普通高等教育"十二五"规划教材
PUTONG GAODENG JIAOYU "12·5" GUIHUA JIAOCAI

Civil Engineering Materials

土木工程材料

陈瑜 编著

冶金工业出版社
Metallurgical Industry Press

普通高等教育“十二五”规划教材

Civil Engineering Materials

土木工程材料

陈　瑜　编著

北　京
冶　金　工　业　出　版　社
2011

内容提要

本书根据土木工程专业本科生培养要求，针对双语教学，在参考多部国外优秀原版教材的基础上，以突出重点、注重实用为原则编写。

本书共分7章，内容包括：绪论、土木工程材料的基本概念、无机胶凝材料、砂石材料、水泥混凝土、结构钢材、沥青与沥青混合料等。为便于教学，各章后均附有思考题，书后附有专业英语词汇表。

本书可作为高等学校土木工程专业以及土建类其他专业本科的双语教学用书或教学参考书，也可供相关专业研究生及土木工程技术人员参考。

图书在版编目（CIP）数据

土木工程材料 = Civil Engineering Materials：英文 / 陈瑜编著．—北京：冶金工业出版社，2011.4

普通高等教育“十二五”规划教材

ISBN 978-7-5024-5464-7

Ⅰ．①土… Ⅱ．①陈… Ⅲ．①土木工程—建筑材料—高等学校—教材—英文 Ⅳ．①TU5

中国版本图书馆CIP数据核字（2011）第028413号

出版人 曹胜利
地　址 北京北河沿大街嵩祝院北巷39号，邮编100009
电　话 （010）64027926 电子信箱 yjcbs@cnmip.com.cn
责任编辑 廖 丹 美术编辑 彭子赫 版式设计 孙跃红
责任校对 侯 瑁 责任印制 张祺鑫
ISBN 978-7-5024-5464-7
北京兴华印刷厂印刷；冶金工业出版社发行；各地新华书店经销
2011年4月第1版，2011年4月第1次印刷
787mm×1092mm 1/16；12.25印张；289千字；182页
27.00元
冶金工业出版社发行部 电话：（010）64044283 传真：（010）64027893
冶金书店 地址：北京东四西大街46号（100010） 电话：（010）65289081（兼传真）
（本书如有印装质量问题，本社发行部负责退换）

前　言

土木工程材料是土木工程的物质基础，“土木工程材料”（原“建筑材料”）是土木工程各专业方向的一门核心专业基础课。近年来，随着双语教学的蓬勃发展，“土木工程材料”课程的双语教学从试点改革逐渐扩大。以往双语教学多采用国外原版教材，而国外原版教材大多侧重工程实际应用，对重视基础知识和基本理论的我国教学特点而言，有利有弊。利是不失为一本很好的参考书；弊是与我国教学大纲、基本教学要点相脱节，部分重要知识点缺失，章节编排不符合我国教学安排。同时，原版教材专业英文程度较高，导致相当部分学生看不懂，学习兴趣下降。

有鉴于此，为便于双语教学的开展，结合我国现行教学大纲，参照国家和行业最新技术标准、规范与规程，参考多部国外优秀原版教材和专著，我们编写了本书。本书编排符合我国现行教学大纲，适应“土木工程材料”课程学时与教学的要求；摒弃了老教材中的陈旧内容，删除了“木材”、“高分子聚合物”、“砌筑材料”等传统章节，重点突出，结构紧凑，章节安排合理；既保留了国内教材注重基础知识和基本技能的优点，又借鉴国外教材，强调学生工程应用能力和创新能力的锻炼；引入了大量新科技和新内容，结合近年来材料学科科研成果，将土木工程材料的基本知识和理论与最新进展有机结合；采用了标准专业英文表述，英文相对国外原版教材较简单，且最后附有专业词汇表，降低了双语教学难度，有利于学生学习。

在本书的编写过程中，黄湘宁负责全书的大部分制图工作，王盛铭、周文芳、梁地做了大量工作，特此致谢！

由于编者水平有限，书中不足之处在所难免，敬请使用本书的同行及高校师生提出宝贵意见，以备再版时进一步完善。

编　者

2010年12月

CHAPTER 1

Introduction

本章为绪论，主要简述材料科学与工程的基本概念，土木工程材料在土建工程中的重要地位、发展历史和未来趋势，土木工程材料的分类、主要技术性质与合理选用原则以及国内外技术标准与规范。

1.1 Material Science and Engineering

A material is defined as a substance or thing from which something else can be made. Cloth, cement, sugar, brick, aluminum, soil, and water are all examples of materials. In engineering, materials are employed to design and build structures, elements, or products. The subject of *materials science* examines the whys and hows of materials, making it possible to advance the development of new materials. The term *material engineering* refers to the understanding and review of properties and uses of materials commonly used in engineering.

Civil engineering is a professional engineering discipline that deals with the design, construction and maintenance of public works of structures, elements or products, including works such as bridges, roads, canals, dams and buildings. Their construction may be under or above ground, offshore or inland, over mile-deep valleys or flat terrains, and upon rocky mountains or clayey soils. It takes place on all levels: in the public sector from municipal through to federal levels, and in the private sector from individual homeowners through to international companies. At the core of civil engineering rests the investigation of materials and methods that can satisfy the needs of the community. For instance, shelter is provided for housing; dwellings are in accordance with a method that is appropriate for the material selected, the method of construction changing with the material. So civil engineers are responsible for the selection, specification, and quality control of materials to be used in job.

All various building substances or their products utilized in civil engineering are called *civil engineering materials*. The basic materials mainly used in civil engineering applications or in construction projects are:

- Aggregates
- Cement and other cementitious materials
- Cement concrete and mortar
- Masonry materials
- Asphalt binders and asphalt mixtures
- Structural steels
- Wood, polymer and other materials

1.2 A Historical Perspective

1.2.1 Critical Position in Civil Engineering

Materials indicate the substantial civilized degree of the society. The earliest human beings have access to only very limited materials including stone, wood and skins. Nowadays, the materials such as concrete, glass, and fiber make our existence so comfortable.

Materials are the function of structure and construction, and engineering quality depends on the materials used because that materials influence all aspects of the qualities, including applicability, durability, safety and beauty. Meanwhile, materials are the substance base of civil engineering, which directly control its cost. For instance, materials make up about 30%~50% of the total expense of a structure in highway or bridge engineering, sometime even reach 70%.

At the core of civil engineering, the improvement of materials plays a key part in promoting new design, new technology and new construction method. For example, the applications of pumping concrete (as shown in Fig.1-1) and prestressed reinforced concrete (Fig.1-2) help to create new construction technologies and improve the quality of structures.

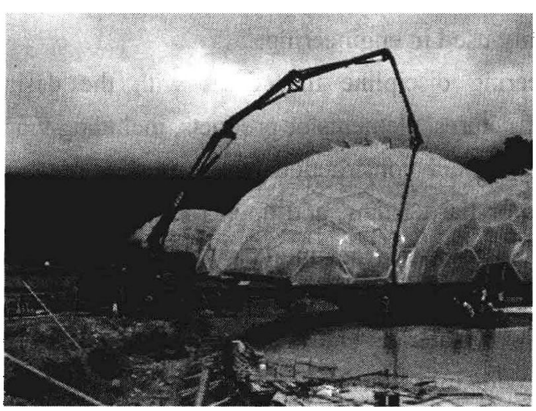


Fig.1-1 Pumping concrete construction

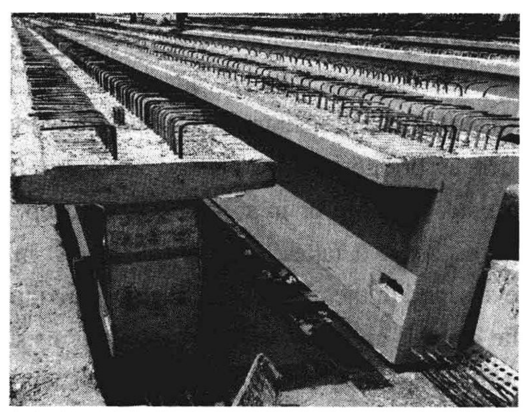
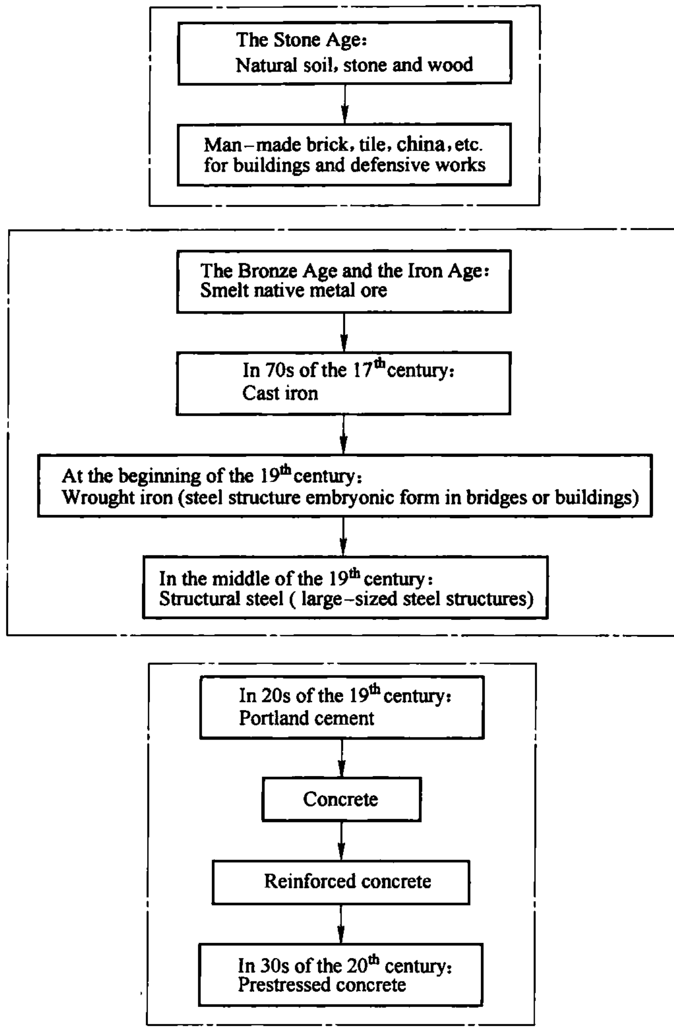


Fig.1-2 Prestressed concrete beam

1.2.2 Historical Progress

There were mainly three leaps in the historical progress of civil engineering materials:



1.2.3 Future Tendency

(1) High-performance: high strength, light weight, e.g. high-performance concrete, modified asphalt, etc.;

(2) Long service life: excellent durability;

(3) Multi-functional: composite materials, e.g. some new wall board materials as plywood;

(4) Product forms: prefabrication, structural member, large dimensions;

(5) Safety: such as fire resistance materials, radiation shield concrete;

(6) Environmentally friendly: low pollution waste, low energy consumption, be economical or recyclable, such as fly ash concrete, recyclable concrete, etc.;

(7) Manufacture technology: advanced technologies of low energy consumption and low pollution.

1.3 Classification, Properties and Selection

1.3.1 Classification

It refers to a general calling of materials and products.

By *material source*, civil engineering materials can be divided into natural materials such as stone, river sand, wood, natural asphalt and so on, and manufactured materials including cement, concrete, glass and so on, as well as waste materials such as fly ash, silicon powder and slag.

By *chemical components*, there are three types: inorganic materials, organic materials and composite materials. Inorganic materials include both metal materials (steel, iron, aluminum, etc.) and nonmetal materials (stone, glass, concrete, etc.). Organic materials include high molecular materials (plastic), plant materials (wood, etc.). Composite materials include glass fiber reinforced concrete, asphalt mixtures, polymer cement concrete and so on.

By *functions*, materials can be divided into load-bearing materials, enclosing materials (thermal insulation, sound absorption, waterproof and so on), decorative materials, repair materials, etc.

By *location*, materials can be named structural materials, roof materials, paving materials, wall materials, ceiling materials, masonry materials and other types.

Besides, materials can be classified into different types based on strength, deformation feature, etc. The above mentioned are some examples of classification of civil engineering materials.

1.3.2 Properties

Materials for engineering applications are selected so as to perform satisfactorily during service. The material for a highway bridge should possess adequate strength, rough surface and sufficient rigidity. A water-retaining structure would be built with a material that is impermeable, crack-free, strong, and does not react with water. A road surface needs such materials that show little movement under the impact of loads, are water-resistant, and are easy to repair.

Performance requirements, or property specifications, are not the same for all structures or structural materials. What is expected of a material used for the construction of a liquid-retaining structure is not the same as that chosen for a pavement. To evaluate the performance characteristics of engineering materials, and to assist an engineer in the selection of the most appropriate and economical material for a particular application, one needs to study the properties of the materials of construction. In general, the common properties of engineering materials are grouped under four major headings.

1.3.2.1 Physical properties

Physical properties are those derived from the properties of matter or attributed to the physical structure. They include density, porosity, void content, specific gravity, moisture content, permeability, and structure (micro or macro). In addition, properties such as texture, color, and shape fall under this classification. Physical properties are helpful in evaluating a material in terms of the appearance, weight, permeability, thermal conductivity, and water retention of a structure.

1.3.2.2 Mechanical properties

Mechanical properties measure the resistance of a material to applied loads or forces. Some reflect the strength of the material, whereas others measure the deformation capacity or stiffness. Strength is a measure of the maximum load per unit area, and can be in relation to tension, compression, shear, flexure, torsion, or impact. If we compare the strength of one individual with the emotional strength of another, we know that the two "strengths" are not the same and that the comparison is inappropriate. The same reason can be applied when describing the strength of a material; it is important to specify the type of strength.

The deformation capacity of a material (its stiffness) is assessed through its elastic modulus. A knowledge of the strength (or various types of strength) and the deformation characteristics of materials is absolutely essential in the selection process. A high-strength material may not necessarily possess adequate deformation capacity or stiffness, and vice versa.

It addition to strength and deformation capacities, the mechanical properties include other measurements such as brittleness, plasticity, and ductility, each of which reflects the deformation behavior of the material.

1.3.2.3 Chemical properties

Chemical properties are those pertaining to the composition and potential reaction of a material. The compounds of composition, such as oxides and carbonates, describe the chemical nature of the material, and the way it would behave in a certain environment. For example, by reviewing the proportions of the principal compounds in various cements, we will be able to choose the right type of cement for a particular application. Knowledge of the chemical composition of clays is indispensable in evaluating the characteristics expected in burned bricks. Chemical properties such as acidity, alkalinity, and resistance to corrosion of materials are especially noteworthy.

1.3.2.4 Work properties

Work properties are liable to be processed or constructed of a material according to certain operating instructions, e.g. fluidity of fresh concrete, weldability of steel, etc.

In civil engineering construction, though some materials are selected primarily for their physical properties or characteristics, most are chosen because of their mechanical properties and durability. Besides, the thermal, electrical, magnetic, acoustical, and optical properties of materials are also of relevance in civil engineering. Thus a proper understanding of the environment and the constraints within which a particular project is to be development is crucial in the material selection process. The goal of engineering design should be to select the most appropriate material for a particular job. A general knowledge of all relevant properties of the various materials that are available, and an appreciation of their performance characteristics, are fundamental in achieving this goal.

1.3.3 Selection and Use

A flowchart describing the materials selection procedure is shown as Fig.1-3. All primary materials of construction, or structural materials, must perform the following six functions:

1. Carry prescribed loads

Mechanical properties meet the request of design, e.g. high strength, high hardness, low deformation, etc.

2. Satisfy serviceability

Be liable to be applied in certain civil engineering project, for instance, earthquake resistance. Timber can't resist fire, while heavy concrete shields radiation.

3. Durability requirements

Long service life, corrosion resistance, cracking resistance, etc.

4. Be economically practical

Low cost, low expenses of exploitation, process, transportation and construction.

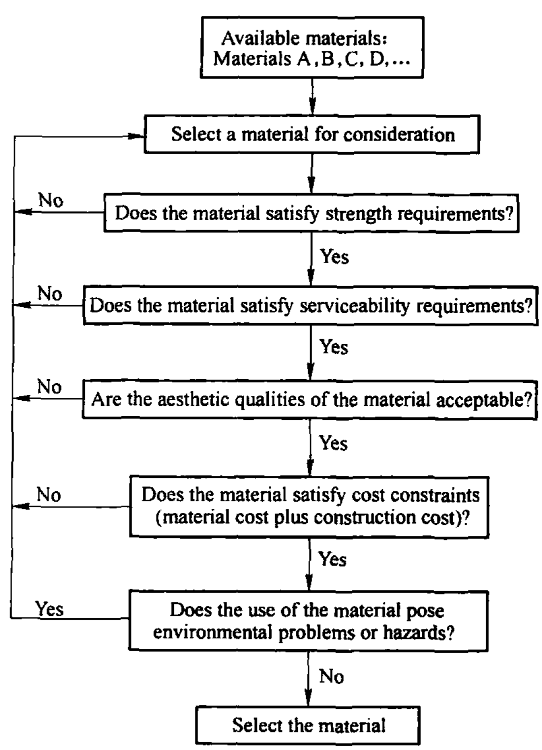


Fig.1-3 Materials selection flowchart
(Adapted from Shan Somayaji, *Civil Engineering Materials*, 2001)

5. Be environmentally friendly

Be compatible with environments, no or low pollution, low energy consumption, be recyclable, etc.

6. Be aesthetically pleasing

Pleasing appearance, such as floor coverings, paints, doors and windows, which are chosen based on aesthetic considerations.

1.4 Standards

When we use a construction material in any civil engineering project, a number of questions come up. For example, if we are designing a concrete footing to anchor a ship, the series of questions may include the following: What is "concrete"? What are the proportions of concrete ingredients? Is there more than one type of concrete? What type of aggregate should be used? How much water should be added while mixing? Should the sand remain dry before adding to the mixer? What procedures should be followed after placing the concrete? What changes in the mixture are necessary when the ground temperature is low? Can the same concrete be used for other types of work, such as a sidewalk?

Knowing the answers to all these questions requires that one be proficient in all aspects of concrete construction, including a thorough understanding of cement chemistry, hydration processes, geology, concrete behavior, and thermal effects. Even then, there is no guarantee that the concrete thus manufactured will be satisfactory; it can fail because of bad quality cement, weak aggregates, contaminated sand, and many other practical reasons. To guarantee satisfactory performance from the materials used in construction projects, they should be manufactured to satisfy minimum quality and product standards. In addition, the methods of use or construction should follow standard procedures.

To establish uniformity in materials and products, and methods of production, application, inspection, and testing, many organizations have developed standards for materials, testing and inspection. Over the years, these guidelines and mandatory recommendations have gone through series of revisions and been updated. In addition to material standards, several organizations also present specifications for the method of application.

Standards represent efforts by organizations—private (like the American Iron and Steel Institute), government (such as the Arizona Department of Transportation), or voluntary (for example, the American Concrete Institute)—for agreement on common procedures or goals. They share technical and scientific knowledge, while the trade associations promote a given material and provide technical and practical information for its proper use. The following is a partial list of prominent organizations in China and also in the world.

GB——Chinese National Standards

JC——Standards of Department of Building Materials in China

JGJ——Standards of Ministry of Construction in China

ISO——International Organization for Standardization

ASTM——American Society for Testing and Materials
ACI——American Concrete Institute
JIS——Japanese Industrial Standards
DIN——Industrial Standards in Germany (*Deutsches Institut für Normung e. V.*)
BS——British Standards

Problems

1-1 Name three material used in wall construction.

1-2 Give two examples of composite materials commonly used.

1-3 Name three important physical properties of materials.

1-4 Name three critical mechanical properties of concrete applied in railway bridge.

CHAPTER 2

Concepts of Civil Engineering Materials

本章阐述土木工程材料一些重要的基本概念，内容主要包括材料的物理性质（密度、表观密度、毛体积密度、堆积密度以及密实度、孔隙率等）、力学性能（强度、应力与应变、弹性变形与塑性变形、脆性、韧性、硬度和耐磨性等）、材料与水的关系（亲水性与憎水性、吸水性与吸湿性、耐水性、抗渗性以及抗冻性等）以及耐久性。本章所介绍的知识点将为后续各章内容的学习奠定初步的材料学理论基础。

2.1 Physical Properties

2.1.1 Density, Apparent Density, Bulk Density and Loose Density

2.1.1.1 Density

Definition: the mass of a unit solid volume of a material (which includes neither permeable nor impermeable pores, referred to Fig.2-1)

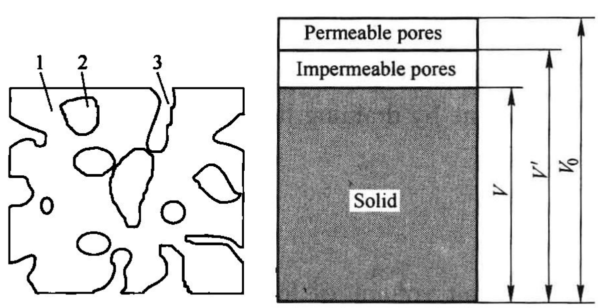


Fig.2-1 Volume diagram of a material under natural status
1—Solid; 2—Impermeable pore; 3—Permeable pore

Calculation:

$$\rho = \frac{m}{V} \tag{2-1}$$

where ρ——Density or true density, g/cm^3;

m——The mass of a dry material, g;

V——The absolutely solid volume of a material, cm^3.

In order to measure the absolutely solid volume of porous materials, first grind and dry the material, and then use a pycnometer to measure its volume. The finer the material is grinded; the more the measured value is close to the true volume of the material.

2.1.1.2 Apparent density

Definition: the mass of a unit volume of the impermeable portion of a material, which includes both the solid volume and the impermeable pores.

Calculation:

$$\rho' = \frac{m}{V'} \tag{2-2}$$

where ρ'——Apparent density, kg/m^3;

m——The mass of a material, kg;

V'——The volume of the impermeable portion of a material, m^3.

In general, the volume of the impermeable portion of a material is measured by draining water and displacing method, or weighing-in-water method.

For some dense materials (such as natural sand or stone), apparent density is very close to density of a material, and apparent density is also called *approximate density*.

2.1.1.3 Bulk density

Definition: the mass of a unit volume of a material under natural status, which includes solid volume, permeable and impermeable pores.

Calculation:

$$\rho_0 = \frac{m}{V_0} \tag{2-3}$$

where ρ_0——Bulk density, kg/m^3;

m——The mass of a material, kg;

V_0——The volume of a material under natural status, m^3.

For a material of regular shape, measure its volume with some tools, and for a material of irregular shape, measure its volume by draining liquid method, sealing wax and draining liquid method or using volume meter.

2.1.1.4 Loose density

Definition: the mass of a unit volume of loose-grained materials or fiber materials. The loose volume of a material includes the solid volume, the volume of permeable and impermeable pores and the void volume among material particles, shown as Fig. 2-2.

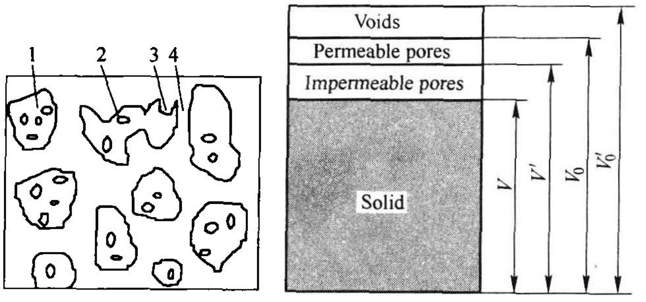


Fig.2-2 Volume diagram of loose-grained materials
1—Solid; 2—Impermeable pore; 3—Permeable pore; 4—Void

Calculation:

$$\rho_0' = \frac{m}{V_0'} \tag{2-4}$$

where ρ_0'——Loose density, kg/m^3;

m——The mass of a material, kg;

V_0'——The volume of a material under natural status, m^3.

The loose density of a material is directly related to the loose or dense degree of stacking, and can be divided into *loose stacking density* and *dense stacking density*. Loose stacking density means the mass of a unit volume of a material loosely stacked, while dense stacking density stands for the mass of a unit volume of a dense stacking material after vibrating.

2.1.2 Solidity and Porosity

2.1.2.1 Solidity

Definition: the compactness of solid in the volume of materials (under natural status).

Calculation:

$$D = \frac{V}{V_0} \times 100\% \tag{2-5}$$

D reflects the dense degree of a material, and higher D means the denser material. For a porous material, D is less than 1.

2.1.2.2 Porosity

Porosity means the percentage of the pore volume within a material to the total volume of this material under natural status, and is divided into total porosity (porosity for short), permeable porosity and impermeable porosity, shown as Fig.2-3.

1. Porosity

Porosity (P) means the percentage of the pore volume within a material to the total volume of this material under natural status, and can be calculated as

$$P = \frac{V_0 - V}{V_0} \times 100\% = (1 - \frac{V}{V_0}) \times 100\% = (1 - \frac{\rho_0}{\rho}) \times 100\% \tag{2-6}$$

It can be seen there is

$$P+D=1 \tag{2-7}$$

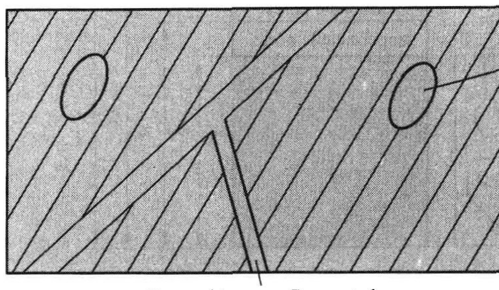


Fig. 2-3 Sketch map of pores

2. Permeable porosity

Permeable porosity is the percentage of the volume of permeable pore within a material (v_k) to the total volume of this material under natural status. Due to the fact that water can penetrate into the permeable pores, the volume of penetrating water into the material at water saturated state is viewed as the volume of permeable pores (v_k), and the permeable porosity (P_k) can be calculated as

$$P_k = \frac{v_k}{v_0} \times 100\% = (1 - \frac{\rho_0}{\rho'}) \times 100\% \tag{2-8}$$

3. Impermeable porosity

Impermeable porosity means the percentage of the volume of impermeable pore within a material (v_b) to the total volume of this material under natural status. And the impermeable porosity (P_b) can be calculated as

$$P_b = \frac{v_b}{v_0} \times 100\% = P - P_k \tag{2-9}$$

When material porosity increases, water absorption goes up, while both strength and durability decrease in general.

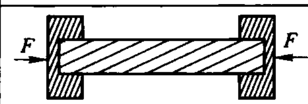
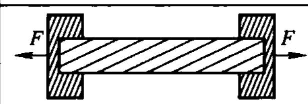
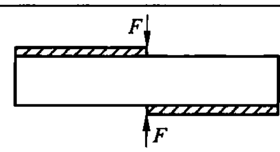
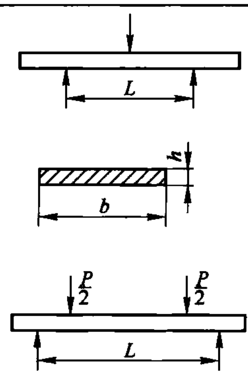
2.2 Mechanical Properties

2.2.1 Strength

Strength is defined as the ability of materials to resist the destructive loads. When a material sustains a load, there will exist stresses within this material, which increases with the increasing of the load. And until the internal particles of the material can't bear any more force, the material is destroyed, at which the corresponding stress is called the strength of material. According to the exerting way of loads, strength can be divided into two types—static strength and dynamic strength. *Static strength* is the measured strength on the condition that the loads increase gradually, which in general is adopted to calculate the structures bearing static loads. *Dynamic strength* is the measured strength provided that the increment of load within a unit time is quite remarkable. In the design of structures or elements sustaining dynamic loads, dynamic strength, such as fatigue strength, impact strength and so on, should be considered.

Based on the stress caused by loads, strength is divided into compressive strength, tensile strength, shear strength and bending strength, listed in Table 2-1.

Table 2-1 Formula of strength

Classification	Sketch map	Formula	Annotations
Compressive strength f_c		$f_c=F/A$	f—Strength, MPa; F—Failure load, N; A—Loaded area, mm^2
Tensile strength f_t		$f_t=F/A$	
Shear strength f_s		$f_s=F/A$	
Bending strength f_b		$f_b=3FL/2bh^2$ $f_b=FL/bh^2$	

Adequate strength is the prime requirement for any building material. It does not matter how perfectly it fulfills its other requirements; if it collapses or breaks under the loads it is required to support, it is useless, or worse. The load to be carried in a structural member may be much greater than the weight of the structural member, but even so-called non-load-bearing members must be able to support their own weight and resist any restraints imposed at their supports.

2.2.2 Stress and Strain

Stress is defined as force per unit area, and *strain* as elongation or contraction per unit length. It is convenient to use these concepts, because the same material will always deform plastically, or fracture, at approximately the same stress. The force needed to produce plastic deformation or fracture depends on the size of the material; the larger the piece, the more force that is needed.

When a material deforms elastically, the amount of deformation likewise depends on the size of the material, but the strain for a given stress is always the same, and the two are related by