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Materials in Civil and Construction Engineering

主编 丁勇杰

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PREFACE

A basic function of civil and construction engineering is to provide and maintain the infrastructure needs of society. Although some civil and construction engineers are involved in the planning process, most are concerned with the design, construction, and maintenance of facilities. The common denominator among these responsibilities is the need to understand the behavior and performance of materials. A basic understanding of the material selection process, and the behavior of materials, is a fundamental requirement for all civil and construction engineers performing design, construction, and maintenance.

First, this book introduces the basic properties of civil engineering materials. The introduction to the basic properties includes basic physical properties, mechanical properties and durability of materials. In addition, one of the responsibilities of civil and construction engineers is the inspection and quality control of materials in the construction process. This requires an understanding of material variability and testing procedures. The atomic structure of materials is covered in order to provide basic understanding of material behavior and to relate the molecular structure to the engineering response. So the second section presents the characteristics of the primary material types used in civil and construction engineering, such as building steel, aggregate, cement, masonry, concrete, wood, asphalt, and synthetic polymers. Since the discussion of concrete and asphalt materials requires a basic knowledge of aggregates, there is a chapter on aggregates. Moreover, since composites are gaining wide acceptance among engineers and are replacing many of the conventional materials, there is a chapter introducing composites.

Efforts have been made to make the teaching materials more applicable, more substantial, more succinct, and more novel. Multiple sample problems have been added to each chapter to allow professors to vary assignments between semesters. Answering these questions and problems will lead to a better understanding of the subject matter.

As one of the civil engineering textbooks, this book is suitable for students majoring in "Civil Engineering", "Transportation Engineering", "Engineering Supervision", "Costing Engineering", and "Water Supply and Drainage Engineering", also for the engineers and technicians engaging in the relevant specialties. 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.

Special thanks are due to the Southwest Jiaotong University Press project team, Ms. Xue Zhang, the chief editor, Ms. Wenyue Zhang, the editor, for their patience, understanding, and encouragement in publishing this manuscript.

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Chapter 1

Basic Properties of Civil Engineering Materials

The building and construction of civil engineering are composed of all kinds of civil engineering materials, which bear different load in different part. Therefore, civil engineering materials should have its corresponding basic properties. For example, good mechanical properties are needed for structural materials; wall materials should have the heat and sound insulation characteristics; roofing materials are waterproof and impermeable; pavement materials require anti-skidding and anti-abrasion properties. Moreover, a lot of civil engineering materials are exposed to atmosphere, and subjected to weathering by wind, rain, waves, ice and solar radiation, which means the durability is necessary.

The basic properties of civil engineering materials include physical property, mechanical property, durability, water resistance, fire-proof properties, decorativeness and so on.

1.1 Basic Physical Properties of Materials

1.1.1 Density, Apparent Density and Bulk Density

1. Density

Density is the mass per unit volume when the material is in the absolute dense state. It can be shown that:

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

In this formula: ρ is the density (g/cm^3);
m is the mass under dry conditions (g);
V is the volume under absolutely compact conditions (cm^3).

Volume in the absolute dense refers to the volume of the individual particles only (no voids). A lot of civil engineering materials include voids, such as brick, stone and concrete. As for these materials, it is required to grind the materials into powder, then dry to constant weight and measure its volume using Li Bottle, which is also called density bottle.

2. Apparent Density

Apparent density is the mass per unit volume when the material is in natural state.

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

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 in natural state includes the volume of the solid and internal pores. The apparent density varies with moisture content. Apparent density generally refers to apparent density in dry state.

3. Bulk Density

Bulk density is mass per unit volume when powdery or particle materials are in the stacking condition.

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

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).

The volume in stacking state includes particle volume, inter-particle void volume, and internal pore volume. Bulk density is not an intrinsic property of a material; it varies from how the material is handled.

Table 1.1 Density, apparent density and bulk density of some civil engineering materials

Name	Density/(g/cm^3)	Apparent Density/(kg/m^3)	Bulk Density/(kg/m^3)
Steel	7.85	7850	-
Granite	2.6-2.9	2500-2850	-
Limestone	2.6-2.8	2000-2600	-
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	-
Cement	3.0-3.2	-	1300-1700
Wood	1.55-1.60	400-800	-
Asphalt Concrete	-	2300-2400	-
Ordinary Concrete	-	2100-2600	-

1.1.2 Solidity Porosity and Voidage

Porosity is a fraction of the volume of voids over the total volume.

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

Porosity represents the densification of material. The higher porosity, the lower densification is. Porosity includes connected pore and closed pore according to its structure, and it can be classified into coarse pore, fine pore and micro pore according to its size.

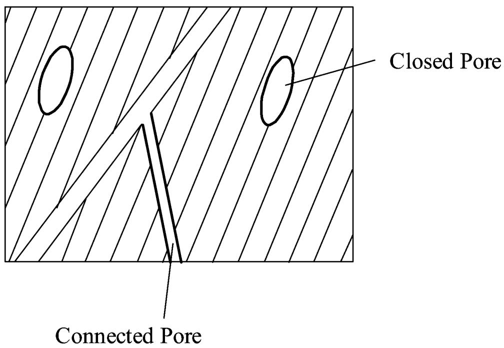


Figure 1.1 Sketch map of pores

Voidage is the proportion of spacing volume among the particles to the bulk volume of the non-coherent material in some container.

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

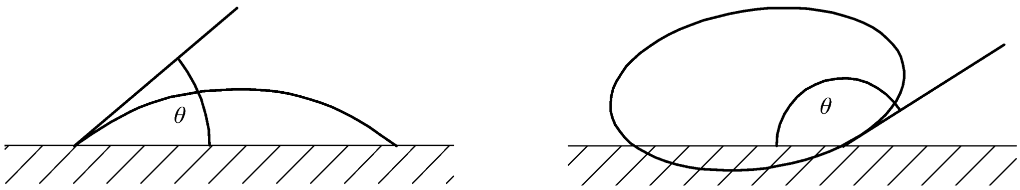
Voidage is an important parameter when controlling the gradation of concrete and calculating sand content.

1.1.3 Hydrophilic and Hydrophobic

Hydrophilic property refers to the material property which can be wetted when it contacts with water in the air ($0°\leq\theta\leq 90°$).

Most civil engineering materials belong to hydrophilic materials, such as stone, brick, block, glass and pottery. As for hydrophilic material, water-proof processing method can be used to improve its water resistance.

Hydrophobic property refers to the material property which cannot be wetted when it contacts with water in the air ($90°\leq\theta\leq 180°$). Asphalt, paraffin wax and some plastic used in civil engineering are hydrophobic materials.



(a) hydrophilic property θ<90°　　(b) hydrophobic property $90° \le \theta \le 180°$

Figure 1.2　Sketch map of wetting angle (θ)

1.1.4　Water Absorption and Moisture Absorption

Water absorption refers to the ratio of the weight of water absorbed by a material, to the weight of the dry materials.

Specific absorption of quality:

$$W_m = \frac{m_1 - m_2}{m_2} \times 100\%$$

Specific absorption of volume:

$$W_V = \frac{m_1 - m_2}{V} \times 100\%$$

In this formula: m_1 is the mass of the material at water-saturated state(g);

m_2 is the mass of the material under dry condition(g);

V is the volume of material under natural condition(cm^3).

The water absorption is related to porosity. Water can't enter into the dead-end pores. As for small interconnected pores, the more the pores are, the higher the water absorption is. Open pores are big, but it's difficult to store water, so its water absorption is less. Different material has diverse water absorption for its different internal structure.

Moisture absorption refers to the ratio of weight of materials with absorbed water in the moist air to that of dry materials.

$$W_m = \frac{m_1 - m_2}{m_2} \times 100\%$$

In this formula: m_1 is the quality of material in the moisture state(g);

m_2 is the quality of material under the dry condition(g).

1.1.5　Water Resistant and Waterproofing

Water resistant describes objects relatively unaffected by water or resisting the ingress of water under specified conditions. Such items may be used in wet environments or under water to specified depths. Waterproofing describes making an object waterproof or water-resistant (such as a camera, watch or mobile phone). "Water resistant" and "waterproof" often refer to penetration of water in its liquid state and possibly under pressure where damp proof refers to the resistance to humidity or dampness. In building construction, waterproofing is a fundamental aspect of creating a building envelope which is a controlled environment. The roof covering materials, siding, foundations, and all of the various penetrations through these surfaces need to be water-resistant and sometimes waterproof.

1.1.6 Anti-permeability

Anti-permeability refers to the property of something that cannot be pervaded by a liquid under pressure. Generally, Permeability coefficient or impermeability grade is used to describe the property. Permeability coefficient derives from Darcy's law.

Darcy's law at constant elevation is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.

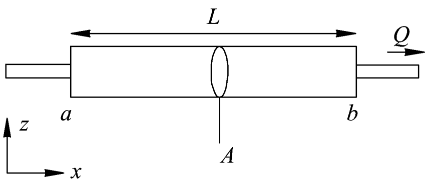


Figure1.3 Definitions and directions for Darcy's law

$$Q = \frac{-kA}{\mu}\frac{(p_b - p_a)}{L}$$

In this formula: Q is the total discharge (m^3/s);

k is the intrinstic permeability of medium;

A is the cross-sectional area of flow (m^2);

($p_b - p_a$) is the total pressure drop (Pa);

μ is the viscosity (Pa · s);

L is the length over which the pressure drop is taking place (m).

The negative sign is needed because fluid flows from high pressure to low pressure.

As for concrete or mortar, impermeability grade is represented as the index of impermeability. Higher the grade is, better the impermeability is.

1.1.7 Freezing Resistance

Freezing resistance refers to the property of materials that can endure repeated freezing and thawing cycle without damage and its strength can't be obviously reduced. Generally, D_n is taken as frost resistance grade, in which n is the maximum times of freezing and thawing cycle when materials reach the regulated damage extent.

Both the anti-permeability and the freezing resistance are related to voidage of materials. Materials with less voidage or end voidage has higher anti-permeability and the freezing resistance. The small and connected pores are disadvantageous to these properties.

1.1.8 Thermal Conduction and Specific Heat

Thermal conduction is the transfer of heat from one part of a body to another or from one body to another through its physical contact. Nonmetals have a low coefficient of thermal conductivity. Metals have a much higher one because their free electrons transfer the vibrations much more rapidly. Thus, metals are good conductors of heat.

The rate of heat transfer by conduction is dependent on the temperature difference, the size of the area in contact, the thickness of the material, and the thermal properties of the material(s) in contact.

The quantity of heat transferred by conduction is defined as follows:

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

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

Q is the conducted heat quantity (J);

A is the heat-transfer area (m^2);

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

T_1 is the temperature on warmer side (K);

T_2 is the temperature on the colder side (K);

d is the thickness of a material (m).

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

Table 1.2 lists a few construction materials and their thermal properties at nominal room temperature.

Table 1.2 Construction material thermal properties at room temperature①-③

Material	Thermal Conductivity /[W/(m · K)]	Specific Heat/[J/(kg · °C)]	Density/(kg/m³)
Brick	0.7	840	1600
Concrete–cast Dense	1.4	840	2100
Concrete–cast Light	0.4	1000	1200
Granite	1.7-3.9	820	2600
Glass (window)	0.8	880	2700
Hardwoods (oak)	0.16	1250	720
Softwoods (pine)	0.12	1350	510
Polyvinyl Chloride	0.12-0.25	1250	1400
Paper	0.04	1300	930
Acoustic Tile	0.06	1340	290
Particle Board (low density)	0.08	1300	590
Particle Board (high density)	0.17	1300	1000
Fiberglass	0.04	700	150
Expanded Polystyrene	0.03	1200	50

1.2 Mechanical Properties of Materials

The mechanical properties of a material describe how it will react to external loads. Mechanical properties occur as a result of the physical properties inherent to each material, and are determined through a series of standardized mechanical tests.

1.2.1 Strength

Strength is the material capacity of resisting breakage by the external force. Strength includes compressive strength, tensile strength, shearing strength and bending strength according to the different form of external force.

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive

① Colorado Energy. R-Value Table (Insulation Values for Selected Materials) [OL]. [2019-07-16]http://www.coloradoenergy.org/procorner/stuff/r-values.html.
② Comfortable Low Energy Architecture[EB/OL]. [2002-11-01] http://www.new-learn.info/packages/clear/index.html.
③ JIM WILSON. "Thermal Properties Of Building Materials" [OL]. [2008-02-01] http://www.electronics-cooling.com/ 2008/02/thermal-properties-of-building-materials/.

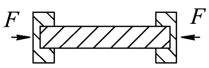
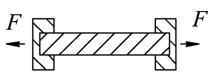
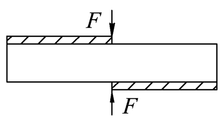
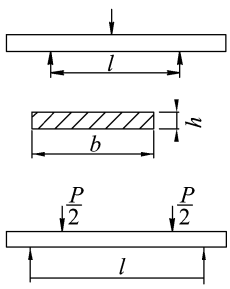
load. Compressive strength is a key value for design of structures.

Tensile strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different. Some materials will break sharply, without plastic deformation, in what is called a brittle failure. Others, which are more ductile, including most metals, will experience some plastic deformation and possibly necking before fracture.

Shearing strength refers to a material's ability to resist forces that can cause the internal structure of the material to slide against itself. Shear strength is the maximum shear stress which a material can withstand without rupture. In structural and mechanical engineering the shear strength of a component is important for designing the dimensions and materials to be used for the manufacture/construction of the component (such as beams, plates, or bolts).①

Bending strength, or flexural strength is a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Three and four points bend tests are commonly used to determine the flexural strength of a specimen.

Table 1.3 Formula of strength

Classification	Sketch map	Formula	Annotations
Compressive strength f_c		$f_c=F/A$	
Tensile strength f_t		$f_t=F/A$	f—Strength(MPa) F—Failure load(N) A—Loaded area(mm^2)
Shearing strength f_v		$f_v=F/A$	
Bending strength f_m		$f_m=3Fl/2bh^2$ $f_m=Fl/bh^2$	

① Corrosion Pedia. Shear Strength [OL]. (2020-09-02) [2013-11-22] https://www.corrosionpedia.com/definition/1026/shear-strength.

1.2.2 Elastic and Plastic Deformation

In materials science, deformation is a change in the shape or size of an object due to an applied force or a change in temperature. A temporary shape change that is self-reversing after the force is removed, so that the object returns to its original shape, is called elastic deformation. Elastomers and shape memory metals such as nitinol exhibit large elastic deformation ranges, as does rubber. However, elasticity is nonlinear in these materials. Normal metals, ceramics and most crystals show linear elasticity and a smaller elastic range.

When a material distorts under pressure but does not return to its original shape after the pressure is released, it is called plastic deformation. This type of deformation is irreversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape. Soft thermoplastics have a rather large plastic deformation range as do ductile metals such as copper, silver, gold and steel, but cast iron does not. Hard thermosetting plastics, rubber, crystals, and ceramics have minimal plastic deformation ranges.

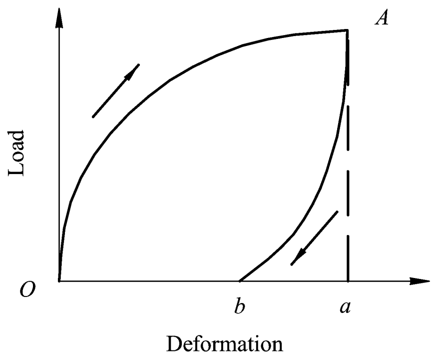


Figure 1.4 Deformation curve

1.2.3 Ductility and Brittleness

Ductility and brittleness are two of the most important physical properties of materials in construction engineering. Brittleness is the property of a material that will fracture without appreciable prior plastic deformation. Brittleness is lack of ductility and for a brittle material there is no plastic deformation. The elastic stage is followed by immediate fracture. Typical brittle materials include glass, concrete, ceramics, stone, and cast iron. Ductility is the property of a material that can be plastically deformed by elongation without fracture. Ductile materials can typically be plastically elongated with more than 15% before they fracture.

Typical ductile materials include copper, mild steel, and thermoplastics.①

Ductility of a material is its ability to deform when a tensile force is applied upon it. It is also referred to as the ability of a substance to withstand plastic deformation without undergoing rupture. Brittleness, on the other hand is exactly an opposite property of ductility as it is the ability of a material to break without first undergoing any kind of deformation upon application of force.②

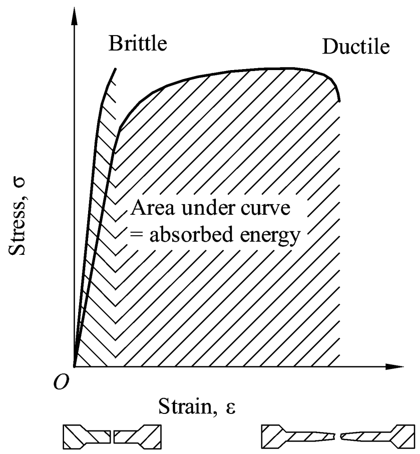


Figure 1.5 Stress-strain curves for brittle and ductile materials

1.2.4 Hardness

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelasticity, and viscosity.

Common examples of hard matter are ceramics, concrete, certain metals, and super-hard materials. There are three main types of hardness measurements: scratch, indentation, and rebound. Within each of these classes of measurement there are individual measurement scales. Scratch hardness tests are often used to determine the hardness of natural mineral. Steel, wood and concrete is usually determined by means of indentation hardness test. Rebound hammer measures the surface hardness of the concrete. The surface of concrete gets harder as concrete gains strength; thus, the strength of concrete can be estimated using this method.

① The Engineering Toolbox. Malleability, Brittlenes and Ductility [OL]. [2020-01-01] http://www.engineeringtoolbox.com/Malleability,-Brittlenes-and-Ductility-d_1851.html.

② OLIVIA. "Difference Between Ductility and Brittleness" [OL]. [2011-06-21] http://www.differencebetween.com/difference-between-ductility-and-vs-brittleness/.

Figure 1.6　Concrete test hammer

1.2.5　Stress and Strain

Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on. Strain is defined as the amount of deformation an object experiences compared to its original size and shape.

It is unique for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading (stress). A lot of useful information about the material can be revealed by plotting the stress-strain diagram. Figure 1.7 shows the typical uniaxial tensile or compressive stress-strain curves for several engineering materials.

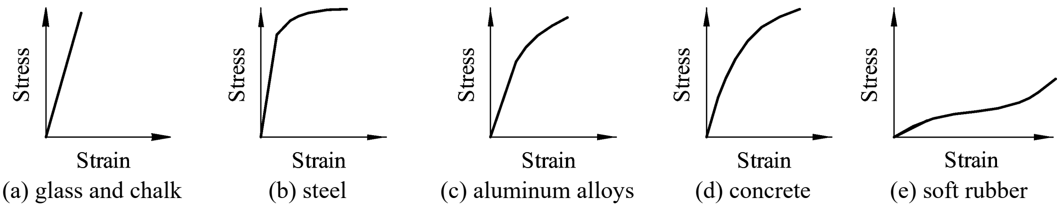


Figure 1.7　Typical uniaxial stress-strain diagrams for some engineering materials

1.3　Durability of Materials

Durability refers to ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. A durable material helps the environment by conserving resources and reducing wastes and the environmental impacts of repair and replacement.

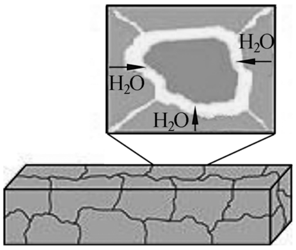
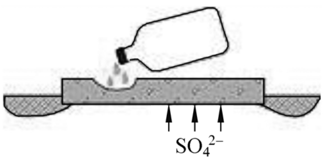
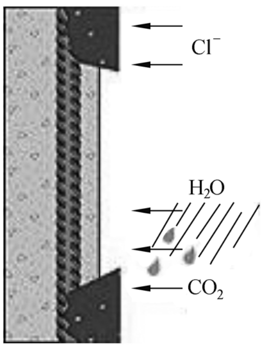
1.3.1　Durability of Concrete

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired.

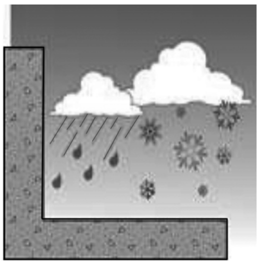
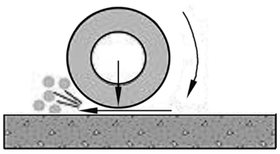
1.3.2 Mechanisms and Test Method

Table 1.4 shows important exposure conditions and deterioration mechanisms in concrete structures. In practice, several of these deterioration mechanisms can act simultaneously with possible synergistic effects.

Table 1.4 Exposure conditions and deterioration mechanisms in concrete structures

Durability Aspect/Exposure	Mechanism	Test Methods and other Standards
 Alkali-Aggregate Reaction	Alkali-Silica Reaction Alkali-Carbonate Reaction	AASHTO PP65 ASTM C856 ASTM C1260 ASTM C1293 ASTM C1567
 Chemical Resistance	Sulfates DEF Seawater Acids	ASTM C1012 ASTM D516 ASTM C1582
 Corrosion of Reinforcement	Corrosion Corrosion Resistance Carbonation	ASTM C1202 AASHTO T 259 ASTM C1556 AASHTO T 260 ASTM C1152 ASTM C1218 ASTM C1524 AASHTO TP 11 AASHTO TP 22 AASHTO TP 26 AASHTO TP 55

Continued

Durability Aspect/Exposure	Mechanism	Test Methods and other Standards
 Freeze-Thaw	Freezing and Thawing Deicer Scaling D-Cracking	ASTM C666 AASHTO T 161 AASHTO TP 18 ASTM C457Links ASTM C672
 Miscellaneous	Abrasion Erosion Fire Resistance Efflorescence	ASTM C131 ASTM C535 ASTM C3744 ASTM C1137 AASHTO TP 58

Resistance to Alkali-Silica Reaction (ASR): ASR is an expansive reaction between reactive forms of silica in aggregates and potassium and sodium alkalis, mostly from cement, but also from aggregates, pozzolana, admixtures, and mixing water. The reactivity is potentially harmful only when it produces significant expansion.

Chemical Resistance: Concrete is resistant to most natural environments and many chemicals. Concrete is virtually the only material used for the construction of wastewater transportation and treatment facilities because of its ability to resist corrosion caused by the highly aggressive contaminants in the wastewater stream as well as the chemicals added to treat these waste products.

Resistance to Sulfate Attack: Excessive amounts of sulfates in soil or water can attack and destroy a concrete that is not properly designed. Sulfates (for example calcium sulfate, sodium sulfate, and magnesium sulfate) can attack concrete by reacting with hydrated compounds in the hardened cement paste. These reactions can induce sufficient pressure to cause disintegration of the concrete.

Chloride Resistance and Steel Corrosion: Chloride present in plain concrete that does not contain steel is generally not a durability concern. Concrete protects embedded steel from corrosion through its highly alkaline nature.

Resistance to Freezing and Thawing: The most potentially destructive weathering factor is freezing and thawing while the concrete is wet, particularly in the presence of deicing chemicals. Deterioration is caused by the freezing of water and subsequent expansion in the paste, the aggregate particles, or both.

Abrasion Resistance: Concrete is resistant to the abrasive effects of ordinary weather. Examples of severe abrasion and erosion are particles in rapidly moving water, floating ice, or areas where steel studs are allowed on tires. Abrasion resistance is directly related to the strength of the concrete.

Questions

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

1.2 What are porosity and voidage? How to calculate? Briefly describe the relationship between them.

1.3 What is water absorption? What are the influencing factors of water absorption？

1.4 What is strength of a material? How to calculate various kinds of strength according to the different form of external force?

1.5 Describe the differences between elastic deformation and plastic deformation.

1.6 What is durability of concrete? Describe the text method of durability.

References

[1] INCROPERA, FRANK P, DEWITT, DAVID P. Introduction to Heat Transfer[M]. 2nd ed. New York: John Wiley and Sons, 1990.

[2] MICHAEL S MAMLOUK, JOHN P ZANIEWSKI. Materials for Civil and Construction Engineers [M]. Stockton: QWE Press, 2005.