《材料概论》

Introduction to Materials

Revision

材料科学与工程学院

考试范围及题型

试卷是全英文，回答中英文均可，范围:覆盖1-5章。

- 填　　空：8分（每空1分）
- 名词解释：15分（每个3分*5题）
- 单项选择：5分（每题1分*5题）
- 简　　答：48分（每题8分*6题）
- 讨　　论：18分（每题9分*2题）
- 阅读分析：6分（每题6分*1题）

Chapter 1 Basic Knowledge on materials

课程学习目的

1. 掌握材料的定义
2. 熟悉材料的基本分类方法和分类原则
3. 掌握材料结构、性质、效能和生产/加工之间的联系；

- Definition
- Classifications
- Structure – properties – processing

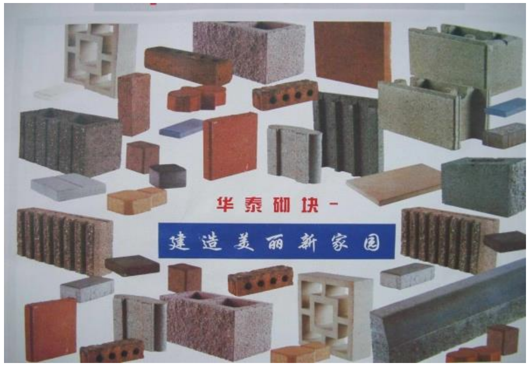
1.2 Definition and Classification of Materials

1.2.1 Definition of materials

- Materials are defined as solids used by man to produce items which constitute the support for his living environment.

◆ Characteristics：

- Have certain compositions;具有一定的成分和配比;
- Can be processed; 可加工成型
- With certain shape and color;保持一定形状和外观;
- Can be used and reused or recycled.具有使用价值并可回收再利用。



可成型加工

保持一定形状和外观

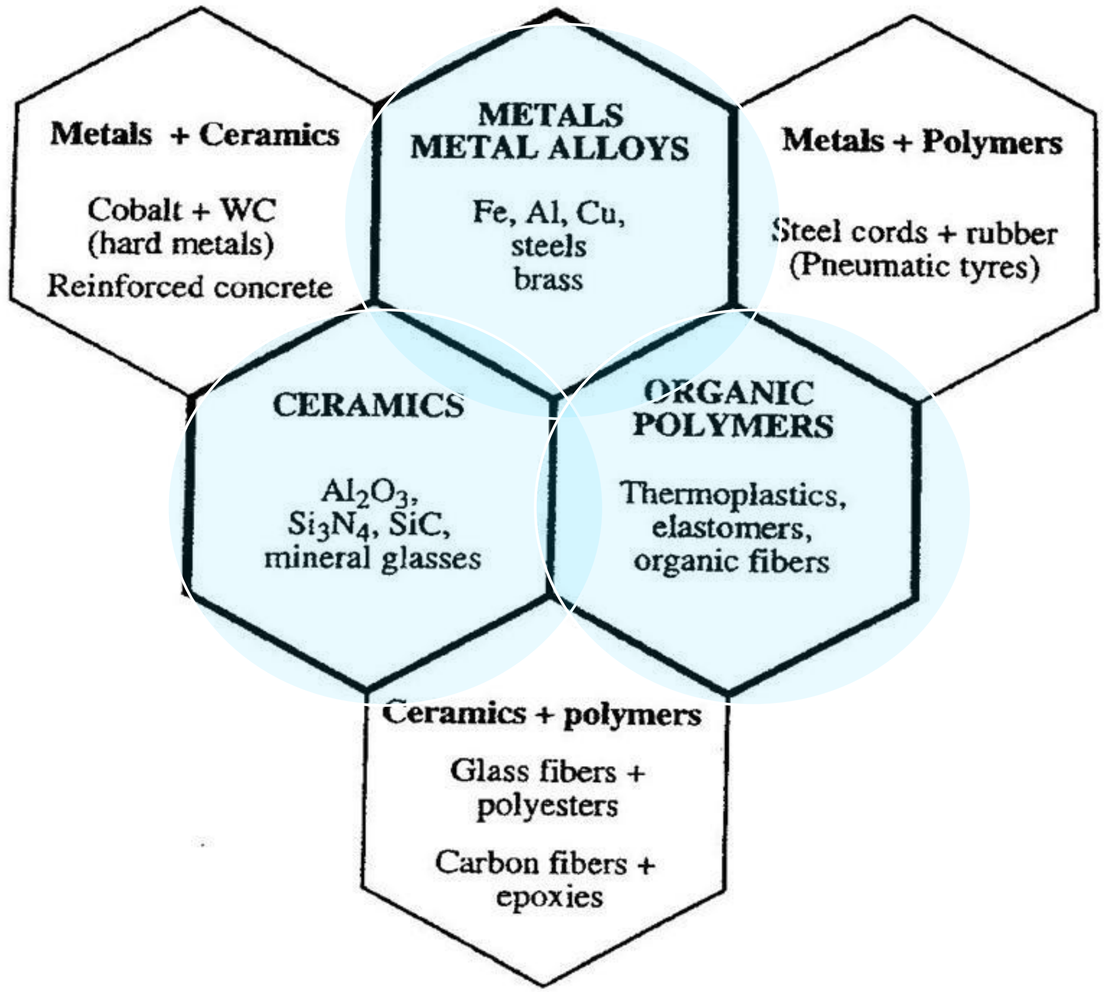
具有使用价值

Classification of materials

分类依据：Nature of chemical bonds: the nature of the atomic bond that holds them together.P4

Metallic bond	金属键
Ionic bond	离子键
Covalent bond	共价键
Van der Waals bond	范德华力
Hydrogen bond	氢 键

Classification of materials



1.2.2 Inorganic & nonmetallic materials/ Ceramics

性能特点

- have high hardness and high-temperature strength but tend to be brittle
- Engineering applications include light weight, high strength and hardness, good heat and wear resistance, reduced friction and insulative properties

1.2.3 Metallic Materials（金属材料）

结构特点

- Crystalline structure： **a crystalline structure in which the atoms are arranged in an orderly (regular) manner**
- Composed of one or more metallic elements and may also contain some nonmetallic elements
- Metallic bonding： Have large number of nonlocalized electrons.(free electron) ; these electrons are not bound to atoms

1.2.3 Metallic Materials（金属材料）

性能特点：

- Good conductors of electricity and heat;
- Opaque(遮蔽性的） to visible light; (not transparent)
- Can undergo plastic deformation (ductile)
- Strong, hard, rigid;
- Have a high melting temperature (T_m).

1.2.4 Polymer Materials

性能特点：

- The strength and ductility of polymers vary greatly
- Most polymeric materials are poor conductors of electricity
- Some polymers typically have low densities and may be extremely flexible

结构特点

- consist of organic (carbon-containing) long molecular chains or networks
- most are noncrystalline, but some consist of mixtures of crystalline and noncrystalline regions
- The "mer" in a polymer is a single hydrocarbon molecule ; Polymers are long-chain molecules composed of many mers bonded together.

1.2.5 Composite materials

- Constitute of two or more different materials to get specific properties.
- **性能特点:**

  A combination of the best characteristics of each component materials.

1.4 Relationship between Structure, properties and processing of Materials

1.4.1 Properties of Materials

Mechanical properties: How the materials responds to an applied force or stress.

- 弹性 Elasticity
- 塑性 Plasticity
- **强度 Strength: is the property to resist deformation under load.**
- 硬度 Hardness
- 韧性 Toughness
- 疲劳特性 Fatigue behaviour
- 耐磨性 Abrasion resistance

1.4.1 Properties of Materials

- **Physical properties**： The behavior of materials subjected to the action of temperature, electric or magnetic fields (磁场), or light

电性能	Electric properties
磁性能	Magnetic properties
热性能	Thermal properties
光性能	Optical properties

1.4.1 Properties of Materials

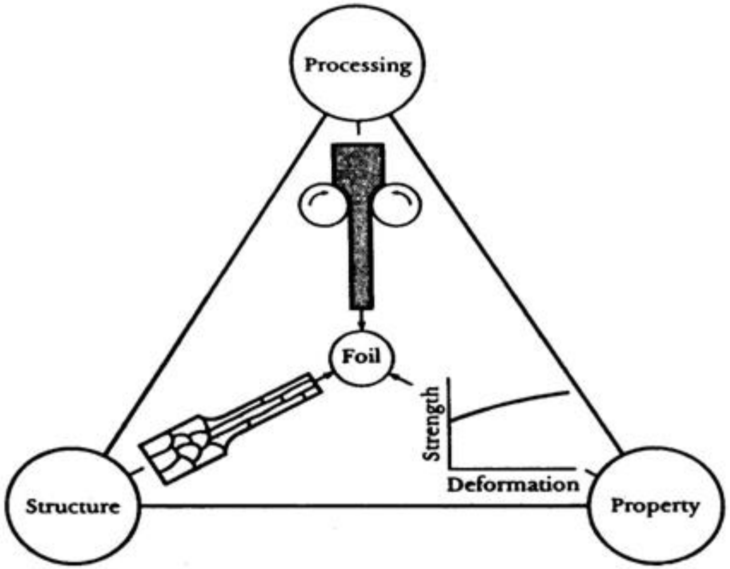
- **Chemical properties:**

  the behavior of material in a reactive environment.

  抗腐蚀能力 Corrosion resistance： atmospherically, chemically (salts, sour, alkali)

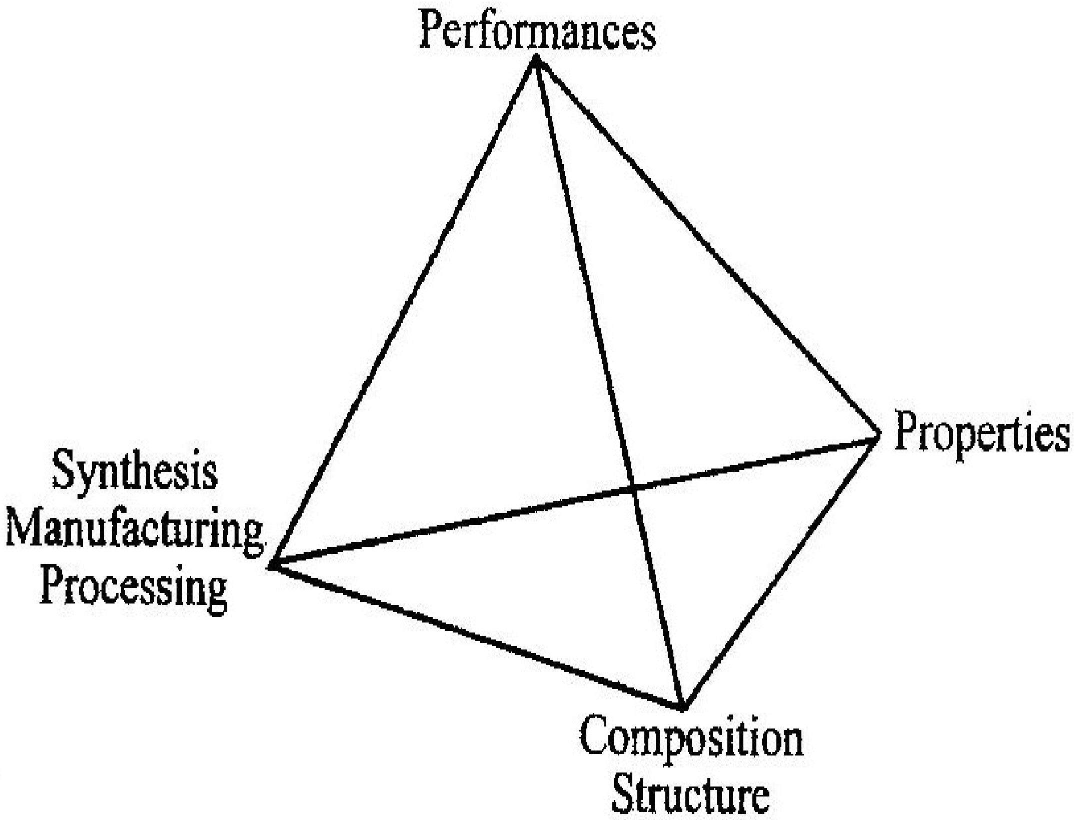
1.4.4 Structure-processing-property Relationship

The structure determine the properties of materials
The original structure and properties determine how we can process the material to produce a desired shape.
The processing of a material affects the structure.



Relationship between structure, property and processing

材料科学与工程的四大要素



Chapter 2 Inorganic Non-metallic Materials
第二章：无机非金属材料

- Definition
- Classification
- Structures
- Properties
- Processing techniques raw materials

Contents

2.1.1 Introduction

Ceramics can be defined as inorganic, nonmetallic materials. They are typically crystalline in nature and are compounds formed between metallic and nonmetallic elements.

定义:陶瓷指经过高温处理所合成的无机非金属材料 (Inorganic & nonmetallic materials),简称无机材料。

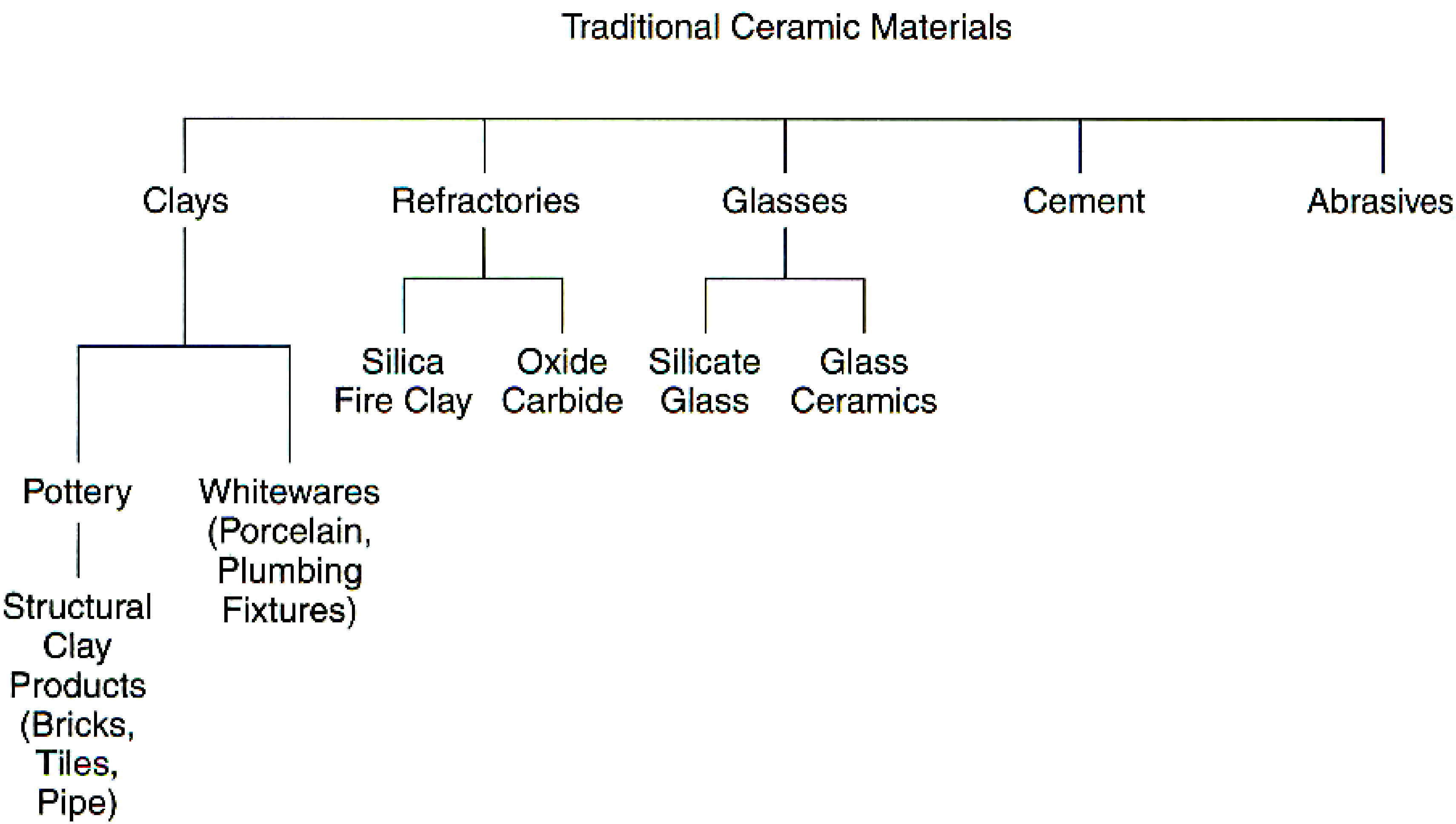
Classification 分类

Ceramics

traditional ceramics: are derived and processed from clay or nonclay minerals, a type of ceramic used in traditional applications, they are common, inexpensive, and easy to manufacture.

advanced ceramics: are synthetically developed from rather simple chemical compounds, and advances in processing which have provided greater control over their structures have resulted in vast new improvements, particularly in electrical, magnetic, and optical properties. High purity

传统陶瓷的分类

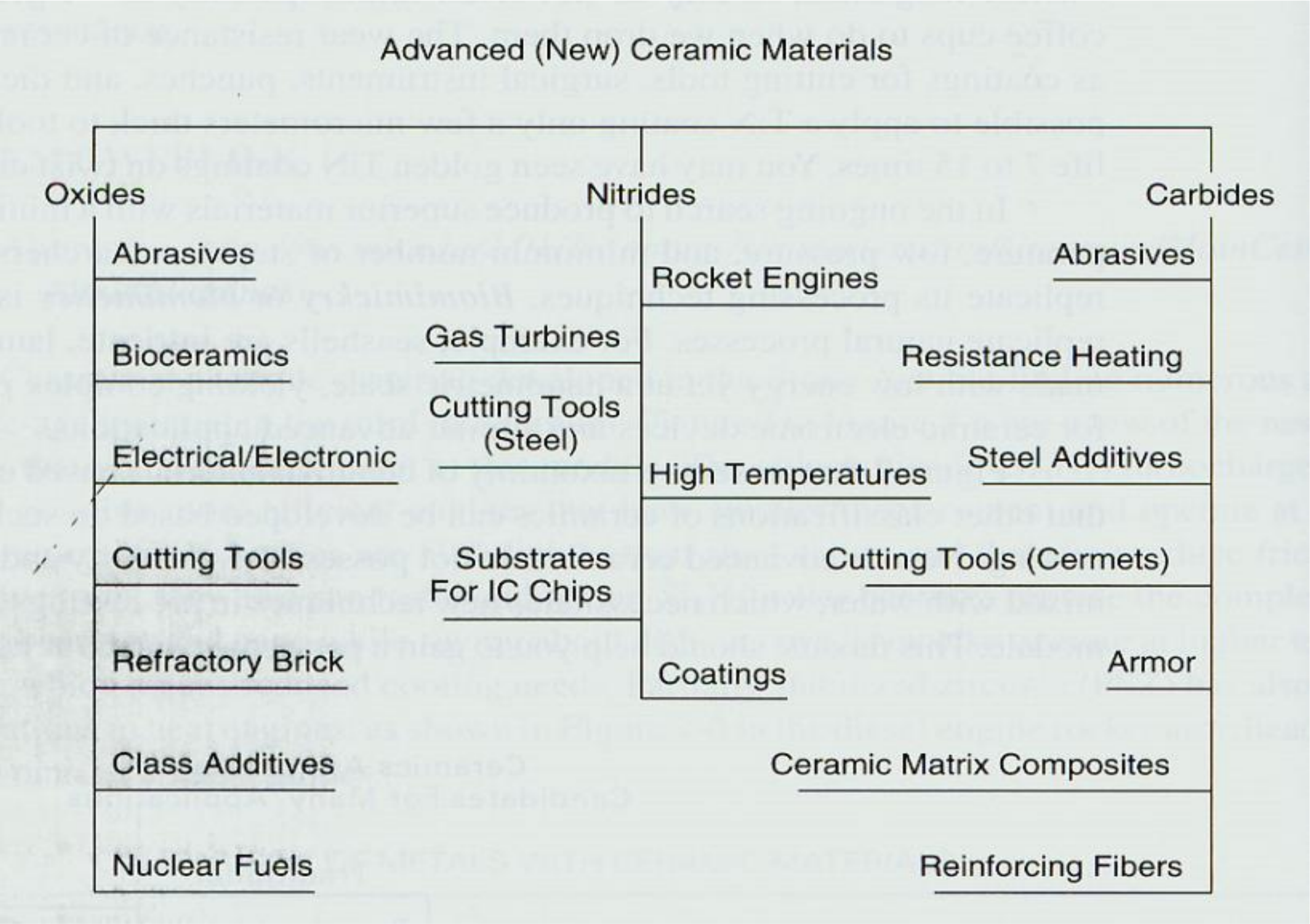

Traditional Ceramic Materials
Clays
Refractories
Glasses
Cement
Abrasives
Silica Fire Clay
Oxide Carbide
Silicate Glass
Glass Ceramics
Pottery
Whitewares (Porcelain, Plumbing Fixtures)
Structural Clay Products (Bricks, Tiles, Pipe)

先进陶瓷的分类

By composition:

- 氧化物 oxides － Al_2O_3, ZrO_2,
- 氮化物 nitride － Si_3N_4, AlN, TiN,
- 碳化物 carbides － SiC, TiC
- 硅化物 silicides － $MoSi_2$, WSi_3.
- 卤化物 halides － MgF_2, LaB_6

先进陶瓷的分类


Advanced (New) Ceramic Materials
Oxides
Abrasives
Bioceramics
Electrical/Electronic
Cutting Tools
Refractory Brick
Class Additives
Nuclear Fuels
Nitrides
Rocket Engines
Gas Turbines
Cutting Tools (Steel)
High Temperatures
Substrates For IC Chips
Coatings
Carbides
Abrasives
Resistance Heating
Steel Additives
Cutting Tools (Cermets)
Armor
Ceramic Matrix Composites
Reinforcing Fibers

2.1.2 structure of ceramics

Properties of Ceramics

(1) extreme hardness
(2) heat resistance
(3) corrosion resistance
(4) low electrical and thermal conductivity
(5) brittleness

2.1.2.1 Crystal Structures

- **Structure of ceramics: most varies from relatively simple to highly complex.**
- **Being compounds, ceramics are made of different types of atoms of varying sizes.**

原料:

- **Clay: a complex mixture of silicates.**

  Silicates: are complex ionic compounds that are exceedingly numerous.
- **The basic unit of the silicate structure is SiO_4 tetrahedron.**

2.1.2.2 Microstructures of ceramics

Porosity and Density

Mass density(质量密度), which uses the mass of a material divided by its volume refers to this theoretical density

The factors influence density:

Atomic weight is a major factor in determining the density of a material

Close-packed metals are more dense than open-structured materials.

Structure of ceramics

普通陶瓷的显微结构：

主要由晶相crystal phase、玻璃相liquid phase、气相pores及晶界grain boundary构成。

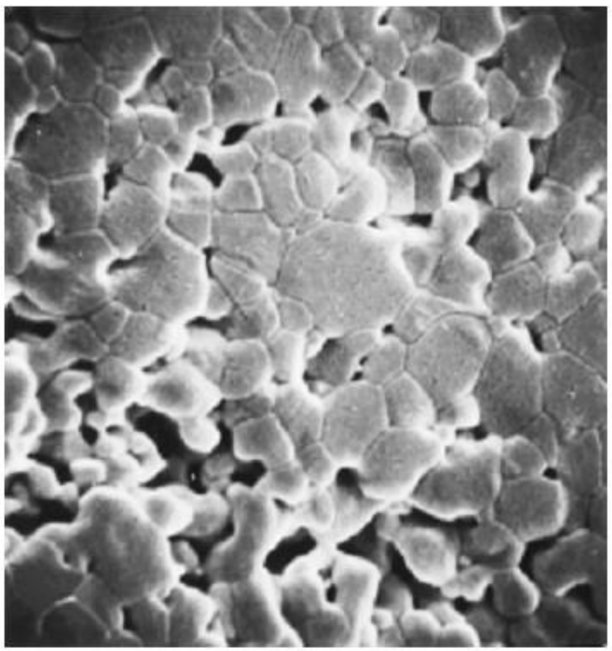
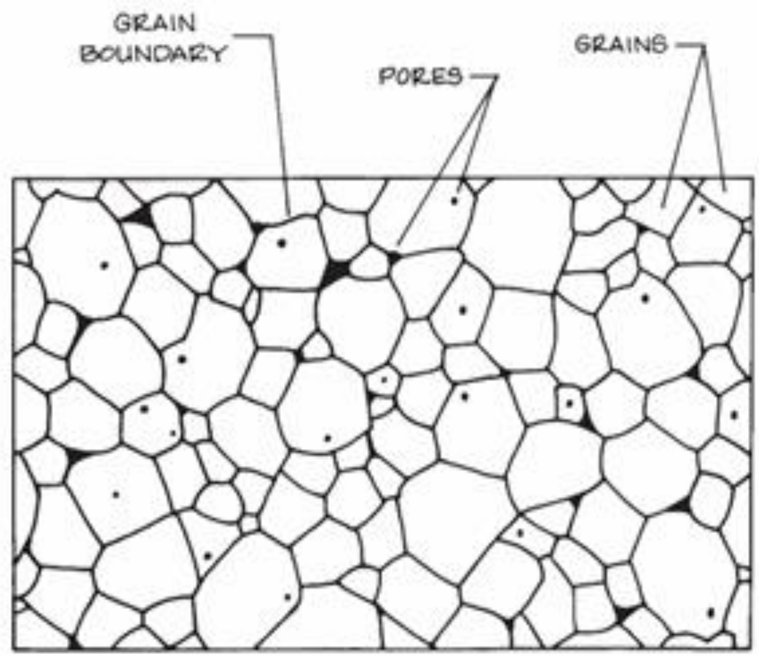


FIGURE 14.25 Scanning electron micrograph of an aluminum oxide powder compact that was sintered at 1700°C for 6 min. 5000×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)



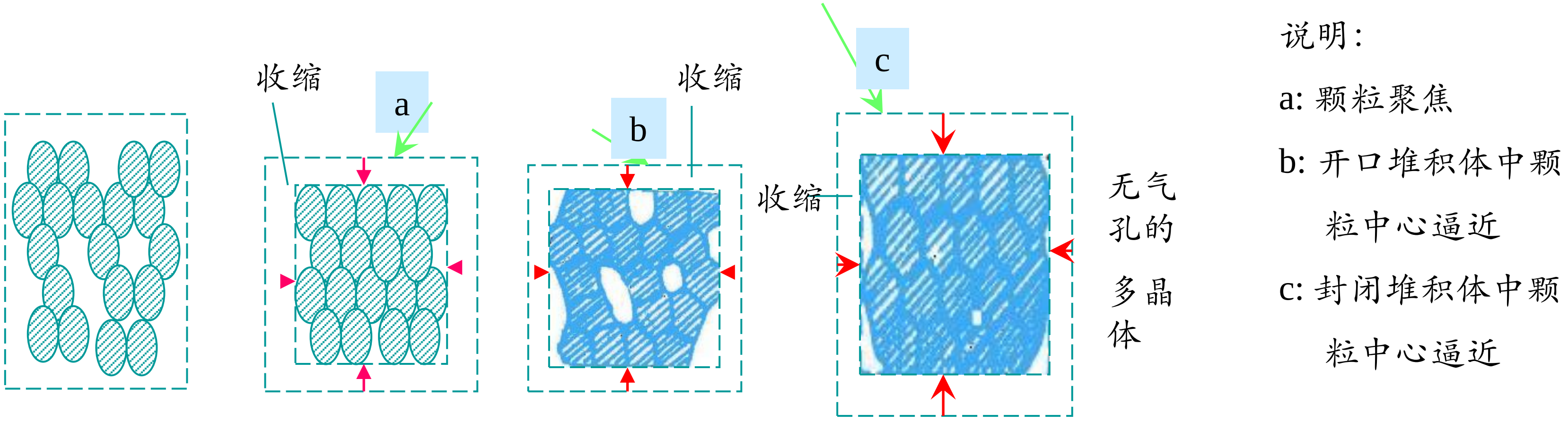
Microstructure of Ceramics

Pores

- bulk density is used in this instance to refer to a ceramic's density, and it includes the material's porosity and the fact that most ceramics contain both a crystalline and a noncrystalline phase
- Open porosity refers to the network of pores in a material that is open to the surface and into which a liquid such as water can penetrate if the part were submerged in it.
- Closed porosity refers to those pores that have become sealed within the grain structure.

Pores affect the strength of ceramics in two ways

- they produce stress concentrations. Once the stress reaches a critical level, a crack will form and propagate.
- pores reduce the cross-sectional areas over which a load can be applied and, consequently, lower the stress that these materials can support.



2.1.3.2 Traditional Cramic Processing

1) **raw materials**

Plastic raw materials: clay, Kaolin and bentonite

Function (clay):

1) **gives plasticity and binding characteristics to mass,**
2) **enhances mechanical characteristic**
3) **produce good rheological flow properties**
4) **produce a light colouring during firing**
5) **gives a good density level during firing.**

（2）Froming Techniques

mixing-forming-drying-sintering.

- **Milling or grinding: reduce the size**
- **Screening or sizing : desired particle size**
- **Mixing with water: give flow characteristics**

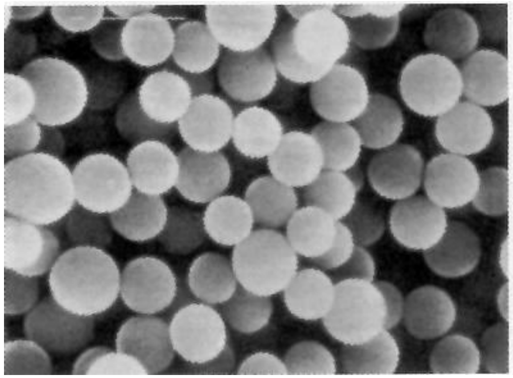
- Forming/Slip casting

- **Dry and Fire / Sinter the component**

Sintering

- Sintering is a densification process to transform a ceramic powder compact into a bulk material. Sintering usually takes place at elevated temperature, but below the melting point of the main constituent material.

- High temperature is required for sintering of ceramics



TiO_2

2.2：Glass and its products

Contents

- **<u>Definition of glass</u>**
- **<u>Composition of glass</u>**
- **<u>Classification of glass</u>**
- **<u>Processing of glass:</u> raw materials**
- Structure of glass

Definition of glass

- Glass is a non-crystalline product of fusion which has been cooled to a rigid condition.

- Glass is an inorganic product of fusion which has cooled to a rigid condition without *crystallization*

— ASTM 1949

- 玻璃是一种在凝固时**基本不结晶**的无机熔融物

— 《无机非金属材料工学》林宗寿主编

Different Types of Glasses---Composition

- Silica and Silicate Glasses 硅酸盐玻璃
- B_2O_3 and Borate Glasses 硼酸盐玻璃
- Other Non-Silica-Based Oxide Glasses 非硅酸盐的其他氧化物玻璃
- Chalcogenide and Halide Glasses 硫化物和卤化物玻璃
- Oxyhalide Glasses, Oxynitride Glasses 卤氧化物玻璃和氮卤化物玻璃
- Metallic Glasses 金属玻璃
- Glass-like Carbon 类玻璃碳

2.2.2 Preparation of Glasses

- **The traditional view is that glass is a solid obtained by supercooling a liquid and that it is X-ray amorphous (structure).**
- **"glass transition" at a temperature, T_g (P115)**
- **At T_g, thermodynamic properties, heat capacity, thermal expansivity and compressibility undergo more or less sudden changes**

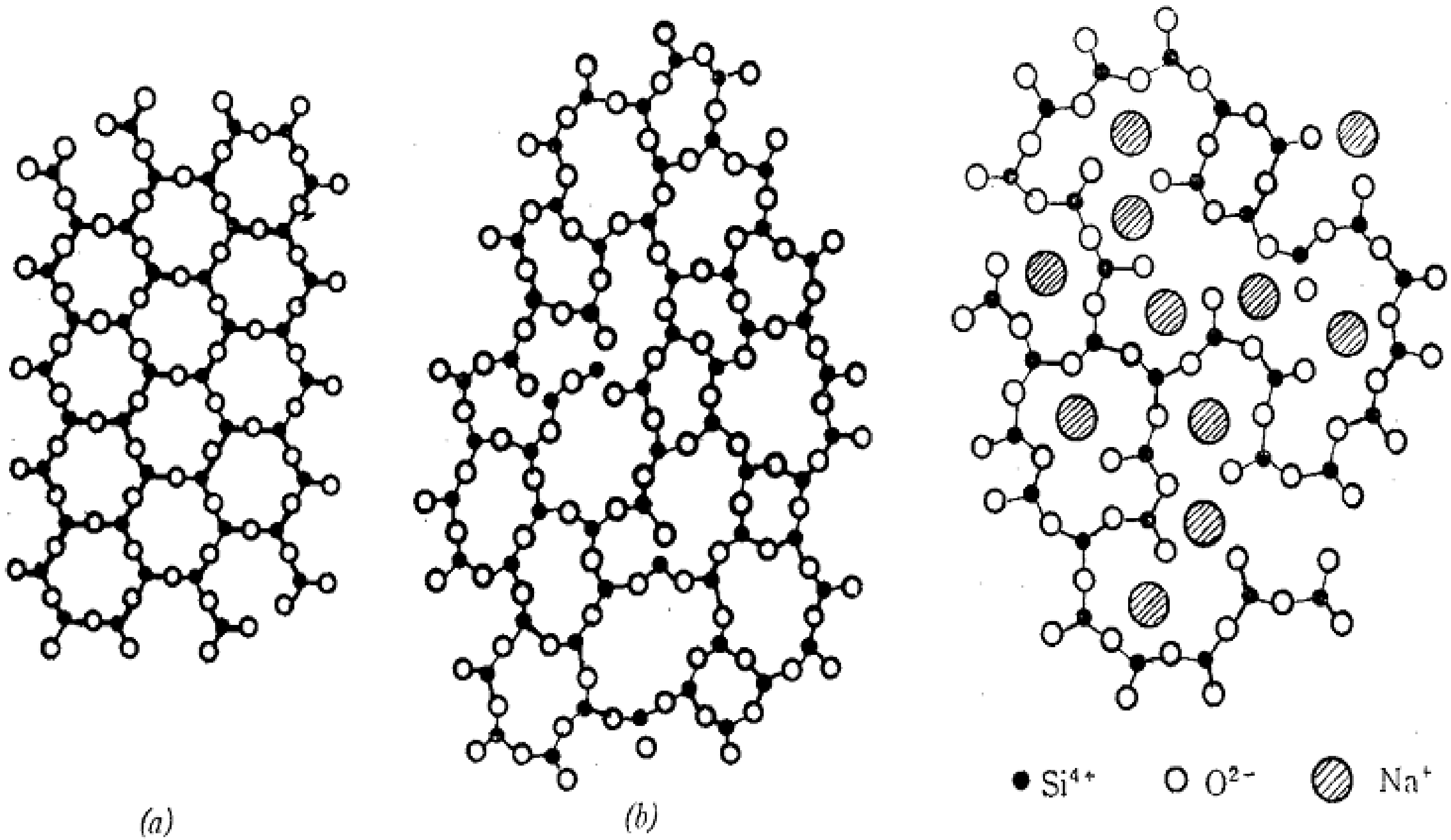
2.2.2.1 Preparation of Glasses

Supercooling techniques

- In the case of good glass forming materials like SiO_2 ,GeO_2 （germanium dioxide） or B_2O_3 （boron trioxide） ,the required rate of cooling of the melts is remarkably low.
- Still higher rates of quenching are achieved in vapour deposition techniques
- Any liquid can be quenched into a glass provided the required high degree of quenching rate is achieved.

Section 2.2.3: Structure of glass

Random Network Theory



SiO_2 crystal and SiO_2 glass

- **The network formers:** form a highly cross-linked network of chemical bonds.
- **The modifiers:** alter the network structure; they are usually present as ions, compensated by nearby non-bridging oxygen atoms, bound by one covalent bond to the glass network and holding one negative charge to compensate for the positive ion nearby.
- **The intermediates:** can act as both network formers and modifiers, according to the glass composition.

Composition of oxide glass

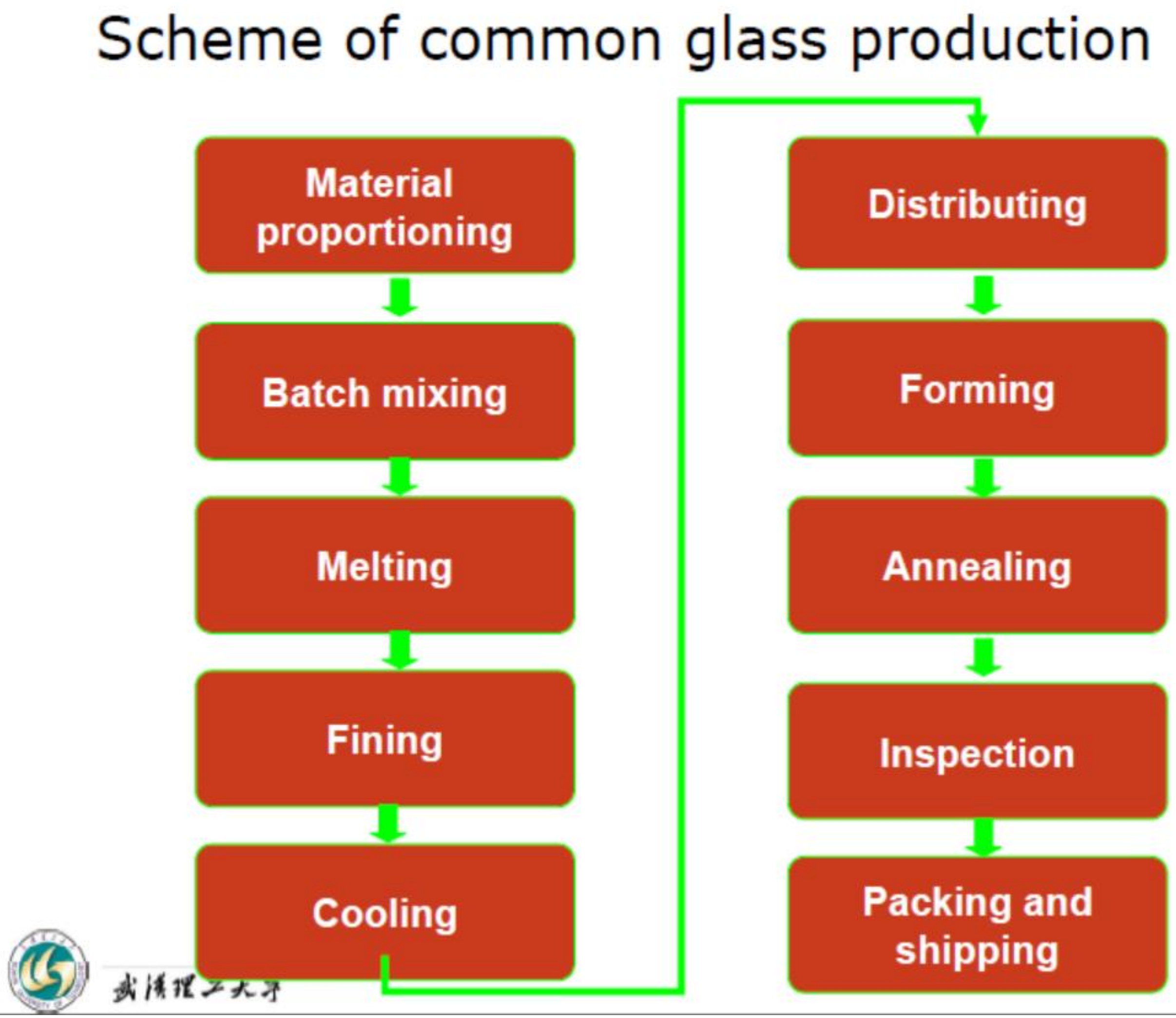
- Main oxides in glass
  - Glass formers: an oxide which forms a glass easily （形成体） B_2O_3, SiO_2, P_2O_5...
  - Glass modifiers: （修改体） Li_2O, Na_2O, K_2O, MgO, CaO ...
  - Intermediates: （中间体） TiO_2, ZnO, PbO, Al_2O_3 ...

What are the differences?

Three types of components for common oxide glasses

Network formers	Network intermediates	Network modifiers
B_2O_3	Al_2O_3	MgO
SiO_2	Sb_2O_3	Li_2O
GeO_2	ZrO_2	BaO
P_2O_5	TiO_2	CaO
V_2O_5	PbO	SrO
As_2O_3	BeO	Na_2O
	ZnO	K_2O

Section 2.2.4: Processing of glass



Annealing of glass

- Annealing, in glassblowing and lampworking, is the process of heating, and then slowly cooling glass to relieve internal stresses

Annealing of Glass

- Annealing is to heat treat glass near the softening point to relieve stresses
- Then to cool more slowly back through the transition region so as to not reintroduce thermal stresses
- Annealing takes time and temperature
  - Thicker glass anneals more slowly, has larger stresses
  - Thinner glass anneals more quickly, has smaller stresses
  - Glass with large thermal expansion requires more annealing

Section 2.2.3: The Properties of Glass

2.2.3.4 Physical Properties

(1) Density

- the density of most glasses is dependent upon its thermal history and decreases with temperature
- Glasses cooled at various rates from above the annealing point will differ in density with the more rapidly cooled glasses having a lower density
- The density of glasses covers a range from $2.2 g/cm^3$ to $8.0 g/cm^3$.
- Thermal conductivity and the specific heat can be calculated from the oxide composition.

(2) Hardness

- Glasses are brittle in a macroscopic scale, but they can flow under shear stresses in a microscopic scale
- Hardness is a property closely related to the mechanical strength of a glass and to its low temperature viscosity

Section 2.3 : Cement and Concrete

Contents

2.3.1 Portland cement

- Cement belongs to a kind of silicate material, and it is used in various civil and construction engineering.
- Portland cement is a fine powder, produced by heating a mixture of limestone and clay, or other materials of similar bulk composition and sufficient reactivity, to 1450 °C to produce clinker, grinding the clinker, and adding small amount of gypsum.

硅酸盐水泥制备——原材料

raw materials:

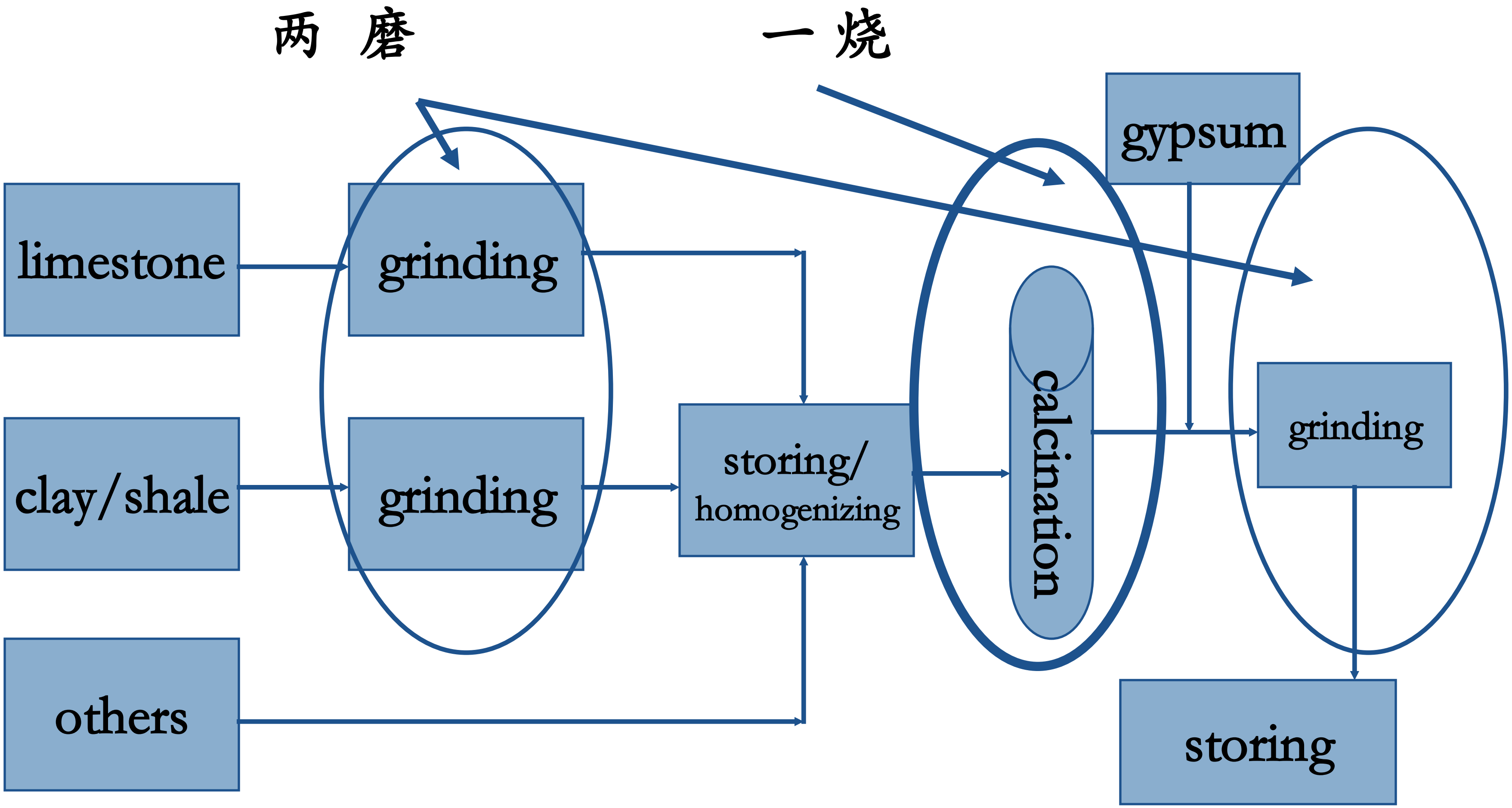
① Limestone

② clay

③ gypsum

④ admixtures such as fly ash and slag

硅酸盐水泥的生产


两 磨
一 烧
limestone
grinding
clay/shale
grinding
others
storing/ homogenizing
calcination
gypsum
grinding
storing

2.3.1.1 Chemical and mineral compositions

- **The clinker typically has a composition in the region of 67%CaO, 22%SiO_2, 5%Al_2O_3, 3%Fe_2O_3 and 3% other components;**
- **The clinker contains four major phases, called *alite*, *belite*, *aluminate* and *ferrite*.**
- **Hardening results from reactions between the major phases and water.**

Alite

- Alite is the most important constituent of Portland cement clinkers, of which it constitutes 50%—70%.
- It is *tricalcium silicate*(C_3S) modified in composition and crystal structure by ionic substitutions.

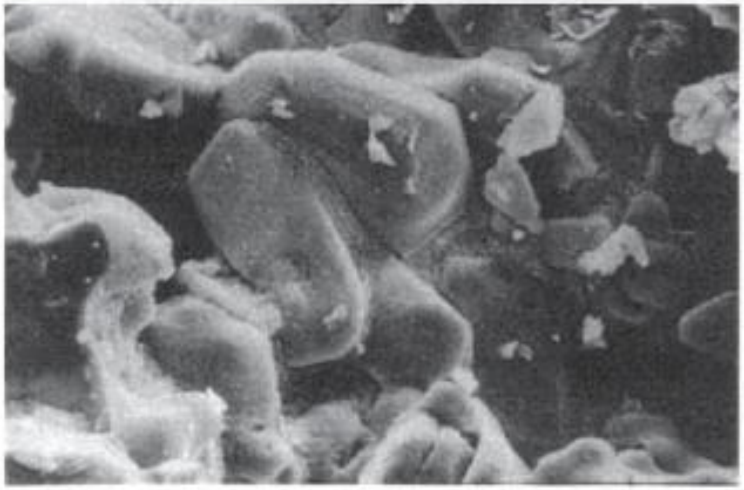


FIGURE 2.8 SEM micrograph of alite crystals separated by interstitial phase.

- It reacts relatively quickly with water, is the most important of the constituent phases for strength development.
- at ages up to 28 days, it is by far the most important.

Belite

- Belite constitutes 15%—30% of normal Portland cement clinkers, It is *dicalcium silicate* (C_2S) modified by ionic substitutions.

FIGURE 2.15 Reflected-light microscopy, belite aggregates (magnification 700×).

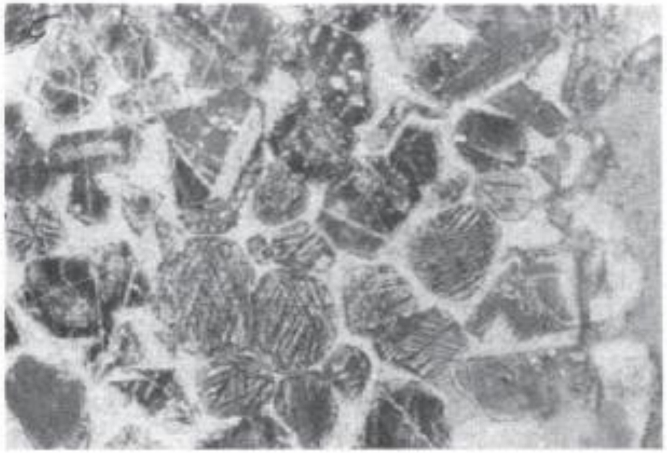


FIGURE 2.16 Reflected-light microscopy, belites with typical lamellae structure (magnification 700×).

- **Belite reacts slowly with water, thus contributing little to the strength during the first 28days, but substantially to the further increase in strength that occurs at later ages.**
- **By one year, the strengths obtainable from pure alite and pure belite are about the same under comparable conditions.**

Aluminate

- Aluminate constitutes 5%—10% of most normal Portland cement clinkers.
- It is *tricalcium aluminate* (C_3A), substantially modified in composition and sometimes in structure by ionic substitutions.
- It reacts rapidly with water, and can cause undesirably rapid setting unless a set-controlling agent, usually gypsum, is added.

Ferrite

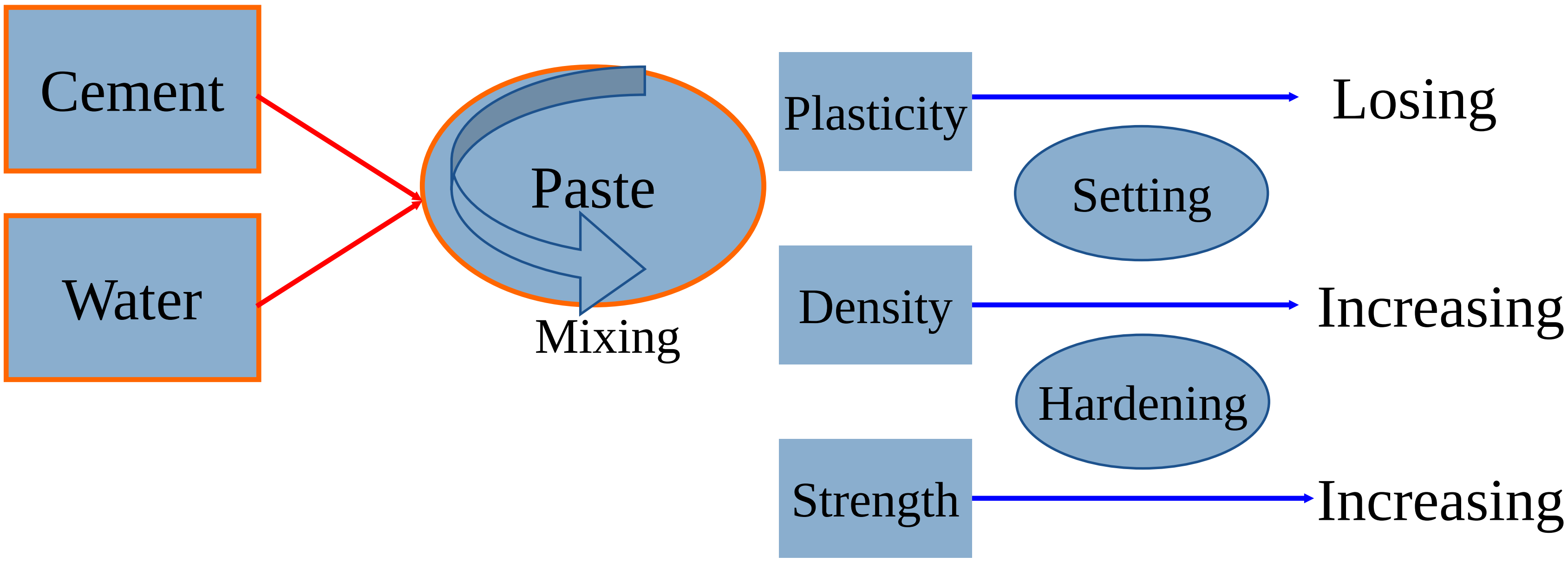
- Ferrite makes up 5%-15% of Portland cement clinkers.
- It is *tetracalcium aluminoferrite* (C_4AF), substantially modified in composition by variation in Al/Fe ratio and ionic substitutions.
- The rate at which it reacts with water appears to be somewhat variable, perhaps due to differences in composition or other characteristics, but in general is high initially and low or very low at later ages.

- There are four minerals containing in cement clinker:

1) C_3A—$3CaO+Al_2O_3$
2) C_2S—$2CaO+SiO_2$
3) C_3S—$3CaO+SiO_2$
4) C_4AF—$4CaO+Al_2O_3+Fe_2O_3$

2.3.2 Hydration of Cement

- The reactions by virtue of which Portland cement becomes a bonding agent take place in a water-cement paste.
- In other words, in the presence of water, the silicates and aluminates form products of *hydration* which in time produce a firm and hard mass--the hydrated cement paste.



塑性:Plasticity, permanent deformation capacity

凝结:Setting, bond stronger, particles gathering

硬化: Hardening, to be hard and stiffer

Setting: refers to a change from a fluid to a rigid stage ,used to describe the stiffening of the cement paste(P60)

Section 2.3.3: Concrete and Its Preparation

Definition of concrete

- Concrete is basically a mixture of two components: aggregates and paste.
- The aggregate component is normally comprised of sand and gravel or crushed stone.
- **The paste component is normally comprised of cementing materials(Portland cement with or without supplementary cementing materials), water, and air.**
- The cement and water form a paste that hardens and bonds the aggregates together.

Raw materials of concrete

- **mixture of aggregate and paste**
- paste 25 to 40%
  - portland cement 7% to 15% by Vol.
  - water 14% to 21% by Vol.
- Aggregates 60% to 75%
  - coarse aggregates
  - Fine aggregates
- Admixtures

Raw materials of concrete

In general hardened concrete should be durable, strong, watertight and resistant to abrasion. All of these properties are influenced by the quality of the Portland cement paste.

The final quality of the concrete depends upon the effectiveness of the hardened paste in binding the aggregate particles together and in filling the voids between the particles. The quality of cement, water-cement ratio, the grading of aggregates, setting conditions, etc. affect the final quality of concrete.

Section 2.3.4: Properties of concrete

Properties of concrete

The durability of concrete: is the ability to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties with minimal loss of mass in an aggressive environment.

Strength

Compressive strength-definition: f_{cu}

- Compressive strength may be defined as the measured maximum resistance of a concrete or mortar specimen to axial loading.
- Standard specimen： 150×150 × 150(mm)
- Standard cure condition：
  - Temperature: 20℃±3 ℃
  - relative index of humidity no less than 90%
  - cured for 28d
- Standard test method：
  - surfaces of specimen is not lubricated with grease, loading speed increases in 0.15~0.25 MPa/s

Strength

Flexural Strength

- Flexural strength or modulus of rupture of concrete is used to design pavements and other slabs on ground.
- pavement and slabs on grade applications.
- Flexural Strength is generally 0.6 – 0.8 $\sqrt{f_{cu}}$.

Strength

Tensile Strength

- ensile strength can be estimated by
  - ≈0.4-0.7 √fcu .
  - 8~14% of compressive strength

Density

- Conventional concrete, normally used in pavements, buildings, and other structures, has a density (unit weight) in the range of 2200 to 2400 kg/m^3.
- The combination of conventional concrete and reinforcing bars is commonly assumed to have a density of 2400 kg/m^3.
- The range from low-density insulating concretes with a density of 240 kg/m^3 to high-density concrete with a density of up to 6000 kg/m^3 used for counterweights or radiation shielding.

Chapter 3 Metallic Materials

Types:

- **Ferrous metals**
  - Cast iron
  - Steel
    - Carbon steel
    - Alloy steel
- **Nonferrous ~**
  - Heavy ~
  - Noble metals
  - Light ~
  - Rare metals
- **Special metal** → Amorphous metals, Shape memory alloys,…

3.1.1 Iron and Steel

- Cast iron alloys: Gray, Ductile (nodular), White, Malleable
- Steels:

(1) High alloy: stainless, tool steel

(2) Low alloy:

i. High-carbon: plain, tool

ii. Medium-carbon: plain, heat treatable

iii. Low-carbon: plain, high strength

钢与铁的主要区别：碳含量不同

钢：　　含碳量<2.11%

铁：　　含碳量>2.11%

工业用钢：含碳量<1.0%

钢

- 碳素钢
  - 高碳钢
  - 中碳钢
  - 低碳钢

含碳量

强度、硬度、脆性

塑性、韧性、可焊性

特点：具有一定的塑性和韧性；但强度低，耐蚀性和抗氧化性较差，低温抗冲击能力差。

- 合金钢 → 铬、锰、镍、硅、硼等
  - 合金结构钢
  - 合金工具钢
  - 特殊性能钢

特点：与碳素钢相比，合金钢的强度大大提高，同时耐蚀性、抗氧化性和耐磨性均显著提高；但价格较高。

（4）Stainless steels – highly resistant to corrosion in a variety of environments.

main alloying element: ≥11 wt% Cr, Ni, Mo

Three classes: on the basis of the microstructure:

(1) Martensitic: compositions similar to ferritic, magnetic, high hardenability

(2) Ferritic: composes of the ferrite (bcc) phase, 12 to 18% Cr, <0.03% C; not heat treatable, magnetic

(3) Austenitic: 16-26% Cr, 8-24% Ni (fcc) not heat treatable, the most corrosion resistant, more expensive than ferritic

3.1.2 Nonferrous metals

do not contain iron as the major constitute

Non-Ferrous metals:

copper – Cu aluminum – Al

magnesium – Mg titanium – Ti

the refractory metals, the superalloys,

the noble metals, and miscellaneous alloys.

3.1.2.2 Aluminum and its alloys

the most important nonferrous metals

Al ~ Fe density: 1/3

Young's modulus: 1/3

Properties:

(1) good corrosion and oxidation resistance

(2) good electrical and thermal conductivities

(3) low density

(4) high reflectivity

(5) high ductility, high strength

3.1.2.4 Titanium and its alloys

Ti: density (ρ=4.51) between that of Al & steel

Properties:

- light weight
- bluish or silvery color
- blue grinding sparks
- chemical reactivity at elevated temperatures
- high corrosion resistance of titanium alloys: virtually immune to air, marine, and a variety of industrial environments

3.2 Structure

3.2.1 Solid solutions

Two types:

(1) substitutional取代的 solid solutions:

- solute atoms substitute for lattice atoms
- the atoms have nearly the same size & valence

(2) interstitial填隙的 solid solutions:

- small atoms fit in the interstices between lattice atoms
- Only small atoms can dissolve interstitially: H, C, N, B

3.3 Properties

3.3.1 Plastic deformation in metals

Two important properties for manufacturing:
elastic and plastic deformation

Stress: is the material's resistance to the applied load or force.

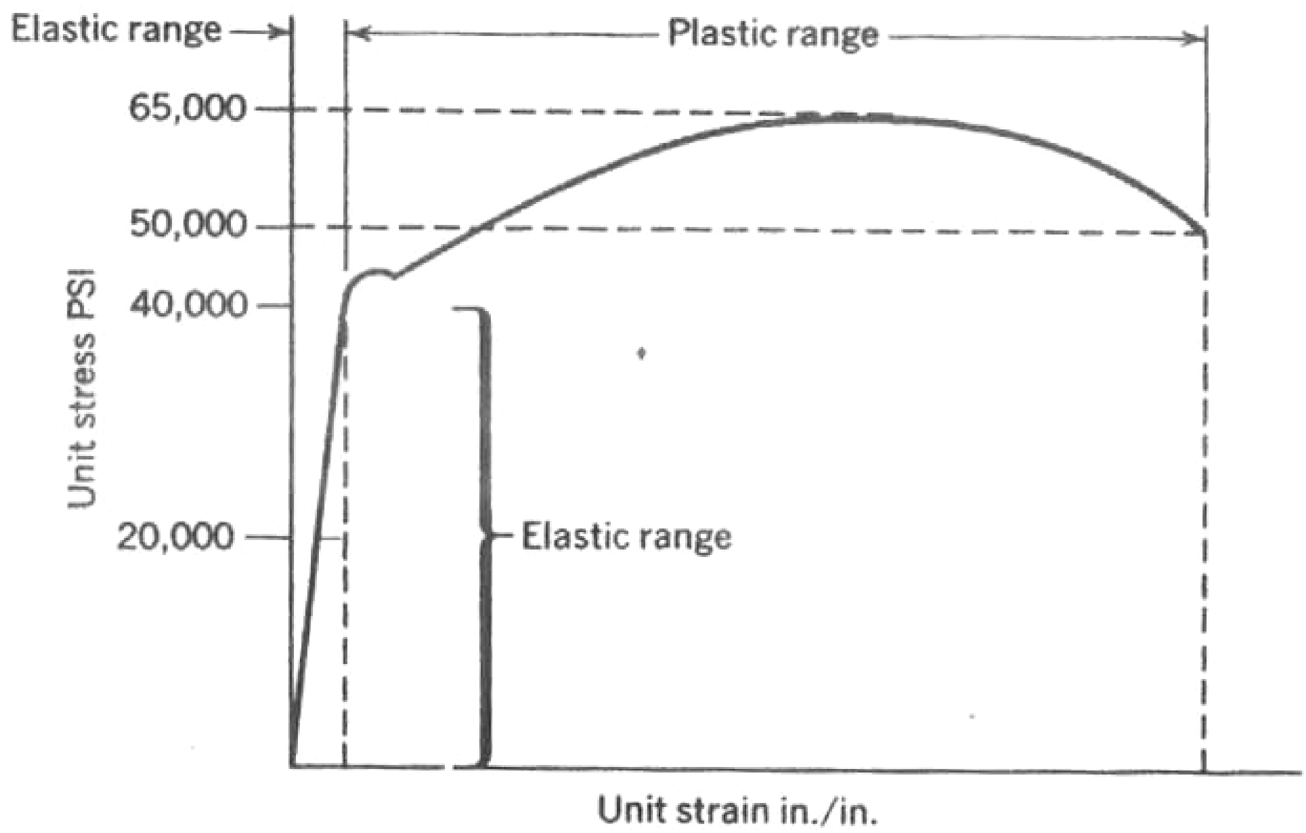
strain: when metals are placed under tensile, torsion, or compression stress, a slight elongation or compression takes place in the crystal lattice. This movement is called ~.

3.3.2 Mechanical and physical properties

Mechanical: the relationship between stress and strain, elasticity, strength, ductility, malleability, hardness, brittleness, creep, and toughness.

Physical: the melting point, coefficient of thermal expansion, electrical and thermal conductivity, specific gravity, magnetic susceptibility, and reflectivity.

Stress-strain diagram for a ductile steel



Plasticity: allows metals to be permanently deformed beyond the elastic limit without failure by rupture or splitting. P95

- When metals reach a certain limit of strain, they are no longer plastic but become brittle and suddenly fail. This is called the ultimate strength.

Strength: the ability to resist deforming or changing shape under external forces.

- Types of strength : tensile, compressive, torsional, shear

Chapter 4 Polymer Materials

第四章：高分子材料

Contents

- Classification and Molecular Weight
- Structural Features
- Basic Properties
- Preparation and processing technology
- Applications of Polymers

4.1.1 Basic Terms and Definitions

- Polymer：A molecule that is made up of many (poly) parts (mers).
- A polymer is a large molecule constructed from many smaller structural units called monomers, covalently bonded together in any conceivable pattern.
- 由原子或原子团（结构单元）以共价键形式连结而成的大分子量同系混合物。
- “mer” represents the simplest repeating unit from which the polymer is composed.

1. Addition polymerization: This occurs when small molecules join together under the stimulus of a catalyst, heat or radiation to form a linear polymer usually without the elimination of a small molecule.

2. Amorphous: A non-crystalline polymer or non-crystalline areas in a polymer.

3. Block-co-polymer: The repeating unit consists of segments or blocks of similar monomers tied together along the macro-molecular chain.

Side chain: It is a group of molecules attached to a backbone chain of a long molecule.

Glass transition temperature (T_g): This is the temperature at which an amorphous polymer starts exhibiting the characteristic properties of the glassy state, (because of the onset of segmental motion) stiffness, brittleness and rigidity.

4.1.2 Classification and products

1. Sources

Polymers

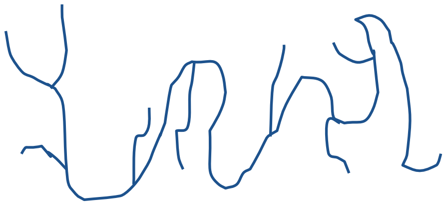
Natural： proteins
polysaccharides
Nucleic Acids
Natural rubber

Synthetic： Polyethene (PE)
Polypropene (PP)
Polyvinyl chloride (PVC)
Bakelite
Synthetic rubber

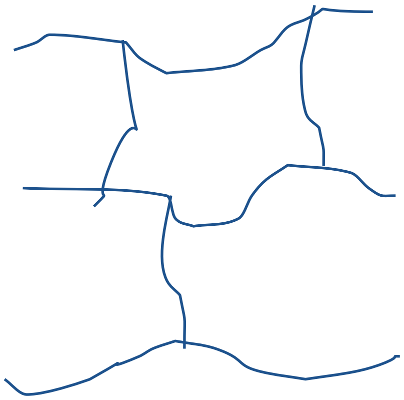
Nature polymers usually have more complex structures than synthetic polymers.

2. Structures

Linear Polymers



Branched Chain Polymers



Cross-linked Polymers or Network Polymers

3. Intermolecular forces

Polymers
- Elastomers
- Fibers
- Thermoplastics
- Thermosetting Polymers

Elastomers

These are the polymers in which the polymer chains are held up by weakest attractive forces. They are amorphous polymers having high degree of elasticity, for example: rubber, whether synthetic or natural.

Fibers

These are the polymers which have quite strong interparticle forces such as hydrogen-bonds. They have high modulus and high tensile strength. These are thread-like polymers and can be woven into fabrics. Silk, terylene, nylon, etc., are some common examples of such types of polymers.

Thermoplastics Polymers

These are the polymers in which the interparticle forces of attraction are in between those of elastomers and fibers. The polymers can be easily moulded into desired shapes by heating and subsequent cooling to room temperature.

Thermosetting Polymers

These are the polymers which become hard and infusible on heating. They are normally made from semi-fluid substances with low molecular masses, by heating in mould. Heating results in excessive cross-linking between the chains forming three dimensional network of bonds as a consequence of which a non-fusible and insoluble hard material is produced.

4.1.3 Molecular Weight

• When polymers are fabricated, there will always be a distribution of chain lengths.

– The properties of polymers depend heavily on the molecule length.

• There are these ways to calculate the average molecular weight:

1. Number Average Molecular Weight

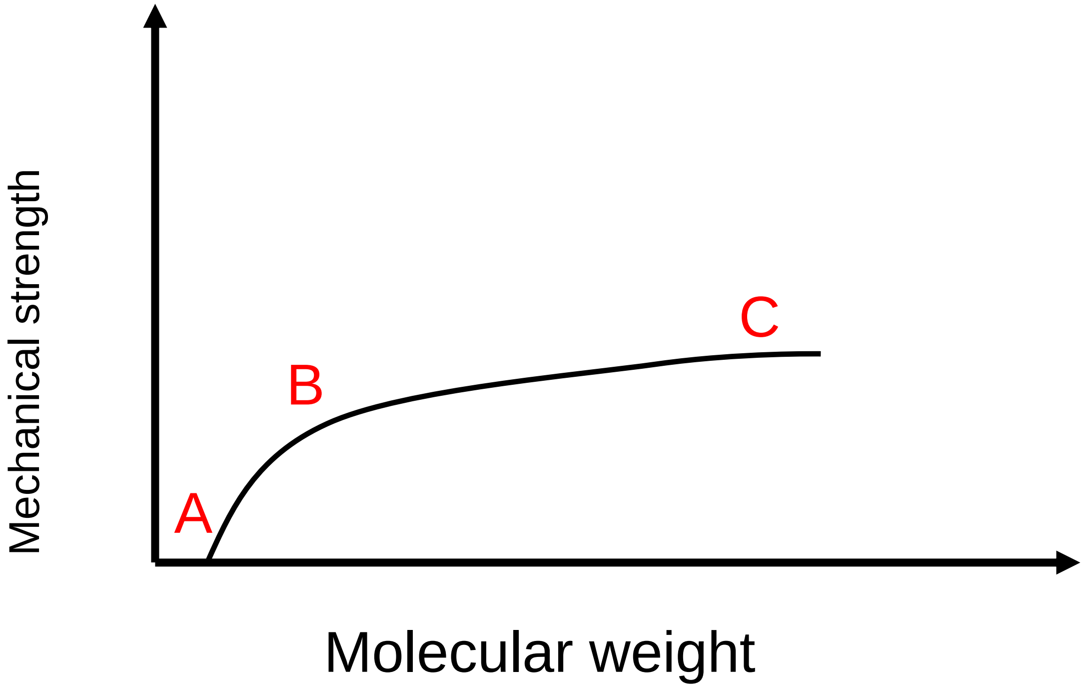
• An indication of the weight that is most common

2. Weight Average Molecular Weight

• An indication of the average weight of each chain in the sample.

3. Z-Average Molecular Weight

Most important mechanical properties depend on and vary considerably with molecular weight as seen in Figure



Number-average Molecular Weight

$$\bar{M}_n = \frac{w}{\sum N_x} = \frac{\sum N_x M_x}{\sum N_x}$$

Weight-average Molecular Weight

$$\bar{M}_w = \frac{\sum c_x M_x}{\sum c_x} = \frac{\sum c_x M_x}{c} = \frac{\sum N_x M_x^2}{\sum N_x M_x}$$

Viscosity-average Molecular Weight

$$\bar{M}_v = \left[\sum w_x M_x^a\right]^{1/a} = \left[\frac{\sum N_x M_x^{a+1}}{\sum N_x M_x}\right]^{1/a}$$

Where: N_x = *number of molecules of species x of molar mass* M_x

数均分子量：按聚合物分子数目统计平均的分子量
质均分子量：按聚合物重量统计平均的分子量

d: polydispersity number（多分散系数)

表征聚合物的多分散程度, 当以分子量来描述时，也叫分子量分布（molecular weight distribution, *MWD*)。

$$d = \bar{M}_w / \bar{M}_n$$

$\bar{M}_n$ → Number Average Molecular Weight

$\bar{M}_w$ → Weight Average Molecular Weight

对于组成单一的聚合物，若其多分散系数$d=1$，即聚合物中各个聚合物分子的分子量（或聚合度）是相同的，这样的聚合物叫单分散性聚合物。

4.2.2 Structure property relations

- The glass transition temperature (T_g) of a non-crystalline material is the critical temperature 临界温度at which the material changes its behavior from being 'glassy' to being 'rubbery'.
  - Glassy: hard and brittle.
  - Rubbery: elastic and flexible.弹性的柔韧的
- The concept of T_g only applies to non-crystalline solids, which are mostly either glasses or rubbers. 或是玻璃或是橡胶

4.2.2.1 control of T_m and T_g

- Chain flexibility is the controlling factor on T_g
- A highly flexible chain has a low T_g, which increases as the rigidity of the chain becomes greater.
- A high T_g is obtained when large pendant groups attached to the chain restricting its internal rotation. Bulky pendant groups tend to impede crystallization
- Strong intermolecular forces tend to raise T_g and also increase crystallinity.

4.3 Basic Properties

4.3.1 Mechanical Properties

The prime consideration in determining the general utility of a polymer is its mechanical behavior, that is, its deformation and flow characteristics under stress. The mechanical behavior of a polymer can be characterized by its stress–strain properties.

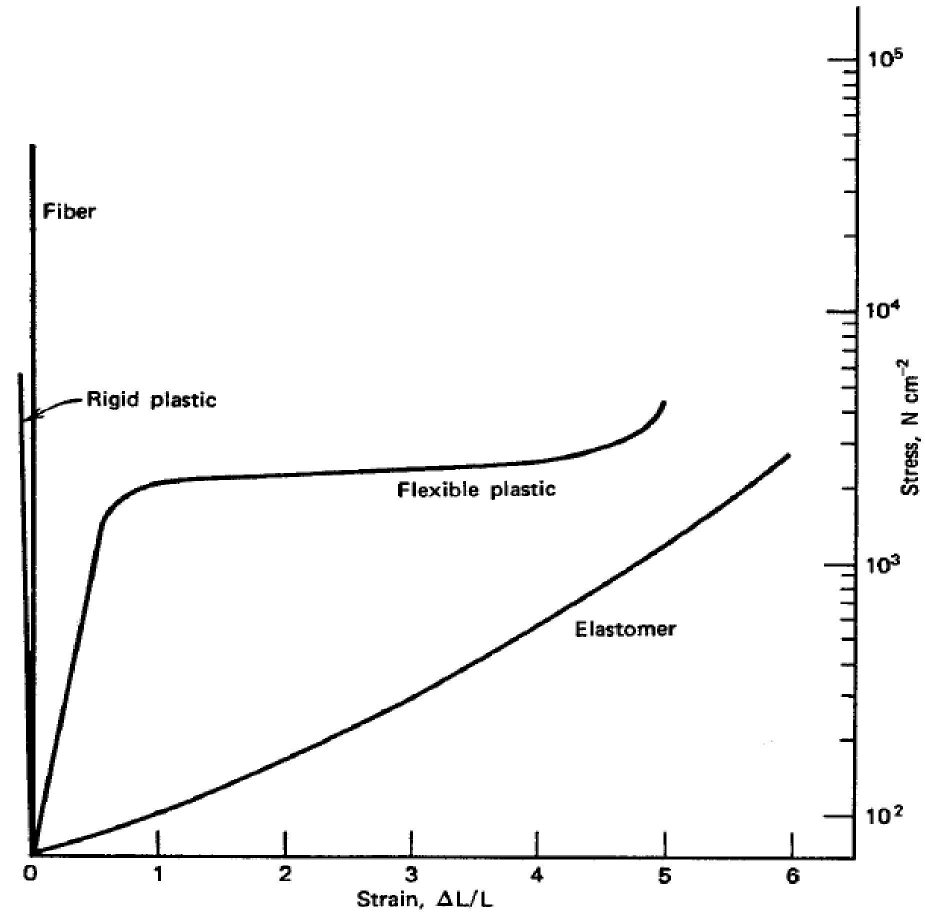
Polymers' mechanical behavior depending on：

degree of crystallinity, degree of crosslinking, T_g， T_m.

High strength and low extensibility are obtained in polymers by having various combinations of high degrees of crystallinity or crosslinking or rigid chains (characterized by high T_g).

High extensibility and low strength in polymers are synonymous with low degrees of crystallinity and crosslinking and low T_g values.

The temperature limits of utility of a polymer are governed by its T_g and/or T_m. Strength is lost at or near T_g for an amorphous polymer and at or near T_m for a crystalline polymer.



Stress-strain plots for a typical elastomer, flexible plastic, rigid plastic, and fiber Modulus. The resistance to deformation as measured by the initial stress divided by ΔL / L.

4.4 Preparation and processing technology

The study of polymer science begins with understanding the methods in which these materials are synthesized.

Polymer synthesis is a complex procedure and can take place in a variety of ways.

4.4.1 Addition Polymerization

Addition polymerization describes the method where monomers are added one by one to an active site on the growing chain.

The most common type of addition polymerization is free radical polymerization.

There are three significant reactions that take place in addition polymerization: initiation (birth), propagation (growth), and termination (death).

4.4.2 Polymerization methods in industry

Processes for manufacturing macromolecular compounds

- Processes in bulk:
  - liquid state
  - solid state
  - gas state
- Processes in solution:
  - aqueous solution
  - organic solution
- Processes in dispersion:
  - suspension
  - emulsion

Chapter 5 Composites
第五章：复合材料

Contents

Section 5.1: Introduction

5.1.2 Definition of Composite Material

A composite is a combined material created by the synthetic assembly of two or more components, (a selected filler or reinforcing agent and compatible matrix binder i.e., a resin) ,to obtain specific characteristics and properties.

复合材料是将两种或两种以上的组分通过人工的方式结合在一起，以获得更好的或者是独有的性能。

We can conclude that composite is a homogeneous material created by the synthetic assembly of two or more materials to obtain specific characteristics and properties. The composite generally has characteristics better than or different from those of either component.

5.1.3 Classification of Composite Material

- composites
  - matrix
    - polymer matrix composites
    - metal matrix composites
    - ceramic matrix composites
  - reinforcement
    - fibrous
    - particulate
  - function
    - conductive composite materials
    - damping composites
    - thermal conductivity of composites

Section 5.2

Constituents of Composite Materials

The majority of composite materials use two constituents: matrix (基体) and reinforcement.（增强材料） (P144)

- The matrix phase is the continuous phase, while the distributed phase, commonly called the reinforcement phase, can be in the form of particles, whiskers or short fibers, continuous fibers or sheet．(P145)

5.2.1 Matrix

Definition

The matrix is the binder material that supports, separates, and protects the fibers.It provides a path by which load are both transferred to the fibers and redistributed among the fibers in the event of fiber breakage.

Characteristics

- lower density, stiffness, and strength than the fibers
- Matrices can be brittle, ductile, elastic, or plastic
- The matrix material must be capable of being forced around the reinforcement during some stage in the manufacture of the composite.

The most commonly used matrices are carbon, ceramic, glass, metal, and polymeric

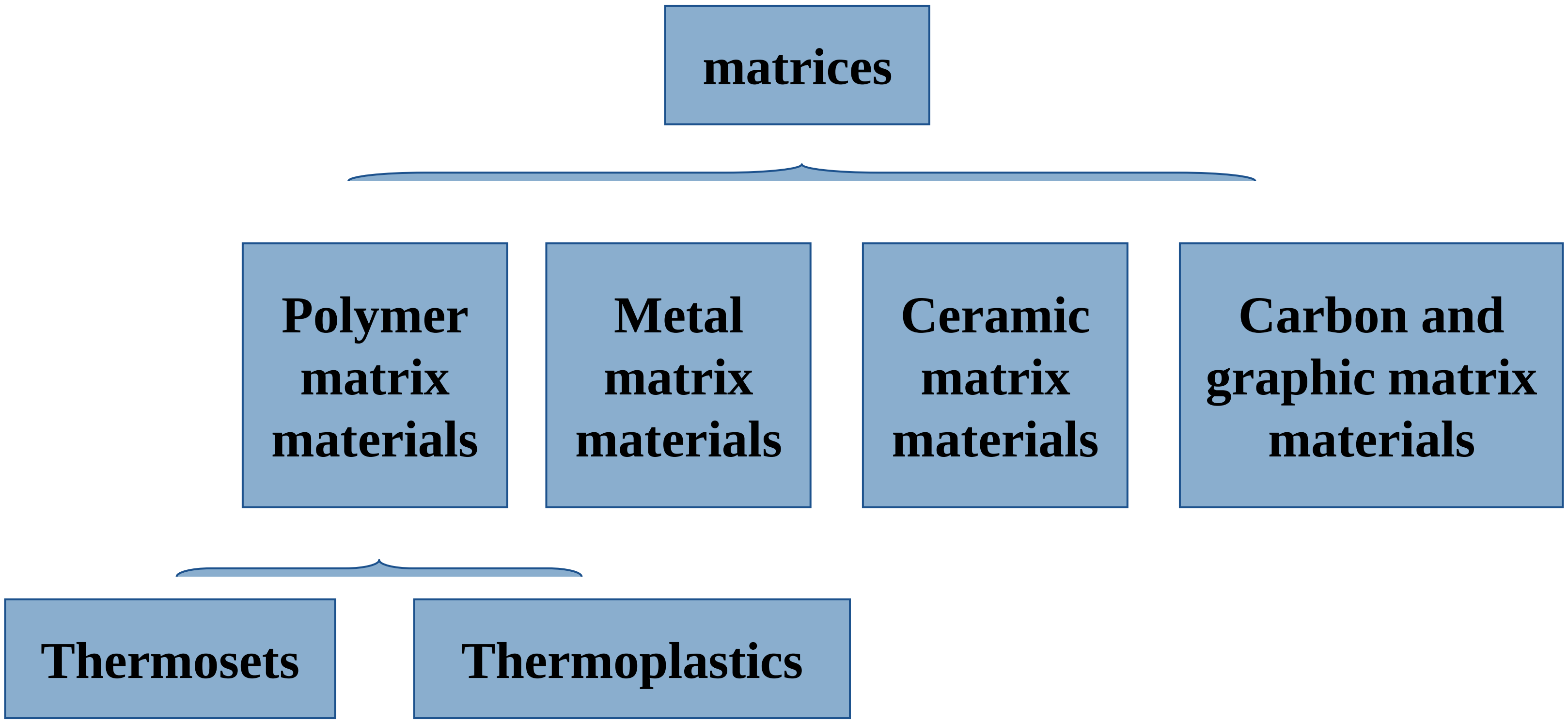


Figure 5.1 Classification of Matrices

5.2.2 Reinforcement

Reinforcements for the composites can be fibers, fabric, particles or whiskers.

Glass fibers, Good impact resistant fiber , Weighs more than carbon or aramid. Excellent characteristics, equal to or better than steel in certain forms. The lower modulus requires special design treatment where stiffness is critical. Good electrical and thermal insulation properties. Low cost

Carbon fiber is created using polyacrylonitrile (PAN), pitch or rayon fiber precursors. More expensive than glass fibers ,Good strength values of 3-10GPa, Excellent combination of strength, low weight and high modulus.

5.2.4 Conformation and Structure of Reinforcement

Fiber-reinforced composite materials can be divided into two main categories : short fiber-reinforced materials and continuous fiber-reinforced materials.

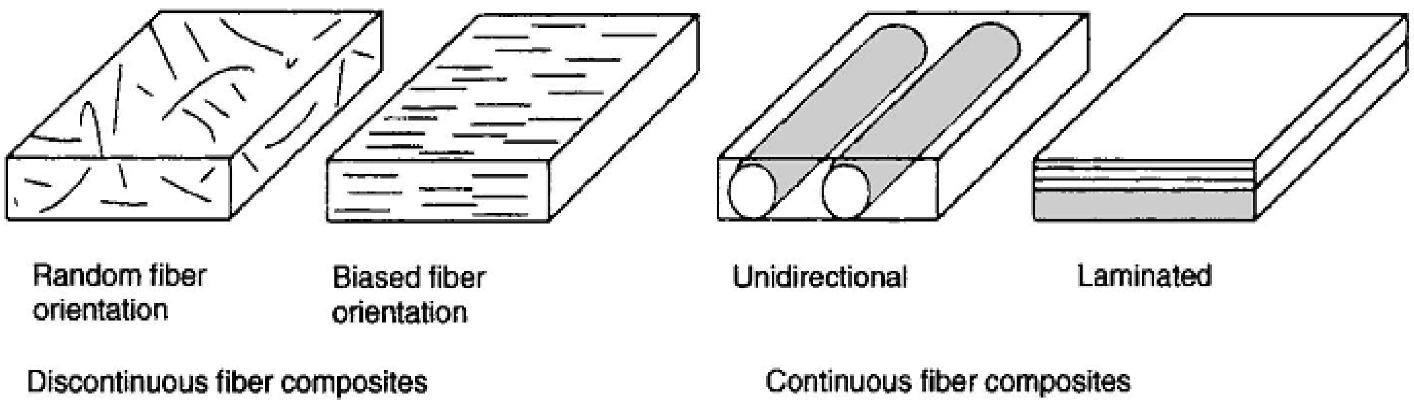


Figure 5.9 Schematic Representations of Fibrous Composites

particulate composite

A particulate composite is characterized as being composed of particles suspended in a matrix.Particles can have virtually any shape,size or configuration.There are two subclasses of particulates: flake and filled/skeletal.

The response of a particulate composite can be either anisotropic or orthotropic.

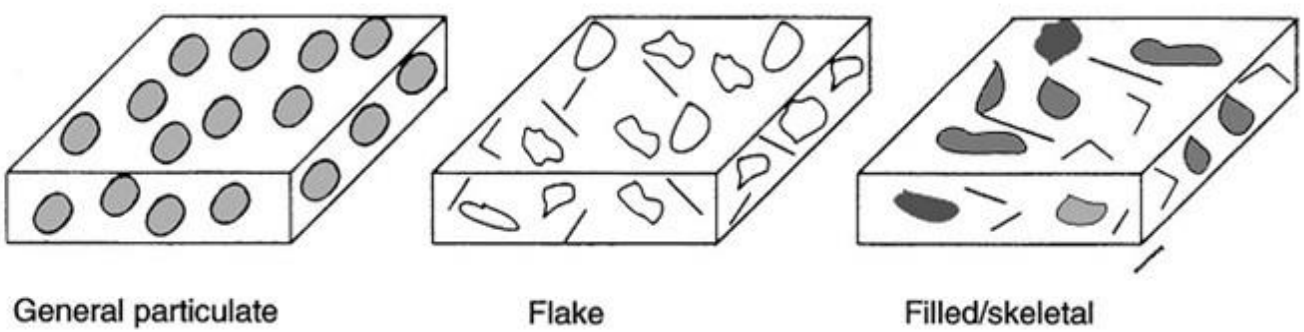


Figure 5.10 Schematic Representations of Particulate Composites

Section 5.3
Properties and Design of Composites

5.3.1 Mechanical Properties of Resin-based Composites

The properties of the composite are usually determined by:

(1)The properties of the fiber;
(2)The properties of the resin;
(3)The ratio of fiber to resin in the composite [Fiber volume fraction (FVF)];
(4)The geometry and orientation of the fibers in the composite.(纤维的几何形状和取向度)

The basic mechanical properties are an important influence on the load-bearing ability and structural performance of the material.

5.3.1.3 Strength

Strength is the property to resist deformation under load.

➢Tensile strength is a measurement of the resistance to being pulled apart when placed in a tension load.

➢Fatigue strength is the ability of material to resist various kinds of rapidly changing stresses and is expressed by the magnitude of alternating stress for a specified number of cycles.

➢Impact strength is the ability of a metal to resist suddenly applied loads and is measured in foot-pounds of force.

5.3.2 Isotropic and Anisotropic

The physical properties of composite materials are generally not isotropic (independent of direction of applied force) in nature, but rather are typically anisotropic (different depending on the direction of the applied force or load).

For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel.For instance, the types of fiber reinforcement and matrix, the building method of panel, type of weave, and orientation of fiber axis to the primary force.

In contrast, isotropic materials (for example, aluminum or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments.

5.3.3 Rule of Mixtures

The Rule of Mixtures is a rough tool that considers the composite properties as volume weighted averages of the component properties. It is important to realize that this rule works accurately only in certain simple situations, such as density and elastic modulus.

Below are some equations derived for unidirectional continuous fiber composite.The principle used is that in longitudinal direction, both fibers and matrix have the same strain (isostrain) and in transverse direction, both fibers and matrix have the same stress (isostress).

5.4.2 Polymeric Composites 聚合物基复合材料

processing techniques:加工工艺

injection molding,compression molding and extrusion (same technique as polymer processing)

filament winding, pultrusion, resin transfer molding, vacuum bagging, hand lay-up, spray-up (only to polymer composite)

END