance, etc..

2) Before construction curing, this material is shapeless liquid substance, and it is easy to construct in base surface whose shape is complicated, with crossing pipelines and variable cross-sections. And it is particularly fit for the yin and yang corner, pipeline root, water falling spot, floor drain and the ends of waterproofing engineering. And this kind of product is easy to bond and offers a firm and intense sealing.

3) During the construction, it is easy to form a cohesive, elastic and whole waterproof paint, which is helpful to improve the property of waterproofing and leakage resistance. And the quality of the waterproofing engineering is ensured.

4) The petroleum asphalt polyurethane waterproof paint has enough tensile strength, extension capability and elasticity, which helps the waterproof paint adapt to the transformation or crack of the base surface.

5) Paint waterproofing project belongs cold construction, which is easy to learn and manage, and can avoid the scald in the hot application.

6) The petroleum asphalt polyurethane waterproof paint is mostly fit for the waterproof engineering which is externally protective and externally painted. Such as the waterproof engineering in basement, toilet, bathroom, spray pond, water channel, etc. And it is also fit for the waterproof engineering on the roof with rigid protective course (upper roof and inverted roof).

7) The disadvantage of the petroleum asphalt polyurethane waterproof paint is that it is hard to get the paint even, so during the construction it is necessary to paint it thin but many times and in a crossing way. And the jerry build should be prohibited.

(3) Silicon Rubber Waterproof Paint

1) Composition and Properties.

① Composition.

The silicon rubber waterproof paint is a kind of emulsion waterproof paint, whose base component is silicone rubber emulsion with other synthetic polymer emulsion, added inorganic filler and various promoters.

② Properties.

In common with various other synthetic polymer waterproof materials, the silicon rubber waterproof paint has the good properties of water resistance, high extensibility, high temperature resistance, and chemical microorganism corrosion resistance. The construction method is cold construction and the construction is particularly easy for those complicated parts. The main technical properties are shown in Table 10.12.

Table 10.12 Comprehensive Technical Properties of Silicon Rubber Waterproof Paint

Item	Property
pH	8
Solid content	No.1: 41.8% No.2: 66.0%
Surface drying time	<45min
Viscosity (paint—4 cups)	No.1: 1'08" No.2: 3'54"
Leakage resistance	Upstream surface 1.1～1.5MPa, constant pressure for a week without transformation; negative side water 0.3～0.5MPa
Permeability	Infiltrate into the basal by 0.3mm or so
Crack resistance	4.5～6mm(the thickness of paint 0.4～0.5mm)
Elongation	640%～1000%
Flexibility in low temperature	-30℃ having been frozen 10d circle ϕ3mm with out crack
Tensile strength at break	2.2MPa
tangential breaking strength	81N/cm
Bond strength	0.57MPa
Heat resistance	(100 ± 1)℃ 6h, no hot drum, no abscission
Alkali resistance	Saturated $Ca(OH)_2$ and 0.1%NaOH mixture, temperature15℃ sipping 15d, no hot drum, and no abscission
Damp heat resistance	In the environment that the relative moisture >95%, temperature (50 ± 2)℃ 168h , no hot drum, no wrinkling, no abscission, the elongation remains above 70%
Water absorption	100℃ 5h vacant 9.08% sample 1.92%
Spring rate	>85%
Aging resistance	Artificial aging 168h, no hot drum, no wrinkling, no abscission, the elongation remains over 530%

2) Characteristics and Applications.

① Characteristics.

The silicon rubber waterproof paint is a kind of water emulsion paint whose dispersion medium is water; when the silicon rubber waterproof paint loses water and gets solidified, elastic film is formed; when the paint is painted onto the surface of various basal, with the infiltration and evaporation of water, the density of particles increases and the fluidity of the paint loses; when the drying process continues, the emulsion particles touch each other and become more and more dense; and under the influence of cross-linking agent and promoter, the cross-linking reaction keeps going, and finally the even and dense elastic rubber paint film is formed. Based on the procedure of film forming and the characteristics of silicon rubber emulsion, the silicon rubber waterproof paint has certain permeability and can form the waterproof film with high impermeability; it uses water as its dispersion medium, non toxic, inodorous, non combustible, security; it can be operated on the damp basal, and the waterproof film is formed soon; it is anti-aging, the waterproof film is colorless and transparent; and the silicon rubber waterproof paint can be made into various colors.

②Applications.

It can be used in waterproof and damp-proof engineering of underground engineering, water delivery engineering and water storage engineering; various kitchen, toilet, bathroom and corridor surface in various buildings; roof waterproofing engineering of Grade III or Grade IV; and it can also be used as one of the waterproofing engineering of Grade I or Grade II.

3. Polymer Cement-based Waterproof Paint

The polymer cement-based waterproofing paint is also called compound waterproof paint which is the compound of the copolymer emulsion of polyacrylate emulsion, the copolymer emulsion of ethylene-Vinyl Acetate, various additives and organic liquid as the material, mixed with cement containing high iron and aluminum, quartz, sand and various additives by certain ratio (two component). The liquid material is milky even liquid without any adhesive blocks. The powder material is even gray or white powder without any impurity. And the finished product is even milky or white liquid.

The polymer cement based waterproof paint is nontoxic and harmless, so it can be used in drinking water engineering. The operation is security, easy and short in time. The coating is high elastic and high-strength, and it can also be made into various colors as the construction needs.

The polymer cement based waterproofing paints are classified into two types: type I and type II. Type I is a kind of paint whose main component is waterproof paint, while type II is a kind of paint whose main component is cement. The type I waterproof paint is used in the environment without soaking for a long term, while type Ⅱ waterproof paint is used in the environment soaking in water for a long term.

The order of the polymer cement based waterproofing paint product grade is: name, type, standard number. For example, the grade of type Ⅰ polymer cement based waterproofing paint is:

JS Ⅰ JC/T894-2001

- JC/T894-2001 — Standard Number
- Ⅰ — Type
- JS — The polymer cement-based waterproof paint

The physical and mechanical properties of the polymer cement waterproof paint should meet the demands listed in Table 10.13.

Table 10.13 Physical and Mechanical Properties of Polymer Cement Waterproof paint (JC/T894-2001)

Serial number	Items of experiment		Technical index	
			Type Ⅰ	Type Ⅱ
1	Solid content (%) (≥)		65	
2	Drying time (h)	Surface drying (≤)	4	
		Fully drying (≤)	8	
3	Tensile strength, (MPa) 20℃	Untreated (MPa) (%) (≥)	1.2	1.8
		Retention after heating treatment (%) (≥)	80	80
		Retention after alkali treated (%) (≥)	70	80
		Retention after ultraviolet treated (%) (≥)	80	80[1]
4	Breaking elongation (%) 20℃	Untreated (MPa) (%) (≥)	200	80
		Retention after heating treatment (%) (≥)	150	65
		Retention after alkali treated (%) (≥)	140	65
		Retention after ultraviolet treated (%) (≥)	150	65[1]
5	Flexibility in low temperature, ϕ 10mm bar		−10℃ crack free	—
6	impermeability	pressure, 0.3MPa duration, 30min	impermeable	Impermeable①
7	Bonding strength ② (MPa)	Dry basal (≥)	0.5	1.0
		Damp basal (≥)	—	0.6

① If the product is used in underground engineering, this item needn't be measured.

② If the product is used in underground engineering, this item must be measured.

Waterproof materials vary a lot in type, quality and property, so that it must be adopted properly. As for the materials used in roof waterproofing engineering, they should be chosen according to the property, importance, using function, architectural characteristics, the serving age of waterproof engineering of the building, as well as the standards listed in *The Technical Specification of Roof Engineering* (GB50207-94), shown in Table 10.14.

Table 10.14 Selections of Roof Waterproof Materials

Item	Grade of waterproofing engineering			
	I	II	III	IV
The specification of buildings	Very important civil buildings and industrial buildings with special waterproofing requirement	Important industrial and civil buildings, high-rise buildings	Normal civil and industrial buildings	Non-permanent buildings
The serving age of waterproofing engineering (year)	25	15	10	5
The adopted material for the waterproof layer	Synthetic polymer waterproof membrane, waterproof curly material of high accumulative changeable asphalt, synthetic polymer waterproof paint, fine waterproof cement, etc.	waterproof curly material of high accumulative changeable asphalt, synthetic polymer waterproof paint, polymer modified asphalt waterproof paint, fine stone waterproof cement, flat tile, etc.	waterproof curly material of high accumulative changeable asphalt, synthetic polymer waterproof membrane, polymer modified asphalt waterproof paint, synthetic polymer waterproof paint, asphalt-base waterproof paint, rigid waterproof layer, flat tile, asphalt shingle, etc.	waterproof curly material of high accumulative changeable asphalt, asphalt-base waterproof paint, pentile, etc.
Protection requirement	Three or more waterproof guard, one of them should be made of synthetic polymer waterproof membrane, and there should be only one synthetic waterproof coating which is not thicker than 2mm	Three waterproof guard, and one of them is made of coiled material or profiled steel sheet	One waterproof guard or compound use of two kinds of waterproof materials	Only one waterproof guard

10.3.3 New Building Sealing Material

1. Introduction

The building sealing material is the material, which is embedded into construction joints to reach the target of air-tightness and water-tightness in the circumstance of tolerable displacement. According to the properties, the building sealing materials are classified into elastic sealing material and plastic sealing material; according to the components in use, the sealing materials are classified into one-component sealing material and multi-component sealing material; according to the composing materials, they are classified into modified asphalt sealing material and synthetic polymer sealing material.

The building sealing material should have good properties, such as good air-tightness and water-tightness, good bonding performance, heat resistance and aging resistance, certain elasticity and plasticity, as well as good tension-compression cycling performance.

When choosing sealing materials, surfaces, structures and properties of bonded basal should be considered in the selection of the sealing materials with good properties of bonding. Different joints in the buildings demand different sealing materials. For example, outdoor joints demand the sealing materials with good properties of anti-aging. Expansion joints demand the sealing materials to have good properties of tension-compression cycling performance.

2. Acrylic Sealing Paste

The acrylic sealing paste is made by acrylic resin added into plasticizer, dispersant, calcium carbonate and extender at certain rate. And there are solvent type acrylic sealing paste and water emulsion type acrylic sealing paste.

The acrylic sealing paste produces no pollution to normal building materials (such as brick, mortar, concrete, marble and granite). This kind of sealing material has good properties of ultraviolet resistance, especially to the ultraviolet ray that goes through the windows. The elongation of the acrylic sealing paste is outstanding, and at the early curing stage it is 200% ~ 600%; after heat aging and weathering aging experiment until the sealing paste reaches full curing stage, it is 100% ~ 350%. The sealing paste still has good properties when the temperature is –43~80℃, and it remains satisfactory properties after being used for 17 years in cold areas in Canada and America. The acrylic sealing paste has the property of self-tightness, but the price is lower than that of rubber-type sealing paste, so it is a product of middle price and property.

The properties of water emulsion-type acrylic sealing paste should meet the demands listed in *The Acrylic Building Sealing Paste* (JC484-92), shown in the Table 10.15.

Table 10.15 The Technical Properties of Acrylic Building Sealing Paste (JC484-92)

Index Name		Excellent	First-class	Qualified
Flexibility in low temperature (℃)		-20	-30	-40
Tensile adhesiveness	The maximum tensile strength (MPa)	0.02~0.05		
	The maximum elongation (%) (≥)	400	250	150
tension-compression cycling performance	Grade	7020	7010	7005
	The destroyed area after 2000 times (%) (≤)	25		

Note: In the table, the first two numbers of the grade of the tension-compression cycling performance stand for the heating treatment temperature of the samples. And the last two numbers stand for the tension-compression cycling performance rate. For example: 7020 means the heating treatment temperature of the samples is 70℃, and the tension-compression cycling performance rate is ±20%.

The acrylic sealing paste is mainly used for sealing joints in roof, wallboard, door or window. But its water resistance is poor, so it is not fit for such soaking engineering as pool, water treatment plant, dame or submarine joints. And the property of anti-fatigue of acrylic sealing paste is also poor, so it is not fit for such frequently shocking engineering as square, road, bridge surface and transportation joints.

The acrylic sealing paste is extruded into various clean and dry joints by extruding gun. In order to save the paste, the joint width should not be too big, and normally it is 9~15mm.

3. Polyurethane Sealing Paste

The polyurethane sealing pastes are classified into one-component type and two-component type. And both of them are classified into non-drooping type and self-leveling type, and the paste should be adopted according to different usage. Two-component polyurethane sealing paste should adopt two steps to compound: make the prepolymer with polyisocyanate and polyether through addition polymerization; then add curing agent and promoter in normal temperature to make the building sealing paste of high elasticity through crossing and curing reaction. The polyurethane sealing paste has following advantages: low modulus, high elongation, high elasticity, good viscosity, low temperature resistance, water resistance, acid and alkali resistance, anti-fatigue and long serving age. And among elastic sealing pastes, its price is low.

The polyurethane sealing paste is well cohesive with concrete. Moreover, it is unnecessary to make the ground lay. Although the concrete is porous, it won't influence the adhesion behavior between the polyurethane sealing paste and concrete. Thus, the polyurethane sealing paste is widely used in sealing joints in roof board, external wallboard, settlement joints and expansion joints in concrete buildings; waterproof sealing engineering in balcony, sash, washing room and other parts; joint sealing and leakage repairing of drainage pipeline, reservoir, swimming-pool, road, bridge and other engineering.

The polyurethane sealing paste can be mixed with a lot of diluents, such as coal tar, heavy oil, asphalt, etc. And the polyurethane sealing paste can also be made into waterproof paint. The paint can be painted onto the basal that needs waterproofing, and it is very useful for the newly built or mended engineering.

The technical properties of the polyurethane sealing paste should meet the demands listed in *The Polyurethane Sealing Paste* (JC482-92), shown in Table 10.16.

Table 10.16 Requirements for the Main Properties of Polyurethane Sealing Paste (JC482-92)

Index Name		Excellent	First-class	Qualified
Flexibility in low temperature (℃)		-40	-30	
Tensile adhesivity	The maximum tensile strength (MPa)	0.2		
	the maximum expansion rate (%) (≥)	400	200	
Tension-compression cycling performance	Grade	9030	8020	7020
	The destroyed area after 2000 times (%) (≤)	25		

4. Polysulfide Sealing Compound

The polysulfide sealing compound is a kind of even ointment sealing material which uses the LP liquid polysulfide rubber as the base material mixed with curing agent, plasticizer and filler through the treatment of blending.

The LP liquid polysulfides used to make the polysulfide-sealing compound are classified into four grades: LP-2, LP-12, LP-31 and LP-32.

The curing agents include lead dioxide, magnesium dioxide, titanium dioxide and cumene hydro peroxide.

The fillers can be used to increase the strength, extensibility or cohesiveness of the polymer. The PH value of the fillers in the polysulfide promoters is very important, because the alkaline fillers can promote the vulcanization, while the acidic fillers (such as some kinds of clays) can promote the depolymerization of polymer. Carbon black is the most usually used filler. The $CaCO_3$ powder, the calcinated silicon oxide, the deposited silicate calcium, the lithopone and the aluminum powder all can be used as fillers.

The elasticizers include chlorinated paraffin, esters (dibutyl ester and dinoctyl), ester ethers (propylene glycol dibenzoic esters), ortho-nitrobiphenyl, etc..

The polysulfide-sealing compound has the properties of good adhesiveness, tear-resistance, weathering resistance, oil resistance, heat and damp resistance, water resistance and low temperature resistance. The polysulfide sealing compound can adapt to a wide range of temperature (−40~96℃), and it has a good flexibility in low temperature, in addition it has a strong ability of ultraviolet resistance and ice, snow and water soaking resistance. The polysulfide-sealing compound can be made into different sealing materials according to different irrigability, flow parallel and drooping resistance.

The polysulfide sealing compounds are classified into two types: high modulus low elongation (type A) and low modulus high elongation (type B). And according to the flowing form and state they can be classified into two types: type N and type L. Type N is used in vertical or slanting joint; while type L is used in horizontal joints. The technical properties of the polysulfide sealing compounds should meet the needs listed in *The Polysulfide Sealing Compounds* (JC483-92), shown in the Table 10.17.

Table 10.17 Technical Properties of Polysulfide Sealing Compounds (JC483-92)

Index Name		Type A		Type B		
		First-class	Qualified	Excellent	First-class	Qualified
Flexibility in low temperature (℃)		−30		−40	−30	
Tensile adhesiveness	The maximum tensile strength (MPa)	1.2	0.8	0.2		
	the maximum expansion rate (%) (≥)	100		400	300	200
Tension-compression cycling performance	grade	8020	7010	9030	8020	7010
	The destroyed area after 2000 times (%) (≤)	25				

The polysulfide sealing compound is used in waterproofing and sealing engineering in various buildings, especially in the buildings that are soaked in the water for a long term (such as the reservoir, dam or swimming pool), the engineering in severely cold areas or cold storage, the engineering that sustain fatigue loading (such as bridge, road or airport runway). It is a kind of good sealing material, which is easily operated, and the solvent is not necessary in the operation (if necessary, direct touch with skin should be avoided). The polysulfide-sealing compound is non-toxic and safe to use.

5. Silicon-copper Sealing Paste

The silicon-copper sealing paste, also called organic silicon sealing mastic, is a kind of high elastic building sealing paste using the organic silicon as the base material. The silicon-copper sealing pastes are classified into two types: one-component type and two-component type, and the former one is commonly used. The one-component type silicon-copper sealing paste is mainly made of siloxane polymer, together with curing agent, curing promoter agent and reinforcer. The silicon-copper sealing pastes are classified into acetate type, alcoholic type and amide type.

The silicon-copper sealing paste has outstanding heat resistance and coldness resistance, and its using temperature is –50 ~ 250℃; it has good weathering resistance and the serving age of the silicon-copper sealing paste is over 30 years; and also the paste has good adhesiveness with other materials, with good tensile-compression fatigue resistance and good water resistance.

The technical properties of the silicon-copper sealing paste should meet the demands listed in the *Silicon-copper Sealing Paste* (GB/T14683-93), shown in Table 10.18.

Table 10.18 Requirements for technical properties of Silicon-copper Sealing Paste (GB/T14683-93)

Index Name		Type F		Type G	
		Excellent	Qualified	Excellent	Qualified
Flexibility in low temperature (℃)		-40			
Sadanobu cohesiveness		Sadanobu 200%	Sadanobu 160%	Sadanobu 160%	Sadanobu 125%
		Cohesive destroyed area, not more than 5%			
Tension-compression cycling performance	Grade	9030	8020	9030	8020
	The destroyed area after 2000 times (%) (≤)	25			

F type is fit for the external joints of precast concrete wallboard, cement board, marble board; the bonding between concrete and metal formula; the waterproofing joints sealing between toilet and roads. And G type the silicon-copper sealing paste is fit for the embedding of glass and joint sealing of building door and window.

The properties and the characteristics of the one-component silicon-copper sealing paste are shown in theTable 10.19.

Table 10.19 Properties and Characteristics of One-component Silicon-copper Sealing Paste

Types	Properties and characteristics
Acetic acid removal type	High strength and bonding strength, the acetic acid produced during curing process has irritatant smell, with certain corrosion. The vulcanization is fast, and the storage period is long. Mainly used in glass fixing sealing engineering. Not fit for the joint sealing treatment in metal structure and cement products
Alcohol removal type	No smell, no flavor, no corrosion. Inferior bonding performance. The vulcanization is fast. Easy to store. Neutral. Can be used in joint sealing of metal and normal cement products
Swage removal type	Good comprehensive properties, good bonding performance, no smell, no flavor. But has corrosion effect to copper and some plastics
Amine removal type	Has the special smell of amine, has corrosion effect to copper. The vulcanization property is good, has no corrosion effect to alkali materials. Can be used in the joint sealing treatment of cement product, and can also be used to seal the joints that transform a lot
Ketone removal type	Good property of vulcanization. No smell, no flavor, no corrosion. The surface drying is fast. Can be used to treat the normal joints

Questions

10.1 What influences do the components of asphalt have on its properties?

10.2 What are the main technical properties of asphalt? With what index are they represented?

10.3 Why does the asphalt have the aging effect? How to resist its aging?

10.4 How are the grades of petroleum asphalt classified? What do they represent?

10.5 Suppose there is a roof engineering needs the petroleum asphalt whose softening point is 80℃, and now there are only No.10 and No.60 asphalt at hand. According to the test, the softening point of No.10 asphalt is 95℃, and the softening point of No. 60 is 45℃, how to use the two grades of asphalts?

10.6 Why is modified asphalt used now? And how to modify the asphalt?

10.7 What are the asphalt waterproof paints? What are they?

10.8 What are the asphalt sealing pastes? And what are the normally used asphalt sealing pastes?

10.9 What technical requirements should the new waterproof membranes have?

10.10 Compared with the traditional asphalt waterproof materials, what outstanding advantages does the synthetic polymer waterproof membrane have?

10.11 What is the polymer modified asphalt waterproof paint? What are the usually used types? And what are the advantages of them?

10.12 What is the synthetic polymer waterproof paint? What types of them are usually used?

10.13 What is the polymer cement waterproof paint? How to label the products?

10.14 What property demands does the building sealing material have?

10.15 What are the sealing pastes usually used in building? And what are the functions of them?

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11

Building Plastic

This chapter mainly concentrates on the technological properties of plastic and the applications of building plastic products.

Plastic, a kind of organic synthetic material, are mainly made from the synthetic resin which can be molded into various shapes under certain temperature and pressure and then keeps unchanged in the normal conditions.

Building plastic has the properties of lightweight, high tenacity and multifunction. It follows the trend in development of modern materials and becomes an ideal new material to replace the traditional construction materials, such as steel and wood. Most of the countries in the world are paying much attention to the uses of plastic in construction. With the further development of plastic resources and improvement of technology, the performance of plastic will become better and the cost will decline. Therefore, plastic has broad prospects.

11.1 Components and Classifications of Plastic

11.1.1 The Components of Plastic

Plastic takes synthetic resin as the main raw material which is added by a certain amount of various additives according to needs. There are also several types of plastics without additives, such as organic glass and polyethylene, etc..

1. Synthetic Resin

Synthetic resin, short for resin, is artificial synthesized high molecular polymer. Therefore, different types of plastic can be called after the name of the synthetic resin it is made from.

Synthetic resin, the basic raw material of plastic, takes up 30%~60% or more of its composition. It has the function of agglutination, not only binding itself together, but also the other materials firmly together. As the type, property, and amount of synthetic resin change, the physical and mechanical properties of plastic also change. Therefore, the main properties of plastic depend on the synthetic resin it is made from.

Synthetic resin is organic compound made by combining carbon atom, hydrogen atom, and a small quantity of oxygen atom, sulphur atom through certain chemical bond. According to the different combining forms of carbon atoms in a molecule, the molecular structure of synthetic resin is classified into three geometric shapes: line type, branched chain type, and somatotype (also called reticular type).

According to the different synthetic method during the production, synthetic resin can be classified into polyaddition resin and polycondensate resin.

Polyaddition resin, also called polymerized resin, is made by breaking the unsaturated double bond of monomeric compound through initiator, and combining it again in covalent bond, thus forming a huge polymer molecule. The common polyaddition resins are polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polyvinyl acetate (PVAC), polypropylene (PP), polymethacrylic acid (PMMA), and acrylonitrile butadiene styrene (ABS), etc..

Polycondensate resin, also called condensation resin, is made by combining two or three types of monomeric compounds in functional groups, which is rid of the small molecules after being heated or catalyzed. The common polycondensate resins are phenolic resin (PF), urea formaldehyde resin (UF), epoxy resin (EP), unsaturated polyester (UP), polyurethane resin (PU), and silicone resin (SI).

According to the changes synthetic resin has when being heated, it can be classified into thermoplastic resin and thermosetting resin.

Thermoplastic resin softens when it is heated and then hardens when it cools down. This process can be repeated for several times without changing the property and appearance of the material. The molecular structure of thermoplastic resin is line type and branched chain type. This material contains all the types of polymerized resin and part of the condensation resin. Thermoplastic resin has the advantage of being easily processed and molded. Moreover, it has better mechanical property. The disadvantage is its weak heat resistance and stiffness. Polyvinyl chloride (PVC) and polyethylene (PE) are the representative thermoplastic resin.

Thermosetting resin softens when being heated and in this chemical change the adjacent molecules are closely connected. After it hardens and becomes molded, it won't change the shape or softens even when being heated again. Thermosetting resin can only be molded for one time. The molecular structure of thermosetting resin is somatotype. The majority of the condensation resin belongs to thermosetting resin. It has the advantage of better heat resistance, and the disadvantage of poor mechanical property.

2. Additives

In addition to the synthetic resin, all the other kinds of materials in plastic such as filling material, plasticizer, stabilizer, lubricant, and colorant, are collectively called additives. By adding a certain amount of additives, the properties of plastic can be changed; the processing technique can be improved; and the uses of plastic can also be enhanced.

(1) Filling Material

It is filler for short. By adding filling material to the synthetic resin, the flow between the chains of macromolecular compound can be slowed down; the strength, stiffness, and heat resistance of the synthetic resin can be improved; and the cost of plastic can be lowered. The common inorganic filling materials are talcum powder, diatomite, mica, limestone powder, and glass fiber, etc. The common organic filling materials are wood flour and wastepaper, etc..

(2) Plasticizer

The purpose of adding plasticizer is to improve the plasticity and flexibility of plastic as well as to lessen the brittleness. Plasticizer is either liquid with high boiling point and poor volatilization or solid with low melting point. Plasticizer has the disadvantage of reducing the mechanical properties and heat resistance of plastics. The common plasticizers are dibutyl phthalate (DBP), dioctyl phthalate (DOP), and camphor, etc. .

(3) Stabilizer

When plastic is being molded and used, it may undergone degradation, oxidative scission and cross bonding under the influence of heat, light, or oxygen. Then the color of plastic will fade and the properties will become weak. However, by adding stabilizer, the quality of plastic can be improved and its useful life can also be extended. The common stabilizers are stearic acid, white lead, and epoxide, etc..

(4) Lubricant

When producing plastic, lubricant is added in order to knock it out easily and also to smooth its surface.

In addition to the additives listed above, others can also be added according to need, such as colorant, hardener or curing agent, foaming agent, antistatic agent, and fire retarding agent, etc..

11.1.2 Classifications of Plastic

There are many varieties of plastic and also various classification methods. According to the synthetic method of resin, plastic is classified into polymer plastic and condensate plastic; according to the changes of resin when being heated, plastic is classified into thermoplastic plastic and thermosetting plastic. When the thermoplastic resin, the substrate material, is added by auxiliary materials or additives, thermoplastic plastic can be made. In the same way, when the thermosetting resin is added by auxiliary materials, filling materials, or other additives, thermosetting plastic can be made.

11.2 Properties and Common Varieties of Plastic

11.2.1 The Main Properties of Plastic

1. Light Weight

The density of plastic is usually between 0.8~2.2g/cm^2 approximately 1/5 of the density of steel, 1/2 of that of aluminum, 1/3 of that of concrete, and similar to the density of wood. This not only allows it to lessen the labor intensity, but also to reduce the dead weight of the building.

2. High Specific Strength

The strength of plastic per unit mass approaches or even exceeds that of steel. It is a kind of splendid material with lightweight and better strength.

3. Good Heat Insulation

The thermal conductivity of plastic [about 0.020~0.046W/(m•K)] is low. And that of foam plastic is even lower. Therefore, it is an ideal heat insulating material.

4. Good Processability

Plastic can be made into products with various shapes through simple processes. Thus make it easy to carry out mechanical mass production.

5. Good Ornamentality

Plastic products can be colored and keep fresh for a long period of time. Through photogravure printing, plastic can copy the texture of natural materials, making it difficult to differentiate the genuine from the fake.

In spite of the merits listed above, plastic has many weak points, such as aging easily, flammability, poor heat resistance, and weak stiffness. These weak points can be improved in some way. The aging process can be slowed down by adding a certain amount of stabilizer and high quality pigment; the flammable property can be lessened by adding a little more inorganic mineral filling material; the strength and stiffness can be enhanced greatly by adding fiber reinforced polymer.

11.2.2 The Common Varieties of Building Plastic

1. Polyethylene Plastic (PE)

Polyethylene plastic is made from the polymerized vinyl monomers. Monomer is a kind of simple compound, which can be polymerized to become macromolecular compound. Three ways are used to polymerize the monomer: high-pressure process, middle-pressure process, and low-pressure process. Different ways make different degrees of crystallinity and density. High pressure polyethylene has low crystallinity and density while low-pressure polyethylene has high crystallinity and density. As the crystallinity and density increases, on one hand, the hardness, softening point, and strength increase accordingly; On the other hand, the impact toughness and elongation decrease.

Polyethylene plastic has better chemical stability and water resistance. Even though its strength is not high, it is quite flexible in low temperature. A certain amount of carbon black can strengthen the aging resistance of polyethylene.

2. Polyvinyl Chloride Plastic (PVC)

Polyvinyl chloride plastic is a kind of common building plastic made from the polymerized vinyl chloride monomer. Polyvinyl chloride plastic has better chemical stability and aging resistance, but poor heat resistance. It may decompose and metamorphose if the temperature exceeds 100℃. Usually, it should be used at temperature of below 60~80℃. By adding different amounts of plasticizer, hard and soft polyvinyl chloride plastic can be made.

3. Polystyrene Plastic (PS)

Polystyrene plastic is made from the polymerized styrene monomer. It has the merits of good light transmittance, easy pigmentation, better chemical stability, water resistance, light resistance, easy processing, and low price. However, polystyrene plastic has the disadvantages of weak stiffness, poor impact toughness, weak heat resistance and easy flammability. These weak points set restrictions to its uses.

4. Polypropylene Plastic (PP)

Polypropylene plastic is made from the polymerized acrylic monomer. It has the properties of light weight (density 0.90g/cm^2), strong heat resistance (100~120℃), regular ductility and water resistance. The weak points are that it has poor stiffness in low temperature; and poor air resistance. Therefore, polypropylene plastic is fit to be used indoors. Recent years have seen the rapid development of polypropylene. Polypropylene, together with polyethylene and polyvinyl chloride, has become the main varieties of building plastic.

5. Polymethyl Methacrylate (PMMA)

Thermoplastic resin, also called organic glass, can be made from the polymerized polymethyl methacrylate. It has the advantages of good light transmittance, high strength at low temperature, low water absorption, better heat resistance, better aging resistance, and easy to be processed. However, it has the disadvantages of poor abrasive resistance and high price.

6. Polyester Resin (PR)

Polyester resin is made by condensing diatomic or polybasic alcohol and diatomic or polybasic acid. Polyester resin has the properties of good bonding capacity, elasticity, better colorability, flexibility, heat resistance and water resistance.

7. Phenolic Resin (PF)

Phenolic resin is made by polymerizing phenol and aldehyde under the influence of acid catalyst or alkaline catalyst. Phenolic resin has better cohesional strength, light resistance, water resistance, heat resistance, corrosion resistance, and electrical insulation. However, it has poor stiffness. Phenolic resin, added by filling material and curing agent, can be made into phenolic plastic. Phenolic plastic is smooth, strong, durable, and cheap. It has become a type of commonly used plastic.

8. Organic Silicon Resin (SI)

Organic silicon resin is made by hydrolyzing of one or more types of organic silicon monomer. Organic silicon resin has the properties of heat resistance, cold resistance, water resistance, and corrosion resistance. However, it is poor in mechanical performance and cohesive force. These two weak points can be improved by adding synthetic resin (phenolic aldehyde, epoxy, and polyester), glass fiber, and asbestos, etc..

Table 11.1 is a list of the properties and main uses of building plastic.

continued

Type		Density (g/cm^3)	Linear Expansivity (10^{-5}/C)	Water Absorption (24h) (%)	Heat Resistance Temperature (℃)	Tensile Strength (MPa)	Extensibility (%)	Compression Strength (MPa)	Bending Strength (MPa)	Modulus of Elasticity (MPa)	Properties	Main Uses
Thermoplastic Resin	Polyvinyl Chloride (hard)	1.35~1.45	5~18.5	0.07~0.4	50~70	35~63	20~40	55~90	70~110	2500~4200	Corrosion resistance, electrical insulation, better strength in normal temperature, poor strength in high and low temperature	decorative sheet, accessory parts in construction, pipeline
	Polyvinyl Chloride (soft)	1.3~1.7	–	0.5~1	65~80	7~25	200~400	7~12.5	–	–	Corrosion resistance, electrical insulation, flexible texture, low strength	thin plate, thin film, pipeline, wallpaper, wall cloth, carpet
	Polyethylene	0.92	16~18	<0.015	100	11~13	200~550	–	–	130~250	Corrosion resistance, electrical insulation, water insulation, low strength	Thin plate, thin film, pipeline, cold water tank, electricity-insulating material, various accessory parts
	Polystyrene	1.04~1.07	6~8	0.03~0.05	65~95	35~63	1~1.3	80~110	55~110	2800~4200	Corrosion resistance, electrical insulation, light transmittance, water resistance	Water tank, foamed plastic, various accessory parts
	Polypropylene	0.90~0.91	10.8~11.2	0.03~0.04	100~120	30~63	>200	39~56	42~56	–	Light weight, stiff, ductility, heat resistance, corrosion resistance, poor abrasive resistance, flammability	Pipeline, container, accessory parts, corrosion-resisting lining board etc.

Table 11.1 Properties and Main Uses of Common Building Plastic

Type		Density (g/cm^3)	Linear Expansivity (10^{-5}/C)	Water Absorption (24h) (%)	Heat Resistance Temperature (℃)	Tensile Strength (MPa)	Extensibility (%)	Compression Strength (MPa)	Bending Strength (MPa)	Modulus of Elasticity (MPa)	Properties	Main Uses
Thermosetting Resin	Phenolic Resin	1.25~1.30	2.5~6.0	0.1~0.2	120	49~56	1.0~1.5	70~210	85~105	5300~7000	good electrical insulation, water resistance, light resistance, heat resistance, corrosion resistance, better strength	Electrical material, bonder, coating
	Organic Silicon Resin	1.65~2.00	5~5.8	0.2~0.5	<250	18~30	–	110~170	48~54	–	Heat resistance, cold resistance, corrosion resistance, electrical insulation, water resistance	Heat-resisting and electricity-insulatin material, electrical material, water-resistin material, coating
	Polyester Resin (hard)	1.10~1.45	5.5~10	0.15~0.6	120	42~70	<5	90~225	60~130	2100~4500	Corrosion resistance, electrical insulation, heat insulation, light transmission	glass fiber reinforced plastics, variou accessory parts

11.3 Applications of Building Plastic

11.3.1 Plastic Doors and Windows

Plastic doors and windows are mainly made from polyvinyl chloride resin (PVC). By blending the polyvinyl chloride resin with a certain amount of additives, various profiles can be made through the pressing process. Then the doors and windows of buildings are made by processing these profiles.

Plastic doors and windows can be classified into wholly plastic, composite, and polyurethane door and window, with the wholly plastic being in the majority. The plastic door and window is made of the assembled PVC hollow profiles. The color can be white, dark brown, two-color, and wood-like.

Compared with the other kinds of doors and windows, plastic doors and windows have the advantages of water resistance, corrosion resistance, air impermeability, water tightness, heat insulation, sound insulation, burning resistance, dimensional stability, and decorativeness, etc. Furthermore, it needs no painting, is easy to maintain, and can save a lot of energy. It is widely used abroad at the present time. Considering the condition of China and basing on the overseas experience, replacing wooden and metal doors and windows gradually with the plastic is an important way to save wood, steel, aluminum, and energy.

11.3.2 Plastic Pipes

Compared with the metal pipes, plastic pipes have the advantages of light weight, rustproof, unfitness for moss to grow, not begriming easily, smoothness in tube wall, small resistance to fluid, easiness of processing, and energy saving, etc. Recent years have seen rapid development in the production and application of plastic pipes. They are in the majority of building plastic products.

Plastic pipes can be classified into rigid tubes and flexible tubes. According to the raw materials, they can be classified into polyvinyl chloride pipe, polyethylene pipe, polypropylene pipe, ABS pipe, polybutylene pipe, and glass reinforced plastic pipe. Most of plastic pipes are made by using polyvinyl chloride resin which is blended with a proper amount of additives, and then molded through injection machine and extruding machine. Plastic pipe thus made is usually called PVC plastic pipes, which is plastic pipe for short. There are various plastic pipes, such as drain pipe, rainwater pipe, water supply pipe, corrugated pipe, wire pipe, gas pipe, etc..

11.3.3 Plastic Wallpaper

Wallpaper is the most widely used wall surface decorative material. Plastic wallpaper, in particular, is various and fresh in its patterns. Using the technique of printing and foaming, plastic wallpaper can copy the texture of wood, stone, brocade, textile, ceramic tile, and common brick, etc. If the processes go on well, no one can tell the genuine from the fake. Therefore, plastic wallpaper makes it much easier for interior decoration.

There are many ways to classify the wallpaper. According to the different raw materials, it can be classified into the following types.

1. Wallpaper of Paper Surface and Bottom

This is the earliest kind of wallpaper made by embossing or printing patterns on the paper surface. It has the advantages of better air permeability, easiness to release the moisture stored in the wall, exemption from discoloration and swelling, as well as low price. However, it is hard to clean, easy to crack, and is not water resistant. Right now, this kind of wallpaper is not produced much.

2. Wallpaper of Textile

This kind of wallpaper is made of the fiber materials, such as silk, wool and linen. It may create an amiable, cozy, and comfortable environment, giving people a feeling of elegance. However, it is quite expensive.

3. Wallpaper of Natural Materials

This kind of wallpaper is made of grass, leaves, and wood. It is plain, natural, lifeful and without the artificial decoration. It is popular with the urban dwellers that live in the downtown or far away from the natural environment. However, it is not durable.

4. Plastic Wallpaper

This kind of wallpaper is fast developing and most widely used.

Plastic wallpaper can be classified into three types: common wallpaper, foamed wallpaper, and special wallpaper.

(1) The Common Wallpaper

It is also called wallpaper of plastic surface and paper bottom. It is made of paper coated with a layer of plastic. In order to bring out better decorative effect, patterns are often embossed or printed on the paper surface before a layer plastic is coated. This kind of wallpaper is water resistant, easy to be cleaned, durable and cheap.

(2) Foamed Wallpaper

It is made by coating the paper surface with a layer of foam plastic. This kind of wallpaper gives strong stereoscopic impression. It is sound absorbing, thus having better sound effects.

In order to strengthen its cohesive force and improve its strength, cotton cloth, linen cloth, and chemical fiber cloth can be used to replace the paper bottom. Foamed wallpaper thus made is called foamed wall cloth. By sticking the foamed wall cloth to the wall, it will not come off easily, and won't crack when being hit. Moreover, it is cheap and can be produced easily. Therefore, the foamed wall cloth is much favored.

(3) Special Wallpaper

Special wallpaper is made for specific needs. It is also called functional wallpaper, such as water-resisting wallpaper, fireproofing wallpaper, corrosion-resisting wallpaper, plastic granular wallpaper, and metal matrix wallpaper, etc..

Plastic granular wallpaper is easy to be stuck. It has some heat-resisting and sound-absorbing effect. Moreover, it can be cleaned easily.

Metal matrix wallpaper is energy saving.

Recent years see the production of electrostatic flocking wallpaper which is printed with patterns, decorative, feeling well, but quite expensive.

11.3.4 Plastic Floor

Compared with the traditional floor, plastic floor has the advantages of light weight, beautiful appearance, abrasion resistance, damp proof, fire proof, sound absorption, heat insulation, elasticity. In addition to these, it is also easy to be processed, cleaned and maintained. During recent years, it has already become one of the main ground decoration materials.

There are various types of plastic floor. According to the resin used, plastic floor can be classified into polyvinyl chloride plastic floor, vinyl chloride—vinyl acetate plastic floor, polythene plastic floor, and polypropene plastic floor. At the present, polyvinyl chloride plastic floor is in the majority.

According to the shape, plastic floor can be classified into floor tiles and floor rolls. Plastic floor tiles can be pieced together to create different colors and patterns. Therefore, it has good decorative effect and is easy to be repaired partially. Plastic floor rolls can be laid quickly and efficiently. According to the texture, plastic floor can be classified into semi-rigid and soft. Semi-rigid plastic floor is the most widely used at the present for its advantages of low cost, dimensional stability, heat resistance, abrasion resistance, good decorative quality, and easiness to be stuck. Soft plastic floor has good elasticity. It is a comfortable experience to walk on it. Moreover, it also has the merits of heat insulation, sound absorption, and moist insulation. According to the structure, plastic floor can be classified into monolayer and multilayer. Plastic floor of monolayer usually belongs to low-foamed floor. The monolayer floor is about 3~4mm in thickness. Its surface can be embossed with ridge design. It has the advantages of abrasion resistance, impact resistance, and skid resistance. However, its defects are poor elasticity, heat insulation, and sound absorption. The multilayer plastic floor usually has three layers: upper, middle, and lower. The upper layer is abrasion resistant and durable; the middle layer is elastic foaming layer; the lower layer is the base layer with many filling materials. The three layers are stuck together through hot-pressing. Multilayer plastic floor has the properties of elasticity, comfortable feeling, heat insulation and sound absorption.

In addition, there is seamless plastic floor, also called plastic coating ground. It has the properties of seamlessness, easiness to be cleaned, corrosion resistance, leakage proof, impermeability, and simple processing. It is suitable to be cast-in-place, used to renew the old one, and used in laboratory and hospital where the floor is easy to be corroded.

By adding a certain amount of asbestos, the asbestos plastic floor has the properties of abrasion resistance, corrosion resistance, poor flammability, self-extinguishing, and good elasticity. It is suitable for the hotels, restaurants, civilian or public buildings.

Rubber floor takes natural rubber, synthetic rubber or regenerated rubber as the principal raw material. This makes rubber floor has the properties of abrasion resistance, sound absorption, elasticity, impact resistance, and electrical insulation. But it has poor heat insulating property. Therefore rubber floor is suitable for the public buildings or industrial factory buildings which set low demand on such a property.

Antistatic plastic floor has the properties of light weight, corrosion resistance, fire proof and antistatic. It is suitable for the computer room, post and telecommunication office, or other buildings which have anti-static requirements and high demand on the air-conditioner.

When laying the plastic floor, the base ground should be dry and smooth. Wastes on the ground must be removed. Furthermore, the plastic floor should be flat and true-to-size. If curling and rake angle occur, it needs to be pressed flat first, and then the damaged corner is dealt with.

The binder used by the plastic floor has two types in China: the solvent and emulsion. Generally, the floor and binder are sold together. Instructions must be followed to carry out the work. Otherwise, the quality will be affected.

11.3.5 Other Plastic Products

1. Plastic Veneer

It can be classified into rigid, semi-rigid and soft plastic veneer. Its surface could be printed with various patterns like wood grain and stone grain. It may also be coated with decorative paper, plastic film, glass cloth and aluminum foil. It can also be embossed with spots, concave-convex patterns, and other various three-dimensional contours. When the raw material is added by fluorescent pigment, fluorescent plastic plate can be made. This type of plastic veneer has the properties of light weight, heat insulation, sound absorption, water resistance, and decorativeness. Moreover, it suitable for the interior wall and suspended ceiling.

2. Glass Fiber Reinforced Plastics

It has the properties of light weight, water resistance, high strength, corrosion resistance, and decorativeness. It is suitable to be used as lighting and decorative sheet.

3. Plastic Film

It has the properties of water resistance, corrosion resistance, and high extensibility. It can be printed and be bound together with veneer, fiberboard, plasterboard, paper, and glass cloth, etc. Plastic film can be used as interior decoration material. In addition to that, it can also be used as water proofing material and cement-maintaining material.

4. Synthetic fiber reinforced film

It is the main raw material used in building aerated house. It has the properties of light weight, airtight, heat insulation, and easiness to be transported. It is suitable for the exhibition hall, gymnasium, agricultural greenhouse, temporary granary, and other kinds of temporary buildings.

Questions

11.1 What are the properties of building plastic?

11.2 What is the composition of plastic?

11.3 Explain the following terms: polymerized resin, thermoplastic resin, and thermosetting resin, thermoplastic plastic and thermosetting plastic.

11.4 Tell briefly the main properties of plastic.

11.5 What are the common types of building plastic?

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12

Heat-insulating Materials and Sound-absorbing Materials

This chapter mainly discusses the basic properties of the heat-insulating materials and sound-absorbing materials and introduces several varieties of them which are commonly used in construction.

Students are required to select and use the heat-insulating materials and sound-absorbing materials properly after studying this chapter.

12.1 Heat-insulating Materials

12.1.1 The Basic Properties of Heat-insulating Material

In architecture, the material which prevents the outflow of indoor heat is normally called adiabator. On the other hand, the material which prevents the inflow of outdoor heat is called heat insulator. These two are collectively called heat-insulating materials.

This kind of material is mainly used for walls, ceilings, thermal equipments and thermal pipelines. It is sometimes used to preserve heat in winter construction. Generally, it may also be used a lot for refrigerating chamber and equipments.

It is known that heat current flows from high temperature to low temperature. In order to keep the room warm in winter, constant indoor heat supply must be provided to compensate for the heat loss due to the temperature difference. This problem can be partly addressed by using the heat-insulating material. For example, a six-storey residential building of four units in Beijing, China, uses the frame structure of mineral cotton composite plate, and this reduces the heat loss by 40% compared with masonry-concrete structure. According to the statistics, a good insulation building can cut down the fuel consumption by 25% ~ 50%. And to achieve this, one should consider the following questions: what kind of structure is easy to lose heat, and vice versa; how the composition of the material relates to its heat-insulating property; what are the factors that influence the material's heat-insulating property, and how to select the proper material.

Exterior protected construction is made of different building materials, the thermal conductivity and specific heat of which are the important parameters to the designation of the wall, roof, floor, and to the heat engineering calculation. The material with low thermal conductivity and high specific heat can improve the heat-insulating property of the exterior protected construction and keep the indoor temperature stable. For more details, please refer to Chapter Two.

The basic requirement for selecting heat-insulating material is that the thermal conductivity is well below 0.23W/ (m•K), the apparent density below 600kg/m^3, and the compression strength above 0.3MPa. Moreover, the material's hygroscopicity, temperature stability, and corrosion resistance all need taking into account according to the characteristics of the project.

The following is an introduction of the basic properties of the heat-insulating material.

1. Thermal Conductivity

Thermal conductivity is the measurement of the heat transfer ability of the material itself. It is influenced by the material constitution, porosity, temperature of the surroundings, and the direction of the heat current.

(1) The Material Constitution

The thermal conductivity can be influenced by the material's chemical composition and molecular structure. Material with simple chemical composition and molecular structure has higher thermal conductivity than the complex.

(2) Porosity

The thermal conductivity of solid matter is higher than that of air. Therefore, the higher the porosity is, the lower the thermal conductivity will be. In this aspect, not only the porosity matters, but also the size, distribution, shape, and connectivity of the pores.

(3) Humidity

Materials in damp conditions have higher thermal conductivity. What should be noted is that if water is frozen, its thermal conductivity will become higher. This is because the thermal conductivity of water is 20 times higher than that of air while that of ice is 80 times higher than air. Therefore, special attention should be taken to guard the heat insulating material against damp.

(4) Temperature

If the temperature becomes higher, the thermal conductivity increases accordingly. As the temperature rises, the thermal motion of the molecular solids becomes more active; the heat conduction of the air in the pore gets boosted, and the radiation effect of the pore wall is strengthened.

(5) The Direction of Heat Current

In case of the material being anisotropic (like the fibrous material wood), when the heat current flows parallel to the fibers, there will be no strong resistance; However, when the heat current flows against the fibers, strong resistance will be incurred.

2. Temperature Stability

Temperature stability is the ability of the material to retain its original property when exposed to heat. It is generally expressed by the ultimate temperature, exceeding the point of which the material will lose its heat-insulating function.

3. Strength

The heat insulating material is usually measured by its compression strength and flexural strength. As the material is highly porous, its strength is weak. Thus it is better not to allow the heat insulating material to carry more weight.

12.1.2 Common Heat-insulating Materials and Their Functions

Commonly used heat insulating materials can be divided into two types: organic and inorganic. The inorganic, often granular, fibrous or porous, is made from minerals.

1. Inorganic Fibrous Heat-insulating Materials

(1) Glass Wool and the Relative Products

Glass wool is a kind of fibrous material made from the melted glass raw materials or cullet. It consists of two types: loose wool and superfine wool. The fiber of the loose wool is 50 ~ 150mm in length and 12×10^{-3}mm in diameter. By contrast, the fiber of the superfine wool is much thinner in diameter, normally under 4×10^{-3}mm. And it is also called superfine glass wool.

The loose wool can be used to make asphalt-bonded glass blanket and glass wool board. The superfine glass wool can be used to make common superfine glass blanket, glass wool board, alkali free superfine glass blanket, hyperoxic silica superfine glass blanket, and it is also used to preserve heat in the exterior-protected construction and the pipelines.

(2) Mineral Cotton and the Relative Products

Mineral cotton takes the industrial waste and slag as its main raw material. After being melted, these waste and slag are made into cotton-silk like heat-insulating material through blowing or centrifugal process. The mineral cotton is light in weight, non-combustible, heat-insulating and electric-insulating. Moreover, its raw material is cheap and has a rich source. The mineral cotton can be used to make mineral wool board, mineral wool waterproof felt, and pipe shroud, etc. In addition to these, it can also be used to build walls, roofs, and ceilings in order to preserve heat and absorb sound.

2. Inorganic Granular Heat-insulating Materials

(1) Expanded Vermiculite and the Relative Products

Expanded vermiculite, made by roasting the vermiculite until it gets expanded, is a kind of loose granular material. The stacking density of this material is 80 ~ 200kg/m^3, λ=0.046 ~ 0.07W/(m•K), And the temperature limit is 1000 ~ 1100℃. Expanded vermiculite can be used to preserve heat in walls, floor slabs, and flat roofs. However, it should be guarded against damp when being used.

Expanded vermiculite, blended with cement, water glass or other cementitious material, can be made into slabs which are utilized in the wall, floor slab, and flat roof. The relative cement composite (cement accounting for 10% ~ 15%, while expanded vermiculite accounting for 85% ~ 90%) is made through the blending, molding, and maintaining process. On the other hand, the relative water glass composite is made by blending the expanded vermiculite, water glass, and adequate sodium fluorosilicate together.

(2) Expanded Perlite and the Relative Products

Expanded perlite, honey-comb like or bubble-like, white or grayish-white granules, is made by calcining the natural perlite. It is high-efficient heat insulating material, and has the advantages of light weight, good performance in low temperature, better hygroscopicity, better chemical stability, incombustibility, corrosion resistance, and easy application, etc. In construction, expanded perlite is widely utilized in exterior protected construction, low- temperature insulation equipments, thermal equipments, and also sound-absorbing products.

The relative expanded perlite products contain, for the most part, expanded perlite, and a certain amount of cementitious materials, such as cement, water glass, phosphate, and asphalt, etc. The products are made through the processes of blending, molding, and maintaining (drying or solidifying) and take the shape of slab, chunk, and tube.

3. Inorganic Porous Heat-insulating Materials

(1) Foamed Concrete

Foamed concrete is a mixture of cement, water and colophony foamable composition. It is porous concrete made through the blending, molding, maintaining, and hardening processes. The foamed concrete has the properties of porousness, light weight, heat preservation, heat insulation, and sound absorption. Fly ash foamed concrete can be made out of fly ash, lime, gypsum, and foamable composition. And this material can be used to preserve heat in the exterior protected construction.

(2) Aerated concrete

Aerated concrete is a compound of cement, lime, fly ash, and gas former (aluminum powder). It is a high-efficient heat- insulating material made through the molding and steam curing processes. It has the properties of heat preservation, heat insulation, and sound absorption. The apparent density of the aerated concrete is small and the thermal conductivity of it is even several times smaller than that of the clay brick. Therefore, the aerated concrete wall of 24cm wide is better than the brick wall of 37cm wide. Moreover, the aerated concrete has strong fire resistance.

(3) Diatomite

Diatomite is the remains of a water plant called diatom and is made of diatom test which is constituted by lots of tiny pores. The porosity of diatomite is 50% ~ 80%, which explains why it has excellent heat insulating property. The chemical composition of diatomite is hydrous amorphous silicon dioxide; its thermal conductivity is λ=0.060W/ (m•K); and its maximum operation temperature is 900℃. Diatomite is constantly used as filling material or used to make diatomite brick.

(4) Micro-porous Sodium Silicate

Micro-porous sodium silicate is a kind of new material. It is made of 65% of diatomite, 35% of lime, and 5% of asbestos, water glass, and water in proportion to the whole weight of diatomite and lime. This mixture must go through a series of processes like blending, molding, steam pressing and drying. Micro-porous sodium silicate can be utilized in exterior-protected construction and pipeline. And it is better than expanded perlite and expanded vermiculite in the heat-preserving aspect.

(5) Foam Glass

Foam glass takes cullet and one or two types of adjuvant (foaming agent, limestone, calcium carbide, or coke) as the raw material. After grinding, blending, and fitting die, the raw material is roasted at the temperature of 800 ℃ until a lot of closed and disconnected pores are formed. The porosity of the foam glass reaches high up to 80% ~ 90%, and the diameter of each pore is 0.1 ~ 5mm. The foam glass has the properties of low thermal conductivity, high compression strength, high frost resistance, and better durability. This material can be used to build walls, regulate heat in refrigerating equipment, or used as floating and filtering material. It is an advanced heat insulating material, easy to be cut and cemented.

4. Organic Heat-insulating Materials

Organic heat-insulating material takes organic materials as its raw material. Lightweight panel can be only used in low temperature for it is porous, highly hygroscopic, but not durable and not highly temperature-resistant.

(1) Foamed Plastics

Foamed plastics take all kinds of resin as the raw material. With certain amount of auxiliary materials such as foaming agent, catalyst, and stabilizer, the resins are heated until foams appear. Foamed plastics are a new type with the properties of lightweight, heat preservation, sound absorption, and quakeproof. This material can be used in wall and cold storage insulation, and can also be used to make sandwich board. At present, the relative products are polystyrene foamed plastics, polyvinyl chloride foamed plastics, Pentaerythrite foamed plastics and urea formaldehyde foamed plastics. The rigid foam is often used in construction.

(2) Vegetable Fiber Insulation Board

Among the different kinds of boards whose main component is vegetable fiber, low density fiberboards are often used as heat insulating material.

1) Cork Board. Cork board is made of the bark of Shuan tree and pineapple tree. After the bark being crushed, blended with the hide glue solution, pressed and molded, it is dried for a whole day in a drying chamber, the temperature of which is set at 80℃. Cork board is known for its light weight, low thermal conductivity, impermeability, and high corrosion resistance.

2) Wood Fiber Board. Wood fiber board takes the regular wood wool as its raw material, which, in its turn, is made of the leftover bits of wood. Firstly, the wood wool is blended with sodium silicate solution and common silicate cement, and then the compound goes through a series of processes: molding, cold pressing, maintaining, and drying. The wood fiber is often used to make ceilings, partition boards, or wall panels.

3) Celotex. Celotex takes Bagasse as its raw material. Celotex is made through the processes of steaming and drying. It has the properties of light weight, sound absorption, and heat insulation.

4) Perforated Plate. Perforated plate, also called honeycomb sandwich structure, is made by fixing two thin panels, each by one side, to a thick layer of honeycomb-like core material. The core material is a hexagonal hollow slab made by cementing together the Kraft paper and glass cloth or aluminum sheet, which have been soaked in the synthetic resin (phenolic aldehyde, polyester, etc.). The panels are made of the Kraft paper, glass cloth, veneer board, fiber board, and plaster board, etc, which are all soaked in the resin. The panels must be glued to the core material firmly by the proper adhesive. Perforated plate has the properties of great strength, low thermal conductivity and better shock resistance. It can be used to make light strong structural board, and also products with good heat insulation property, such as sound-insulating materials and other non-structural boards. Its heat insulation property will be enhanced if the core material is replaced by the foamed plastics.

(3) Adiabatic Diaphragm for Windows

Adiabatic diaphragm for windows, also called neotype heat-protector, is 12 ~ 50μm thick. This material is utilized in the window insulation. It is used to prevent sunshine from entering and the color of the furniture from fading. Moreover, it can reduce the heat loss in winter, thus save the energy and create a comfortable environment. Adiabatic diaphragm is stuck to the glass, and works to reflect outwards a majority of the sunshine which has permeated. The reflectivity is as high as 80%. In addition to this, adiabatic diaphragm can reduce the permeation rate of ultraviolet rays; alleviate the harm of ultraviolet radiation to the furniture and textile; regulate the temperature changes indoors; and overcome the non-uniformity in the appearance of the building. It can also prevent the broken glass from flying to wound people.

Adiabatic diaphragm is generally used in window insulation of commercial and industrial buildings, public buildings, apartments, and hotels, etc. It is also used to protect the artworks and paintings in the museum from ultraviolet harm. At present, some hotels in Beijing and Guangzhou have already started to use it.

12.1.3 Technical Properties of Common Heat-insulating Materials

Table 12.1 shows the technical properties of common heat-insulating materials.

Table12.1 Technical Parameters of Common Heat Insulating Materials

Name	Surface Density(kg/m^3)	Strength (MPa)	Thermal Conductivity [W/(m•K)]	Uses
Expanded Perlite	40 ~ 300		Normal Temperature 0.02 ~ 0.044 High Temperature 0.06 ~ 0.17 Low Temperature 0.02 ~ 0.038	High-efficient filling material heat insulation cold insulation
Cement Expanded Perlite	300 ~ 400	f_c0.5 ~ 1.0	Normal Temperature 0.05 ~ 0.081 Low Temperature 0.081 ~ 0.12	Heat Preservation Heat Insulation
Water Glass Expanded Perlite	200 ~ 300	f_c0.6 ~ 1.2	Normal Temperature 0.056 ~ 0.065	Heat Preservation Heat Insulation
Asphalt Expanded Perlite	400 ~ 500	f_c0.2 ~ 1.2	0.093 ~ 0.12	Used in normal temperature or negative temperature
Cement Expanded Vermiculite	300 ~ 500	f_c0.2 ~ 1.0	0.076 ~ 0.105	Heat Preservation Heat Insulation
Micro Porous Calcium Silicate Product	250	f_c>0.5 f_t>0.3	0.041	Heat insulation of exterior protected construction and pipeline

continued

Name	Surface Density(kg/m^3)	Strength (MPa)	Thermal Conductivity [W/(m•K)]	Uses
Foamed Concrete	300 ~ 500	f_c≥0.4	0.081 ~ 0.19	Exterior protected construction
Aerated Concrete	400 ~ 700	f_c≥0.4	0.093 ~ 0.16	Exterior protected construction
Wood Fiber Board	300 ~ 600	f_t0.4 ~ 0.5	0.11 ~ 0.26	Ceiling, Partition Board, Wall Panel
Soft Fiber Board	150 ~ 400		0.047 ~ 0.093	Ditto Smooth surface
Reed Board	250 ~ 400		0.093 ~ 0.13	Ceiling Partition Board
Cork Board	150 ~ 350	f_t0.15 ~ 2.5	0.052 ~ 0.70	Low water absorption non-corrosion non-combustion Heat insulation
Polystyrene Foamed Plastics	20 ~ 50	f_t=0.15	0.031 ~ 0.047	Heat insulation of roof and wall
Hard Polyurethane Foamed Plastics	30 ~ 40	f_c≥0.2	0.037 ~ 0.055	Heat preservation of roof and wall Heat insulation of cold storage
Glass Fiber Product	120 ~ 150		0.035 ~ 0.041	Heat preservation of exterior protected construction and pipeline
Soft Calcified Plastic Board	100 ~ 150	f_c0.1 ~ 0.3 f_t0.7 ~ 0.11	0.047	Heat preservation Heat insulation Water resistance decoration
Foamed Glass	150 ~ 200	f_c0.55 ~ 1.6	0.042	Wall construction Heat insulation of cold storage

12.2 Sound-absorbing Materials

12.2.1 The Sound Absorption

When the sound waves encounter the surface of the material: part of them reflects; part of them permeates, and the rest are absorbed by the material itself. The ratio of absorbed sound energy (E) to incident sound energy (E_0) is called sound absorption coefficient (α). This ratio is the main indicator used to evaluate the sound-absorbing property of the material. A formula can be used to demonstrate this.

$$\alpha = \frac{E}{E_0} \tag{12.1}$$

In this formula: α is the sound absorption coefficient;

E is the absorbed sound energy (including the permeating part);

E_0 is the incident sound energy.

If 65% of the incident sound is absorbed and the rest 35% is reflected, the sound absorption coefficient of the material is 0.65. When all sound waves are absorbed, the ratio will be one, and when the door and window is open, the ratio equals to one. Generally, the sound absorption coefficient of the materials is between 0 ~ 1. The larger the numeral is, the better the sound absorbing property is. The sound absorption coefficient of suspended absorber may be more than one because its effective sound-absorbing area is larger than its calculated area.

The sound absorption of the material is not only related to its other properties, its thickness, and the surface conditions (the air layer and thickness), but also related to the incident angle and frequency of the sound waves. The sound absorption coefficient will change according to high, middle, and low frequencies. In order to reflect the sound-absorbing property of one material comprehensively, six frequencies (125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz) are set to show the changes of the sound absorption coefficient. If the average ratio of the six frequencies is more than 0.2, the material can be classified as sound-absorbing material. These materials can be used for sound insulation of walls, floors, and ceilings of concert hall, cinema, auditorium, and broadcasting studio. By using the sound absorbing material properly, the indoor transmittance of sound waves can be enhanced to create better sound effects.

12.2.2 The Basic Requirements for Selecting Sound-absorbing Materials

1) One must choose material with open and connected pores in order that it can work well. If the pores are more closely connected together, the sound absorbing property will become better. This is quite different from the heat insulating material which requires that the pores be closed and unconnected. In one word, porous materials can be used for various purposes each of which has different demands on the shape of the pores.

2) Most of the sound absorbing materials have weak strength, so that they should be fixed above the height of wall protective plate to avoid being

damaged. For the sound absorbing materials are easy to absorb heat, the resultative expansion and shrinkage have to be taken into consideration.

3) It is advisable to choose material with high sound absorption coefficient, so that a fewer amount will do.

4) Attention should be paid to the differences between sound-absorbing material and sound insulation shield.

12.2.3 Sound Absorption Coefficients of the Common Materials

Table 12.2 shows the sound absorption coefficients of common materials.

Table 12.2 Sound Absorption Coefficients of Common Materials in Construction

Class and Name	Thickness (cm)	Apparent Density (kg/m³)	Sound Absorption Coefficient at Each Frequency						Installation
			125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
① Inorganic materials									
Plasterboard(with decorative pattern)	-	350	0.03	0.05	0.06	0.09	0.04	0.06	Plaster firmly
Cement vermiculite plate	4.0		-	0.14	0.46	0.78	0.50	0.60	Plaster firmly
Gypsum mortar(blended with cement glass fiber)	2.2		0.24	0.12	0.09	0.30	0.32	0.83	Paint walls
Cement expanded perlite plate	5		0.16	0.46	0.64	0.48	0.56	0.56	
Cement mortar			0.21	0.16	0.25	0.40	0.42	0.48	
Brick (Plain brick wall)	1.7		0.02	0.03	0.04	0.04	0.05	0.05	
② Organic materials									
Cork board	2.5	260	0.05	0.11	0.25	0.63	0.70	0.70	Plaster firmly to the wood keel with an air layer of 10cm or 5cm in between
Shuisi board	3.0		0.10	0.36	0.62	0.53	0.71	0.90	
Veneer board (three layers)	0.3		0.21	0.73	0.21	0.19	0.08	0.12	
perforated plywood (five layers)	0.5		0.01	0.25	0.55	0.30	0.16	0.19	
Zylonite	0.8		0.03	0.02	0.03	0.03	0.04	-	
wood of fiberboard	1.1		0.06	0.15	0.28	0.30	0.33	0.31	
③ Porous material									
Foamed glass	4.4	1260	0.11	0.32	0.52	0.44	0.52	0.33	Plaster firmly
urea formaldehyde foamed plastics	5.0	20	0.22	0.29	0.40	0.68	0.95	0.94	Plaster firmly
Foamed cement(exterior plaster)	2.0		0.18	0.05	0.22	0.48	0.22	0.32	Closely against walls
Sound absorbing perforated plate			0.27	0.12	0.42	0.86	0.48	0.30	
Foamed plastics	1.0		0.03	0.06	0.12	0.41	0.85	0.67	
④ fibrous material									
Slag wool	3.13	210	0.10	0.21	0.60	0.95	0.85	0.72	Plaster firmly
Glass wool	5.0	80	0.06	0.08	0.18	0.44	0.72	0.82	Plaster firmly
Phenolic aldehyde glass fiber board	8.0	100	0.25	0.55	0.80	0.92	0.98	0.95	Plaster firmly
Industrial felt	3.0		0.10	0.28	0.55	0.60	0.60	0.56	Plaster to the wall

12.2.4 Sound-insulating Materials

Sound insulation is a kind of measure to prevent the sound waves from permeating. It is demonstrated by the sound transmission loss which is expressed by the difference of decibels between the incident sound and permeated sound. The higher the numeral is, the better the sound insulating property is.

According to the way of transmittance, the sound that people would like to insulate can be divided into air-borne sound (due to the vibration of the air) and solid-borne sound (due to the impact on solids or solid vibration). The sound permeation complies with the "mass law" in acoustics. The sound insulation property of wall or plate depends on its mass area ratio. The greater the mass is, the harder it is to vibrate this material, thus the better the insulating property will be. Therefore, it is better to choose dense and heavy material (clay brick, reinforced concrete, steel plate, etc) as sound insulating material. The best way to insulate the solid-borne sound is to use the unconnected structure. That means to fill in elastic liner between wall and spandrel girder, as well as between the frame of the building and the wallboard. The elastic liner can be chosen from felt, cork, rubber, and elastic carpet. Do not mistake sound absorbing material for sound insulation material. Note that good sound absorbing material is light, loose and porous.

Questions

12.1 What is heat-insulating material? What are the basic requirements for the heat insulating material?

12.2 What are the main factors which affect the thermal conductivity of constructional materials?

12.3 Why should we guard against water and damp when using the heat-insulating materials?

12.4 What are the heat-insulating materials commonly used in construction?

12.5 What is sound absorption coefficient? What are the differences of technical requirements between sound-absorbing material and heat insulating material?

12.6 Why can't the sound-absorbing materials be replaced with some sound-insulating materials?

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13

Finishing Materials

This chapter mainly deals with the basic functions and selecting principles of the finishing materials. Meanwhile, it also touches slightly on the common used finishing materials in the construction engineering, such as natural stones, artificial stones, architectural ceramics, architectural glass, architectural decorative paint, and different kinds of wood, mental and embroidered decorations.

The materials, which are attached to the surface of the buildings to decorate and beautify the environment, are defined as finishing materials. The overall effects and functions of the decorative construction engineering are all realized through the use of finishing materials and the form and structure, texture, color, function of other equipments. In the average buildings, the finishing materials occupy about 50% of the total construction material cost; while in the splendid buildings, this figure soars up to more than 80%. For example, the White Swan Hotel in Guang Zhou has used more than 4500 different kinds of finishing materials.

There are many kinds of finishing materials and the material varies according to different part of the building. This chapter only introduces some commonly used types.

13.1 Basic Requirements and Selecting Principles of Finishing Materials

Finishing materials create the external environment with certain architectural art style and the elegant internal environment with different functions. Generally speaking, the outer surface of the building should resist the invasion of sun, rain, frost, snow, ice, weathering, and dielectric force; and the internal surface should face the challenge of scrubbing, humid and so on. Hence, the finishing materials should be not only beautiful, durable, but also satisfy different using functions.

Due to different kinds, functions and characteristics of the finishing materials, the following four issues should be considered in the selection of finishing materials.

13.1.1 Different Styles and Classes of Buildings

The finishing materials used in public buildings such as offices, classrooms, libraries, mega malls, etc, differentiate from those used in buildings inhabited by human beings. Houses are the main places which can satisfy different needs of human beings, so the selection of finishing materials should be oriented at people, while for public buildings, the focus should be shifted to building classes and durability.

The high standard hotels and mega malls, where the public places are crowed with people, should select slabs with granite as the surface, because which can resist scrubbing and beautify the environment, while the ceramic flooring tile is suitable for the guest halls. Wood floor is usually used in bedrooms and living rooms, because it is comfortable, natural and can keep the heat. Plastic floor is fit for offices due to its flexibility and can attenuate sound, but the price of which is high, hence just suitable for hotels. Only such places as few of state-standard hotels and meeting halls select hand-knitted carpet, which elegant, splendid and effective in beautifying, but the price of which is expensive. The hard wares of the splendid sanitation are gilded at a level of 24K and only fit for few super-splendid hotels.

13.1.2 Decorative Effects

1. Color

Color, which is the first decoration of the man-made environment, is the most attractive character of the finishing effect. The ancient buildings in our nation often use the materials' colors to show the beauty of the architectures. Nowadays, the architects try bravely in the building's color to enrich the architectural art space and create new architectural style belonging to one nation.

These factors, such as the building's size, environment, function etc, determine the external colors. The high-rise buildings should select dark color to show the gravity under the clear blue sky; the lower-buildings should select light color so that people will not feel they are small, low and scattered.

The inner color of the buildings should produce good effects both psychologically and mentally. Warm colors (red, orange, yellow) make people excited and warm; cool colors (green, blue, violet) make people feel quite and cool. Hence, light blue or light green should be selected to decorate bedrooms to increase the quietness and comfortableness; the activity rooms in kindergarten should use warm colors such as medium yellow, light yellow and pink to satisfy the curiosity of the children; colors inside the room should vary from darker to lighter determined by the temporal space from higher to lower, so that people can feel stable and comfortable.

2. The Texture, Line Style, Size and Grain of Materials

The decorative effect of the material's texture, line style, size and grain is apparent. Concerning grain, what should be made full use of are the natural grain, form and ground color of the material or the different grains and forms of artificial materials to create a plain, elegant, majestic and dignified atmosphere. Concerning the size, the size of the material should be in proportion with other things. For example, the marble and the colorful slab of the terrazzo is only effective in halls rather than in living rooms; concerning the line style and texture, except for the innate texture of the material (seen in Chapter Two), to some extent, line style is part of the overall texture. For example, decorating the external wall face with the decorative sheet of briquetting aluminum alloy can make special line style effect.

Different materials' texture can produce different senses concerning about size, cold and warm. For example, the same size of two armchairs, the rattan-weaved products feel spacious than the one made by wood.

13.1.3 Durability

The durability of the finishing material is a synthetic technical property, which includes the material's mechanical property, such as compressive strength, tensile strength, bending strength, impact ductility, arching effect, agglutinating value, abrasive resistance; the material's physical property, such as density, water absorption, water resistance, impermeability, frost resistance, heat resistance, adiabaticity, glossiness, light absorption, light reflex and so on; and the material's chemical property, such as acid-proof alkaline, atmospheric corrosion resistance, stain resistance, weathering resistance, fire resistance and so on.

The durability of the construction is conditioned by that of the finishing material. Hence, proper finishing material should be used according to the property of the material and the different place and conditions where it is used. Thistle board can only be used in dry environment rather than wet; plastic and other organic materials will change their innate properties when exposed to light, heat and other natural forces, so they are not fit for decorating the outer wall. The ideal finishing material for outer wall is inorganic material (ceramics, glass and colored Portland cement) and aluminum alloy products, which are pleasant in color and durable in utility.

13.1.4 Economical Efficiency

The economic indicator of the finishing material is used to estimate the price and expenditure of the construction, and can be considered from the following three aspects:

1) Reference price, which is known through the product overview provided by the producer and concerning manuals.

2) Market price.

3) Construction extra charge.

The price of the finishing material has a direct relation with the decorative price of the construction. So the first investment and the following maintenance costs should be considered when the finishing materials are selected. With the increasing of the living standard, the consensus is that people would rather invest heavily for the first time to prolong the usage time of the materials. This action can satisfy most people.

As the development of the society and human civilization, people now try their best to create their living environment. It should be noticed that the beautiful art effect of the construction relies on the internal structures and beauty of materials and the rational combination of materials and harmonious use of their color, grain and texture, rather than the accumulation of the different materials. As to those expensive and charming materials, they should be used properly to fully display their plasticity.

Finishing material is the physical basis of the construction. Human beings make higher and higher demands on the types, quality and class of the finishing material to show their endless pursuit on construction art. Different kinds of new finishing materials pop up from time to time, which makes the construction style newer and human's appreciation level increased.

13.2 Common Finishing Materials

13.2.1 Natural Stone and Artificial Stone

1. Natural Stone

After processed, the surface of the natural stone is of high quality in decoration and its finishing effect is determined by its type. The mainly used natural stones consist of natural marble, natural granite, natural shale and so on.

(1) Natural Marble

The name of Da Li Stone (marble) derives from its main place of production Da Li County in Yun Nan province. The marble in Da Li County is fine in texture and soft in color, hence is decorative. Now, the mainly used types are: ash grey marble, white marble and colorful marble. Besides Yun Nan, other places, which produce marbles, are Shan Dong province, An Hui province, Jiang Su province, Zhe Jiang province, Bei Jing, Liao Ning province, Guang Dong province, Fu Jian province, Hu Bei province and so on. The main properties of marbles are:

1) Colorful and gainful. The pure color of marble is white, and the kind of such marble is called Han Bai Yu (white marble).

2) The hardness is moderate, and the abrasive resistance is inferior to granite.

3) Their acid-proof ability is poor, and the acid medium can erode the surface of the marble.

4) It is easy to be ground and polished.

5) The durability is inferior to granite.

The main comments and selection index of marble are the appearance quality, color and grain. The appearance quality consists of the dimension and flatness of the sheet material, angular deviation, glossiness and beauty .The most popular types in the market are pure white, pure black (with the white grain narrower than 5mm), pink and pale green marbles.

The regular sizes of the natural stones are: 300mm×150mm, 300mm×300mm, 400mm×200mm, 400mm×400mm, 600mm×300mm, 600mm×

600mm, 900mm×600mm, 1070mm×750mm, 1200mm×600mm, 1200mm ×900mm, 305mm×152mm, 305mm×305mm, 610mm×305mm, 610mm× 610mm, 915mm × 610mm, 1067mm × 762mm, 1220mm × 915mm, the thickness is 20mm.

Natural marble is high-ranking finishing material which is fit for the inner wall face, cylinder, floor face and stair-step of the memorial architectures and mega public constructions, such as hotels, exhibition halls, malls, libraries, airport stations, etc; and sometimes is also for banister, service desk, facade, dado, window sill, and skirt board, etc. Natural marble stone is easy to be eroded by acid rain; hence, it is not suitable for outer door decoration. Only a few kinds of white marbles, wormwood green are used to decorate the outer door wall face.

(2) Natural Granite

Granite is the typical type of plutonic rocks, it consists of feldspar, quartz, a few dark—colored mineral, sand, mica. The main chemical propositions of the granite are SiO_2 (65%~70%), a little of Al_2O_3, CaO, MgO and Fe_2O_3, thus the granite is acid rock.

The characteristics of the granite are as following:

1) High decorative quality. The color of granite is mainly determined by the color of syenite and the outlay of the mica and dark—colored mineral. Usually, the granite is flesh red, grey, grey and red. After polishing, it appears as beautiful spotted grain and different color. The grain is fine, and the granite is colorful, splendid, and majestic caused by the dark mica and the starry quartz sand.

2) Intense hardness and high abrasive resistance.

3) Good durability. The granite's porosity and water absorption are small and it is also highly weather-resistant

4) Good acid resistance and erosion resistance. The chief chemical composition of granite is SiO_2, hence it is acid-resistant.

5) Poor fire resistance. The quartz in the granite will have crystalline transition in 573℃ and cubical dilatation in 870℃; hence the granite will break when fire takes place.

According to the surface processing mode, the granite can be divided in the following four types:

1) Chip-axe Slate. The surface of it is coarse, and has regular axe grains.

2) Machine Planned Slate. The relative flat surface is made by the planning machine, and the surface appears as parallel planned grain.

3) Coarse Grinding Slate. After coarse grinding, the surface is lubricous, but no of glossiness.

4) Polished Slate. After polishing, the surface is bright in color and the crystals are exposed. After planned, the polished slate can become mirror surface granite.

According to the processing demand of the design plans, the commonly used size of the coarse grinding slate and polished slate is: 300mm×300mm, 305mm×305mm, 400mm×400mm, 600mm×300mm, 600mm×600mm, 610mm×305mm, 610mm×610mm, 900mm×600mm, 915mm×610mm, 1067mm×762mm, 1070mm×750mm, and the thickness is 20mm.

The quality supervision of the granite consists of dimension error, flatness, angular deviation, the glossiness and beauty defects of the polished slate.

The famous types of granite are the Chrysanthemum Black, Snow Black and Yun Li Mei in Yan Shi county of He Nan province; Ji Nan Black in Shan Dong province; Red of Shimian in Si Chuan province and Green of Bean in Shang Gao county of Jiang Xi province.

Besides, the other production places of granite are Hengshan in Hu Nan province, Jinshan and Jiaoshan in Jiang Su province, Moganshan in Zhe Jiang province, Xishan in Bei Jing, Huangshan in An Hui province, Huashan inShaan Xi province, Fu Jian province, Shan Xi province, Hei Long Jiang province, etc..

Granite belongs to the high standard architectural materials. In history, it is mainly used to decorate the external floor face, flight of steps, foundation bed, monument, gravestone, nameplate eaves etc. In modern city constructions, the mirror granite mainly used in the external wall face, floor face, cylinder, stair-steps, etc..

(3) Imported Stones

The different texture of stone is caused by different regions and different geographical conditions. Due to the special geographical conditions, the imported stones are superior to native stones in texture, luster and natural grain. Besides, the processing technology of the imported stones is advanced; thus from a general view concerning exterior appearance and function, the imported stones are better than native stones. Therefore, some public buildings, star hotels, high standard meeting halls usually adopt imported stones.

Most of the imported stones are pale in color, such as ivory white of Spain, Russo Alicante, Black of Grace, the red ramie of Carrier, the Monte Carol an of India, general red and Indian red etc..

2. Artificial Stones

Artificial stone is the general name of artificial marble and artificial granite. It belongs to the cement concrete or polyvinyl acetate concrete. To decorate the internal surfaces, natural stones are usually used because of their grain, texture, weight (only half of the natural stone), high intensity, thin thickness and easiness to adhesive.

(1) Characteristics of Artificial Stone

The natural stone is made by first blending small marble scraps, quartz, sand, and rock flour, resin, colophony, cement and adhesive together, then violently being stirrred under vacuum condition and molded under force, and last being planned, polished and sliced.

(2) Classifications of Artificial Stone

According to its differènt components, the artificial stone can be divided into the following four types:

1) Resin-based Artificial Stone.

The resin-based artificial stone selects organic resin as cement, then are blended with natural small scraps, rock flour and pigment to form mixture, and goes through the procedure of molding, solidifying, knockout, drying and polishing.

2) Cement-based Artificial Stone.

The cement-based artificial stone selects white cement and common cement as cementing agent. It is made by blending marble scraps, rock flour, pigment etc and then molding and maintaining them.

3) Compound Artificial Stone.

Compound artificial stone selects inorganic binders (such as cement) and organic polymer material (colophony) as cementing agent. In production, first mould the mixture of scrap stones and rock flours with inorganic binders, then solidify the mixture, and at last, dip the mixture into organic monomer to make the compound artificial stone ensemble under certain circumstance.

Now the compound artificial stone is widely used. The bottom of it is made by the' cheap and stable inorganic material; the surface of it is made by polyester and marble flour.

4) Sintered Artificial Stone.

The produce method of sintered artificial stone is similar to that of ceramics. First, it bends such rock flours as feldspar, quartz, omphacite, calcite etc, ground hematite, and a certain proportion of Kaolin together to form a certain kind of mixture. The rock flour occupies 60% and the Kaolin occupies 40%. Then the cementing method is used to produce the stock; use half dry pressing to mould and then it is baked under the temperature more or less than 1000^0C in the kiln.

(3) Common Varieties of Artificial Stone

1) Polyester-based Artificial Stone.

The polyester-based artificial stone selects unsaturated polyester resin as cementing agent. Its different grain, design, color and texture are caused by a variety of factors, which include the different kinds of pigment, and the different types, granularity, purity of the natural stone together with the different techniques during the processing procedure. It is also called as artificial marble, artificial granite and artificial picture agate, because it adopts the grain and texture of imitated artificial marble, artificial granite and artificial picture agate. Besides, it also can be made into semi-apparent artificial stone (also called artificial jade) with the luster similar to jade. Artificial jade can also be imitated into such precious jade products as amethyst, Cai Cui, Ross quartz and so on. All these products are like to the genuine articles.

The polyester-based artificial stone can be made into artificial marble slate, granite slate and jade slate and sanitary wares such as bathtub, single and double washbasin with toilet table, pedestal washbasin, pedestal pan and so on. It also can be made into such handicraft articles as artificial marble mural painting.

2) Terrazzo Tile of Imitation Granite.

The terrazzo tile of imitation granite is produced by using grinded granolithic, adding different kinds of pigments and adopting such processing techniques as pressing, coarse grinding, waxing and so on. Its color, grain is very similar to natural granite. Besides, it has high degree of luster and its decorative effect is good.

It is used to decorate the outer and inner walls and the floor face of hotels, restaurants, office buildings, living quarters and so on.

3) Artificial Black Marble.

The artificial black marble is made by mixing steel scoria and waste glass (the raw materials) with water glass, admixture and water into the raw materials and then sintering them. It has such characteristics recycling of wastes, light and energy efficiency, and simpleness of technique. The applied scope of it is the outer and inner walls, floor face, and table surface and so on.

4) Light-penetrable Marble.

It is made by blending the thin transparent stone and glass, using butyraldehyde membrane as core layer, and then pressing the mixture under the temperature about 140~150℃ for about 30min. It has such characteristics as making the light become soft. It is used to make day-lighting ceiling, outer wall decorations, etc..

5) Advanced Petrochemical Ceramic Tile.

The outlook of it is very similar to natural granite and it also has such characteristics as acid resistance, alkali resistance, abrasive resistance, high temperature resistance, bitter cold resistance, high sense of stone, non absorption of water, stain resistance, wet resistance, unlikeness to blast and so on.

It is used to decorate advanced luxurious buildings.

6) Artistic Stone.

It is made by the reversely moulding the raw materials which are blended by well-chosen Portland cement, lightweight aggregate and ferric oxide. All of the stony membrance is well-chosen natural stone. Its texture, luster and grain are the same as those of the natural marble. It is original, quaint, light and easy to fix. It is used to decorate the outer and inner walls and outdoor sites etc.

13.2.2 Architectural Ceramics

1. Classifications of Ceramics

The ceramics can be divided into three kinds: ceramic, porcelain and stoneware produces.

(1) Ceramic Products

The ceramic products can be divided into two kinds: unglazed products and glazed products and are of high porosity and water absorption quality. The cross-section is coarse and lightless. when the products are knocked on, the sound is harsh.

According to the different proportion of impurity dust, the ceramic products can be divided into crude pottery and fine pottery. The crude pottery is not glazed and the commonly used sintering clay brick in architectures belongs to the common crude pottery products. The fine pottery goes through the procedure of biscuit firing and glost firing appears as ivory white. The water absorption of it is 9%~22%. The glazed brick, sanitary ceramics and painted pottery all belong to fine pottery. Besides architectural fine pottery, it still exits domestic fine pottery and artistic fine pottery.

(2) Porcelain Products

The porcelain products have dense arrangement, and do not absorb water, white and semi-transparent, and the surface of it is glazed. According to the different chemical compositions and the processing techniques of the raw material dust, the porcelain can be divided into crude porcelain and fine porcelain. The porcelain products are mainly used in daily tableware, tea service, display porcelain, electro technical porcelain and articles of fine arts.

(3) Stoneware Products

The stoneware products sit between the ceramic products and porcelain products, hence called semi-porcelain. Its structure is denser than that of porcelain; the water absorption is small but not as white as porcelain. Its clay body is colored and not semi-apparent

The stoneware can be divided into crude and fine. The water absorption of the crude stone ware is between 4% and 8%, and that of the fine stoneware is lower than 2%. The crude products include facing tile, floor tile and mosaic tile; the fine products include household utensils, chemical and electrical ceramics.

The ceramic products used in finishing construction belong to the extent of fine pottery and crude stoneware.

2. The Important Techniques of the Architectural Pottery Products

1) Apparent quality: Usually, the classification of the architectural pottery products is made according to its apparent quality.

2) Water absorption: It has close relationship with bending strength, extreme cold and heat resistance, and is the important quality index of the products. The product with high water absorption is not suitable for outer door decoration.

3) Extreme cold and heat resistance: The coefficient of heat expansion is different in the inner face and outer glazed surface of the products. The extreme changes of the temperature can make the glazed layer break.

4) Bending strength: The porcelain products are fragile, so there is certain demands on the bending strength.

5) Abrasive resistance: Tests should be conducted on the colored glazed brick used to decorate the floor.

6) Cold resistance: Such a requirement is needed for the products used for outer door decoration.

7) Chemical resistance: Such a requirement is needed for outer door ceramics and chemical ceramics.

3. Commonly-used Architectural Pottery Products

The commonly-used architectural pottery products are glazed tile, facing tile, floor tile, mosaic tile, color glazed earthen ware, ceramic mural painting, sanitary pottery and so on..

(1) Glazed Brick

Glazed brick is also called ceramic tile, and is mainly used to decorate the inner wall of the constructions.

The glazed brick is gentle and elegant, such as white, multi-color, embossment, patterns and spots. The decorative effect of it is determined by its color, pattern and texture. It is plain, and meanwhile the thermal stability of it is high and it has such characteristics as fire resistance, wet resistance, acid and alkali resistance. The surface of it is flat and it is also easy to wash.

It is mainly used to decorate the inner wall face, table-board, dado of kitchen, bathroom, lab, precision instruments workshop, hospitals and so on. It is clean, beautiful and usable.

The glazed brick is not suitable for outer door decoration. Because the clay body of it is porous and water-absorbing. After absorbing water, it will swell, while the glazed surface does not swell that much as the clay body. If the glazed tile is used externally, it will break or peel off, hence badly affecting the decorative effect. All these are caused by the humidity level; weathering .The bending strength of the glazed is surpassed by that of the clay body.

The commonly used sizes of it are: 108mm × 108mm × 5mm, 152mm×152mm×5mm.

(2) Floor Tile

The raw materials of the floor tile are china clay of good quality and other ingredients, and after half drying molded, they are roasted under the temperature about 1100℃. The floor tile can be divided into two kinds: glazed and unglazed.

Using different kinds of ingredients and processing techniques, the surface textures of the floor tile are various, such as flat surface, pitted surface, unfinished surface, planned surface, polished surface, spotted surface, granitoid surface, embossment surface, matt glazed surface, metallic luster surface, skid-resistant surface, wear-resistant surface, and the floor tile also has different kinds of products, such as monocular and multicolor products.

The floor tiles are mainly used to decorate the exterior wall surface and the floor face. The commonly used sizes applied to decorate the outer wall are: 150mm×75mm, 200mm×100mm; and the sizes used to decorate the floor are: 300mm×300mm, 400mm×400mm, its thickness is between 8mm and 12mm.

(3) Mosaic Tile

Mosaic tile is also called mosaic. It is made by the embedding small scraps of tiles with different colors and forms. The side length of the scraps is less then 40mm.The mosaic is made by baking excellent ceramic dust into small and thin square, rectangular and hexagon ceramic pieces, and then sticking them adversely on apiece of cowhide paper according to the designed patterns through paving and pasting box, called one unit. The dimension of such a unit is 305.5mm, and every box has 40pieces of such papers, and the overall areas are 3.7m^2.

The mosaic tiles are bright and clean in luster, beautiful in design, dense in structure, high in bending strength, resistant in stain, erosion, abrasive, water, fire, cold and skid, meanwhile they are easy to wash, durable and cheap.

The mosaic is mainly used to decorate the floor. Because the piece of it is small, it is hard to be crushed. The floors adopt such materials are the clean handicraft workshop, lab, and civil restaurants, kitchens, bathrooms and so on.

It has high decorative effect when used to decorate the outer wall face of high standard buildings, and can prolong their durability. This kind of tiles can be used to form different designs as characters, laces, Temple of Heaven, pandas, the Great Wall and so on.

(4) Ceramic Split Tile

The ceramic split tile is individual, quaint, and used to decorate the external wall faces. It is made by adding ingredients into clay, and then molding, parching, roasting, and splitting the mixture.

(5) Glazed Earthenware Products

The glazed earthenware products are the ancient treasure in the ceramics. It is made by adding ingredients into insoluble clay, and then molding, and drying, biscuit firing, glazing and baking the mixture.

They usually appear in golden, yellow, blue and cyan. The surface of such products is lubricous. They are also colorful, quaint, durable, and full of national characteristics. The major products include: glazed tile, glazed brick, glazed beast, glazed window, rail, desk, flower pot, vase, etc.. It is mainly used to decorate plain tile, round tile, drip tile, eave tile, birds and beasts, blocking course, ridge, pavilions, terraces, and towers.

(6) Ceramic Murals

The ceramic murals are big in size. They are formed by sticking ceramic veneer and ceramic slate and so on. They are modern finishing materials of high artistic value, belonging to advanced finishing materials. They are not the simple copy of the original picture but belong to the artistic recreation. The technical procedures, which they go through, are templating, plate making, painting, compounding of glaze, glazing, and roasting. The glazing technique includes dipping, painting, spraying and filling, etc.. They are excellent artistic articles.

Every piece of ceramic mural is big, thin, of high intensity and flatness and of lower water absorption, cold resistant, chemical resistant, and extreme cold and heat resistant. The functions of the ceramic murals are various, such as painting, calligraphing, scrolling and so on. The surface of the ceramic plate can be flat surface or embossment surface.

The ceramic murals are mainly used to decorate high-rise buildings (edifices, hotels, inns) and public places(airport lounge, waiting room, mega meeting hall, reception room, tourist area, metro, tunnel, etc.).They can beautify the environment.

(7) Sanitary Ceramics

Sanitary ceramics include washing basin, urinal and lavatory pan, water tank and sink. They are mainly used in bathrooms, washrooms, toilets and so on.

13.2.3 Architectural Glass

1. The Properties of Common Glasses

1) Transparence: 82%of the light can pass through the clean common glasses.

2) Fragility: It is easy to break under force.

3) Poor thermal stability: It is easy to shatter under extreme temperatures.

4) High chemical stability: It is good at salt resistance and acid resistance.

5) High apparent density: It is about 2450~2550kg/m^3.

6) High thermal conductivity: It is about 0.75W/ (m•K).

2. Glass Products

(1) Common Flat Glass

Common flat glass is the most widely used glass in construction with a depth of 2~12mm which are mainly used in windows and doors. Such glass is light translucid and can keep off rain, wind or sound and at the same time keep warm. Though such glass has certain mechanical intensity but is fragile and has low ultraviolet radiation transmittance.

Common flat glass is packed in standard cartons. Common flat glass with a depth of 2mm can cover area of 10m^2 and coverage of glass with other depth can be conversed to standard carton according to conversion coefficient.

(2) Safety Glass

Safety glass includes physical toughened glass, wire glass and laminated glass which have high mechanical intensity and good impact resistance. When smashed, the broken pieces will not splash or injure people and is fireproof.

1) Toughened Glass.

Physical toughened glass is a kind of safety glass. When common flat glass is heated to the temperature near heat distortion point (around 650℃), the change of shape will eliminate inside stress and then move the glass out of heating furnace and cool it fast and uniformly by blowing its two sides with cold wind from multiple jet nozzle and when room temperature is reached to common level and the process of making toughened glass is finished. The properties of this kind of glass include: high intensity, good impact resistance and thermal stability and good security performance. The security performance of the toughened glass means that the whole glass has high initial stress that the glass will have map cracking and the pieces are small and not sharp which will not injure people when broken.

Physical toughened glass is mainly used in the door, window, partition and curtain wall of high-rise buildings.

2) Wired Glass.

Wired glass is made by pressing wire mesh into melted glass. This kind of glass has good compact resistance and is fire-proof. When broken, though there are many cracks, the pieces will still hang on the wire rather than splashing to injure people.

Wired glass is mainly used in the skylight window of workshop, lighting roof and fire-proof door and window.

3) Laminated Glass.

Laminated glass is made by inserting hyaloids plastics plates into two or more pieces of glasses which are heated, pressed and bound together to form flat, curved or compound glass products.

(3) Heat-insulating Glass

Heat-insulating glass includes heat-absorbing glass, heat-reflecting glass, and hollow glass which have both decoration and heat preservation and insulation functions. This kind of glass is mainly used in door, window and curtain wall.

1) heat-absorbing glass.

Heat-absorbing glass is flat glass that can not only absorb lots infrared radiation but also have good light transmission rate. Most common colors of this kind of glass are gray, tawny, blue, green, etc..

2) heat-reflecting glass.

Heat-reflecting glass has good heat reflection and light transmittance and is also called coated glass or mirror glass. Heat-reflecting glass is made by spraying gold, silver, nickel, chrome, iron or other metal or metallic oxide in ways of heating, vaporizing or chemical methods.

3) hollow glass.

Hollow glasses are made of two or more pieces of flat glass which are separated by frames and whose sides are sealed by glue with dry air in. Hollow glassed are made of heat-absorbing glass, heat-reflecting glass, etc..

Hollow glass has good heat preserving, energy saving and sound insulating functions and can effectively prevent frozen dew. This kind of glass is mainly used in buildings which need the functions of heating, air-condition, noise and dew prevention and need no direct light but particular light, e.g. houses, restaurants, offices, schools, hospitals and stores.

(4) Figured Glass, Frosted Glass and Sprayed Glass

Figured glass is made by pressing melted glass with carved roller. The designs can be pressed on both sides of glass in colors of pale yellow, blue and olive color. Finished figured glass is three dimensional and the intensity increase 50%~70%.

Frosted glass is a kind of ground glass which is made by sanding the surface with the mixture of silica sand, adamas, garnet and water by machine or hand and then etching the surface with hydrofluoric acid uniformly. This kind of glass is light translucent and the light go through is soft.

Sprayed glass is made by sticking painting to glass and painting with protective coating.

These three kinds of glass are commonly used in windows, doors of toilet, bathroom and office.

(5) Hollow Glass Brick

Hollow glass brick is made by melting or sticking of two pieces brick in "concave" shape. This kind of brick has function of heating preservation and sound insulation. Because the light going through is soft and gracious, the brick is used in hyaloids walls, partition, hall and corridors.

(6) Glass Mosaic

Glass mosaic is made of glass and un-melted small crystals (mainly quartz) in color of red, yellow, blue, white, black, etc..

Glass mosaic is a kind of small size colorful glaze glass with coverage of 20mm×20mm, 30mm×30mm, 40mm×40mm and depth of 4~6mm. The glass is hyaloids, translucent or opaque and has golden or silvery spots or streaks.

Glass mosaic makes light soft, has good chemical and thermal stability and is plain, elegant and beautiful. This glass can be well felted with cement mortar because its one side has slots which make construction easier. Glass mosaic is used for decoration of the outside walls of hotel, hospital, office building, hall and house.

(7) Laser Glass

There are two kinds of laser glass, one is made of common plat glass and the other is made of toughened glass. The first kind is used for the decoration of wall, window and ceiling. The second kind is used for floor decoration. Besides, there is also curved laser glass used in decoration of cylinder, interlayer laser glass used as curtain wall and laser glass brick.

The width of laser glass with patterns is no more than 500mm and length no more than 1800mm; the width of laser glass with paintings is no more than 1100mm and length no more than 1800mm. Length of arc of curved laser glass is no more than 1500mm and length no more than 1700mm. Good aging resistance is the main advantage of laser glass.

13.2.4 Architectural Decorative Paint

Paint is a waterproof material which is painted to the surface of buildings and has functions of protection, decoration, rust prevention, corrosion prevention, etc. Natural oil paint and paint is the same thing and generally called paint.

Architectural paint is made of main coating material (base, glue and sticker), secondary coating material (color and filler), medium (thinner) and auxiliary material (auxiliary).

Paint varies according to main coating material, including organic coating, inorganic coating and compound coating. Per usage places, paint includes outside wall paint, inside wall paint and floor paint; per disperse medium, includes solvent based paint, emulsion paint and water soluble paint.

1. Exterior Wall Paint

Exterior wall paint is used to decorate buildings and protect outside walls. Such paint provides plenty choices in color and color sense, good hydrolytic resistance and durability to bear sunlight, wind, rain and frost, and is easy to clean. The main types include: emulsion paint, solvent based paint and inorganic silicate paint. The most commonly used paint in China is as follows:

(1) Solvent Acrylic-acid Outside Wall Paint

Acrylic acid paint is grinded solvent outside wall paint made of modified acrylic acid copolymerization coating material, ultraviolet absorbent, filler, organic solvent, additive, etc.. This kind of paint is convenient to use and has no irritating smell, good weathering resistance, color stability, alkali resistance, strong adhesive power, impermeability and will not become powder or fall.

(2) BSA Acrylic Acid Outside Wall Paint

BSA acrylic acid outside wall paint is an emulsion paint made of polypropylene, filler, additive, etc.. Such paint is scentless, quick to dry, fire-proof and convenient to use and is commonly used in to decorate out side walls of civil house, commercial building and plant.

(3) Polyurethane Acrylic Acid Exterior Wall Paint

Polyurethane acrylic acid exterior wall paint is grinded solvent paint made of polyurethane acrylic acid resin, colors, filler and additive. This kind of paint is mainly used for exterior walls made of concrete or cement mortar.

(4) Durable Exterior Wall Paint

Durable exterior wall paint is grinded solvent acrylic acid paint made of polyurethane acrylic acid resin, petroleum solvent, rutile titanium white, filler, additive, etc.. This kind of paint combines the advantages of traditional solvent paint and emulsion paint and has better weathering and dirt resistance which is mainly used in the decoration of exterior wall of high-rise building, apartment, plants, etc..

(5) Chlorinated Polyvinyl Chloride Paint

Chlorinated polyvinyl chloride paint is solvent paint made of chlorinated polyvinyl chloride resin, other kinds of modified resin coating material, plasticizer, filler, color and additive which are mixed, sliced up, dissolved, and filtered. This kind of paint is in many colors and the coating is smooth which can be used to paint both interior and exterior walls. It is quick to get dry (the time to dry under normal temperature is 2h) even in bright winter. It has good weathering resistance, chemical stability, and water resisting property but low thermal decomposition temperature, so must be used under 60℃. Because only coating is quick to dry and before it's dry absolutely, the water ratio of building surface should be no more than 8%.

(6) Sand Plastic Exterior Wall Paint

Sand plastic exterior wall paint is made of PVA aqueous solution, little vinylidene chloride vinyl chloride emulsion, quartz sand, colorful stone chips, small glass debris and mica powder, certain amount of flour filler, color and foam killer. This kind of paint is non-toxic, aosmic, quick to try and sticky which can be used for decoration of exterior wall of house, shop, hotel, mine and other enterprise.

(7) Chlorinated Rubber Exterior Wall Paint

Chlorinated rubber exterior wall paint is made of chlorinated rubber, solvent, plasticizer, color, filler and additive. This kind of paint is adhesive to cement concrete and steel surfaces and has good water, alkaline and weathering resistance.

(8) JH80-1 Inorganic Exterior Wall Paint

JH80-1 inorganic exterior wall paint is made by mixing and grinding potassium silicate, filler, color and additive (sodium hexametahposphate).

(9) JH80-2 Inorganic Exterior Wall Paint

JH80-2 inorganic exterior wall paint is made through grinding mixture of silica sol (colloidal silica), coating aid, filler, color and surface active agent and has good water resistance, corrosion resistance, freeze-thaw resistance, aging resistance and smooth coating. It is commonly used to paint cement mortar wall, uralite, brick and plasterboard.

2. Interior Wall Paint

Interior wall paint is mainly used to decorate and protect interior walls and ceilings.

(1) Water-soluble Interior Wall Paint

106 interior wall paint is non-toxic, odorless and incombustible that can be painted on moist surfaces (concrete, cement mortar, paper reinforced lime face, asbestos-cement board, gypsum board lime).

803 interior wall paint is non-toxic, odorless, quick to dry, easy to paint and has good hiding function.

(2) Synthetic Resin Emulsion Interior Wall Paint (Emulsion Paint)

The mostly used paint includes styrene-acrylic latex paint, ethylene-propylene latex paint, poly acetate emulsion paint and chlorine-partial copolymerization paint. This kind of paint is mainly used for decoration of interior wall rather than kitchen, lavatory, bathroom where walls are usually wet.

(3) Solvent Interior Wall Paint

Solvent interior wall paint includes chlorinated polyvinyl wall paint, chlorinated rubber wall paint; acryl ate wall paint and polyurethane department wall paint, etc..

This kind of paint has bad ventilation and is easy to condense, rarely used for interior walls of house. It is easy to clean and durable so can be used in hall and corridor.

(4) Colorful Interior Wall Paint

Colorful interior wall paint is durable which can make color-rich coating and good sense of space, good decoration effect and has excellent oil resistance, water resistance, decay resistance good air permeability. Because the coating is thick and flexible like wallpaper so the paint makes good overall effect.

(5) Symphony Paint

Symphony paint is high-grade water-based interior wall paint made of special resin emulsion, specialized organic and inorganic color which is mainly used in decoration of interior walls of office, house, hotel, shop, meeting room and ceiling.

3. Floor Paint

The function of floor paint is to decorate and protect floor and make it in accordance with other decoration. Floor paint is reasonable in price and convenient in use with properties of good durability, corrosion resistance, water resistance and impact resistance.

The commonly used floor paint includes chlorinated polyvinyl chloride floor paint, polyurethane floor paint and epoxide resin floor paint.

13.2.5 Wooden Decoration

Wood is widely used in interior decoration of buildings like door, window, stair railing, railing, floor, baseboard, ceiling, mopboard, decorative acoustic board, painting frame, etc.. Wooden decoration can provide enjoyment of natural beauty and make room warm and cordial. In ancient architecture, wood is widely used as fine wood decoration which is a very skillful and demanding art deco.

1. Strip Wooden Floor

Strip wood is the most commonly used wooden floor material. It can be hollowly or solidly paved. When hollowly paved, the main structure parts include keel, horizontal strut and floor. There are two kinds of floor: mono-layer and double layer whose lower layer is rough board and the higher layer hard wood. Common strip wooden floor is made of pine, fir or other cork tree wood and hard strip wood is made of Manchurian ash, oak, maple, teak, elm or other rigid timber. Such wood material is required not easy to corrupt, deform or crack. The width of wooden strip is commonly less than 120mm and depth 20~30mm. The strip woods are fixed to the keel with tongue-and-groove joints or staggered joints. After a period of time during which the wood become stable in state, the strips are planed, cleaned and painted. The strip-wood floor uses the ready-mixed paint. However, when the wood has good color and texture, transparent varnish is used to show this. This will enhance the indoor decorative effect.

The strip-wood floor is light, flexible, and comfortable. It is low in thermal conductivity, cool in summer and warm in winter, and easy to be cleaned. Therefore it is acknowledged as good indoor decorating material. The strip-wood floor is widely used in offices, meeting rooms, reception rooms, lounges, hotels, living rooms, kindergartens, and instrument rooms, etc..

2. Patterned Wood Floor

Patterned wood is advanced indoor decorating material. Patterned wood floor can be classified into double layer and monolayer. Both two kinds take patterned hard wood as the surface. In double layer, rough board is used as the bottom. The surface wood is mainly chosen from manchurian ash, Chinese oak, walnut, oak, Elmwood, and locust. These kinds of hard wood are good in quality and not easy to rot or crack. Such wood strips are usually 250~300mm in length, 40~60mm in width, 20~25mm in thickness. And they are tongued-and-grooved.

Various patterns are made by weaving the wood strips in different ways. There are straight reed mat pattern, slanting reed mat pattern, chevron, and neat work pattern, etc. Patterned wood floor is painted with varnish to show the beautiful natural grain of the wood.

Patterned wood floor has three grades: the highest, the middle, and the lowest. The floor of the highest grade is used in high standard hotels with more than three stars, and convention rooms; the middle is used in offices, sanitariums, nurseries, stadiums, dance halls, and saloons, etc; the lowest is used in different kinds of residential houses.

3. Baseboards

Baseboards are mainly used in the room with patterned wood floor. In this way, the indoor materials fit each other quite well and thus a harmonious feeling is created. Baseboards are made by furnishing the planks, tongue-and-groove strips, and veneers. In order to make the baseboards more decorative, particular methods such as panel strip, edge joint, setting-in are used. The wall under the baseboard must be covered by a layer of damp proof. And it is better to paint the baseboard with varnish to show its graining.

Baseboards are mainly used to decorate the inner walls of good hotels, offices, and residences.

4. Timber Lattice

Timber lattice is a kind of wooden stand with several divisions which are different in their sizes and shapes. It is made of planks and square lumbers. And the best choice for timber lattice is the hardwood and the fir wood. Moreover, it is required to choose wood with few gnarls, good color, no damage by worms, and no rot.

Timber lattice is widely used as the beautiful indoor window, partition wall, and antique-and-curio shelves. It can adjust the interior design; enhance the use of space and improve the artistic flavor.

5. Peeling Micro Veneer

Peeling Micro Veneer takes color wood, birch, and gnarled root as the raw material. After the materials being softened in boiling water, they are cut into thin slices of 0.1mm in thickness. Then the slices are glued onto the hard papers and coiled materials are thus made. In addition to this, teak wood and Manchurian ash wood can be peeled into micro-veneers of 0.2~0.5mm in thickness. Then these veneers are glued onto the plywood with advanced gluing processes and cementing compounds. In this way, laminated board of micro veneer is made. Moreover, the micro veneer made of root nodules is characterized by the bird's-eye pattern, and will create better decorative effect.

Peeling micro veneer is beautiful, natural and friendly. It will give people strong stereoscopic impression. When decorating a vertical face with micro veneer, people should compare the two ends concerning the beauty and feature of their patterns and then decide the upper end and the lower end. Moreover, one also has to bear in mind the color of the furniture, the lamps and lanterns, and also the color of the accessories. Better decorative effect can be achieved by choosing the proper type of wood.

6. Wood Decorative Line (Wood Line)

There are many types of wood decorative lines, such as handrail of staircase, rim, lumbar line, ceiling line, crooked line, and picture rail, etc. All these wood lines are different in their three-dimensional shapes, such as horizontal line, half-round line, twisting line, dovetail line, astragal, omphalos, S-like molding, planted molding, clamp dentil molding, flower molding, cinquefoil, foiling, and carving ornamentation, etc..

The wood line used in houses is made of high-quality materials. It is mainly used as the lumbar line of the interior wall, the decorative line of the opening in the wall, the decorative line of the door, the decorative line of the ceiling, the handrail of the staircase, the picture-hanging line, the decorative line of the mirrors, and also the decorative line of windows and furniture in high-grade buildings.

13.2.6 Metal Finishing

The mainly used materials in metal finishing are aluminum, stainless steel, and copper. And they decorate by being made into different kinds of plates, such as diamond plate, corrugated plate, formed plate, and perforated plate, etc..

1. Decorative Aluminum Alloy Plate

The diamond aluminum alloy plate is made of rust preventive material which is rolled with particular patterns. These patterns are beautiful and elegant, not easy to be worn, skid proof, anticorrosive, and also easy to be cleaned. The surface of the diamond plate can be done with various colors. It is widely used as wall decoration and stair tread in modern buildings.

The corrugated aluminum alloy plate has many colors. It has strong light-reflecting ability. With fireproof and damp-proof properties and anticorrosion, it has a lifespan of more than 20 years. It is mainly used in the construction of walls and decoration of the roof.

The formed aluminum alloy plate is light, beautiful, anti-corrosion, and durable. After the surface processing, the plate can be quite colorful. It is mainly used as wall surface and roof.

The perforated aluminum alloy plate is a kind of new product which not only reduces noise, but also decorates the house. The design of the passes can be round, square, oval, rectangular, delthyrium, and composite. This kind of plate is used in the roof of public buildings which need better sound effects. By this, the interior sound condition can be improved.

2. Decorative Steel Plate

The decorative steel plate includes: stainless steel sheet, colored stainless steel sheet, colored coated steel sheet, and colored profiled steel sheet.

The stainless steel sheets for decoration are mainly thin plates less than 4mm in thickness. And the most used type is the plate less than 2mm. they can be classified into plane steel plate and concave-convex steel plate. The former is made through the processes of grinding and polishing while the latter also go further through the processes of rolling, carving, and special grinding. The plane steel sheet includes mirror plate (the reflection rate exceeding 90%), light plate (the reflection rate exceeding 70%), and sub optical plate (the reflection rate being lower than 50%). The concave-convex steel plate includes embossed plate, the patterned plate with shallow embossment, and lattice plate. The stainless steel plate can be used as decoration to interior and outer walls, and also as curtain wall, partition wall as well as roof, etc. Nowadays, the stainless mirror plate is widely used in malls and hotels, because of its better decorative effect.

Colored stainless steel is gotten through the further technical and artistic treatment of stainless steel which later becomes various kinds of colorful and decorative steel sheets. These colors include blue, grey, purple, red, cyan, green, golden yellow, and brown. The colored stainless steel has the properties of anticorrosion, abrasion resistance, and high temperature resistance. And its color will not fade easily. It is usually used as the wall panel of auditorium, ceiling, booth plate of elevator and the decorative finish of the outer wall.

Colored coated steel sheet can be classified into three categories: the organic, the inorganic, and the compound. The organic coated steel sheet can have different colors and patterns and therefore it is also called colored coated steel sheet. Its primitive plate is hot-rolled steel sheet, and galvanized steel sheet. The commonly used organic coat is polyvinyl chloride, polyacrylic ester, epoxide resin, and alkyd resin, etc. The colored coated steel sheet has the merits of strong stain resistance, unchanged color and luster after being cleaned, good thermal stability, better decorative effect, easiness to be processed, and durability. It can be used as external wall panel, wainscot, and roof, etc..

Colored profiled steel sheet takes galvanized steel sheet as the base material which is rolled, molded, covered with anticorrosion stuff, and painted. The properties and uses of colored profiled steel sheet is the same as the above.

13.2.7 Decorative Fabric

The interior decorative fabric mainly includes carpet, artistic tapestry or wall hanging, curtain, sheet, and tablecloth, etc. The proper use of decorative fabric will enhance the modern indoor decoration.

1. Carpet

According to the quality of the material, carpet can be classified into woolen carpet, blended carpet, chemical fiber carpet, and plastic carpet.

The woolen carpet is beautiful in its patterns, gorgeous, flexible, soft, and durable. It is mainly used in places which set high demand on the decoration, such as high standard hotels, restaurants, guest rooms, residences, staircases, and saloons.

The chemical fiber carpet has the properties of being light, abrasion resistant, fresh, comfortable, flexible, plain, cheap, sound absorbing, sound insulating, and heat preserving. It is mainly used in hotels, restaurants, guest houses, reception rooms, dining halls, living rooms, ships, vehicles, and airplanes, etc..

2. Tapestry

Tapestry is a kind of elegant artwork. Not only does it have the practical function of sound and heat absorbing, but also it gives people an intimate feeling with its special texture and grain. Tapestry has various sizes with the largest surpassing 100 square meter and the smallest below 1 square meter. It is hung on the wall for interior decoration and enjoyment. The tapestry will also change one's indoor spatial sense, and give people a sense of beauty, bringing out better artistic spatial effect.

3. Wall Cloth

The wall cloth can be used in different conditions, each of which has particular character. The common types of wall cloth are glass fiber printing wall cloth, non-woven wall cloth, and chemical fiber decorative wall cloth, etc..

Glass fiber printing wall cloth takes middle-alkali glass fiber cloth as the raw material. It is a kind of coiled material coated with abrasion-resistant resin and printed with colorful patterns. The cloth is 0.15~0.17mm in thickness and 800~840mm in width. Its color is fresh and various; its texture is good; and it is decorative. This kind of cloth can do as good decoration to the interior wall of hotels, restaurants, shops, exhibition halls, meeting rooms, dining halls and residences. Moreover, it is quite suitable to decorate the inner wall of washrooms and bathrooms, etc..

Non-woven wall cloth, a kind of inner wall material, takes natural fibers (cotton and linen) and synthetic fibers (silk ribbon and nitrile) as the raw material, which is processed without the weaving procedure, coated with resin and printed with colorful patterns. It is stiff, smooth, flexible, and will not crack easily; its fiber is non-aging, non-dissipating, and will not do harm to the skin; it has fresh color which will not fade after cleaning, and is printed with elegant patterns; furthermore, it also has certain air permeability and moisture resistance. Concerning with the above properties, the non-woven wall cloth is suitable to inner wall decoration in hotels, restaurants, shops, meeting rooms, dining halls, and residences.

Decorative wall cloth is produced by coating the cotton calico with abrasion-resistant resin and printing it with certain patterns. It has the properties of great strength, weak static electricity, weak creep resistance, dead luster, sound absorption, no toxicity, odorlessness, elegant color and patterns. This type of cloth can be used as decoration in hotels, restaurants, public buildings, and high-grade civil architectures.

Chemical fiber decorative wall cloth has many varieties. Among these, the wall cloth *Duolun* is made by blending various fibers and cotton yarn together. There is also one type made by processing and printing pure chemical fiber cloth. Collectively, the chemical fiber decorative wall cloth is nontoxic, odorless, air permeable, damp-proof, abrasion-resistant, and non- delaminate-ing. It is suitable to hotels, inns, offices, meeting rooms and residences. Its size may be 820~840mm in width, 0.15~0.18mm in thickness, and 50m in length.

Questions

13.1 What are the main functions possessed by the finishing materials?

13.2 What should be consider when choose finishing materials?

13.3 Why the marble slab is mainly used in the inner space of the buildings?

13.4 Why the fire-resistance of the granite is poor?

13.5 What is artificial stone? According to the different materials used, how many kinds can the artificial stone be classified?

13.6 What are the mainly used artificial stones in the constructions?

13.7 What are the characteristics of the fine pottery products, stoneware products and porcelain products?

13.8 What are the common finishing ceramics and where they are used?

13.9 Why the glazed brick can be only used in the inner space and not the outer space?

13.10 What are the types of the common used safety glass?

13.11 What are the properties of the insulating glass and where are they used?

13.12 What is the definition of building coating? And how many parts can it be divided?

13.13 Say something about the integrated application of the wood furniture.

13.14 What is the stainless steel sheet? How many types does it have and where it can be used?

13.15 What are the advantages of the colored coating steel sheet and where can they be used?

13.16 How many types of inner house decorative fabrics are there? And please tell the decorative functions of them.

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Appendix

Tests of Building Materials

Building Materials Course is a practical course. Tests of building materials are an important part of this course. And the aim to learning these tests are: to understand, verify, and consolidate the theories and improve the perceptual concept; to understand the equipment and master test methods; and also to be the basic trainings for scientific researches and foster the ability to analyze and solve problems. ①

The tests in this book are selected according to the outline of course compilation and are composed on the basis of the existing national (or) standards or other norms and requirements, not including all the tests of building materials. If other tests are encountered, refer to the relevant guidance documents. And various building material standards and test method amendments should be paid attention to in order to amend the tests accordingly.

Test One　Tests of Materials' Basic Properties

There are many tests for testing the basic properties of building materials. For different materials, the tested items are not the same. The items usually tested are the density, the apparent density and the ratio of water absorption.

1. Density Test

(1) Purposes

Density is the dry mass per unit volume of a substance under absolute compact conditions. The understanding of density is useful for mastering the quality and performance of materials. And density can be used to calculate the porosity.

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① Some of the symbols used in the test formulas mainly apply the existing norms of symbols, so pay attention to the distinction between these symbols and those in chapter Two.

(2) Apparatus and Equipment

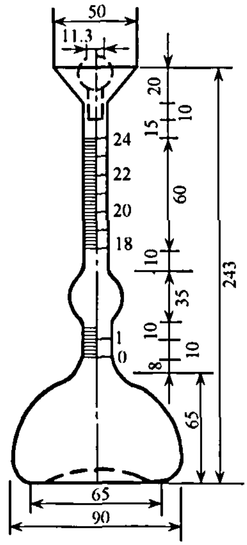
Lee's density bottle (see Test Figure1.1) (the smallest scale of 0.1mL), balance (sensitivity of 0.01g), thermometer, glass container, oven, dryer, ladle and funnel.

(3) Steps

1) Grind the sample into powder, and sift out screenings with a screen of 900 holes/ cm^2. Put the screened powder into an oven of 105~110℃ and dry it to constant quality. Then cool it to room temperature in a dryer.

2) Pour the liquid that doest not react with the sample into Lee's density bottle to the liquid level of 0~1mL.

3) Put Lee's density bottle in a glass container with water. Dip it into water completely and clip it with stent to prevent it floating or slanting. The temperature of the water in the container should be the same with the standard temperature of Lee's scale, namely, (20±2)℃.



Test Figure 1.1 Lee's density bottle

4) After 30 min, read the scale value V_1 (accurate to 0.1mL, the same below) of the concave liquid surface.

5) Pull Lee's density bottle out of the glass container, and dry the inside of bottleneck over the liquid surface with filter paper.

6) Weigh 70~80g (accurate to 0.01g, the same below) powder with a balance scale, marking it m_1. Pour the powder into Lee's bottle with a ladle and a funnel slowly (to prevent blockage in the throat of the bottle) until the liquid surface rises to 20mL.

7) Weigh the mass of the remaining sample m_2 (g). Tilt Lee's bottle to a certain angle and rotate it so that the air bubbles in the powder will escape.

8) Put the bottle into the glass container again. After 30 min when the temperature of the liquid becomes the same with water, read the scale value of the concave liquid surface V_2 (mL).

(4) Results

1) Calculate the density with the following formula (accurate to 0.01g/ cm^2):

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

In this formula: m is the mass of the powder in Lee's bottle (g), namely, the difference between m_1 and m_2;

V is the absolute volume of the powder in Lee's bottle (cm^3), namely, the difference between V_1 and V_2.

2) The average value of the results of the above two test is the test result of the density. The difference of the two results should not be greater than 0.02 g/cm^2. Or, it should be re-tested.

2. Apparent Density Test

(1) Purposes

Apparent density is the dry mass per unit volume of a substance under natural conditions. The strength, thermal conductivity and water absorption can be evaluated by apparent density; and also it can be used to calculate the porosity, volume, quality and the structure weight.

(2) Apparatus and Equipment

1) A balance (weighing of 1000g and division value of 0.1g), liquid balance (Archimedes balance, division value of 0.01g).

2) Vernier caliper (accuracy of 0.1mm), oven, dryer, paraffin wax, alcohol and so on.

(3) Steps

1) For the materials in regular shape (such as brick, stone and block).

① Put the three test pieces in each group in oven of (105±5)℃ to dry them to constant quality. Then cool them to room temperature in a dryer and weigh the mass m(g).

② Measure the size of every test piece with vernier caliper and calculate their volume V (cm^3).

a. For a hexahedral specimen, measure their length, breadth and height three times at different points in each direction, and calculate their average a, b, and c, then:

$$V_0 = a \times b \times c$$

b. For a cylinder specimen, measure the diameter in the two mutually perpendicular directions on the two parallel sections and the waist of the specimen. Calculate the average of the six values d. And then measure its height at the four endpoints of the two mutually perpendicular diameters on the circle. And calculate their average h.

$$V_0 = \frac{\pi d^2}{4} \times h$$

③ Result Calculation.

The apparent density ρ_0 is defined by (accurate to 10kg/m^3 or 0.01g/cm^3).

$$\rho_0 = \frac{m}{V}$$

For regular specimens, the average results of three specimens can be the test results. And the error of each result should be within 20 kg/m^3 or 0.02 g/cm^3; if the specimen is irregular, the test results should be the average results of five specimens and the maximum and the minimum should be marked.

2) For the materials in irregular shape (such as rubble and gravel).

① Process (or select) 5~7 specimens of 20~50mm long. Put them into a (105±5)℃ oven and dry them to constant mass. And then cool them to room temperature in a dryer.

② Weigh the mass of one specimen, m (accurate to 0.1g, the same below).

③ Put the specimen into melt paraffin wax, and take them out after 1~2s. There is a wax film (no more than 1mm thickness) on the specimen.

④ Weigh the mass of the waxed specimen, m_1 (g).

⑤ Weigh the mass of the waxed specimen in water, m_2 (g).

⑥ Calculate the density of the paraffin wax (normally 0.93g/cm^3).

The steps of other specimens are the same with ②~⑤.

⑦ Test Results.

The apparent density ρ_0 is defined by (accurate to 10kg/m^3 or 0.01g/cm^3)

$$\rho_0 = \frac{m}{m_1 - m_2 - \dfrac{m_1 - m_2}{\rho}}$$

For regular specimens, the average results of three specimens can be the test results. And the error of each result should be within 20 kg/m^3 or 0.02 g/cm^3; if the specimen is irregular, the test results should be the average results of five specimens and the maximum and the minimum should be marked.

3. Water-absorption Ratio Test

(1) Purposes

Water-absorption ratio refers to the ratio of the mass or volume of water to the dry mass or volume of a material when the material is saturated. The water-absorption ratio affects the strength, frost resistance, thermal conductivity and other functions greatly. The test of water-absorption ratio is useful for evaluating various functions. Now, take stone as an example to introduce the testing methods.

(2) Apparatus and Equipment

Balance (1kg, division value of 0.1g), sink, oven, dryer, and so on.

(3) Steps

1) Process (or select) cube specimens with the edge length of 4~6cm or cylinder specimens with the diameter or height of 4~6cm.

2) Put them into a 105~110℃ oven and dry them to constant mass. And then cool them to room temperature in a dryer.

3) Take specimens out of the dryer and measure their mass, m (g).

4) Put the specimens in a sink and remain 1~2cm distance between every two specimen. Lay glass bars under the bottom of the specimens to avoid direct contact with the bottom of the sink.

5) Inject water into the sink until the water rose to 1/4 height of specimens, add water to 1/2 height after two hours, add water to 3/4 height after another two hours, and add water to 1~2cm above specimens after two hours. Then take them out after a day and night.

6) Press the surface of specimens slightly with screwed wet towel until the water on the surface is absorbed (do not wipe). And weigh the mass. Then put them back into the water.

Follow the above procedures every other day and night until the mass of the soaking specimens are constant (the quality difference between a day and night should be within 0.05g), and then weigh the mass, m_b (g).

(4) Test Result

The water-absorption ratio is calculated by:

Specific Absorption of Quality:

$$W_m = \frac{m_b - m}{m} \times 100\%$$

Specific Absorption of Volume:

$$W_v = \frac{m_b - m}{V_0} \times \frac{1}{\rho_w} \times 100\%$$

In this formula: W_m is the specific absorption of quality;
m_b is the mass of a saturated specimen (g);
m is the dry mass (g);
W_V is the specific absorption of volume (%);
V_0 is the volume of a specimen in natural state (cm^3);
ρ_w is the density of water (g/cm^3), normally $1.0g/cm^3$.

Test Two Lime Test

1. Inspection Rules

(1) Factory Inspection

Building quicklime is inspected in batch by the quality supervision departments of factories. The tested items are all the ones in Table 3.2 of Chapter Three. And the inspected items of building quicklime are those in Table 3.3 of Chapter Three. The tested items of building hydrated lime are those in Table 3.4 of Chapter Three.

(2) The Inspected Batch

The inspected batch of building quicklime and quicklime powder are:

If the daily output is more than 200t, each batch is less than 200t;

If the daily output is less than 200t, each batch is less than 100t;

If the daily output is less than 100t, each batch is less than the daily output.

The inspected batch of building hydrated lime is divided according to the production capacity. 100t is regarded as a batch, and less than 100t is still regarded as a batch.

(3) Sampling

1) The samples of quicklime are taken from different part of the whole batch in accordance with the regulations. The sampling locations should not be less than 25, and the sampling amount should not be less than 2kg. The sample should be reduced to 4kg and packed in sealed containers.

2) The sampling of quicklime powder: the samples of the powder in bulk can be taken randomly or by the use of automatic sampler. In the sampling of bagged quicklime powder, 10 bags should be taken randomly from the bulk. And the total sampling amounts should not be less than 3kg. The samples should be stored in containers during the collection process. When the

sampling is over, the samples should be reduced to 300g by quartering immediately, installed in the ground wild-mouth bottle, sealed and labeled: the product name, volume, production date, frequency, sampling location, and the signature of sampler, and finally sent to the laboratory.

3) The sampling of hydrated lime powder: 10 bags of samples are taken from each batch, and 100g are taken from different points of each bag. The total amount should not be less than 1kg, evenly mixed. The samples should be shrunk by quartering and finally selected 250g for the physical testing and chemical analysis.

(4) Judgment

When all the technical indicators of products have reached the corresponding technical requirements in Table 3.2, Table 3.3, and Table 3.4 in Chapter Three, the grade of products can be determined. If there is one index below the qualified grade, the product is not qualified.

(5) Rechecking

When customers have objections to the product quality, the physical indicators can be rechecked. The product sample that is taken according to the above requirements of sampling can be sent to quality supervision department for rechecking

2. The Physical Test Method of Building Lime

(The method is applicable to the physical performance tests of building quicklime, quicklime powder and building hydrated lime powder.)

(1) Fineness

1) Apparatus.

① Test sieve: a set of standard sieves of 0.900mm and 0.125mm of 20 principal series that meets GB6003 regulation.

② Goat hair brush: No. 4.

③ Balance: metage of 100g; the division value of 0.1g.

2) Sample.

Quicklime powder or hydrated lime powder.

3) Testing Steps.

Take 50g sample and pour them into the square-hole sieve of 0.900mm and 0.125mm for screening. In the process of screening, grip the test sieve by one hand and gently knock it by the other. In regular intervals, rotate the sieve horizontally and gently knock the sieve on a fixed base. Brush the sieve lightly with the goat hair brush until the throughput within 2mm is less than 0.1g. And weigh the mass of sieve residue m_1 and m_2 respectively.

4) The Calculation of Results:

The percentage of screen residue (x_1) and (x_2) are calculated as follows:

$$x_1 = \frac{m_1}{m} \times 100\%$$

$$x_2 = \frac{m_1 + m_2}{m} \times 100\%$$

In the formulas: x_1 is the percentage of the residue of 0.900mm square-hole sieve (%);

x_2 is the percentage of the total reside of both 0.125m and 0.900mm square-hole sieve (%);

m_1 is the mass of the residue of 0.900mm square-hole sieve (g);

m_2 is the mass of the residue of 0.125mm square-hole sieve (g);

m is the mass of the sample (g).

The results are rounded to two decimal places.

(2) The Slaking Rate of Quicklime

1) Apparatus.

① Vacuum-bottle: the full length of the bottle liner is 162mm; the diameter of the bottle body is 61mm; the inner diameter of the bottle mouth is 28mm; the capacity is 200mL; the upper cover should be the white rubber stopper with hole in the center for hygrometer.

② Long-tailed water thermometer: the range of 150℃.

③ Stopwatch.

④ Balance: the metage of 100g; the division value of 0.1g.

⑤ Glass graduated cylinder: 50mL.

2) Sample Preparation.

Take the quicklime sample of about 300g and grind it to pass through the round-hole sieve of 5mm. Take 50g by quartering and grind it in the porcelain bowl to pass through the square-hole sieve of 0.900mm. Mix it evenly and put it into a ground bottle for standby.

Mix the sample of quicklime powder evenly. Take 50g by quartering and put it into a ground bottle for standby.

3) Testing Steps.

Check the upper cover of vacuum-bottle and the thermometer. Make sure the bottom of the thermometer be inserted into the sample. After the inspection, add (20±1)℃ distilled water of 20mL into the vacuum-bottle. Weigh 10g sample (accurate to 0.2g) and pour it into the water in the vacuum-bottle. Start the stopwatch immediately and cover the cap at the meantime. Press the vacuum-bottle lightly several times. Read the temperature every 30s since the moment when the sample is poured into the water. Near the end, observe carefully and record the highest temperature and the time when the temperature begin to fall. The time to achieve the maximum temperature is the slaking rate (in mm).

The arithmetic average of the two results is regarded as the result, rounded to two decimal places.

(3) The Slurry Yield of Quicklime and the Content of Unslaked Residue

1) Apparatus.

① Round-hole sieve: two sieves of which the apertures are 5mm and 20mm respectively.

② Quicklime residue determinator (see Test Figure 2.1).

③ Glass graduated cylinder: 500mL.

④ Balance: metage of 1000g; the division value of 1g.

⑤ Enamel dish: 200mm×300mm.

⑥ Steel ruler: 300mm.

⑦ Oven: the maximum temperature is 200℃.

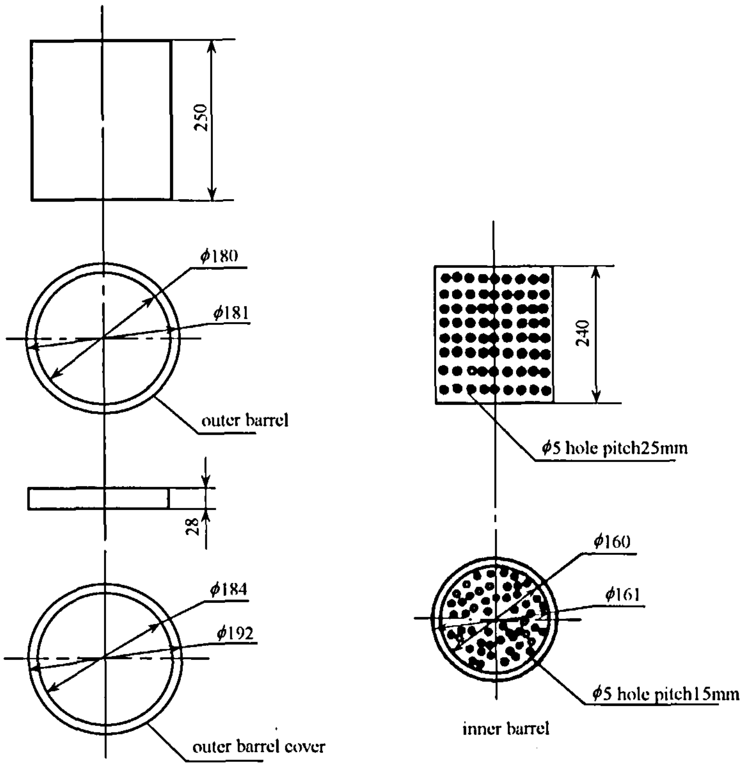
⑧ Insulation cover.

2) Sample Preparation

Crush 4kg sample to pass through the round-hole sieve of 20mm. The amount of the sample whose size is below 5mm should not be more than 30%. Mix it evenly for standby. Just mix the quicklime powder evenly.

3) Testing Steps.

Weigh 1kg quicklime sample that has been prepared. Pour it into the barrel (sift barrel placed outside the outer barrel) with (20±5)℃ water of 2500mL. Cover the cap and let the sample slake for 20 min. Stir it with a round wooden stick for 2 min and let the lime slake for 40 min. Then stir it for another 2 min. Lift the sift barrel and flush the residue with water until the water is clear (the water used for flushing is still poured into the sift barrel and the total volume should be controlled within 300mL). Put the residue in the enamel dish (or evaporation dish) and dry it to constant weight in (100~105)℃ oven. Screen the lime with round-hole sieve of 5mm after it decreases to room temperature and weigh the screening residue. Calculate the content of unslaked residue. Measure the height (the total height of the outer barrel minus the height from the slurry surface to the barrel mouth) of the slurry with steel ruler after the slurry stands for 24h.



Test Figure 2.1 Quicklime Residue Determinator

4) The Calculation of Results.

① The slurry yield of quicklime (x_3) is defined as follows:

$$x_3 = \frac{R^2 \cdot \pi \cdot H}{1\times10^6}$$

In this formula: x_3 is the slurry yield of quicklime (L/kg);

π is 3.14;

H is the height of the slurry (mm);

R is the semi-diameter of the slurry barrel (mm).

② The percentage of the unslaked residue is calculated as follows:

$$x_4 = \frac{m_3}{m} \times 100\%$$

In this formula: x_4 is the content of unslaked residue (%);

m_3 is the mass of the unslaked residue (g);

m is the mass of the sample (g).

The result is rounded to two decimal places.

(4) The Soundness of Hydrated Lime Powder

1) Apparatus.

① Balance: metage of 200g and the division value of 0.2g.

② Graduated cylinder: 250mL.

③ Horn spoon.

④ Evaporation dish: 300mL.

⑤ Asbestos screen board: outer diameter of 125mm; the asbestos content of 72%.

⑥ Oven: the maximum temperature is 200℃.

2) Experimental Water.

It should be the clear fresh water of (20 ± 2)℃.

3) Testing Steps.

Weigh 100g sample and pour it in the evaporation dish of 300mL. Add 120mL clear fresh water of (20 ± 2)℃ and mix them into a thick paste within 3 min. Pour it on two asbestos screen boards at one time. The cake block diameter is 50~70mm and the central height is 8~10mm. After the blocks standing in the room temperature for 5 min, put the blocks on another two dry asbestos screen boards and then put them in the oven. Adjust the temperature to 100~105℃ and take them out after drying for 4h.

4) The Evaluation of Results.

After drying, inspect the cake block with naked eyes. If there is no collapse, cracks or bulges, the soundness is qualified; if there appears one of the above three phenomena, it indicates that the soundness is not qualified.

(5) The Free Water in Hydrated Lime Powder

1) Apparatus.

① Balance: metage of 20g; and the division value of 0.2g.

② Oven: the maximum temperature is 200℃.

2) Testing Steps.

Weigh 100g sample and put it in the enamel dish. Dry it to constant weight in the oven of 100~105℃. Calculate the free water after it decreases to the room temperature.

3) The Calculation of Results.

The percentage of the free water (x_5) in hydrated lime powder is calculated as follows:

$$x_5 = \frac{m - m_1}{m} \times 100\%$$

In the formula: x_5 is the free water in hydrated lime powder (%);

m_1 is the mass of the dried sample (g);

m is the mass of the sample (g).

3. The Chemical Analysis of Building Lime

The inspection items of building lime also are: the determination of silicon dioxide; the determination of iron, aluminum, calcium, and magnesium; the determination of lime bound water, carbon dioxide content, and ignition loss. All these items are tested by chemical analysis of building lime (see the relevant provisions for details).

Test Three Cement Test

1. The Conventional Requirements for Cement Test

1) The samples should be taken from the same factory, be produced in the same period, and belong to the same variety and same strength grade. The cement products with the same factory codes entering factory at the same time are taken as a batch (namely a sampling unit). The batch of bulk cement should not be more than 500t in total and that of sacked cement should not be more than 200t. The samples should be representative and continuous. And they can be taken from different parts, with the total of over 12kg.

2) Samples should be mixed well. Record the percentage and properties of the screenings left on the square-hole sieve of 0.9mm.

3) The test water should be clean and fresh water.

4) The temperature of laboratory should be controlled around (20 ± 2) ℃, and the relative humidity should be more than 50%. The temperature of curing box should be(20 ± 1)℃, and the relative humidity should exceed 90%.

5) The moisture of cement samples, standard sand, and the mixing water should be the same with the laboratory.

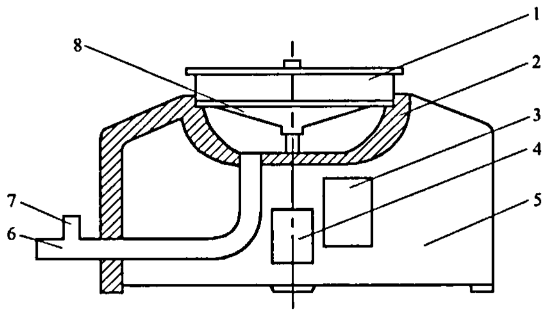
2. Determination of Cement Fineness

(1) Determination of Cement Fineness

The fineness of cement is an important index for cement and has great impact on its strength, soundness, water segregation, energy consumption and production. There are specific surface area and screen analysis, the two testing methods. The method of specific surface area is mainly used for Portland cement and screen analysis method is used for the other kinds of cement. Screen analysis method can also be divided into negative pressure screen analysis, water screen, and manual dry screening. In the actual testing, if the result tested by negative pressure screen analysis confronts with the one tested by water screening or manual dry screening, the former prevails. Manual dry screening can be adopted when there is no negative pressure sieve and water sieve. The method of negative pressure screen analysis is mainly introduced here.

(2) Apparatus

1) Negative Press Sieve Analysis Device: is consisted of sieve steadier, negative pressure sieve, negative pressure source, and dust collective device. Thereinto, the sieve steadier is consisted of air nozzle with the speed of (30 ± 2)r/min, negative pressure gage, control board, micro-motor and shell (See Test Figure 3.1).



Test Figure 3.1 The Schematic Diagram of Negative Pressure Sieve Analysis Device

1. the square-hole sieve of 0.045mm; 2. rubber washer; 3. control board; 4. micro-motor; 5. shell; 6. extraction opening; 7. air door (adjusting negative pressure); 8. air nozzle.

2) Balance (with the largest weighing of 100g and the division value of no more than 0.05g).

(3) Steps

1) Before screen analysis testing, install the negative pressure sieve well, connect it to the power, conduct control system inspection, and then adjust negative pressure to 4000 ~ 6000Pa.

2) Take samples of 25g, put it in the clean negative pressure sieve, cover the screen cap, put it on the sieve steadier, and start the sieve analysis device for screening 2 min continuously. During the screen analysis, all the samples left on the sieve cap should be all knocked off to the sieve. When the analysis finishes, weigh the screenings by balance (accurate to 0.05g).

3) When negative pressure is under 4000Pa, clean the cement left in the vacuum cleaner to recover the negative pressure to normal range.

(4) Result

The percentage of cement sample screenings is calculated as follows:

$$F = R_s / m \times 100\%$$

In the formula: F is the percentage of screenings (%);

R_s is the mass of screenings;

m is the mass of samples (g).

The result is accurate to 0.1%.

3. Determination of the Water Consumption for Cement Normal consistency

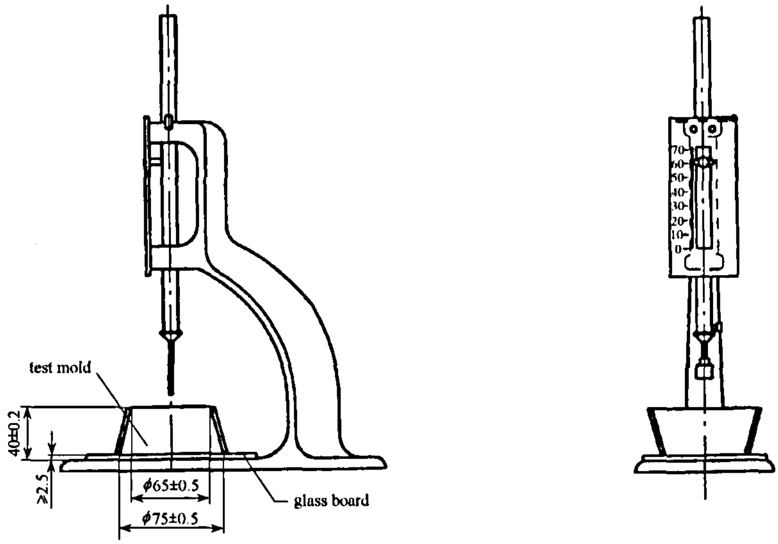
(1) Purposes

The test of the water demanded by purified cement paste when it achieves to the normal consistency will facilitate the test of setting time and soundness of cement with standard purified paste. The testing methods include standard method and substitution method (to adjust water demand and fixed water demand). If there is conflict, the result is subject to the standard method.

(2) Apparatus

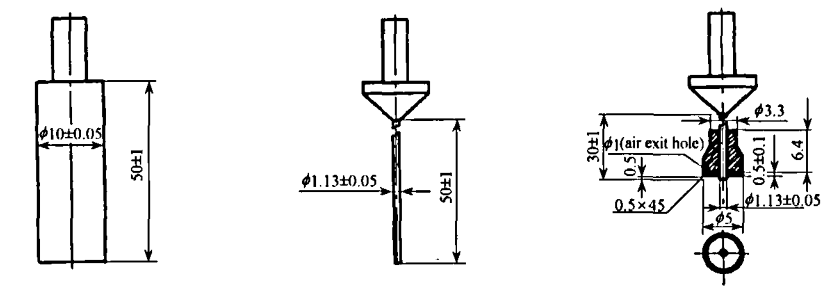
1) Vicat Apparatus of Standard Method.

As shown in Test Figure 3.2, the normal consistency will be measured by cylindrical test bar, made of corrosion-resistant metals, with effective length of (50±1)mm and diameter of ϕ 10±0.05mm. The surface of connecting sliding bar should be smooth, free falling by gravity, and without any tight and loose phenomenon.



(a) the vertical view of vertical test mold for the test of the initial setting time

(b) the front view of reversal test mold for the test of the final setting time;



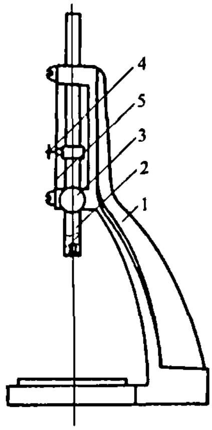
(c) test bar of normal consistency (d) the index finger for the initial setting (e) the index finger for the finial setting

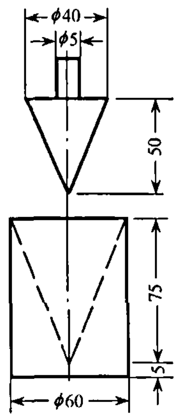
Test Figure 3.2 The Vicat Apparatus for the Test of Normal consistency and Setting Time

The test mold containing purified cement paste [see Test Figure 3.2 (a)] should be made by corrosion-resisted and hard metals. The test mold is a truncated cone with the depth of (40 ± 0.2)mm, the top diameter of ϕ 65 ± 0.5mm, and bottom diameter of ϕ75 ± 0.5mm. Each test mold should be equipped with a flat glass backboard bigger than test mold whose thickness should be more than 2.5mm.

2) Normal Consistency Detector.

As shown in Test Figure 3.3, the mass of the sliding part of the cone is (300±2)g, the bottom diameter and the height of the hollow metal test cone are 40mm and 50mm respectively, and the upper diameter and the height of the cone mode used for containing paste are 60mm and 75mm respectively (see Test Figure 3.4).





Test Figure 3.3 Normal Consistency Detector Test Figure 3.4 Test Cone and Cone Mold

1. iron steadier; 2 metalic bar; 3. elastic screw;
4. index finger; 5. yardstick

3) Cement purified paste mixer includes agitator kettle, mixing blade, transmission mechanism, and control system. The mixing blade rotates with double wheels in double-speed. It is regulated: the space between agitator kettle and mixing blade should be (2 ± 1) mm; the stirring process and time should be like this: slow stirring for 120s, halting for 15s, and fast stirring for 120s.

4) Water gauge (with the minimum scale of 0.1mL and accuracy of 1%), balance (accurate to 1g).

(3) Steps

1) The Test of the Water Consumption of the Standard Consistency (Standard Method).

① Pre-test Check: can the metal bar of the device slide smoothly; does the index finger point at zero when the test cone fall down to the top of the mold; and can the agitator kettle work normally.

② The Mixing of Cement Purified Paste: before mixing, wipe the stirring tools (agitator kettle, mixing blade, test cone or mold) with wet cloth, pour the mixing water into mixing pot, and then put the weighed cement of 500g into the water within 5~10s carefully; in mixing, fix the agitator kettle on its steadier, raise it to the mixing position, and start it; make it stir slowly for 120s and halt for 15s, meanwhile scratch the cement paste left on the blades and the pot wall into the pot, and make it stir fast for 120s and then stop. The mixing water is used by experience (accurate to 0.5mL).

③ The steps to test the water requirement of normal consistency: after mixing, fit the mixed purified paste into the mold standing on the glass board immediately, disturb it with knife, and scratch the excess paste after several-time vibration; move the mold and the board to the vicat apparatus quickly after towelling, fix its center under the test bar, lower the bar until it contacts with the paste, tighten the screw for 1~2s, and release it suddenly (that is to open the screw) to let the bar vertically sink into the paste; record the distance between the bar and the board after it stop falling or release for 30s, raise the bar and clean it right away; the whole operation should be finished within 1.5 min after mixing.

2) The Test of the Water Consumption for the Standard Consistency (Substitution Method: Adjusting Water Consumption Method and Fixed Water Consumption Method).

① Pre-test Check: can the metal bar of the device slide smoothly; does the index finger point at zero when the test cone fall down to the top of the mold; and can the agitator kettle work normally.

② The Mixing of Cement Purified Paste: the same with the above standard method. When adjusting water consumption method is adopted, the amount of mixing water depends on experience; if the fixed method is adopted, the amount of mixing water should fixed to 142.5mL. And if there is a conflict, the adjusting method prevails.

③ The steps to test the water requirement of normal consistency: after mixing, fit the mixed purified paste into the test cone immediately, disturb it with knife, and scratch the excess paste after several-time vibration; move it to the fixed position under test cone quickly after trowelling, lower the cone until it contacts with the paste surface, tighten the screw for 1~2s, and release it suddenly (that is to open the screw) to let the cone vertically sink into the paste; record its sinking depth after it stop falling or release for 30s, and the whole operation should be finished within 1.5 min after mixing.

(4) Results

1) (GB/T1346-2001) The Water Consumption for Cement Normal Consistency (Standard Method).

When the distance between the test bar and the board is (6 ± 1)mm, the cement paste is known as purified paste. Its amount of mixing water is the water requirement of normal consistency (P), calculated by the percentage of the cement mass. If the distance is more than or less than (6 ± 1)mm, the proper amount of mixing water should be found according to experience.

2) Adjusting Water Consumption Method.

When the sinking depth of the test cone is (28 ± 2)mm, the purified paste is the paste of normal consistency. If the sinking depth is beyond the range, try to re-conduct the experiment until it accords with the standard. The water requirement for the normal consistency (P) is calculated as the percentage of the cement mass, as follows:

$$P = W / 500 \times 100\%$$

In this formula: W is the amount of mixing water.

3) Fixed Water Consumption Method.

Based on the tested sinking depth of the test cone S (mm), the water consumption for the normal consistency P can be calculated as follows (or refer to the corresponding scale):

$$P=33.4\text{-}0.185S$$

If the sinking depth is less than 13mm, the adjusting method should be adopted.

4. Determination of the Setting Time (GB/T1346-2001)

(1) Purposes

The purpose is to test the setting time and make sure whether it can meet the demand of projects.

(2) Apparatus and Equipment

1) The apparatus for setting time.

As Test Figure 3.2 shows, the needles to determine the setting time [see Test Figure 3.2 (d), (e)] are made of steel. They are the cylinders whose effective length of the initial setting needle is (50±1)mm and that of the final setting needle is (30±1)mm, and the diameter ϕ is (1.13±0.05)mm The total mass of the sliding part is (300±1)g. The sliding rod connecting with needles should be smooth and can fall by gravity freely, no tightening or shaking.

2) The use of cement paste mixer is the same to the determination of normal consistency.

3) Standard curing box.

(3) Steps

1) Before determination, put the circle matrix [see Test Figure 3.2 (a)]on the glass board and coat a layer of oil on its inner wall and glass board slightly. Adjust the index finger of the final setting time determinator to zero scale.

2) Take cement sample of 500g, mix the cement paste with the amount of water of normal consistency, and record the time to add water as the starting time for condensation.

3) Immediately pour the mixed cement paste into the circle matrix at a time, scrape it smoothly after several vibration and then put it into the curing box.

4) The determination of the initial setting time: conduct the first test after 30min that the samples stay in the standard curing box until water is added. In determination: take out the circle mold from curing box and put it under the test needle, make the paste surface contact with the needle, fasten the screw, and suddenly release it after 1~2s to let the needle fall down vertically into the paste, and observe the index finger when it stops falling or after releasing for 30s. If the distance between the needle and the bottom board is (4 ± 1)mm, the cement reaches the initial setting state; the time from the cement paste being put into water completely to the initial setting state is known as the initial setting time of cement, expressed in "min".

5) The determination of the final setting time: a circular accessory [see Test Figure 3.2(e)] is installed to the finial setting needle in order to correctly observe the sinking of the needle. After the determination of the initial setting time, immediately move the test mold with paste off the glass board horizontally, turn it 180 ° with the big head up and small head down, put it on the glass board again, and then put them into the moisture curing box for maintenance; test it every 15 min near the end of final setting, and do not leave any traces on the specimen when the needle sinks into 0.05mm of the specimen, namely, the beginning of the installation of the accessory. This is known as the final setting state. The final setting time is from the cement being put into water completely until the final setting time, expressed in "min".

6) Attention: the metal bar should supported slightly be in the initial test operation to let it sink slowly so that the needle cannot be bended, but the result should be subject to that when it fall down freely; the distance between the position that the needle sink and the test inner wall should be at least 10mm. Test it every 5min near the initial setting; test it every 15min near the final setting. Test the cement paste again urgently after it reaches the initial

setting or the final setting. If the two results are the same, it can be determined that the cement paste has gotten to the initial setting state or the final setting state.

The needle should not fall into its original hole in every determination. And the needle should be cleaned and the circle matrix should be put back to the standard curing box after each test. In the whole testing process, the circle mold should be avoided vibrating. If the automatic setting time apparatus is used, the specimen does not have to be turned in the test.

(4) Results

The time from the addition of water to the initial setting state and the final setting state should be the initial setting time and the final setting time of the cement respectively, shown as "h" and "min".

5. The Inspection of Soundness (GB/T1346-2001)

(1) Purposes

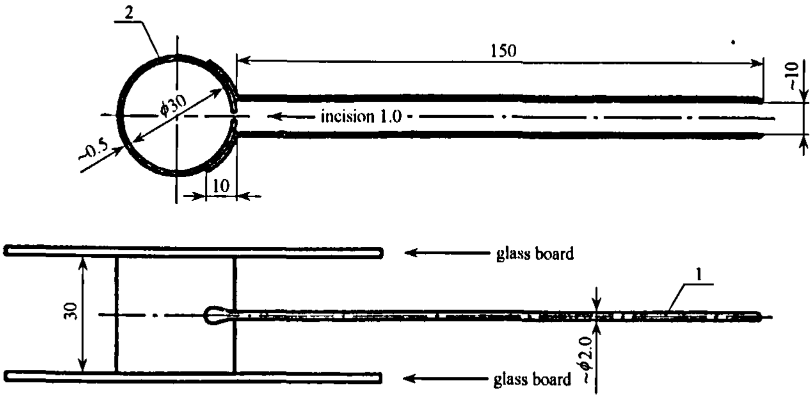
The inspection of the evenness of the cement volume changes in hardening can determine whether the cement can be used or not. The test method is boiling method which is mainly used for the inspection of the poor dimensional stability produced by the disassociated calcium; pat test and Le Chatelier soundness test can be used as the determination methods, and if there is conflict, the Le Chatelier prevails. Pat test means to observe the changes of the shape after the boiling of paste pat in order to check the soundness of cement; Le Chatelier is used to determine the expansion value after cement paste is boiled between the Le Chatelier needles.

(2) Apparatus and Equipment

1) Boiling box: its effective capacity is 410mm×240mm×310mm; it contains grid plate and heater inside; it can heat the inner water from room temperature to boiling within 30 min ± 5 min, and the boiling can be kept for 3h without adding water.

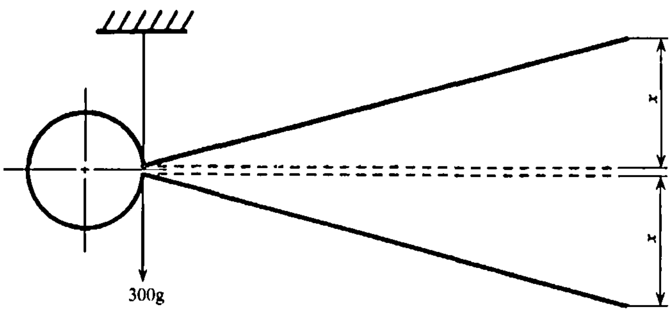
2) Le Chatelier needles: is made of copper material (see Test Figure 3.5).

Le Chatelier soundness test should accord with the following requirements: when the root of a needle is hung up to a wire or nylon yarn and 300g weights are added to the other one, the increase of the distance between the two needles' pointers should be within (17.5 ± 2.5)mm, namely, $2x$=17.5 ± 2.5mm (see Test Figure 3.6). And the pointers should go back to the original state after the remove of weights.



Test Figure 3.5 Le Chatelier Needles

1. index needle; 2. circular mold.



Test Figure 3.6 The Force Diagram of Le Chatelier Needles

3) Determinator for the expansion value of Le Chatelier needles with the minimum bench mark of 0.5mm (see Test Figure 3.7).

4) Cement paste mixer, standard curing box, balance, and water gauge.

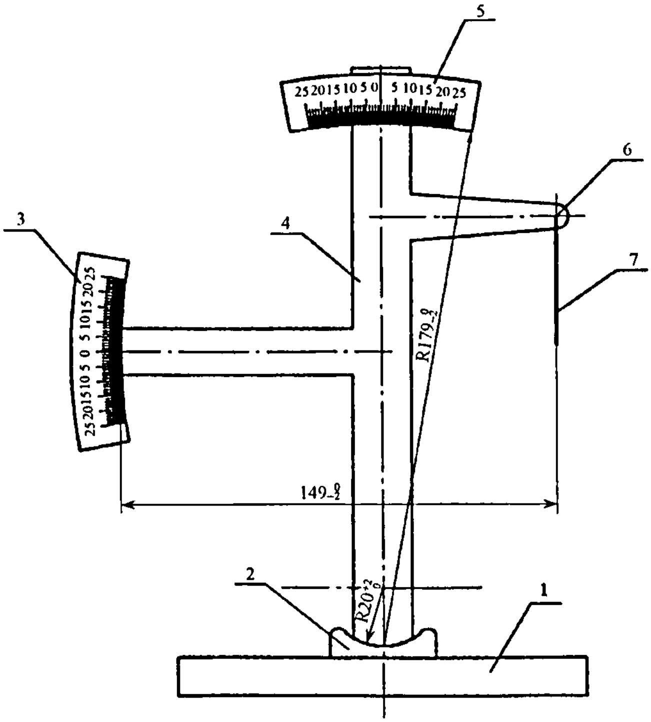
(3) Steps

1) The Prepare of Cement Paste in Normal consistency.

Weigh cement of 500g, and use the paste mixer to stir cement paste with the water requirement of normal consistency.

2) The Sample Production.

Through the Pat test method, take out a part of the prepared cement paste (about 150g), divide it into two equal parts and make them into a ball. Take one sample for an example, put it on the prepared glass board (of 100 mm×100 mm and also painted with a little oil), slightly vibrate the board, and scrape it from the edge to the center with the knife wiped by a wet cloth to make it into a smooth thin cake whose diameter is 70~80mm, central circle is 10mm, and edge becomes thin gradually. Put the prepared cake into the curing box for (24 ± 2)h conservation.



Test Figure 3.7 The Determinator for the Expansion Value of Le Chatelier

1. steadier; 2. mold base; 3. scale to measure elasticity; 4. column; 5. cantilever; 6. suspension wire

With Le Chatelier method, put the Le Chatelier needles whose inner surfaces are painted with oil on the glass board (of 75~80g) painted with a little oil, and immediately load the prepared paste into the test mold. When loading the paste, one hand slightly hold the needles, and the other one use the knife of 10mm wide to insert the paste about 15 times. Then scrape it and cover the glass board (of 75~80g) painted with oil a little. Move the test mold into the curing box right away for (24 ± 2)h conservation.

3) Boiling.

After the conservation, move the mold off the glass board.

Adjust the water level of the boiling box to make the sample immerge into the water through the whole boiling process without adding water midway and meantime make sure that it can be heated to boiling within 30 min ± 5 min.

With Pat test method, first of all check whether the cake is perfect or not (for example, if it cracks, find the reason; and if there is no external cause, the sample is unqualified and does not need to be boiled). If the cake is perfect, put it on the grid plate in the curing box and heat it to boiling within 30 min ± 5 min and constant boiling for 3 h ± 5 min.

With Le Chatelier method, check the distance between the index needles (A) at first and make it accurate to 0.5mm. And put the Le Chatelier needles on the grid plate in water with the index needles up, and the samples should not cross. Then heat them to boiling within 30min ± 5min and constant boiling for 3h ± 5min.

When boiling is over, release the hot water, open the box cover, and take out the sample to check after the box is cooled to the room temperature.

(4) Results

1) For Pat test method, if the sample does not crack and bend by checking with a ruler, the soundness of the sample is qualified; on the contrary, it's not. If the results of the two cakes have conflict, the cement is also unqualified.

2) For Le Chatelier method, measure the distance between the index needle points (C), and calculate the increasing distance after boiling ($C-A$). Take the average of the two samples for the test result. If ($C-A$) is no more than 5.0mm, the soundness of the cement is qualified; on the contrary, it's not. If ($C-A$) is more than 4mm, the same cement should be tested again. If the result is still the same, the soundness of the cement is unqualified.

(5) Record Format and Conclusion of the Tests

1) Record Format.

Sample Name

Code	Distance between the index needle points before boiling, A/mm	Distance between the index needle points after boiling C/mm	Increasing distance between the index needle points after boiling ($C-A$)/mm	Average

2) Conclusion.

Determine whether the soundness of cement is qualified or not according to the national standards.

6. The Test of the Strength of Cement Gel Sand (ISO)

(1) Purposes

Test and determine the strength degrees of cement by soft method according to the regulation, GB/T17671-1999.

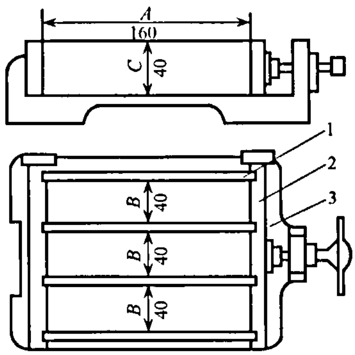
(2) Apparatus and Equipment

1) Mixer for mixing mortars which is the general type of ISO standard. The blades can auto-rotate round its axis, and also revolve along the circle of the mixer. It is a cement gel sand mixer with a planet-like trajectory.

2) Plain bumper for sample molds of cement gel sand consists of vibrating table plate and cams which make it jump. The amplitude of plain bumper is 15mm ± 0.3mm, and vibration frequency is 60 times/ (60s±2s).

3) Baiting die sleeve.

4) Test mold: is the removal triple-mold which consists of partition, the end plate and base. The inner cavity of the mold is 40mm×40mm×160mm. And the three sides should be perpendicular to each other (see Test Figure 3.8).



Test Figure 3.8 Test Mold

1. partition; 2. end plate; 3. base

5) Flexure testing machine: is usually the electric flexure machine with the leverage ratio of 1 : 50. The loading of bending fixture and the diameter of the supporting column should be (10±0.1)mm (the wear size of 10~0.2mm is allowable), and the distance between the centers of the two supporting column is (100±0.2)mm.

6) Anti-fracture machine: its maximum load is 200~300kN and it should be used within four-fifths of the range; the recorded load should be accurate to 1%, and the loading capacity with the speed of 2400N/s±200N/s.

7) Anti-compression fixture: it is made of hard steel. Pressure board is 40mm±0.1mm long, and more than 40mm wide. The surface of the pressure board must be scraped smoothly.

(3) Sample Mold

1) Wipe the test mold clean, paint butter on the surface that surrounding plates contact with the base to prevent leakage, and brush a thin wall of oil on the inner wall evenly.

2) The sand of ISO standard should accord with *Test Methods of the Strength of Cement Gel Sand* (GB/T17671-1999). The ratio between the mass of sand and that of the standard sand is 1 : 3, and the water-cement ratio is 0.5. Every three shaping samples need the cement of 450g, the standard sand of 1350g, and the mixing water of 225g.

3) Gel sand of each pot should be mixed by mixing machinery. First make the mixer be at work, and then conduct the process based on the following process.

Add water into the pot at first, pour cement into it, put the pot on the fixed stand, and raise it to the fixed position. Start the machine immediately, let it stir slowly for 30s, and add the sand when the second 30s start. Switch it to the high stirring for another 30s and stop for 90s. In the first 15s, scrape the gel sand off the blades and the pot inner wall into the pot with rubber tool. Continue to stir it for 60s under high speed. The time error of each mixing stage should be within 1s.

4) Fix the test mold and die sleeve on the plain bumper. Divide the gel sand into two layers and install them into the test mold with a proper spoon directly from the mixing pot. When load the first layer, put 300g gel sand into the pot; stir the materials along the mold for one time with the big stirring-up device vertically over the mold head; and vibrate it for 60 times. Load the second layer, stir it with the small stirring-up device, and vibrate it for 60 times. Remove the die sleeve, take the test mold off the plain bumper, stand a metal ruler on one side of the top end of the test mold approximate to 90°, move it slowly to the other side along the length of the test mold in the movement as horizontal cut, scrape the gel sand beyond the mold at a time, and scrape the surface of the specimen smoothly with the same ruler in the almost horizontal direction.

5) Put a mark or a note showing the sample code and the relative position to the plain bumper to the test mold.

6) The temperature of the test molding laboratory should be maintained at (20 ± 2) ℃ and the relative humidity not less than 50%.

(4) Maintenance of Specimens

1) Put the test mold with mark on the level shelf in the fog cabinet or moisture box for maintenance, and the moisture air (the temperature of (20 ± 1)℃ and the humidity not less than 90%) should be connected with all the sides of the test mold. The maintenance should last to the regulated

demoulding time (for the age of 24h, the mold should be unloaded within 20min before the mould-breaking experiment; for the age of more than 24h, the mold should be unloaded between 20h to 24h after it is shaped). Before demoulding, waterproof ink or color pens can be used to mark the code or other signs. If the specimen has more than two ages, the three specimens in the same test mold should be divided into over two ages when being marked.

2) Put the marked specimens horizontally or vertically into the water of (20 ± 1) ℃ for maintenance immediately. In the horizontal direction, the scraped surface should be upward. The interval between the specimens or the water over them should be not less than 5mm.

(5) Strength Tests of the Specimens

The strength tests of the specimens in different ages should be conducted in the following time periods:

·24h±15min;

·48h±30min;

·72h±45min;

·7d±2h;

·28d±8h;

The specimen should be covered by wet cloth after being taken out of the water.

1) Bending Strength Test.

Put one side of the specimen on the supporting column of the machine, the axis of the specimen should be perpendicular to the column. The column adds load to the relative side of the prism with the speed of 50N/s±10N/s evenly until it snaps.

Keep the two half prisms in the moisture condition until the compression test.

The bending strength R_f should be in Newton per square millimeter (MPa), calculated as follows (accurate to 0.1MPa):

$$R_f=1.5F_fL/b^3$$

In the formula: F_f is the failing load (N);

L is the center distance (mm);

b is the side of the square cross-section (mm).

The result is the average of the above values of the three specimens. If any value of the specimens is beyond ± 10% of the average, it should be removed and then calculate the average as the result.

2) Compressive Strength Test.

The two fault blocks after the bending strength test should be conducted compressive strength test immediately. The anti-compression fixture must be used in the compressive strength test. And in the whole loading process, loads are added at the speed of 2400N/s±200N/s evenly until the specimens are damaged.

The bending strength R_c is in Newton per square millimeter (MPa), calculated as follows (accurate to 0.1MPa):

$$R_c=F_c/A$$

In the formula: F_c is the failing load (N);

A is the pressure area 40×40 (mm^2).

The result is the average of the six compressive strength values of a group of three prisms. If any of the values is beyond ±10% of the average, it should be removed and the average of the left five is treated as the result. If any of the five values is beyond ±10% of the average, the test of this group is void.

Test Four Concrete Aggregate Test

1. Sampling Methods

(1) Sampling Method of Fine Aggregate

Fine aggregate——the sand samplings of the same origins and same specifications should be tested in batch. If it is transported by large vehicles (such as trains, cargo ships, automobiles), Each batch should not be more than 400m^3 or 600 t. if it is transported by small vehicles (such as carriage), every 200m^3 or 300t is a batch.

When samples are taken from stock pile, the sampling parts should be evenly distributed. Before sampling, the surfaces of these parts should be shoveled, and then 8 similar pieces of samples will be taken from every part. And the 8 pieces samples, totally 30kg, are ready for the sieve analysis, apparent density test and bulk density test. The splitting of sand samples can be conducted by distributor or by manual quartering.

By distributor: mix the sample evenly in the wet state, let sample get through distributor, and keep one piece from the remaining left in the hopper; repeat the above process with other samples until samples are split into the needed quantity.

By manual quartering: put sample on slab and mix it evenly in the wet state; pile it up into a "round cake" of 20mm thick, and quarter the "cake" along its two mutual perpendicular diameters; re-mix the two shares in opposite angles, pile them up into a "round cake", and repeat the above process until the split material mass is a little more than the needed quantity.

(2) Sampling Method of Coarse Aggregate

The sampling method of coarse aggregate is the same with that of fine aggregate.

When samples are taken form stock pile, the sampling parts should be evenly distributed. Before sampling, the surfaces of these parts should be shoveled, and then 15 similar pieces of stone samples will be taken from every part (namely, 15 different parts distributed on the top, the middle, the bottom of the sample pile). They are ready for the sieve analysis, apparent density test and bulk density test (if the size fraction is 4.75~19.0mm, it needs about 140kg sample; if the size fraction is 4.75~75.0mm, it needs about 430kg sample). Put sample on slab, mix it evenly in the natural state; and get the needed quantity by the aforementioned manual quartering.

The quantities of sand and stone needed in each test are shown in Test Table 4.1 and Test Table 4.2.

Test Table 4.1 Minimum Sampling Amount of Single Sand Test

Items	Sieve Analysis	Apparent Density	Bulk Density	Water-content Ratio
Minimum Sampling Amount (g)	4400	2600	5000	1000

Test Table 4.2 Minimum Sampling Amount of Single Stone Test

Items	Maximum Particle Diameter(mm)							
	9.5	16.0	19.0	26.5	31.5	37.5	63	75.0
Sieve Analysis	9.5	16.0	19.0	25.0	31.5	37.5	63.0	80.0
Apparent Density	8	8	8	8	12	16	24	24
Water-content Ratio	2	2	2	2	3	3	4	6
Bulk Density	40	40	40	40	80	80	120	120

2. Sieve Analysis Test of Sand

(1) Purposes

To determine the grain composition of sand, calculate the fineness modulus of sand, and evaluate the fineness of sand is to provide a basis for the mix proportion design of concrete.

(2) Major Apparatus and Equipment

1) Square-hole sieves: the holes' sizes of 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.60mm, 0.30mm, and 0.15mm, and a base as well as a cover.

2) Counter balance: weighing of 1kg, and sensitivity of 1g.

3) Oven: the temperature controlled at (105±5)℃.

4) Sieve shaker.

5) Tray, and hard and soft brush, etc..

(3) Sample Preparation.

Make the sand sample get through the sieve of 9.50mm and calculate the retained percentage. Then weigh two pieces of samples, each of 550g, and respectively pour them into two trays. Dry them at the temperature of (105±5)℃ to constant weight and then cool them to room temperature for standby.

(4) Steps

1) Accurately weigh dried sample of 500g and put it on the top sieve (namely, the sieve of 4.75mm) of the sieve set sorted by size; cover it and fix the sieve set in sieve shaker, shaking for 10min; then put out the sieve set and shake them in order over a clean tray by hands until the throughput is no more than 0.1% of the total mass of sample; particles passing through the first sieve and fall to the next one, and shake the particles with the sample already in the next sieve together; repeat this process till the last one. If there is no sieve shaker, sieves can be shaken directly by hands.

2) For arbitration, the sieve residues left on each sieve should not be more than the following amount:

$$m_r = \frac{A\sqrt{d}}{300}$$

For the test of production control, the residues should not be more than the following amount:

$$m_r = \frac{A\sqrt{d}}{200}$$

In the formula: m_r is the sieve residue on one sieve;

d is the size of sieve (mm);

A is the square of sieve (mm^2).

Otherwise, the sample of sieve residue should be divided into two samples for further screening, and the sum of their sieve residues should be the sieve residue of the sieve.

3) Separately weigh the screen residues of all the sieves (accurate to 1g), and the difference value between the sum of all the unit sieve residues and the remaining on the tray and the total mass of the sample before screening should be no more than 1%.

(5) Results

1) Calculate unit retained percentage: the percentage that the residue on each sieve divided by the total mass of sample (accurate to 1.0%).

2) Calculate the accumulated retained percentage: the sum of the unit retained percentage of the sieve and those of the sieves bigger than this one (accurate to 1.0%).

3) Evaluate the grain composition of the sample according to the accumulated retained percentage of each sieve.

4) Calculate the fineness modulus M_x of the sample by the following formula (accurate to 0.01)

$$M_x = \frac{(A_2 + A_3 + A_4 + A_5 + A_6) - 5A_1}{100 - A_1}$$

In this equation: A_1, A_2, A_3, A_4, A_5 and A_6 respectively are 4.75mm, 2.36mm, 1.18mm, 0.60mm, 0.30mm, and 0.150mm.

5) Sieve analysis test should be conducted by two parallel sample tests. The fineness modulus should be determined by the arithmetic mean value of the two tested results (accurate to 0.1). If the difference value between the two tested fineness moduli is over 0.20, new samples should be taken for new test.

3. Apparent Density Test of Sand

(1) Purposes

To determine the sand mass (including the inside closed pores) per unit volume is to provide a basis for the calculation of voidage and the mix proportion design of concrete.

(2) Main Apparatus and Equipment

1) Balance: weighing of 1kg, and sensitivity of 0.2g.

2) Volumetric flask: 500mL.

3) Oven: the temperature controlled at (105±5)℃.

4) Desiccator, tray, aluminum spoon, and thermometer, etc..

5) Beaker: 500mL.

(3) Sample Preparation

Dry the sample split to about 650g in the oven of (105±5)℃ to constant mass and cool it to room temperature in dryer.

(4) Steps

1) Weigh the dried sample for 300g (m_0) and put it in the volumetric flask filled with half flask of cooled boiled water.

2) Shake volumetric flask to the specimen stir fully in water to expel bubbles, block it with a stopper and let the flask stand for about 24h. Then use a burette to add water until the water surface is as high as the scale of bottleneck. Fasten the stopper and clean the water on the outside surface of the flask. Weigh the mass (m_1).

3) Pour the water and the specimen and clean inside and outside surfaces of the flask. Fill the flask with the cooled boiled water (the temperature difference between the two filled water should be within 2℃). Fasten the stopper and clean the outside surface of the flask. Weigh the mass (m_2). The test should be conducted between 15~25℃ and the temperature difference should be no more than 2℃.

(5) Results

The apparent density of the specimen should be defined by the following formula (accurate to $10\text{kg}/\text{m}^3$):

$$\rho_0 = \left(\frac{m_0}{m_0 + m_2 - m_1} - \alpha_t\right) \times 100\text{kg}/\text{m}^3$$

In this formula: m_0 is the moisture-free mass (g);

m_1 is the total mass of specimen, water and flask (g);

m_2 is the total mass of water and volumetric flask (g);

α_t is the correction coefficient for the influence of temperature on the relative density, see Test Table 4.3:

Test Table 4.3 Correction Coefficient for the Influence of Different Temperature on Apparent Density of Sand

Water Temperature (℃)	15	16	17	18	19	20	21	22	23	24	25
α_t	0.002	0.003	0.003	0.004	0.004	0.005	0.005	0.006	0.006	0.007	0.008

Measured value should be the arithmetic mean of the two test results. If the difference between the two results is bigger than 20kg/m^3, new samples should be tested again.

4. Bulk Density Test of Sand

(1) Purposes

To determine the mass per unit in the natural stacking state is to provide a basis for the calculation of voidage and mix proportion of concrete.

(2) Main Apparatus and Equipment

1) Balance: weighing of 10kg and sensitivity of 1g.

2) Volumetric cylinder: metal cylinder whose inner diameter is 108mm, clear height is 109mm, wall is 2mm, bottom is 5mm and volume was about 1L.

3) Funnel, spoon, enamel tray, brush, etc..

4) Oven: the temperature controlled at (105±5)℃.

5) Square-hole sieve of 4.75mm and baker rod (the cylindrical steel with diameter of 10mm and length of 500mm)

(3) Sample Preparation

Take sample of about 3L with tray and dry it to constant in the oven of about (105±5)℃. Take it out and cool it to room temperature. Screen it with the sieve of 4.75mm and divide it into two similar shares. There are agglomerates after drying and they should be crumbed before test.

(4) Steps

1) Weigh the mass of volumetric cylinder m_1, and put it under the funnel and put sand into the funnel with spoon.

2) Open the valve of the funnel, and let the sand sample fall into the cylinder slowly until it form a taper to the cylinder opening (the distance between the opening of the funnel and the cylinder opening should be no more than 500mm).

3) Shave it smooth with a ruler in the opposite directions along the center line, and weigh the mass (m_2).

(5) Results

1) The bulk density is calculated by the following equation (accurate to 10 kg/m^3).

$$\rho_1 = \frac{m_2 - m_1}{V} \times 1000(\mathrm{kg/m^3})$$

In the equation: m_1 is the mass of volumetric cylinder (kg);

m_2 is the total mass of cylinder and sand (kg);

V is the volume of volumetric cylinder (L).

The arithmetic mean of two results is the measured value.

2) The voidge of sand is calculated by the following equation (accurate to 1%).

$$V_1=\left(1-\frac{\rho_1}{\rho}\right)\times100\%$$

In the equation: V_1 is the voidage of bulk density of sand (%);
ρ_1 is the bulk density of sand (kg/m^3);
ρ is the apparent density of sand (kg/m^3).

The arithmetic mean of two results is the measured value.

5. Water-content Ratio Test of Sand

(1) Purposes

To determine the water-content rate is to calculate the construction mix proportion of concrete.

(2) Major Apparatus and Equipment

1) Oven: the temperature controlled at (105±5)℃.

2) Balance: weighing of 2000g and sensitivity of 2g.

3) Desiccator, tray, etc..

(3) Steps

1) Weigh two specimens respectively of about 500g and put them in the desiccator whose mass (m_1) is already known. Weigh the mass and record the total mass of the container and the sample on each tray (m_2).

2) Put the container and the specimen into the oven of (105±5)℃ together, and dry them to constant mass. Weigh their total dried mass (m_3).

(4) Steps

The water-content ratio of sand is calculated as follows (accurate to 0.1%):

$$\omega_{wc}=\frac{m_2-m_3}{m_3-m_1}\times100\%$$

In the equation: m_1 is the mass of container (g);
m_2 is the mass of the specimen and container before drying (g);
m_3 is the mass of the specimen and container after drying (g).

The arithmetic mean of two results is the measured value.

6. Test of Sieve Analysis of Crushed Stones or Gravels

(1) Purposes

To determine the grain composition of crushed stones or gravels to provide a basis for the mix proportion design of concrete.

(2) Major Apparatus and Equipment

1) Square-hole sieves: the holes' sizes of 90mm, 75.0mm, 63mm, 53mm, 37.5mm, 31.5mm, 26.5mm, 19.0mm, 16mm, 9.5mm, 4.75mm, and 2.36mm, and a base as well as a cover whose specification and quality should be in line with *Test Sieve* (GB6003) (the inner diameter of sieve frame should be 300mm).

2) Balance or counter scale: weighing of 10kg, sensitivity of 1g, and the mass of sample accurate to 0.1%.

3) Oven: the temperature controlled at (105±5)℃.

4) Tray.

5) Sieve shaker.

(3) Sample Preparation.

Split the sample into four shares by quartering method to the required quantity a little more than that regulated in Test Table 4.4. Dry or weather them for standby.

Test Table 4.4 Minimum Quantity Required in Sieve Analysis

Maximum nominal Particle Size (mm)	9.5	16.0	19.0	26.5	31.5	37.5	63.0	75.0
Quantity of Sample (kg) (≥)	1.9	3.2	3.8	5.0	6.3	7.5	12.5	16.0

(4) Steps

1) Weigh samples according to regulation and record the quality of samples.

2) Screen the samples with the sieve set sorted by size; if the thickness of residues is bigger than the maximum particle size of samples, the screening residues should be divided into two shares and be screened again until the throughput is no more than 0.1%.

3) Weigh the mass of residues left on each sieve, accurate to 0.1% of the total mass. The difference value between the sum of all the unit sieve residues and the remaining on the tray and the total mass of the sample before screening should be no more than 1%.

(5) Results

1) Calculate unit retained percentage and the accumulated retained percentage (the same to the sieve analysis of sand), respectively accurate to 0.1% and 1%.

2) Evaluate the grain composition of the sample according to the accumulated retained percentage of each sieve.

7. Apparent Density Test of Crushed Stones or Gravels (Simple Methods)

(1) Purposes

To determine the mass of crushed stones or gravels (including the inside closed pores) per unit volume is to provide a basis for the calculation of voidage and the mix proportion design of concrete.

(2) Main Apparatus and Equipment

1) Balance: weighing of 5kg, and sensitivity of 5g

2) Oven: the temperature controlled at (105±5)℃.

3) Jar: 1000mL, with polished rim and glass sheet.

4) Test sieve: hole size of 4.75mm.

5) Towel, brush, etc..

(3) Sample Preparation

According to regulations, split the sample into the required quantity a little more than that regulated in Test Table 4.5. After weathering, screen the particles under 4.75mm and split the sample to no less than 2kg by quartering method. Divide it into two shares for standby after cleaning.

Test Table 4.5 Minimum Quantity Required in Sieve Analysis

Maximum nominal Particle Size (mm)	<26.5	31.5	37.5
Minimum Quantity of Sample (kg)	2.0	3.0	4.0

(4) Steps

1) Soak a share of sample into water, and install it in a jar after saturation. The jar should be leaned when the sample is installed into it. Inject drinking water and cover the jar mouth with a glass sheet. Expel bubbles by shaking the jar in each direction.

2) After bubbles are expelled, add drinking water to the jar until the water surface rise to the edge of the mouth. Then glide the glass sheet along the jar mouth quickly and make the glass tightly stick to the water surface. Clean the water on the outside surface of the jar. Weigh the total mass of specimen, water, jar and glass sheet (m_1).

3) Pour the specimen in the jar to a tray and dry it in the oven of (105±5)℃ to constant mass. Then put it out in a container with cover and cool it to room temperature. Weigh the mass (m_0).

4) Clean the jar, and re-inject drinking water. Make the glass sheet tightly stick to the water surface of the jar and clean the water on the outside surface of the jar. Weigh the mass (m_2).

(5) Results

The apparent density ρ can be calculated as follows (accurate to 10kg/m^3):

$$\rho = \left(\frac{m_0}{m_0 + m_2 - m_1} - \alpha_t\right) \times 1000\,(\text{kg/m}^3)$$

In the above equation: m_0 is the mass of specimen after drying (g);

m_1 is the total mass of specimen, water, jar and glass sheet (g);

m_2 is the total mass of water, jar, and glass sheet (g);

α_t is the correction coefficient for the influence of temperature on the relative density, see Test Table 4.3.

Measured value should be the arithmetic mean of the two test results. The difference between the two results should be less than 20kg/m^3, or new samples should be tested again. For the uneven specimen, if the difference is beyond 20kg/m^3, the arithmetic mean of four test results can be the measured value.

8. Water-content Ratio Test of Crushed Stones or Gravels

(1) Purposes

To determine the water-content ratio of stones is to provide statistics for the calculation of the construction mix proportion of concrete.

(2) Major Apparatus and Equipment

1) Oven: the temperature controlled at (105±5)℃.

2) Balance: weighing of 5kg and sensitivity of 5g.

3) Container, such as tray.

(3) Steps

1) Take the similar amount of stone sample regulated in Table 4.2 and divide it into two shares for standby.

2) Put the sample in a clean container and weigh the mass of sample and container (m_1). Dry it to constant mass in the oven of (105±5)℃.

3) Take out the sample and weigh the total mass (m_2) of specimen and container after they are cooled.

(4) Results

The water-content ratio of stones can be defined as follows (accurate to 0.1%):

$$\omega_{wc} = \frac{m_1 - m_2}{m_2 - m_3} \times 100\%$$

In this equation: m_1 is the mass of sample and container before drying (g);

m_2 is the mass of sample and container after drying (g);

m_3 is the mass of container (g).

The arithmetic mean of two results can be the measured value.

9. Bulk Density Test of Crushed Stones or Gravels

(1) Purposes

To determine the stone mass per unit in the loose state is to provide a basis for the design of mix proportion and the calculation of voidage.

(2) Major Apparatus and Equipment

1) Counter scale: weighing of 50kg and sensitivity of 50g; weighing of 100kg and sensitivity of 100g, the two scales.

2) Volumetric cylinder: metal; and the specifications shown in Test Table 4.6.

Test Table 4.6 Specification Requirements for Volumetric Cylinder

Maximum Particle Diameter of Crushed Stones or Gravels (mm)	Volume of Cylinder (L)	Specification of Cylinder		Thickness of Cylinder (mm)
		Inner Diameter	Net Height	
9.5, 16.0, 19.0, 26.5	10	208	294	2
31. 5, 37.5	20	294	294	3
53.0, 63.0, 75.0	30	360	294	4

3) Oven: the temperature controlled at (105±5)℃.

4) Flat-head shovel.

(3) Sample Preparation

Put similar amount of stone sample regulated in Test Table 4.2 on a tray, dry it in the oven of (105±5)℃ or weather it on the clean floor, and mix it evenly and divide it into two shares for standby.

(4) Steps

1) Weigh the mass of volumetric cylinder (m_1).

2) Put a share of sample on the neat and clean floor (or iron board) and scoop it up with flat-head shovel to let stones freely fall into volumetric

cylinder. The distance from the edge of shovel to the top mouth of the cylinder should be about 50mm. Fill the cylinder full of stones and remove the particles high above the mouth of cylinder and fill the sags with proper particles to make the volume of convex parts is the almost the same with that of the concave parts. Weigh the mass of sample and cylinder (m_2).

(5) Results

1) The bulk density of stone is defined as follows (accurate to 10kg/m^3):

$$\rho_1 = \frac{m_2 - m_1}{V_0'} \times 1000(\mathrm{kg/m^3})$$

In the above equation: m_1 is the mass of volumetric cylinder (kg);

m_2 is the total mass of cylinder and sample (kg);

V_0' is the volume of cylinder (L).

The measured value should be the arithmetic mean of two test results

2) The voidage of stones can be calculated by the following equation (accurate to 1%):

$$V_1 = \left(1 - \frac{\rho_1}{\rho}\right) \times 100\%$$

In the equation: V_1 is the voidage of stones (%);

ρ_1 is the bulk density of stone (kg/m^3);

ρ is the apparent density of stone (kg/m^3).

Test Five Tests of the Main Technical Properties of Ordinary Concrete

1. Sampling of Mixtures

1) The mixtures used in concrete should be sampled from the same mixing tray or the same transport vehicle, or singly mixed in laboratory in mechanical or manual way, based on different requirements.

2) To test the concrete sampled from concrete construction works, the sampling method and principle should be in line with the existing standards—*Code for Quality Measuring and Acceptance of Concrete Structure Works* (GB50204-2002) and *Standard for Inspection and Evaluation of Concrete Strength* (GBJ107-87).

3) As to present mixed concrete, the concrete sample should be taken randomly from the casting site, and the sampling frequency should accord with the following regulations:

① The sampling of concrete with the same mix proportion of every 100 trays but no more than $100m^3$ should be no less than once.

② If the quantities of the concrete with the same mix proportion mixed by the same operating crew are less than 100 trays, the sampling should not be less than once.

③ For the present mixed concrete structure, the detained blocks should be in line with the following requirements:

a. For each cast-in-place floor, the sampling of the concrete with the same mix proportion should not be less than once;

b. For each acceptance and check item of the same project, the sampling of the concrete with the same mix proportion should not be less than once.

④ As to the bulk fly-ash concrete, every $500m^3$ needs at least a group of blocks; if the regulated numbers can not be reached, there must be at least one group of samples taken from the concrete mixed by each crew.

4) When concrete is mixed in laboratory, the aggregate used for mixing must be moved into the room in advance. The room temperature for mixing should be kept at (20±5)℃.

5) When concrete is mixed in laboratory, the using amount of materials should be calculated in mass. And the accuracy of weighing: of aggregate is ±1% and of cement, water, and admixtures is ±0.5%.

6) Mixtures should be tested as soon as possible after being mixed. Before test, samples should be mixed a little by tester to ensure the uniformity of quality.

2. Lab Mixing Method of Concrete

(1) Major Apparatus and Equipment

1) Mixer: capacity of 30~75L, and speed of 18~22r/min.

2) Platform scale: weighing of 50kg and sensitivity of 50g.

3) Other apparatuses: balance (weighing of 5kg and sensitivity of 5g), measuring cylinder (200mL and 100mL), mixing board (1.5m ×2m), mixing spade, vessels, rag, etc..

(2) Mixing Method.

1) Manual Mixing.

① Prepare materials according to the regulated mix proportion.

② Wet the mixing spade and board with wet cloth, pour sand, cement on the board, turn them over from one side of the board to the other, and repeat the action until the color becomes even. Add stones and mix them evenly.

③ Pile up the mixtures, dig a pit in the middle, pour part of mixing water, and then carefully mix them. Gradually add water and continue fully mixing them.

④ The mixing time should be counted from the time of adding water, which should accord with the following provisions:

If the volume of mixtures is under 30L, the time should be 4~5min;

If the volume of mixtures is between 30~50L, the time should be 5~9min;

If the volume of mixtures is between 51~75L, the time should be 9~12min.

⑤ After mixing, conduct slump determination or specimen moulding immediately. From the moment of adding water, the whole process should be completed within 30min.

2) Mechanical Mixing.

① Prepare materials based on the regulated mix proportion.

② Premix it once, which is to swill the mixer with mortar composed by cement, sand, and water in a proper mix proportion as well as a little amount of stones. Then pour them out and raze the remaining mortar. The purpose is to make the cement mortar adhere to the inner wall of mixer fully to protect the mix proportion from being changed in the formal mixing.

③ Start mixer and add stones, sand and cement into mixer in order. Dry-mix them evenly and then slowly add water. The whole time of adding materials should not be more than 2min. When all the water is added, continue stirring them for 2min.

④ Remove the mixture from mixer to the mixing board and mix it manually for 1~2min. Then conduct slump determination or specimen moulding. From the time of adding water, the whole process should be finished within 30min.

3. Consistency Test of Concrete Mixtures

(1) Slump Test Method

This method is used for the consistency test of the concrete mixture of which the maximum aggregate particle size is not more than 40mm and the slump value is not less than 10mm. The mixture used for consistency test is about 15L.

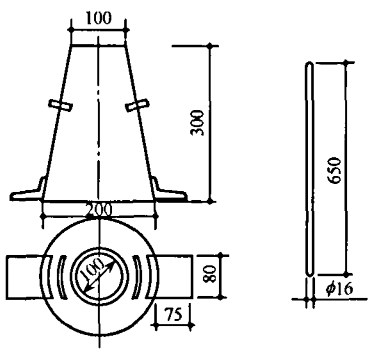
1) Purposes.

① Master the slump test method to determine the consistency of ordinary concrete mixture.

② Check weather the designed mix proportion of concrete accords with the workability requirements to provide a basis for controlling concrete quality by adjusting mix proportion.

2) Major Apparatus and Equipment.

① Slump cone: is a cone made by thin steel board or other kinds of metal (see Test Figure 5.1); its inner wall is smooth without convex and concave parts; the undersurface and the top surface are parallel to one another and meanwhile perpendicular to the axis of the cone. There are two handles outside on the two-third height of the cone, and footplates at the bottom. The inner size of the cone is like this: the diameter of bottom is (200±2)mm; the top diameter is (100±2)mm, the height is (300±2)mm, and the wall thickness is no less than 1.5mm.



Test Figure 5.1 Slump Cone and Tamping Rod

② Tamping rod: is a steel rod with diameter of 16mm and length of 600mm; its top end is rounded.

③ Other tools: a small spade, a funnel and a ruler.

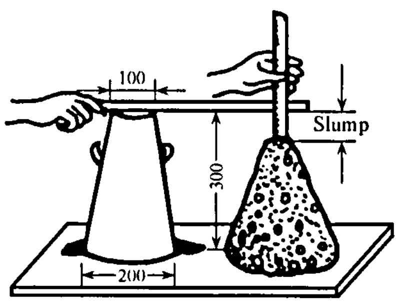
3) Steps.

① Wet slump cone and other tools, lay the cone on the non-absorbent horizontal steel board, and stamp on the foot plats on the two sides to fix the cone in a place when loading materials.

② Evenly shovel the mixed concrete sample into the cone with a small spade by three layers and make sure that the height of each layer is one third of the cone height. Tamp each layer with a tamping rod for 25 times. And the tamping should be conducted from the outside to the center along the spiral direction and each tamping should be distributed evenly on the cross-section. The tamping rod can be leaned slightly when the concrete is tamped. When the bottom layer is tamped, the rod should go through the whole depth; when the second layer and the top layer are tamped, the rod should be inserted into the next layer. When the top layer is cast, the concrete should be filled high above the cone mouth. In the process of tamping, if concrete fall below the cone mouth, more concrete should be added at any moment. After the top layer is tamped, excess concrete should be shaved and the surface should be scraped smoothly.

③ After clearing the concrete left on the base plate, lift up the cone vertically. The lifting process should be finished within 5~10s. The whole process from loading materials to lifting the cone should be conducted continuously and be completed within 150s.

④ After lifting up the cone, measure the height difference between the height of slump cone and the top point of the concrete specimen, that is the slump value of concrete mixture (in the unit of mm and accurate to 5mm). Test Figure 5.2 is the schematic diagram of slump test. When the slump cone is lifted, new sample should be tested if the concrete cracks or one side is broken. If this situation appears again, it proves that the workability of the concrete mixture is bad, recorded for future reference.



Test Figure 5.2 Determination of Slump

⑤ Observe the cohesion and water retention of the concrete specimen after slump. The checking method of cohesion is to slightly tap the side face of the concrete specimen by tamping rod. If the cone gradually sinks, it means that the cohesion is good; if the cone collapses, or partly cracks, or breaks, it shows that the cohesion is bad.

Water retention is evaluated by the precipitation of thin pulp from the mixture. When the slump cone is lifted, if a lot of thin pulp precipitates from the bottom and the aggregate appears on part of the cone due to the lose of pulp, it reveals that the water retention of the concrete mixture is bad; if no or only a little thin pulp precipices from the bottom, it shows that the water retention is good.

(2) Vebe Consistency Method

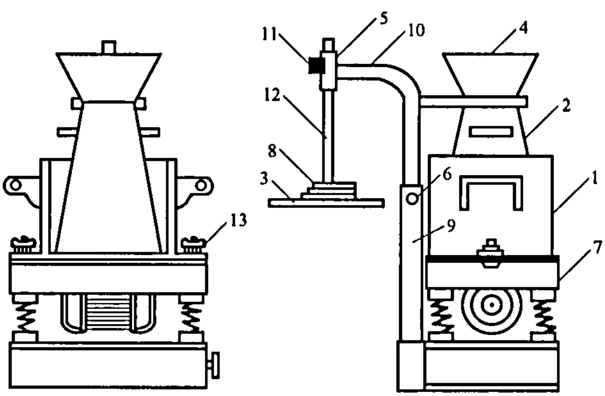
This method is mainly used to determine the consistency of concrete mixtures whose maximum aggregate particle size is no more than 40mm and vebe consistency is between 5~30s. 15L mixtures are needed for the determination.

1) Purposes.

Master the vebe consistency method to determine the consistency of ordinary concrete mixtures.

2) Major Apparatus and Equipment.

① Vebe Consistometer (see Test Figure 5.3) is consisted of the following parts.



Test Figure 5.3 Vebe Consistometer

1. container; 2. slump cone; 3. transparent disc; 4. feeding hopper; 5. sleeve; 6. set screw; 7. platform vibrator; 8. load; 9.pillar; 10. spinner rack; 11. dipstick screw; 12. dipstick; 13. fixed screw

a. Platform vibrator: the table-board is 380mm long and 260mm wide; the frequency of vibration is (50±3) Hz; when it's loaded with empty container, the amplitude of the table-board is (0.5±0.1)mm.

b. Container: made of steel board, inner diameter of (240±5)mm, height of (200±2)mm, wall of 3mm, and bottom of 7.5mm.

c. Spinner rack: which is connected with dipstick and feeding hopper; there is a transparent disc under the dipstick which is fixed in the sleeve by the dipstick screw; the diameter of the disc is (230±2)mm and its thickness is (10±2)mm; load blocks are directly fixed on the disc; the mass of the sliding part consisted of dipstick, disc and load blocks is (2750±50)g.

d. Slump cone and tamper are the same as those in the slump test, but the cone has no pedals.

② Other tools: stopwatch, and spade, etc..

3) Steps.

① Put the vebe consistometer on a stable and horizontal floor and wet the container, slump cone, feeding hopper, inner wall and other tools with wet cloth.

② Lift the feeding hopper to the top of the slump cone and fasten it; correct the position of the container and let its center and the center of the feeding hopper coincide; and then fasten the screw.

③ Input the required concrete sample into the cone evenly with the spade by three layers through the feeding hoper; both the inputting method and the tamping method are the same with those in the slump test.

④ Divert the feeding hopper, and vertically lift up the slump cone; pay attention that prevent the concrete sample from moving laterally.

⑤ Divert the transparent disc to the top of the concrete cone, loosen the screw, and lower the disc to make it slightly touch the top of the concrete; fasten the set screw and inspect whether the dipstick screw is totally loose.

⑥ Start platform vibrator and meanwhile record time with stopwatch; when the bottom of the disc is full of cement paste, stop the watch and close the vibrator; and read the time (s) that is the vebe consistency value of the concrete mixture.

4. Compressive Strength Test of Ordinary Concrete Cube

(1) Purposes

To determine the compressive strength of ordinary concrete cube is to provide the major basis for the check and determination of concrete quality.

(2) Major Apparatus and Equipment

1) Pressure Tester: its precision (the relative error of indication) should be at least ±2%, and the range can make the expected failure load change between 20% and 80% of total range; steel backing plate can be put between

the upper and the lower pressure plates; and the load bearing face of the steel backing plate should be processed mechanically.

2) Platform vibrator: its frequency of (50±3)Hz and unloaded amplitude of 0.5mm.

3) Testing mold: made of iron or steel should have certain rigidity for disassembly; the inner surface of the mold should be processed mechanically; and its roughness of every 100mm should be no more than 0.5mm; the non-perpendicular angle between two adjacent surfaces should be within ±0.5°.

4) Other tools: tamper, spade, metal ruler, and trowel, etc..

(3) Steps

1) Every group of cube specimens used in the compressive strength test should be made at the same time, be curved under the same condition and have the same age. Each group contains three specimens. The size of specimens should be chosen by the maximum particle diameter of their aggregates from Test Table 5.1, according to *Code for Acceptance of Constructional Quality of Concrete Structures* (GB50204-2002).

Test Table 5.1 Specimen's Sizes, Tamping Times and Conversion Coefficients of Compressive Strength of Different Aggregates with the Maximum Particle Diameter
(GB50204-2002)

Specimen's Size(mm×mm×mm)	Maximum Particle Diameter of Aggregate/ mm	Tamping Times of Every Layer (times)	Conversion Coefficient of Compressive Strength
100×100×100	≤31.5	≤12	0.95
150×150×150	≤40	≤25	1
200×200×200	≤63	≤50	1.05

2) The concrete mixtures used in specimens of each group should be extracted from the mixtures made at the same time.

3) In production, clean the test mold and paint a layer of mineral oil or other releasing agent on the inner wall.

4) Platform vibrator can be used for the concrete mixture whose slump is no more than 70mm. Pour the mixture into the mold by one time. When input the mixture, use the spatula tamp it along the inner wall and make it high above the mouth of the mold. Prevent the test mold jumping freely on the platform during the vibrating process. The vibration should continue until there appears pulp on the surface of concrete. Scrape the excess concrete and smooth it with spatula.

For the concrete whose slump is more than 70mm, it is appropriate to tamp the concrete with tamper manually. Put the mixture into the mold by two times. The thickness of every layer should be almost the same. Tamping should be conducted from the edge to the center along the direction of spiral evenly. When the lower layer is tamped, the tamper should reach the bottom of the mold; when the upper layer is tamped, the tamper should get through 20~30mm of the length of the lower layer; and the tamper should be vertical in tamping. Meanwhile, use the spatula to tamp the specimen along the inner wall for many times. The tamping times for each layer should be in line with the cross section of the specimen. Generally every $100cm^2$ needs more than 12times tamping (see Test Table 5.1).Scrape the excess concrete and smooth it with spatula after tamping.

(4) Maintenance

1) According to different test purposes, specimens can be maintained under the standard condition or the same condition with components. Standard maintenance should be adopted to determine the eigenvalue and the labeling of concrete or study the properties of materials; the same condition curing should be adopted to check the strength of the cast-in-place concrete or pre-cast members. Generally, specimens have been maintained for 28d. However, they can be conserved to the required age.

2) The surface of the specimens maintained under standard conditions should be covered to avoid the evaporation of water. And specimens should stand for one or two days at the temperature of (20±5)℃ and then can be labeled and be removed from the mould. Then, specimens should be maintained in the room of (20±3)℃ with moisture of 90% above at once. Specimens should be put on the shelf in standard curing room and the interval between them should be 10~20mm. They should avoid direct water shower.

3) If there is no standard curing room, concrete specimens can be maintained in immobile water of (20±3)℃ whose pH value should be no less than 7.

4) The surface of the specimens maintained under the same condition should be covered. And the time of removal from mould should be the same with that of the actual components. After that, their maintenance under the same condition should remain.

(5) Steps

1) When being removed from the curing place, the specimens should be tested as soon as possible to avoid the significant temperature changes inside.

Clean specimens at first, check their appearance, measure their sizes (accurate to 1mm) and calculate the bearing area. If the difference between the measured size and the nominal size is less than 1mm, the area can be calculated by the nominal size. The roughness of the pressure bearing surface of every 100mm should be no more than 0.05mm and the non-perpendicular angle between the pressure bearing surface and its adjacent surfaces should not exceed ±1°.

2) Put a specimen on the lower pressure plate of the tester and its pressure bearing surface should be vertical to the top surface after being moulded. Its center should coincide with that of the lower plate. Start the tester, adjust the ball cup to make it touch the specimen evenly when the upper plate gets close to the specimen.

3) The loads should be added evenly and continuously and the loading speed should be: 0.3~0.5MPa per second if the concrete strength is lower than C30; 0.5~0.8MPa if the concrete strength is equal to or upper than C30. When the specimen is getting damaged and start deforming rapidly, stop adjusting the throttle of the tester until the specimen is damaged. Then record the failure load.

(6) Results

1) The compressive strength of concrete cube is calculated as follows (accurate to 0.1MPa):

$$f_{cc} = \frac{P}{A}$$

In this equation: f_{cc} is the compressive strength of concrete cube (MPa);

P is the failure load (N);

A is the area of load bearing surface (mm^2).

2) The compressive strength value of this group is the arithmetic mean of measured values of the three specimens. If the difference between the medium value and one of the maximum and the minimum values is over 15% of the medium value, both the maximum and the minimum values should be removed, and the medium value is the compressive strength value of this group. If the difference between the medium value and both the other two values is over 15% of the medium value, the result is invalid.

3) The compressive strength of the specimen of 150mm×150mm×150mm can be the standard value. The strength values of the specimens of other sizes should be multiplied by a conversion coefficient, shown in Test Table 5.1.

Test Six Building Mortar Test

1. Sampling and Preparation of Mortar Mixtures

(1) Sampling

1) According to different requirements, the materials of building mortar used in test can be taken from the mortar in the same mixer or the same truck; in laboratory, the samples can be taken from the mortar mixed mechanically or manually.

2) In construction, the sampling method and principle should be in line with the code for acceptance of construction. The samples should be taken from at least three different parts from mortar trough, delivery truck or material mouth of mixer. The sampling amount should be one or two times than the materials used in test.

3) After sampling, the mortar mixture should be tested as soon as possible. The sample taken from the constructive site should be re-mixed manually to guarantee the uniformity.

(2) Preparation

1) Major Apparatus and Equipment.

① Mortar mixer.

② Platform scale: weighing of 50kg and sensitivity of 50g.

③ Platform balance: weighing of 10kg and sensitivity of 5g.

④ Iron mixing board: of about 1.5m×2m and its thickness of about 3mm.

⑤ Mixing spade, spatula, and measuring cylinder, etc..

2) General Requirements.

① In laboratory, the mixed materials should be moved into the room in advance, and the temperature of the room should be maintained at (20±5)℃ for mixing.

② In laboratory, the materials should be measured by weighing. And the accuracy of the metage of: cement and admixtures should be ±0.5%; sand, lime paste, clay puddle, fly ash, and ground quicklime should be ±1%.

③ The water used in test and other raw materials should be the same with the materials used on the site. If there are blocks in cement, it should be mixed evenly and be screened by the sieve of 0.9mm; and sand should be screened by the sieve of 4.75mm.

④ Before mixing mortar, wet mixing board, mixing spade, spatula and other tools by water. And pay attention that there should be no water left on the iron mixing board.

3) Mixing Method.

Mechanical Mixing:

① Mix appropriate amount of mortar (with the same mix proportion as that of tested mortar) at first to let a layer of cement mortar adhere to the inner wall of the mixer, which can make the mix proportion of mortar more accurate in actual mixing.

② Weigh the using amounts of all the materials and fill the mixer with sand and cement.

③ Start the mixer, inject water slowly (lime paste needs to be diluted with water into pulp) and stir it for about 3min (the amount used in stirring should not be less than 20% of the mixing capacity and the stirring time should be more than 2min).

④ Pour the mortar mixture on the mixing board, and malaxate it with mixing spade for about twice to make it uniform.

Manual Mixing:

① Pour the weighed sand on the mixing board, add cement, and mix it with spade until the color becomes uniform.

② Pile up the mixture and make a concave hole in the middle, pour the weighed lime paste into the hole (if it is cement mortar, pour half of the weighed water into the hole), inject appropriate amount of water to dilute the lime paste, and then mix them with cement and sand together. Inject water gradually and mix them carefully and evenly. For each mixing, all the mortar should be pressed once by the spade. Generally, the mixing time is 3~5min (record it after adding water) and mix them until the color becomes uniform.

2. Mortar Consistency Test

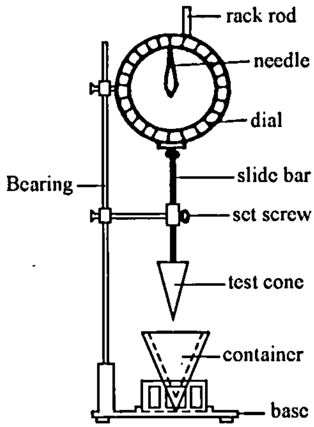
(1) Purposes

To determine the consistency of mortar is to calculate the required water quality for the regulated consistency.

(2) Major Apparatus and Equipment

1) Mortar consistometer: is consisted of test cone, container and bearing, the three parts (see Test Figure 6.1); the test cone made of steel or copper is 145mm high and its bottom diameter is 75mm, and the mass of the test cone

and slid bar is 300g; the container made of steel board is 180mm high and its bottom's inner diameter is 150mm; the bearing contains base, supporter and consistency dial, made of iron, steel or other metals.



Test Figure 6.1 Mortar Consistometer

2) Copper tamper: is 350mm long and its diameter is 10mm, with rounded ends.

3) Stopwatch, spade and other tools.

(3) Steps

1) Clean the surface of container and test cone with a damp cloth, wipe the slid bar with a small amount of lubricant and clean the excess oil by oil-absorbing sheets to make the slide bar move freely.

2) Fill the container with the mortar mixture once and make the surface of the mortar 10mm lower than the mouth of the container; tamp the mortar from the center to the edge by tamper for 25 times and slightly shake or knock the container for 5~6 times to smooth the surface of mortar; and then put the container on the base of consistometer.

3) Loosen the set screw of the slide bar and let it slide downward; when the conical tip just touches the mortar surface, fasten the set screw and let the bottom of the rack rod just touch the top of the slide bar and the needle hand point just point at zero.

4) Loosen the set screw and record time at the same time; after 10s, fasten the screw at once and let the bottom of the rack rod touch the top of the bar; and then read the sinking depth on the dial (accurate to 1mm), namely, the consistency value of mortar.

5) The mortar in the cone container just can be tested for one time. New samples are needed for the re-determination of the consistency.

(4) Results

1) The arithmetic mean of two results is the final result, accurate to 1mm.

2) If the difference between the two tested results is more than 20mm, new samples should be mixed for re-determination.

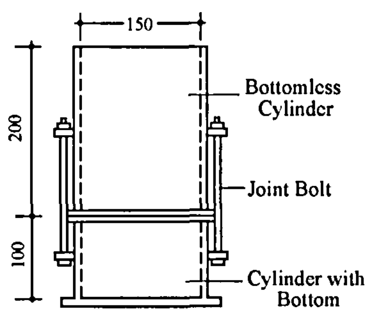
3. Mortar Layer Degree Test

(1) Purposes

Test the stability of mortar mixture in transporting or parking stage.

(2) Major Apparatus and Equipment

1) Mortar layer degree cylinder (see Test Figure 6.2): its inner diameter is 150mm; the upper part is 200mm high and the lower part is 100mm high, made of metal boards; the joint connected the upper and the lower should be widened to 3~5mm, without rubber gasket.



Test Figure 6.2 Mortar Layer Degree Tester

2) Cement mortar platform vibrator: amplitude of (0.85±0.05)mm and frequency of (50±3)Hz.

3) Consistometer and wooden hammer, etc..

(3) Steps

1) Test the consistency of the mortar mixture by consistency method.

2) Put the mortar mixture in the layer degree cylinder once; when the cylinder is full, knock four different parts around the container with wooden hammer for 1~2 times; if the mortar falls under the cylinder mouth, add more and then scrape the excess mortar and smooth it with spatula.

3) After standing for 30min, remove the mortar of 200mm in the upper part, and pour the remaining 100mm mortar out to the mixing pan; re-mix the

remaining mortar for 2 min, and test the consistency according to the above test method. The difference between the former tested consistency and the latter one is the layer degree (mm) of the mortar. The layer degree can also be tested by rapid method. But if it is disputed, the standard value prevails.

(4) Results

1) The arithmetic mean of two test results is the layer degree of mortar.

2) If the difference between the twice layer degree test is more than 20mm, the degree should be re-tested.

4. Compressive Strength Test of Mortar Cube

(1) Purposes

To determine the real strength of mortar is to test whether the mortar can reach the required strength.

(2) Major Apparatus and Equipment

1) Test mold: made of iron or steel, it is a metal cube mold with inner side length of 70.7mm; it should be rigid enough for disassembly.

2) Tamper: a copper rod with diameter of 10mm and length of 350mm, rounded ends.

3) Pressure tester: its precision (the relative error of indication) is less than ±2%; the range can make the expected failure load change between 20% and 80% of total range.

4) Backing plate: the steel backing plate can be put between the upper and the lower pressure plates; and its roughness of every 100mm should be no more than 0.02mm.

(3) Production and Maintenance

1) When producing the masonry mortar specimen, put the bottomless mold on a ordinary clay brick covered with a layer of water-absorbing wet paper (the water-absorbing rate is greater than 10% and the water-content is no more than 2%), and paint the inner wall of the mold with a thin layer of oil or releasing agent; the wet paper should be fresh (or without any cementing materials); the surface of the brick should be level; any vertical face of the brick stuck with cement or cementing materials should not be used.

2) Inject mortar into the mold once, and tamp it from outside to inside along spiral direction with a tamper for 25 times; a putty knife can be used to tamp along the mold wall for many times in order to avoid leaving pores in the mortar with low consistency after tamping, and let the mortar be 6~8 mm high

above the top of the mold; when there appear spots on the surface of mortar (about 15~30min), scrape the excess mortar along the top of the mold.

3) After production, the specimen should stand at (20±5)℃ for one day (24h±2h); if the temperature is low, the time can be extended, but no more than two days; and then mark it and remove it from the mold; finally, the specimen should be maintained under the standard condition for 28d, then used for pressure test.

4) Standard curing condition includes:

① The temperature of cement mixed mortar should be (20±3)℃, and the relative humidity should be 60% ~ 80%.

② The temperature of cement mortar and little foam mortar should be (20±3)℃; and the relative humidity should be 90% above.

③ During the curing period, the intervals between specimens should be no less than 10mm.

If there is no standard curing condition, specimens can be maintained under natural condition. And the requirements are: the temperature of cement mixed mortar should be positive temperature, and the relative humidity should be 60%~80% (maintained in curing box or stuffy room); the temperature of cement mortar and little foam mortar should be positive temperature, and the surface of the specimens should be damp (such as in a pile of wet sand); the temperature during the curing period must be recorded. If there is any dispute, the standard curing condition prevails.

(4) Steps

1) When being removed from the curing place, the specimens should be tested as soon as possible to avoid the significant temperature changes inside. Clean specimens at first, check their appearance, measure their sizes (accurate to 1mm) and calculate the bearing area. If the difference between the measured size and the nominal size is less than 1mm, the area can be calculated by the nominal size.

2) Put a specimen on the lower pressure plate (or lower backing plate) of the tester and its pressure bearing surface should be vertical to the top surface after being moulded. Its center should coincide with that of the lower plate. Start the tester, adjust the ball cup to make it touch the specimen evenly when the upper plate gets close to the specimen. The loads should be added evenly and continuously and the loading speed should be: 0.5~1.5kN per second (if the

mortar strength is no more than 5MPa, the lower limit is appropriate; if the mortar strength is over 5MPa, the upper limit is appropriate). When the specimen is getting damaged and start deforming rapidly, stop adjusting the throttle of the tester until the specimen is damaged. Then record the failure load.

(5) Results

The compressive strength of the mortar cube should be defined as follows (accurate to 0.1MPa)

$$f_{m,cu} = \frac{N_\mu}{A}$$

In the equation: $f_{m,cu}$ is the compressive strength of the mortar cube (MPa);

N_μ is the failure pressure of the cube (N);

A is the pressure bearing area (mm^2).

The arithmetic mean of the measured values of six specimens is the compressive strength value of this group (accurate to 0.1MPa).

If the difference between the maximum or the minimum value and the mean is over 20%, the mean of the measured values of the middle four specimens is the compressive strength of this group.

Test Seven Fired Common Brick Test

Based on the regulations GB/T2542-2003 and GB5101-2003, this test is to check the size deviation and appearance quality, and to determine the strength grade of bricks by testing compressive strength.

1. Sampling Method

The formation principle and size of the inspection batch is regulated in JC/T466. 35,000~150,000 blocks is one batch, and less than 35,000 is calculated as one batch. The samples used for appearance quality check are taken randomly from each batch; the samples used for size deviation check and other tests should be taken randomly from the samples used for appearance quality check. The quantities sampled for test are shown in Test Table 7.1.

Test Table 7.1 Quantities of Bricks Sampled for Single Test (piece)

Test Items	Appearance Quality	Size Deviation	Strength Grade	Frost	Lime Burst	Freeze-thaw	Water-content and Saturation Coefficient
Sampled Quantities	50	20	10	5	5	5	5

2. Size Deviation and Appearance Quality Tests of Fired Common Brick

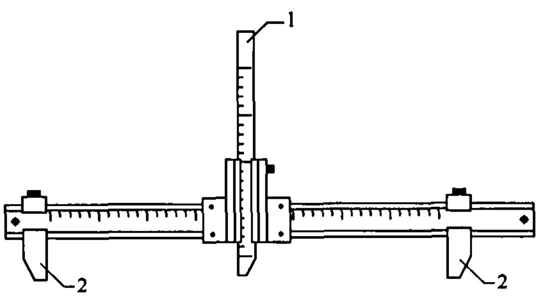
(1) Major Apparatus and Equipment

Brick Caliper (See Test Figure 7.1): division value of 0.5mm; steel ruler: division value of 1mm.

(2) Measurement Method

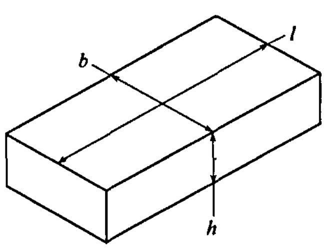
1) Dimensional Measurement.

Measure the two sizes of length and breadth on the middle parts of the two big faces of a brick respectively, and measure two sizes of height on the middle parts of the two strip faces (see Test Figure 7.2). If there is defected or convex part on the measured place, measure the adjacent part, but it would be better to choose the bad side (accurate to 0.5mm).



Test Figure 7.1 Brick Caliper

1. Vertical Ruler; 2. Support feet



Test Figure 7.2 Dimensional Measurement

l. Length; *b*. Breadth; *h*. Height

The sizes of length, breadth and height should be the arithmetic means of their respective two measured values, accurate to 1mm.

2) Appearance Quality Check.

Defects: if a brick lacks a corner angle, the damaged part should be measured by its projective size on length, breadth and height of the brick, called failure size (see Test Figure 7.3). The failure surface is the projective area of the damaged part on strip and top surfaces of the brick (see Test Figure 7.4).

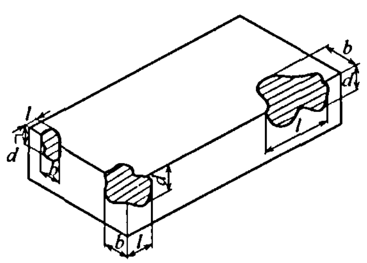
Cracks: there are three kinds of cracks respectively at the directions of length, breadth and height, expressed by the projective length at the measured direction. If a crack extends from one face to another face, its projective length should be accumulated (see Test Figure 7.5). The crack length should be the longest one measured respectively at the three directions.

Bends: bended part is measured on the big face and the strip face respectively. Put the two feet of a brick caliper on the two ends of the edge and use the vertical ruler to measure the most bended part (see Test Figure 7.6). The concave part caused by impurities or bump should be excluded.

The bigger bended size is the measured result.

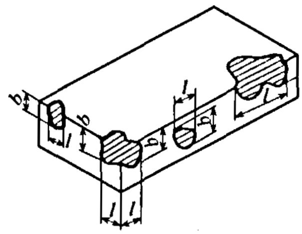
The convex height of impurity: impurities may produce convex heights on the surface of brick, expressed by the biggest distance between the impurity and the brick surface. Put the two feet of a brick caliper on the two sides of the convex part on the brick surface and use the vertical ruler to measure it (see Test Figure 7.7).

"mm" is the unit of all the above measured sizes of appearance quality. If the size is less than 1mm, it should be calculated as 1mm.



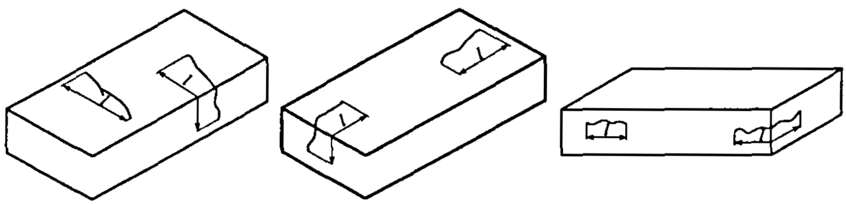
Test Figure 7.3 Measurement of Failure Size

l. Projective Size at the Length Direction; *b*. Projective Size at the Breadth Direction



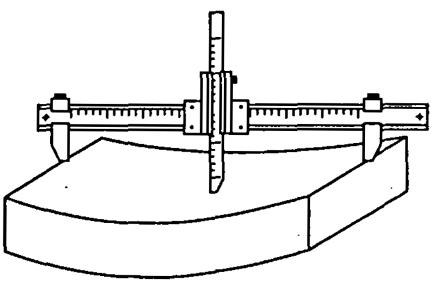
Test Figure 7.4 Measurement of Failure Face

l. Projective Size at the Length Direction; *b*. Projective Size at the Breadth Direction; *h*. Projective Size at the Height Direction

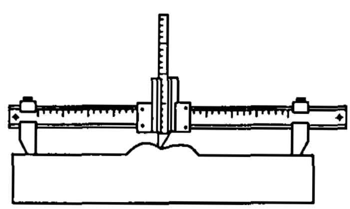


(a) Measurement of Crack Length at the Breadth Direction (b) Measurement of Crack Length at the Length Direction (c) Measurement of Crack Length at the Horizontal Direction

Test Figure7.5 Measurement of Crack



Test Figure 7.6 Measurement of Bend



Test Figure 7.7 Measurement of Convex Impurity

3. Compressive Strength Test of Fired Common Brick

(1) Major Apparatus and Equipment

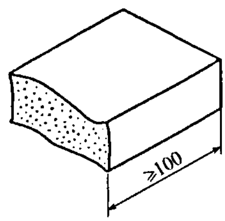
Pressure tester, brick saw or brick cutter, platform for specimens' preparation, spirit level, and steel ruler, etc..

(2) Preparation

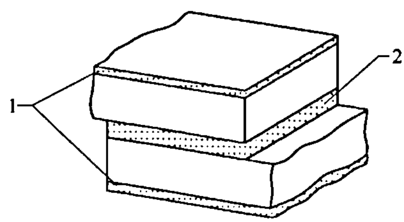
1) Cut or saw a group of sample bricks (10 pieces) into half bricks; and the side length of half bricks should be no less than 100mm, shown in Test Figure 7.8; if it is less than 100mm, use a new sample brick.

2) On the platform, soak the half bricks into clean water at room temperature for 10~20min.

3) Take them out, and pile them up at the direction opposite the fractures; stick them with less than 5mm clean cement paste with appropriate consistency confected by ordinary Portland cement with the strength grade of 32.5 or 42.5; and smooth the upper and the lower faces with the same cement of less than 3mm; the upper and the lower faces of the finished specimen should be parallel with each other and be perpendicular to the side faces, shown in Test Figure 7.9.



Test Figure 7.8 The Length of Half Brick



Test Figure 7.9 The Thickness of Cement Paste

1. Cement Paste Thickness of 3mm; 2. Cement Paste Thickness of 5mm

4) The finished specimens should be maintained in a stuffy room over 10℃ for 3 days and then can be tested.

(3) Test Methods and Steps

1) Measure two sizes of length and breadth of the joint face of each specimen respectively and use the mean of the two sizes (accurate to 1mm).

2) Put a specimen in the middle of the pressure plate, and add loads perpendicularly to the pressure face; loads should be added evenly and stably without any impact or vibration and the speed is (5 ± 0.5)kN/s until the specimen is damaged; record the maximum failure load P.

(4) Results

The compressive strength of every specimen is defined as follows (accurate to 0.1MPa):

$$f_i = \frac{P}{Lb}$$

In the above equation: f_i is the compressive strength (MPa);

P is the maximum failure load (N);

L is the length of pressure face (mm);

b is the breadth of pressure face (joint face) (mm).

(5) Evaluation

After test, the variation coefficient of strength δ and standard deviation s can be calculated by the following equations:

$$\delta = \frac{s}{\overline{f}}$$

$$s = \sqrt{\frac{1}{9}\sum_{i=1}^{10}(f_i - \overline{f})^2}$$

In the equation: δ is the variation coefficient of strength (accurate to 0.01MPa)

$\overline{f}$ is the arithmetic mean of the compressive strength values of 10 pieces of sample bricks (accurate to 0.01MPa);

f_i is the measured value of the compression strength of a sample brick (accurate to 0.01MPa);

s is the standard deviation of the compression strength of 10 pieces of bricks (accurate to 0.01MPa).

1) Average—Evaluation of Standard Value.

When variation coefficient $\delta \leqslant 0.21$, the strength grade of bricks is evaluated by the average of compression strength $\overline{f}$, the standard value of strength f_k. When the sample size n=10, the standard value of strength is defined as follows (accurate to 0.1MPa):

$$f_k = \overline{f} - 1.8s$$

2) Average—Evaluation of Minimum Value.

When the variation coefficient $\delta > 0.21$, the strength grade of bricks is evaluated by the average of compression strength $\overline{f}$, the minimum strength value of a single brick $f_{\min}$ which is accurate to 0.1MPa.

The results of compression strength should accord with Test Table 7.2, and it is unqualified under MU10.

Test Eight Steel Bar Test

1. Acceptance and Sampling Methods of Steel Bar

1) Steel bars should contain outgoing quality certificate or experiment report. Each bundle (tray) of reinforced steel bars should have signs. The steel bars in factory should be checked in furnace ports (batches) and diameters, including: checking on signs as well as appearance and conducting mechanical property tests on the samples. There are tensile test and cold bending test. If the samples are unqualified in one of the two tests, the batch of steel bars is unqualified.

2) When the steel bars with the same cross-section size or the same furnace-pot number are checked in batches, each batch should not be more than 60t; if the furnace-pot numbers are different, the steel bars should be checked in line with the code——*Hot-rolled Steel Bar used in Reinforced Concrete Structure.*

3) If there are brittle fractures, bad weld performances, and abnormal mechanical properties happening to steel bars in use, chemical composition analysis should be carried out.

4) It is regulated in sampling methods and results evaluation that randomly select two bars from each batch of steel bars, take a set of samples (two specimens) at 50cm to the top, and take one from each set of samples to conduct tensile test and the other the cold bending test. If one of the two specimens used for tensile test can not reach all the three regulated indexes of yield point, tensile strength and elongation, twice (four) steel bars should be selected for re-test. If one of the bars can still not reach the indexes, the steel bars are unqualified for the tensile test no matter whether the indexes are reached by the others. In the cold bending test, if one of the specimens can not meet the standard requirement, twice steel bars should be used for re-test. If there is still one specimen that cannot meet the requirement, the steel bars are unqualified for the cold bending test.

5) Tests should be conducted at (20 ± 10)℃; and if the test temperature is beyond this range, it should be marked in the record and report.

2. Tensile Test

(1) Purposes

To determine the yield strength, tensile strength and elongation of low-carbon steel is to provide means and basis to identify and test the mechanics and processing properties of steel.

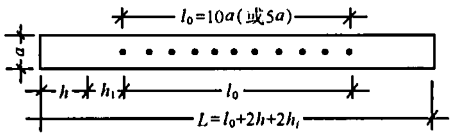
(2) Major Apparatus and Equipment

Universal material testing machine, steel ruler, vernier caliper, micrometer, and compasses, etc..

(3) Production and Preparation

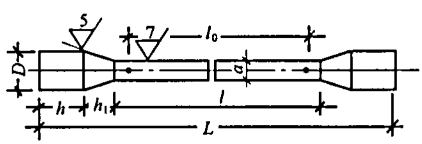
1) The steel-bar specimens with the diameter of 8~40mm do not need turning (see Test Figure 8.1).

2) If the test machine has tonnage restrictions, the steel bar with the diameter of 22~40mm can be made into turning samples, its shape and size shown in Test Figure 8.2 and Test Table 8.1.



Test Figure 8.1 Unturned Specimen

a. calculated diameter; l_0. gauge length; h. (0.5~1)a; h. grip length.



Test Figure 8.2 Turned Specimen

Test Table 8.1 Sizes of Turned Specimen (mm)

<table>
<tr><th colspan="4">Normal Size</th><th colspan="3">Long Specimen l_0=10a</th><th colspan="3">Short Specimen l_0=5a</th></tr>
<tr><th>a</th><th>D</th><th>h</th><th>h_1</th><th>l_0</th><th>L</th><th>L</th><th>l_0</th><th>l</th><th>L</th></tr>
<tr><td>25</td><td>35</td><td rowspan="4">No Regulations</td><td>25</td><td>250</td><td>275</td><td rowspan="4">$L=l+2h+2h_1$</td><td>125</td><td>150</td><td rowspan="4">$L=l+2h+2h_1$</td></tr>
<tr><td>20</td><td>30</td><td>20</td><td>200</td><td>220</td><td>100</td><td>120</td></tr>
<tr><td>15</td><td>22</td><td>15</td><td>150</td><td>165</td><td>75</td><td>90</td></tr>
<tr><td>10</td><td>15</td><td>10</td><td>100</td><td>110</td><td>50</td><td>60</td></tr>
</table>

Note: the length of head (h) decides the size of grip.

3) Draw a straight line on the surface of a specimen parallel to its axis with a pensile, and dot endpoints (punches) of gauge length on the line, and draw 10 equal division points along gauge length with oil paint.

4) Measure the gauge length l_0, accurate to 0.1mm.

5) For the unturned specimen, the cross-sectional area A_0 can be calculated by mass method.

$$A_0=m/7.85L$$

In the equation: A_0 is the cross-sectional area (cm^2), converted into mm^2;

$m$is the mass of the specimen (g);

L is the length of the specimen (cm);

7.85 is the density of the steel bar (g/cm^3).

6) The cross-sectional area of the turned specimen A_0 can be calculated by the following method:

① Measure the diameters by micrometer along the gauge length respectively in the middle and at the two ends. On each part, measure the diameters respectively in the mutually perpendicular directions. And their average is the diameter of this part. And take the minimum value of the three diameters as the diameter for the calculation of cross-sectional area.

② Round the result of cross-sectional area A_0: if A_0<100mm^2, round it to one decimal; if $A_0 \geqslant 100mm^2$, round it to integer; and the digits after the required numbers can be rounded off.

(4) Identification of Yield Strength σ_s and Tensile Strength σ_b

1) Adjust the major indicator of force-measuring dial of the tester to zero and set the minor indicator to overlap with the major one.

2) Fix a specimen in the chuck of the tester and start it to stretch the specimen. The speed is: before yield, the increasing speed of stress is 10MPa per second; after yield, the speed of the chuck moving under loads should not be more than 0.5l per minute ($l=l_0+2h_1$).

3) In the stretching process, the yield point load F_s is the constant load when the indicator on the dial stops or the minimum load when it rotates at the first time.

The yield strength of the specimen can be defined by:

$$\sigma_s = F_s / A$$

In the equation: σ_s is the yield strength (MPa);

F_s is the yield point load (N);

A_0 is the original cross-sectional area of the specimen, (mm^2).

σ_s should be rounded to 10MPa, and the figures behind decimal dot should be rounded off.

4) Continue adding load to the specimen until it is pulled off, and read the maximum load F_b on the dial.

The tensile strength σ_b can be defined by:

$$\sigma_b = F_b / A_0$$

In the equation: σ_b is the tensile strength (MPa);

F_b is the maximum load (N);

A_0 is the original cross-sectional area of the specimen (mm^2).

The precision of σ_b is the same with that of σ_s.

5) Result Identification: compare the calculated σ_s and σ_b with those regulated in national codes for the mechanism of various steel bars. If they cannot meet the requirements, double samples should be re-tested; and if the standard still cannot be reached, the elongation is unqualified.

(5) Determination of Elongation

1) Align the two broken parts of the specimen at their fractures and try to place their axes in a straight line. If there is gap between the fractures, it should be included into the gauge length after the specimen is pulled off.

2) If the distance between the fracture point and its adjacent endpoint on the gauge length is more than $\left(\frac{1}{3}l_0\right)$, measure the stretched gauge length l_1 by a caliper directly.

3) If the distance between the fracture point and its adjacent endpoint on the gauge length is less than or equal to $\left(\frac{1}{3}l_0\right)$, l_1 can be identified by the following shifting method: on the longer part, measure the divisions almost as long as the shorter part from O point at the fracture and obtain point B; then take half of the remaining divisions [even number, see Test figure 8.3 (a)] and get point C; or take half of the remaining divisions [odd number, see Test figure 8.3 (b)] plus or minus 1 and get points C and C_1; the shifted l_1 is $AO+OB+2BC$ or $AO+OB+BC+BC_1$. If the elongation calculated through direct measurement can meet the required value, the shifting method cannot be used.

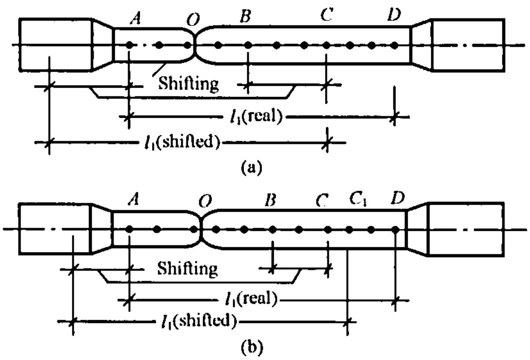
4) Elongation can be defined by the following equation (accurate to 0.1%):

$$\delta_{10}(or\,\delta_5) = \frac{l_1 - l_0}{l_0} \times 100\%$$

In the equation: δ_5 and δ_{10} are respectively the elongations when $l_0 = 10d$ and $l_0 = 5d_0$; l_0 is the original gauge length $10d_0(5d_0)$ (mm);
l_1 is the length of gauge distances determined by direct measurement or shifting method after the specimen is pulled off (mm).

5) If the specimen is broken at the endpoint of or outside gauge length, the result is invalid and new test should be conducted.

6) Result Identification: compare the calculated δ_5 or δ_{10} with those regulated in national codes for the mechanism of various steel bars. If they cannot meet the requirements, double samples should be re-tested; and if the standard still cannot be reached, the elongation is unqualified.



Test Figure 8.3 Calculation of the Gauge Length by Shifting Method

3. Cold Bending Test

(1) Purposes

To check the bending deformation performance borne by steel bars is to determine their processing property and reveal their defects.

(2) Major Apparatus and Equipment

Press, universal tester, special tester or round vice and hook bending machine.

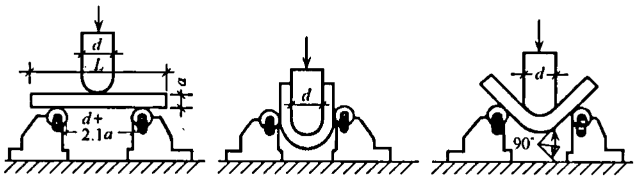
(3) Methods and Steps

1) The unturned specimen is $5a_0$+150mm long; and a_0 is the calculated diameter of the specimen (mm).

2) The diameter and bending angle of the bending center should be chosen from the tables of the grades of hot rolled bars and the technical requirements in the building steel chapter.

3) According to Test Figure 8.4 (a), adjust the distance between the two rollers equal to $d+2.1a$.

4) According to Test Figure 8.4 (a), stably add loads after the specimen is installed; and the steel bar should circle the bending center and bend in line with the required bending angle [see Test Figure 8.4(b) and Test Figure 8.4(c)].



(a) Installed Specimen (b) Bending 180° (c) Bending 90°

Test Figure 8.4 Device for the Cold Bending Test

(4) Result Identification

After the specimen bends, check the outside and sides of the bending part; if there is no cracks, fractures and layers, the specimen is qualified for the cold bending test.

Test Nine Petroleum Asphalt Test

This test determines the penetration rate, ductility rate and softening point of petroleum asphalt, and then evaluate the grades of asphalt according to GB / T 4507~4509 standard.

1. Sampling Method

Take the asphalt sample of the same batch, specification and grade from barrels (bags or boxes). And the sample should be taken from the place under the surface, and at least 5 cm from the container wall. When the asphalt is a solid breakable piece, break it and take the sample with clean tools. And when the asphalt is semisolid, then cut it with clean tools. And the mass value of the taken sample is 1~1.5kg.

2. The Determination of Penetration Rate

(1) Purposes

Determine the penetration rate of asphalt, judge its viscosity, and evaluate the grade of asphalt according to the index of penetration rate.

(2) Apparatus and Equipment

1) Penetrometer (see Test Figure 9.1).

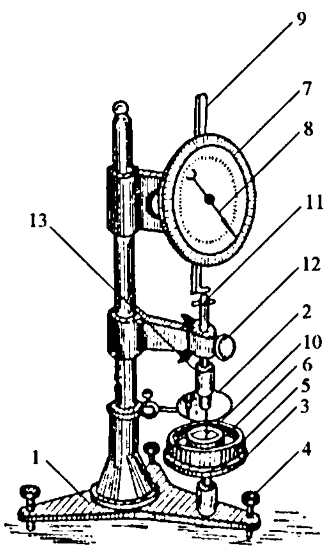
2) Constant temperature water bath, sample dish, thermometer, stopwatch and so on.

(3) Steps

1) Preparation of sample. Heat the asphalt to 120~180℃ and then dewater it and then filter it with screen, put it into the sample dish, and the depth should be 10mm deeper than the expected penetration rate. Put the dish into the atmosphere whose temperature is 15~30℃ to cool for 1~2 hours, and dust should be avoided at the moment of cooling. And then put the dish into the constant temperature water bath with temperature of (25±0.5)℃ for 1~2 hours. The water level of the constant temperature water bath should be 25mm higher than the sample.

2) Adjust the penetrometer to horizontal level, check the pointer, connecting rod and guide rail to ensure there is no water or other sundries, and no obvious friction, fix the preparation needle and put on the weight.

3) Take out the sample dish from the constant temperature water bath, and put it into the flat-bottom warmer of (25±0.1)℃, and the water level above the sample surface should not be less than 10mm. Put the flat-bottom warmer onto the platform of the penetrometer.



Test Figure 9.1 Penetrometer

1. base; 2. small mirror; 3. round platform; 4. leveling screw; 5. warmer; 6. sample; 7. dial; 8. pointer; 9. movable rod; 10. standard needle; 11. connecting rod; 12. button; 13.weight

4) Put down the needle connecting rod gradually, fix it when the needlepoint touches the surface of the sample. Pull down the movable rod to contact with the needle connecting rod, and modify the pointer or dial to make the pointer point to zero. Then press the button heavily and at the same time start the stopwatch. Make the standard needle fall down freely to penetrate into the asphalt sample. After 5 seconds, stop pressing the button to stop the pointer from falling.

5) Pull down the movable rod to contact with the top of the standard needle connecting rod. And this time the difference between the value pointed by the pointer and the original value is the penetration rate of the sample.

6) At least three tests should be done on the same sample, and each time the water temperature in the temperature holding dish should be checked and adjusted to keep the temperature at (25±0.1)℃. And after each test, the standard needle should be taken off and cleaned with a cloth or cotton soaked with organic solvent (toluene or turpentine). The distance among determination points or between determination point and sample dish should be less than 10 mm.

(4) Results

Take the average value of three tests as the penetration rate of the sample (1/10mm), the test result takes integer. And the difference among three tests' results should not be more than the value listed in the Test Table 9.1.

Test Table 9.1 the maximum allowed difference among the penetration rate of petroleum asphalt

Penetration rate	0~49	50~149	150~249	250~350
The maximum difference	2	4	6	10

3. Determination of Ductility

(1) Purposes

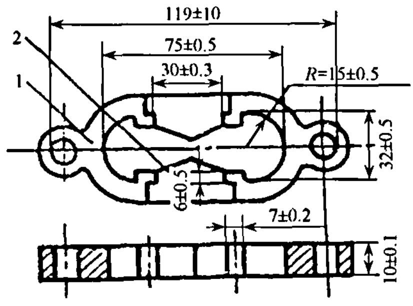
Determine the ductility of asphalt to understand its plasticity. And regard it as one of the indexes to judge the labels of asphalt.

(2) Apparatus and Equipment

1) Ductility Device.

The ductility device is made of rectangle flume and transmission. The slide plate driven by silk pole stretches the sample at a speed of (50±5)mm per minute. The pointer on the slid plate shows the distance of movement.

2) "8"-shaped Mode which is made of 2 end modes and 2 lateral modes (see Test Figure 9.2).



Test Figure 9.2 Test Mode

3) Other instruments are the same as those that are used in penetration rate test.

(3) Steps

1) Preparation of sample. Paint the isolating agent (glycerol : talc = 2 : 1) evenly onto the internal sides of metal bottom plate of the two lateral modes (except the end mode). Then fix the modes onto the bottom plate. Inject the melted, dewatered and filtered asphalt into the mode from one end to the other in form of trickle. Fill it by several times and the level of asphalt should be a bit higher than that of the mode. And then cool it at the temperature of 15~30 ℃ for about 30min. Put it into and keep it in the constant temperature water bath for 30min, and then take it out. Cut down the asphalt higher than the mode with heated knife to keep the asphalt level parallel with the mode level. The cutting method should be conducted from the central to sides. The level of the sample should be smooth and flat. Finally move it into the constant temperature water bath with the temperature of (25±0.1)℃ for 1~1.5 hour.

2) Check the movement speed of ductility instrument slid plate and see if it meets the demand. Adjust the water level in the flume (the water level should be 25mm higher than the sample level) and the water temperature (25℃±0.5 ℃).

3) Take the sample from the constant temperature water bath, and remove the bottom plate and lateral mode. Put the both mode holes onto the slide plate in the flume and the metal pillar respectively. Then check the water temperature and keep it at (25±0.5)℃.

4) Adjust the pointer on the slide plate to zero, run the ductility instrument and observe the tension of asphalt. During the determination, if there is asphalt

filament floating on the water level or sink onto the flume bottom, add ethanol or salt water should be added to modify the density of water to approach that of the sample, and then continue the test.

5) When the sample is broken, read the value the pointer points on the ruler. That is the ductility of the sample, represented with cm.

(4) Results

Take the average value of three paralleling samples as the ductility of the sample. If the difference between the three determined values and average is not within 5% of the average value, but the two higher values are within 5% of the average value except the lowest value, then abandon the lowest value and take the average value of the two higher values as the test result.

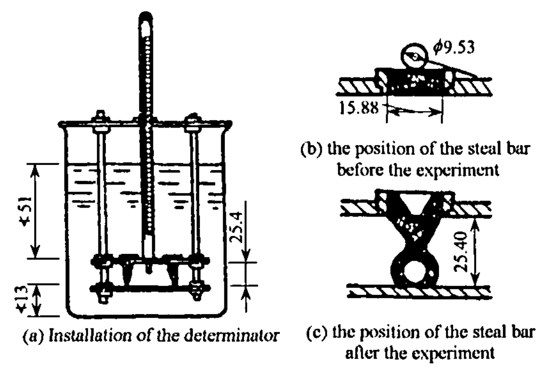
4. Determination of Softening Point

(1) Purposes

Determine the softening point of petroleum asphalt and understand the degree of its viscosity and plasticity changes with the temperature change. And take it as one of the indexes of petroleum asphalt.

(2) Apparatus and Equipment

1) Softening point tester (ring and ball method), include 800mL beaker, determining frame, sample ring, shroud ring, steel ball and thermometer (shown in Test Figure 9.3).



Test Figure 9.3 The Determinator of Softening Point

2) Electric furnace or other heaters, metal board or glass board, screen (the screen hole should be 0.3~0.5mm metal screen).

(3) Steps

1) Preparation of the sample. Put the brass ring onto the metal board or glass board which is painted with isolating agent. Inject the melted, dewatered and

filtered asphalt into the brass ring until the asphalt is a little higher than the ring level (if the expected softening point is over 120℃, preheat the brass ring and the metal board to 80~100℃). Cool the sample in the atmosphere with the temperature of 15~30℃ for 30 min. And then cut the asphalt that is higher than the ring level with heated knife to make the asphalt level the same with that of the ring.

2) Inject the distilled water that is boiled and cooled to 5℃ into the beaker, or inject the glycerol that is preheated to 32℃(the expected softening point of the sample is over 80℃), and make the liquid level a little lower than the depth mark on the link rod between the ring and the frame.

3) Put the ring which contains the sample into the holes in the upper board of the ring frame, add the shroud ring, and then put the whole ring frame into the beaker. Adjust the liquid level to the depth mark, and there should not be bubble on any part of the ring frame. Inject the thermometer from the hole on the upper board vertically to make the mercury ball parallel with the bottom of the brass ring. Keep the constant temperature for 15min, and the temperature should be kept at (5±0.5)℃ (the temperature of glycerol should be kept at (32±1)℃).

4) Move the beaker onto the electric furnace, on which there is asbestos shingle, and then put the steel ball onto the sample (the level of each ring should be kept completely in the state of horizontal level during the procedure of heating) to heat immediately. And the heating rate of the liquid in the beaker should be kept at (5±0.5)℃/min. Otherwise do it again.

5) Observe the sample being heated and softened, when it is softened, falls and touches the bottom board (that is 25.4mm), write down the temperature at that time. And that is the softening point of the sample (the precision should reach 0.5℃)

(4) Results

Take the average value of the two paralleling tests as the test result.

5. Evaluation

Check the test results above according to standards (shown in Table 10.1 in Chapter Ten), and then judge the label and the specification of the asphalt.

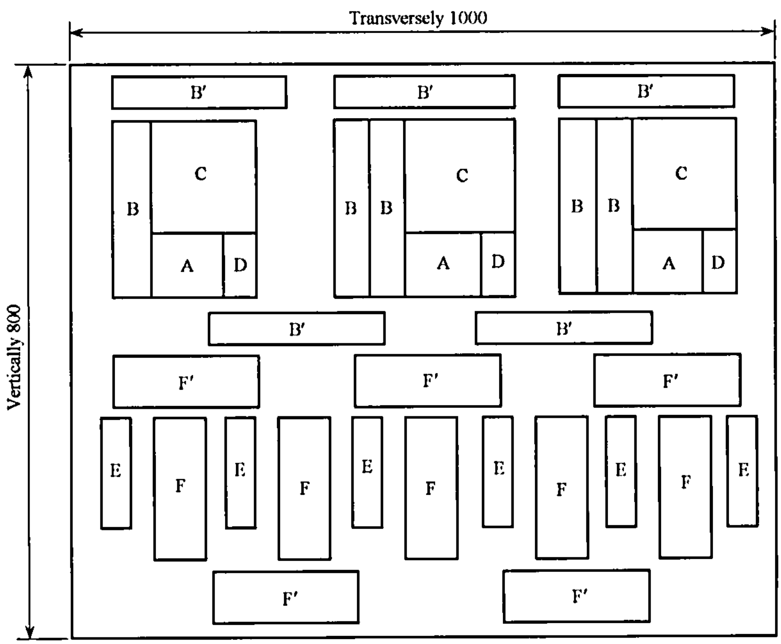
Test Ten Test of Elastic (Plastic) Modified Asphalt Waterproof Coiled Materials

1. Sampling Method

(1) The 10,000m^{2}asphalt made in the same factory, the same type and the same specification is regarded as a batch, even though some are not enough. Take 5 rolls of sample from each batch to check their roll weight, area, thickness and appearance. And then take one (normally the lightest one) from the samples whose roll weight, area, thickness and appearance are qualified for physical and mechanical tests.

(2) Production of sample. Cut off the segement which is 2 500mm from the external volume header from the sample. Cut two whole samples which are 800mm long, along the vertical direction. One of them is used for the physical property test, and the other for standby.

Cut the sample as the segments in Test Figure 10.1 and as the sizes and the quantities in Test Table 10.1. And the distance between the edge of the sample and the edge of coiled material should not be less than 75mm.



Test Figure 10.1 Segments of Samples

The samples used in the artificial weathering test should be divided as GB / T18244. Two groups should be taken, and one of them is used for aging test, and the other is used to compare with the sample to determine its properties.

2. Solvable Substance Content Test

(1) Purposes

Determine the asphalt content that is soaked onto the fetus basis in the petroleum asphalt waterproof coiled material.

(2) Prepared Solvents

Carbon tetrachloride, chloroform or trichloroethylene, commercial pure or chemical pure.

(3) Apparatus and Equipment

Analytical balance: sense quality of 0.001g;

Extractor: 500mL soxhlet extractor;

Electrothermal drying oven: the temperature of 0~300℃, the precision of ±2℃.

Test Table 10.1 Sizes and Quantities of the Samples of Elastic (Plastic) Coiled Materials

Test item	The code name of sample	The size of sample (mm×mm)	Quantity
Solvent content	*A*	100×100	3
Tension force and elongation	*B*,*B'*	250×50	Vertical and transverse 5 respectively
Impermeability	*C*	150×150	3
Heat resistance	*D*	100×50	3
Flexibility in low temperature	*E*	150×25	6
Breaking strength	*F*,*F'*	200×75	Vertical and transverse 5 respectively

Note: The 6 items above are compulsory ones in physical and mechanical tests except the breaking strength.

Infiltrating paper: the diameter should not less than 150mm.

(4) Steps

1) Pack the three cut samples with infiltrating paper and fasten them with cotton lines, then weigh them respectively.

2) Put the infiltrating paper bag into the extractor, and the solvent agent content should be 1/2~2/3 of the flask, and then heat and extract until the refluxing solvent is light in color, take out the infiltrating bag and let the absorbed solvent evaporate at first. Then put it into the electrothermal drying

oven preheated to 105~110℃ to get dried for an hour, and put it into the dryer to cool down to the room temperature.

3) Weigh the cooled infiltrating paper bag.

(5) Calculation

The content of solvable substance is calculated by the following formula:

$$A = K(G - P)$$

In the formula: A is the content of solvable substance (g/m^2);

K is coefficient, $K = 100$ (1/m^2);

G is the weight of infiltrating paper bag before extraction (g);

P is the weight of infiltrating paper bag after extraction (g).

The arithmetic mean value of the three samples is the solvable substance content of the coiled material.

3. Test of the Elongation under Tension force and the Maximum Tension Force

(1) Purposes

Test the capability of transformation resistance of the waterproof coiled materials.

(2) Apparatus and Equipment

Tension testing machine: the machine can test the tensioning force and the elongation at the same time; testing range is 0~2000N, and the minimum readable number is 5N; the tension range can make the fixture distance expand by one time and the fixture clamping width is more than 50mm.

(3) Steps

1) The test should be held under the temperature of (23±2)℃, put the samples (B,B') cut according to Test Figure 10.1 under the testing temperature for not less than 24 hours.

2) Adjust the tension testing machine (the tension speed is 50mm / min), and then fix the samples which have been treated under constant temperature in the center of the fixture, and the fixture should not be twisted, and the distance between the upper fixture and the bottom one should be 180mm. Run the tension testing machine until the sample is broken.

3) Read the value number when the sample is broken, record the maximum tension force, and meanwhile determine the elongation value under the maximum tension force. If the distance between the broken place of the

sample and the fixture is less than 20mm, the test result is ineffective, and the test should be done again.

(4) Calculation

Calculate the average tension force value of five samples as the vertical and transverse tension forces of the sample. And it is measured by N/50mm.

The elongation under the maximum tension force is calculated through the following formula:

$$E = 100(L_1 - L_0)/L$$

In the formula: E is the elongation under the maximum tension force (%);

L_1 is the standard distance when the sample is under the maximum tension force (mm);

L_0 is the original standard distance of the sample (mm);

L is the distance between the fixtures (180mm).

Calculate the vertical and transverse elongation of five samples respectively under the maximum tension force and take the average value of them as the vertical and transverse elongation of the coiled material.

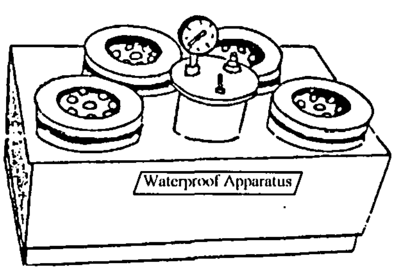
4. Impermeability Test

(1) Purposes

Check the impermeability of the waterproof coiled material under certain water pressure and in the fixed time duration.

(2) Apparatus and Equipment

Waterproof apparatus: this is an apparatus which has three or four permeable plates. The interior diameter of the permeable plate is 92 mm, and there are seven evenly laying permeable holes with diameter of 25 mm on the metal cover. The testing range of the pressure gauge is 0~0.6MPa, and the precision is grade 2.5. And the duration period of pressure is not shorter than 30min (shown in Test Figure 10.2).

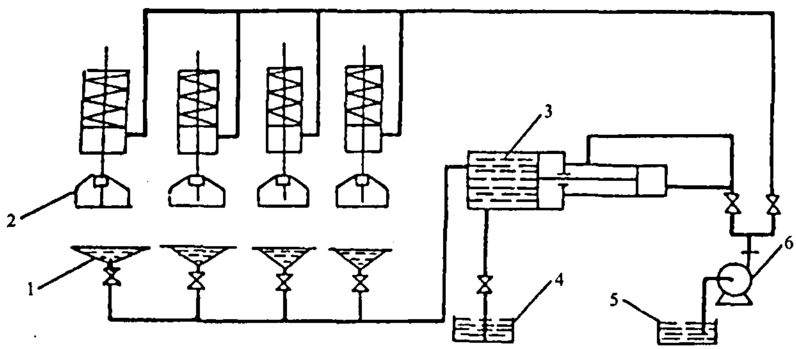


Test Figure 10.2 Waterproof Apparatus

(3) Steps

1) The upper surface of the coiled material is the upstream face, and when the upper face is the sanded face or mineral partial face, the bottom face is used as the upstream face. When the bottom is sanded face, exclude the surface sand on the sanded face along the circle of the sealing circle around, and then paint the No.60~No.100 heated asphalt around the circle and test the impermeability after being cooled for an hour.

2) Fill the water box with clean water and then start the oil pump. Under the oil pressure, the clip-foot piston drive the clip-foot upward, let out the atmosphere in the water box and then absorb the water from the box into the tank, and fill the water into three sampling seats at the same time. When the three seats are filled with water and the state is approaching overflow, shut the input valves. If the water in the tank is almost over, more water should be put into the tank through the box to ensure there is sufficient water in the tank (see Test Figure 10.3).



Test Figure 10.3 Schematic Diagram of Waterproof Apparatus

1. sampling seat; 2. clip-foot; 3. tank; 4. water box; 5. oil pump; 6. pressure gauge

3) Put the three samples onto the three permeable sampling seats, fix the sealing ring and cover the sample with metal cover. Fasten the samples onto the sampling seats tightly by clip-foot.

4) Open the input valves to fill the water and add the pressure, and when the pressure reaches the assigned pressure, stop adding the pressure and shut the input valves. And at the same time start the timing clock. Observe timely if there is seepage on the surface of the sample until the lasting time reaches the assigned length. If there is seepage on any sample, shut the machine and record the time. During the assigned time period if there is seepage on one or two samples, stop the relative input valve(s) to ensure other samples to

continue the test, until the time period reaches the assigned length. Unload the pressure and take out the samples. Start the oil pump, when the clip-foot rises the samples can be taken out and the oil pump can be turned off.

(4) Result Evaluation

During the assigned time and under the assigned pressure, if there is no seepage on none of the three samples, the product is judged to be qualified. But if there is seepage on any of them, the product is judged to be unqualified.

5. Heat Resistance Test

(1) Purpose

Check the movement state of asphalt on the coiled material under the given temperature, on assigned slop and in given time.

(2) Apparatus and equipments

Electric thermostat box.

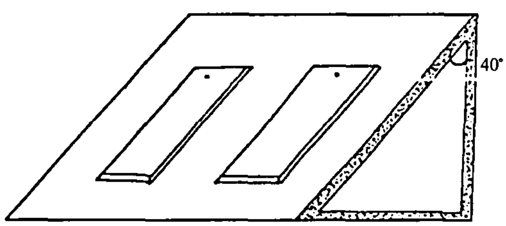
(3) Steps

1) Puncture a hole on each samples, and the hole is 1cm from the short side and at the center of the sample.

2) Penetrate the samples through the holes with thin iron wire or pin, and then put the samples onto the slops (shown in Test Figure 10.4). The distance between the position of sample and box wall should not be less than 50mm. And there should be certain distance between samples to avoid being bonded together. And then put it into the electric thermostat box that has fixed the temperature to 90~130℃ or higher. After samples are heated for more than 2 hours, take them to observe if there is sliding, flowing or drooping.

(4) Result Evaluation

There should not be movement from the fetus basis on either side when being heated for two hours. If the bottom part of the samples is coherent with the fetus basis and there is no sliding, flowing or drooping then the sample is judged to be qualified.



Test Figure 10.4 The Test Stand of Heat Resistance of the Coiled Material

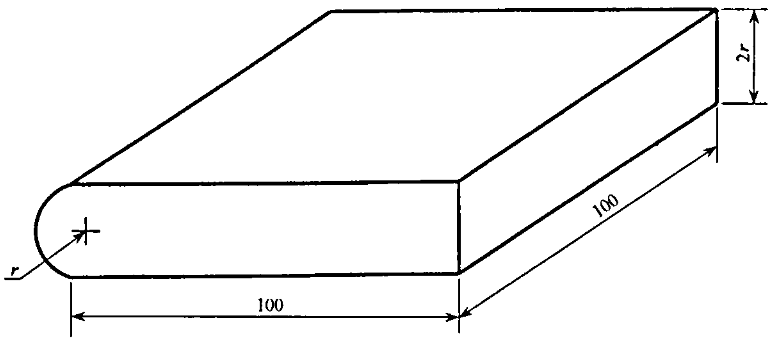
6. Low-temperature Flexibility Test

(1) Purposes

Check the flexibility of the waterproof coiled material through test, test the capability of transformation resistance under minus temperature (0~-30℃), and determine whether the coiled material can be operated under low temperature.

(2) Apparatus and Equipment

1) The flexible bar or bending plate: the radius is 15mm or 25mm. And the bending plate is shown in Test Figure 10.5.



Test Figure 10.5 Bending Plate

2) The low-temperature controller: range of 0~-30℃ and controlling precision of ±2℃.

3) The semiconductor thermometer: measurement range is 30~ -40℃,and the precision is 0.5℃.

4) Freezing liquid: the substances that do not react with coiled materials, such as antifreezing fluid used in automobile, polyhydric alcohol, multicomponent ethers.

(3) Test Method

Method A (arbitration method): put the freezing liquid (more than 6L) into the container whose content is over 10L, put the container into the low temperature controller. And then put the samples and the flexible bar together into the liquid, when the temperature reaches the assigned standard, and then keep the temperature at least for half an hour. Under the given standard temperature, bend the sample around the flexible bar (bending plate) in the liquid within 3 seconds at the constant speed.

Method B: put the samples and the flexibility together into the liquid whose temperature is modified into the assigned standard. And then keep being in the liquid for at least 2 hours, and then bend the sample around the flexible bar (bending plate) in the liquid within 3 seconds at the constant speed.

(4) Steps

1) The flexible bar (bending plate) whose radius is 15mm is fit for 2mm or 3mm coiled materials. And the flexible bar (bending plate) whose radius is 25mm is fit for 4mm coiled material.

2) In the six samples, the upper surfaces f three touch the flexible bar (bending plate), and the bottom surfaces of the others touch the flexible bar (bending plate).

(5) Results

After the test, observe the coiled material to see if there is any crack. If there is no crack, then the product is qualified.

7. Tear Strength Test

(1) Purposes

Check the capability of breaking resistance of waterproof coiled material through test. And judge whether the waterproof material meets the breaking in normal engineering or wind force breaking.

(2) Apparatus and Equipments

Tension testing machine: the clipping distance of clip-feet should be more than 75mm.

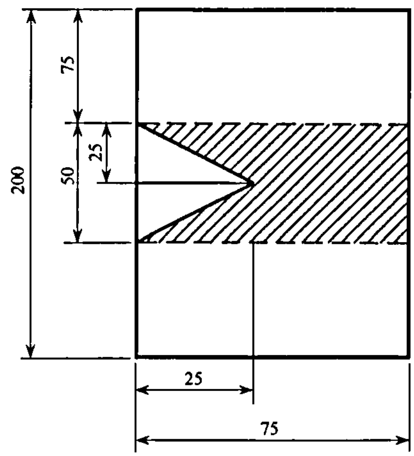
(3) Steps

1) Cut the samples (*F* and *F'*) according to the demands listed in Test Table 10.1 and then cut them again with knife or mode into the shape shown in Test Figure 10.6, and then put and keep it under the testing temperature (23℃±2℃) for more than 2 hours.

2) Calibrate the testing machine, and the tension speed should be 50mm / min. Fix the samples to the center of the fixture without twist, and the distance between upper and bottom fixture is 130mm. Run the testing machine until the sample is broken. Record the maximum tension strength.

(4) Calculation

Calculate the average vertical and transverse tension strength value of five samples respectively, and take it as the vertical and transverse tension strength of the coiled material.



Test Figure 10.6 Torn Specimen

8. Artificial Weathering

Conduct the test according to GB/T18244, after 720 hours of weathering test, check the appearance of the samples, determine the vertical tension strength and flexibility in low temperature, and calculate the vertical tension retention percentage.

9. General Judgment

If each test result meets the demands listed in Table 10.6 and Table 10.7, then it can be judged that this batch of products is qualified in the physical and mechanical properties. If one of the indexes does not meet the standard demands, it is allowed to take 5 rolls randomly from the batch of products. And pick out a single roll randomly from the 5 rolls and recheck the unqualified items. If the rechecked one meets the standard demands, then the batch of products is judged to be qualified.

When the roll weight, area, thickness, appearance and physical properties meet all the demands of GB18243-2000, and the package and the mark meet the demands of standard, and then the batch of products can be judged to be qualified.

Index

D

E

F

J

K

L

M

Q

R

S

T