《材料概论》

Introduction to Materials

Revision

材料科学与工程学院

考试范围及题型

上课的所有章节，PPT为主。

- 填　　空：8分（8个，每个1分）
- 名称解释：15分（5个，每个3分）
- 单项选择：5分（5题，每题1分）
- 简　　答：48分（6题，每题8分）
- 论 述 题：18分（2题，每题9分）
- 分　　析：6分（1题，一段文字，回答问题）

课程基本内容：

Chap.1Basic knowledge on materials

§ 1.1 An brief history of materials
§ 1.2 Definition and classification of materials
§ 1.3 Substances, resources and materials
§ 1.4 Relationship between structure-property-processing of materials
§ 1.5 Material science and engineering

Chap.2 Inorganic Nonmetallic materials

§ 2.1 Ceramics
§ 2.2 Glass and its product
§ 2.3 Cement and concrete

Chap.3 Metallic materials

§ 3.1 Types of metal alloys
§ 3.2 Structure
§ 3.3 properties
§ 3.4 Fabrication of metals
§ 3.5 Metal corrosion
§ 3.6 Application of metals

课程基本内容(续)：

Chap.4 Polymer materials

§ 4.1 Classification and molecular weight
§ 4.2 Structure features
§ 4.3 Basic properties
§ 4.4Preparation and processing technology
§ 4.5 Applications of polymers

Chap.5 Composite materials

§ 5.1 Introduction
§ 5.2 Constituents of composite materials
§ 5.3Properties and design of composite materials
§ 5.4 Fabrication of polymeric composite
§ 5.5 Application of composites

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

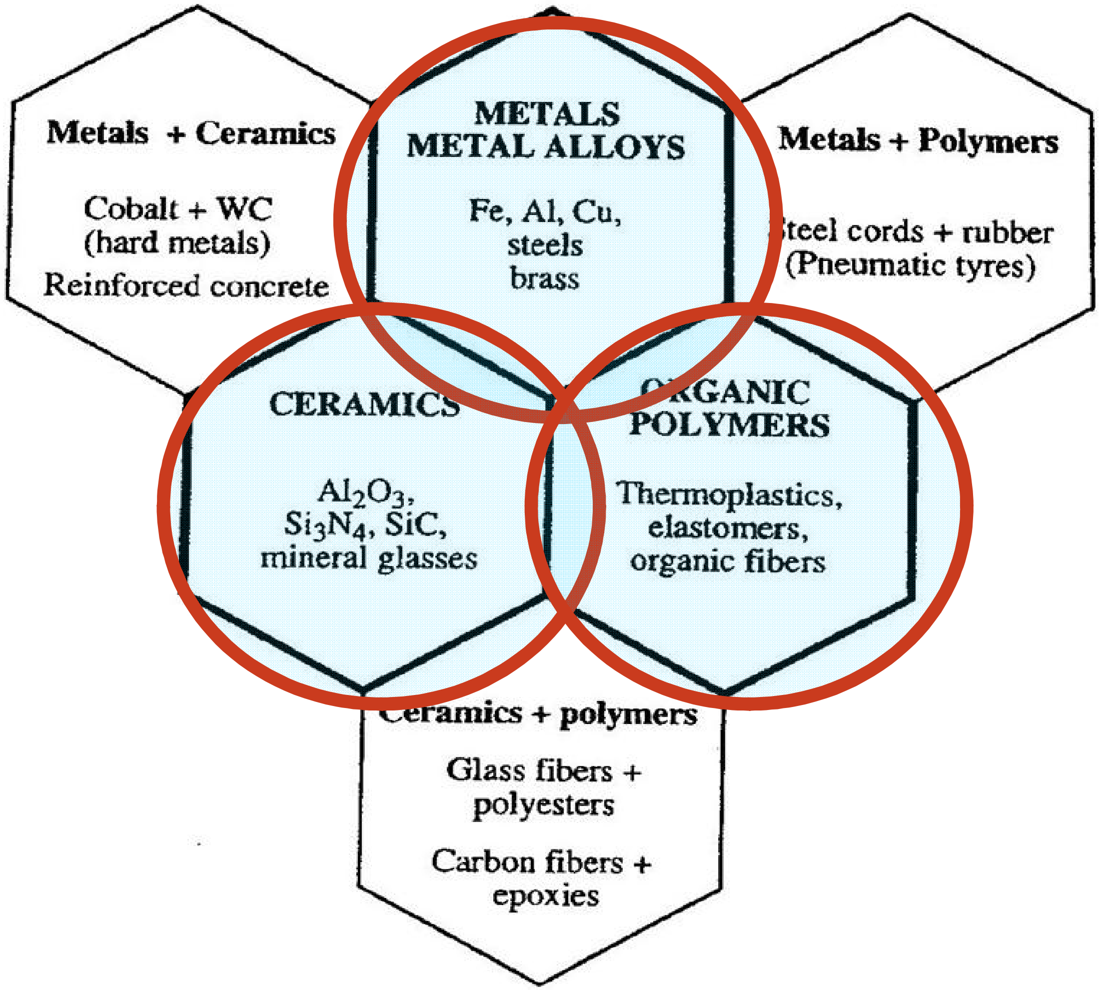
具有使用价值

Classification of materials

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

- 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



Inorganic & nonmetallic materials/ Ceramics

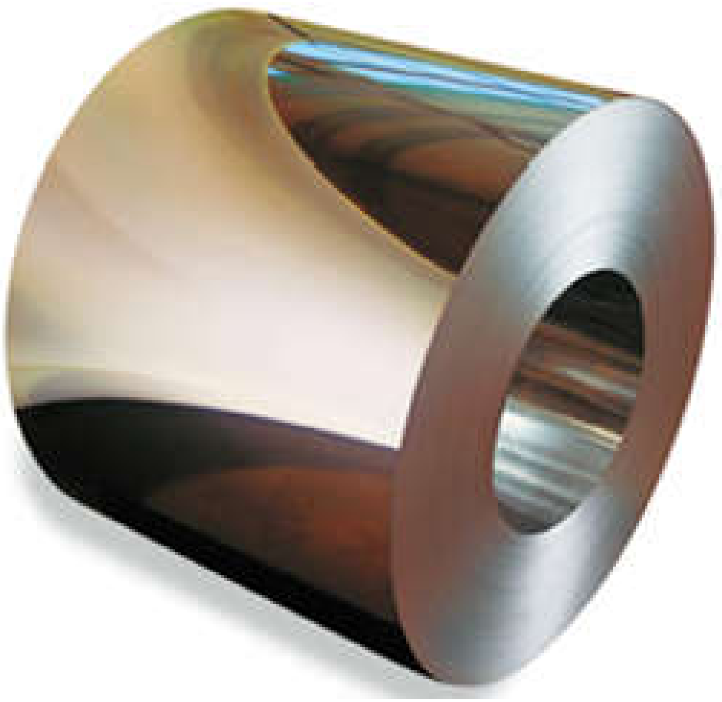
- Ionic bonding & covalent bonding

Inorganic & nonmetallic materials/ Ceramics

- includes glass, cement (concrete), pottery and porcelain, refractory, and so on
- consist of metallic and nonmetallic elements chemically bonded together
- can be crystalline, noncrystalline or mixtures of both
- engineering applications include light weight, high strength and hardness, good heat and wear resistance, reduced friction and insulative properties

Metals and their alloys

- ◆ Metallic bonding



Metals and their alloys

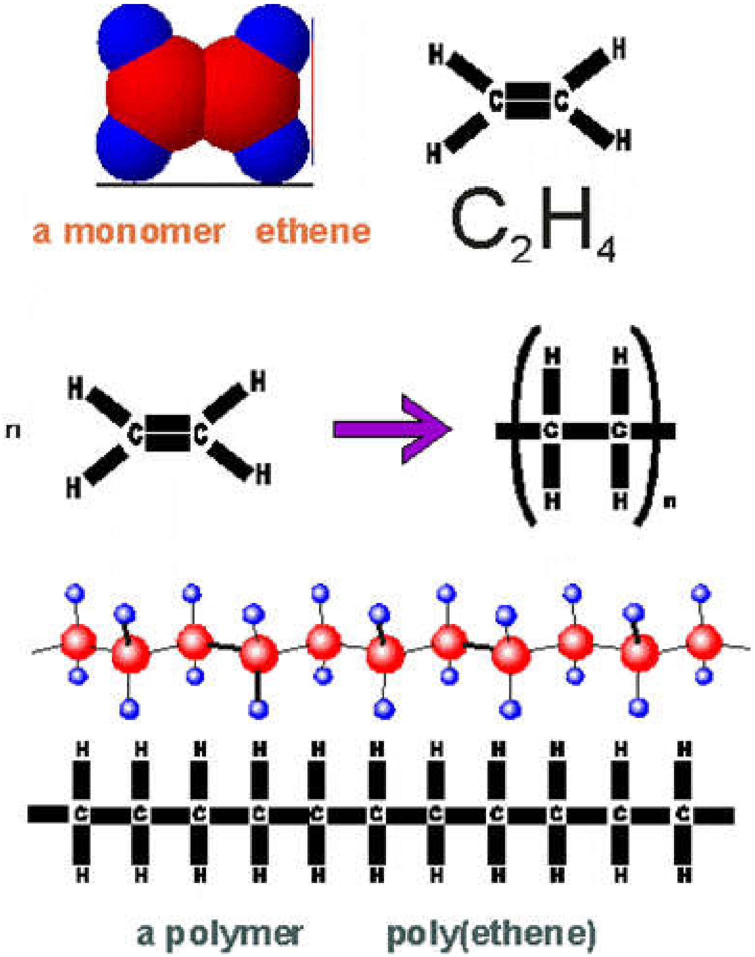
- composed of one or more metallic elements and may also contain some nonmetallic elements
- a crystalline structure in which the atoms are arranged in an orderly manner
- have large number of nonlocalized electrons; these electrons are not bound to atoms

Metals and their alloys

- Are good conductors of heat and electricity;
- Are opaque （遮蔽性的）to visible light;
- Are hard, rigid;
- Can undergo plastic deformation
- Have a high melting temperature (T_m).

Polymers

- Covalent bonding & secondary



Composite materials

- Are constituted by two or more different materials with specific properties.

- Two examples:
  - Glass fiber reinforced resins (玻璃钢):
    - lightweight composites with high mechanical strength
  - Concrete (混凝土):
    - an agglomeration (聚合体) of cement, sand and gravel (碎石)

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
- 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)

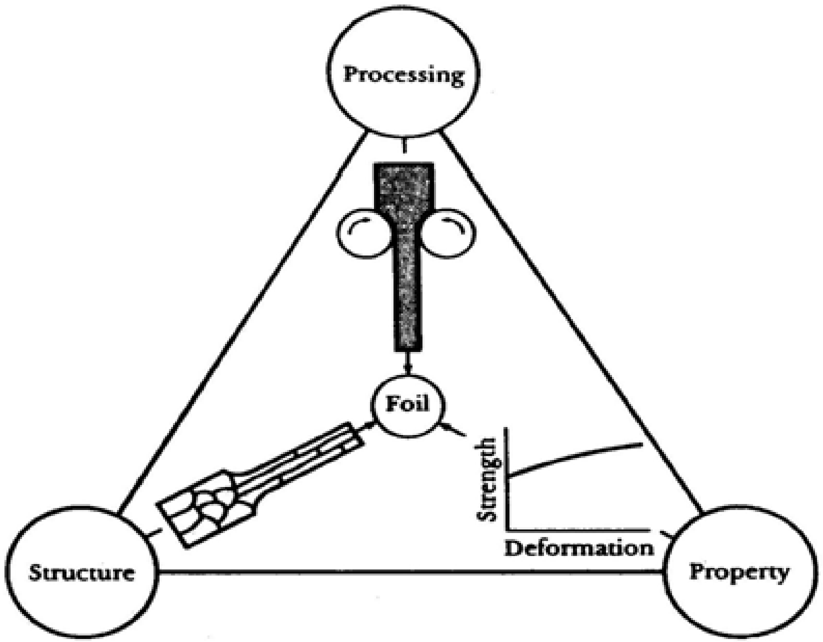
1.4.3 Processing

Processing: how materials are shaped into useful components（加工工艺）

- Casting ： Pouring liquid metal into a mold
- Welding: Joining individual pieces of metal(brazing, soldering, adhesive bolding)
- forging, drawing, extrusion, rolling, bending：forming the solid metal into useful shapes using high pressures
- Machining: removing excess materials.

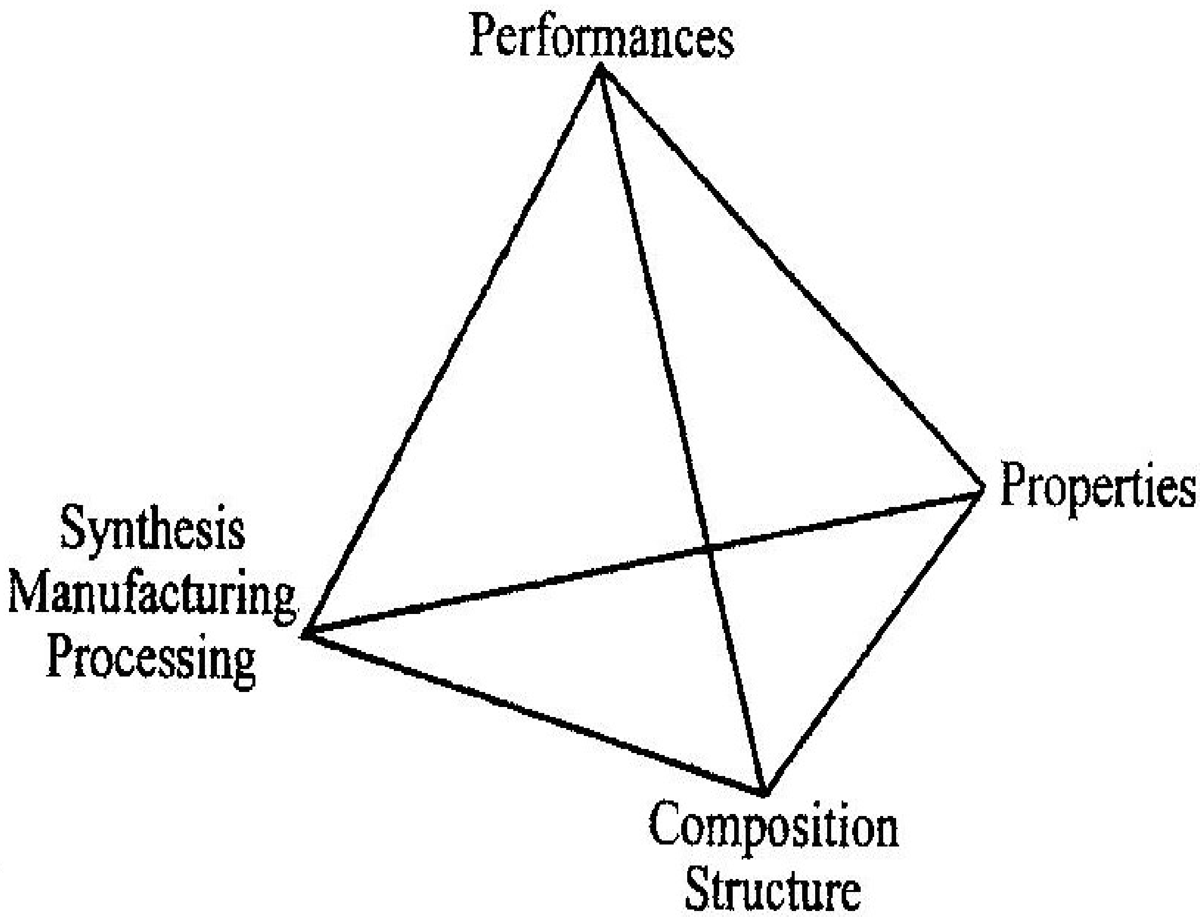
1.4.4 Structure-processing-property Relationship

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



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. Ceramics are divided to traditional ceramics and advanced ceramics.

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**

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

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

2.1.2.2 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。

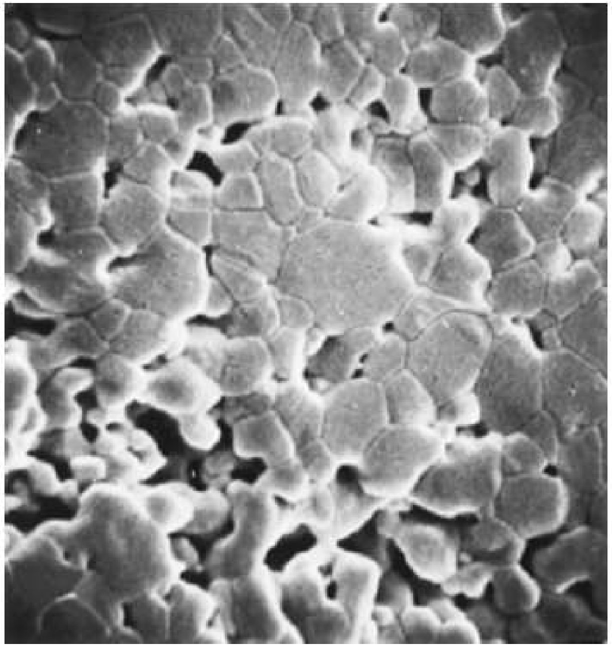
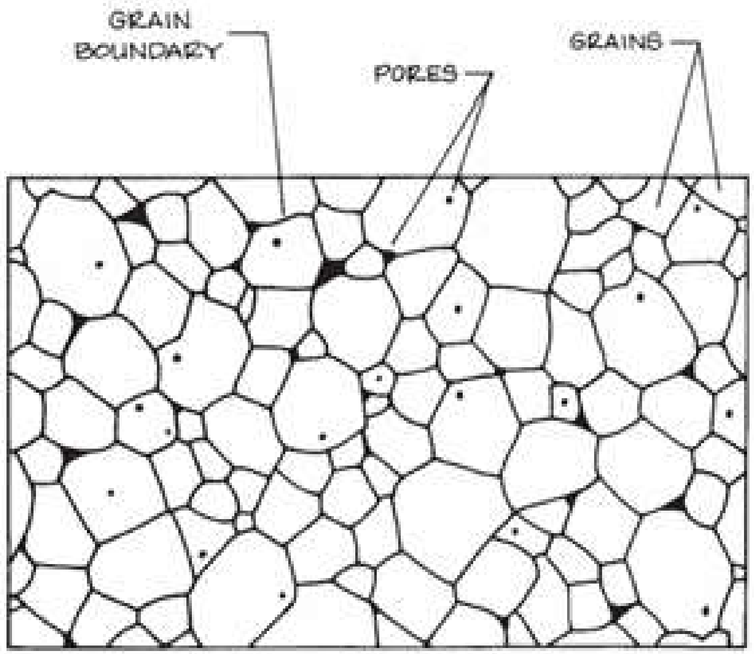


FIGURE 14.25 Scanning electron micrograph of an aluminum oxide powder compact that was sintered at 1700°C for 6 min. 5000×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of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



Microstructure of Ceramics

晶相 crystal phase

Crystal phase: the **main phase** in ceramic materials, and composed of some **solid solutions** and **compounds**. Its structure and morphology decide the microstructure, properties and applications of ceramics.

晶相：陶瓷的主要组成，由固溶体及化合物组成。其结构和形貌决定了陶瓷材料的微观结构、性能及应用。

Pores

- 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.

2.1.3 ceramic processing

2.1.3.2 Traditional Ceramic 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）Forming Techniques

- Milling or grinding: reduce the size

➢ Screening or sizing : desired particle size

➢ Mixing with water: give flow characteristics

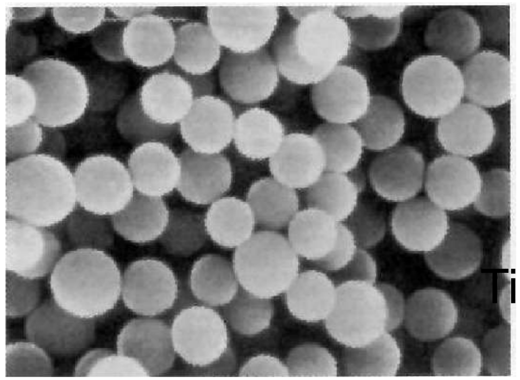
- Slip casting

➢ 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

- **Definition of glass**
- **Composition of glass**
- **Classification of glass**
- **Processing of glass: 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*

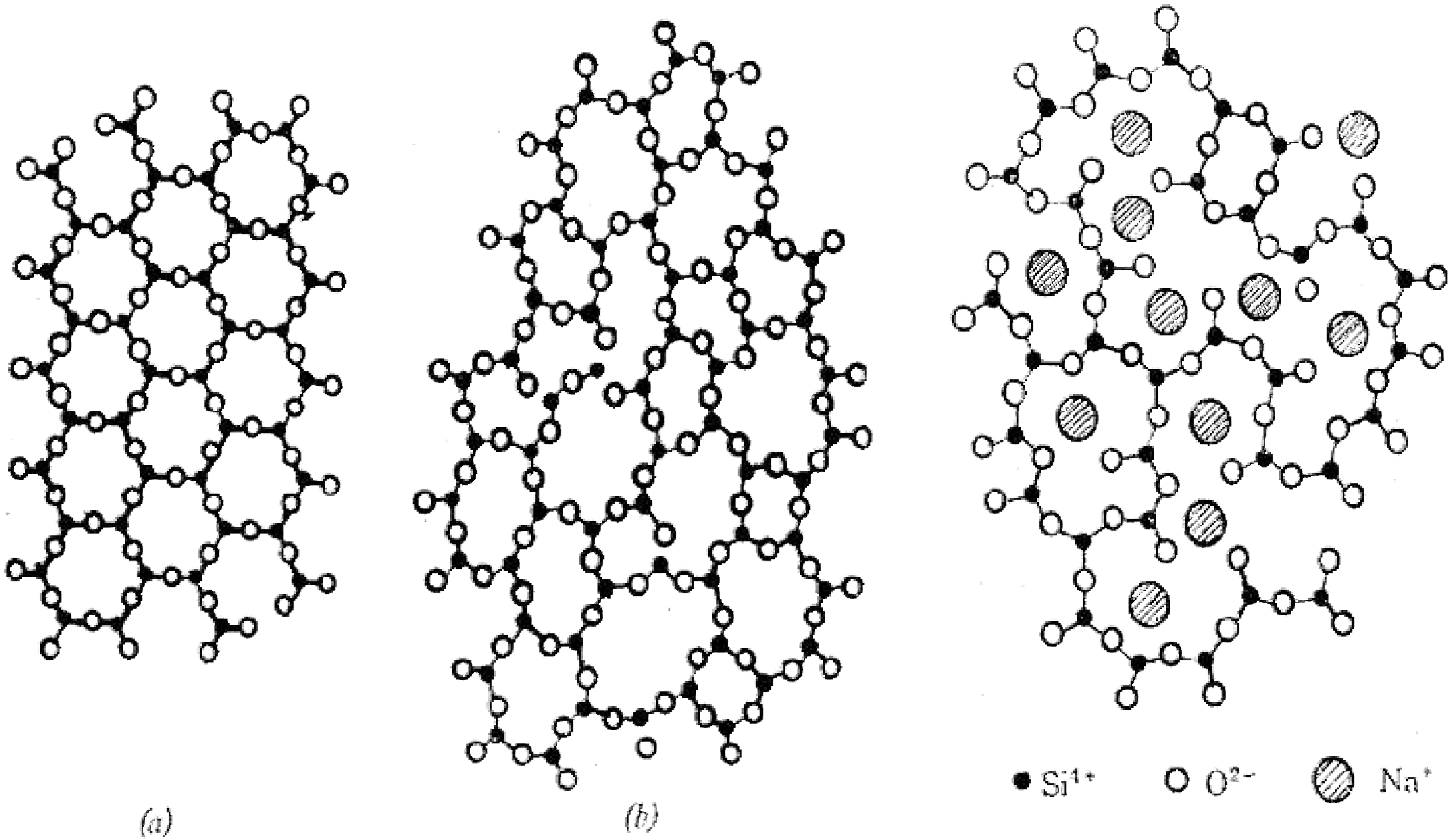
— ASTM 1949

- 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

Section 2.2.3: Structure of glass

Random Network Theory



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SiO_2 crystal and SiO_2 glass

Three types of components for common oxide glasses

- **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

Crystallite Theory

Early theories relating to the structure of glass included the crystallite theory whereby glass is an **aggregate of crystallites** (extremely small crystals).

The atomic structure of a glass **lacks any long range translational periodicity**. However, due to chemical bonding characteristics glasses do possess a **high degree of short-range order** with respect to local atomic polyhedra.

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 2.2g/cm^3 to 8.0g/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**

(3) Strength

- The mechanical strength of glass is much lower than the theoretical strength.
- A great deal of work has been done in attempting both to explain this discrepancy
- Brittle behaviour of glass and the effect of flaws or defects.
- Most glasses show a reduction of strength with increasing temperature

(4) Brittleness

Glass , the strength is very much less than the theoretical value.

- One of the main causes of this loss of strength is the presence of surface defects.
- glass is rigid they act to concentrate any applied stress over only a few interatomic bonds at the apex of the crack
- If the glass is cooled too rapidly it does not have time to release stresses set up within it during cooling these are "frozen-in" and can cause the glass to shatter when it becomes a solid

Section 2.2.7: The glass transition and phase separation

The glass transition is the reversible transition in amorphous materials (or in amorphous regions within semicrystalline materials) from a hard and relatively brittle state into a molten or rubber-like state.

amorphous : 无定形的　　　brittle : 易碎的

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 ℃ to produce clinker, grinding the clinker, and adding small amount of gypsum.

硅酸盐水泥定义（国标GB175-1999）

- 凡是由硅酸盐水泥熟料、0～5%石灰石或粒化高炉矿渣、适量石膏磨细后制成的水硬性胶凝材料称为硅酸盐水泥（国外称为**Portland Cement**).

- **Portland cement is produced by grinding and intimately mixing clay and lime-bearing minerals in the proper proportions, and then heating the mixture to about 1450℃ in a rotary klin; this process, sometimes called calcination(煅烧), produce physical and chemical changes in the raw materials. The resulting “clinker（熟料）” product of then ground into a very fine powder to which is added a small amount of gypsum to retard the setting process.**

硅酸盐水泥制备——原材料

- **The raw mix for making Portland cement clinker is generally obtained by blending a calcareous(钙质的) material, typically limestone, with a smaller amount of an argillaceous（粘土质）one, typically clay or shale（页岩）.**
- **The clinker is mixed with a few percent of calcium sulfate and finely ground, to make the cement. It is commonly described as gypsum, but this may be partly or wholly replaced by other forms of calcium sulfate.**

raw materials:

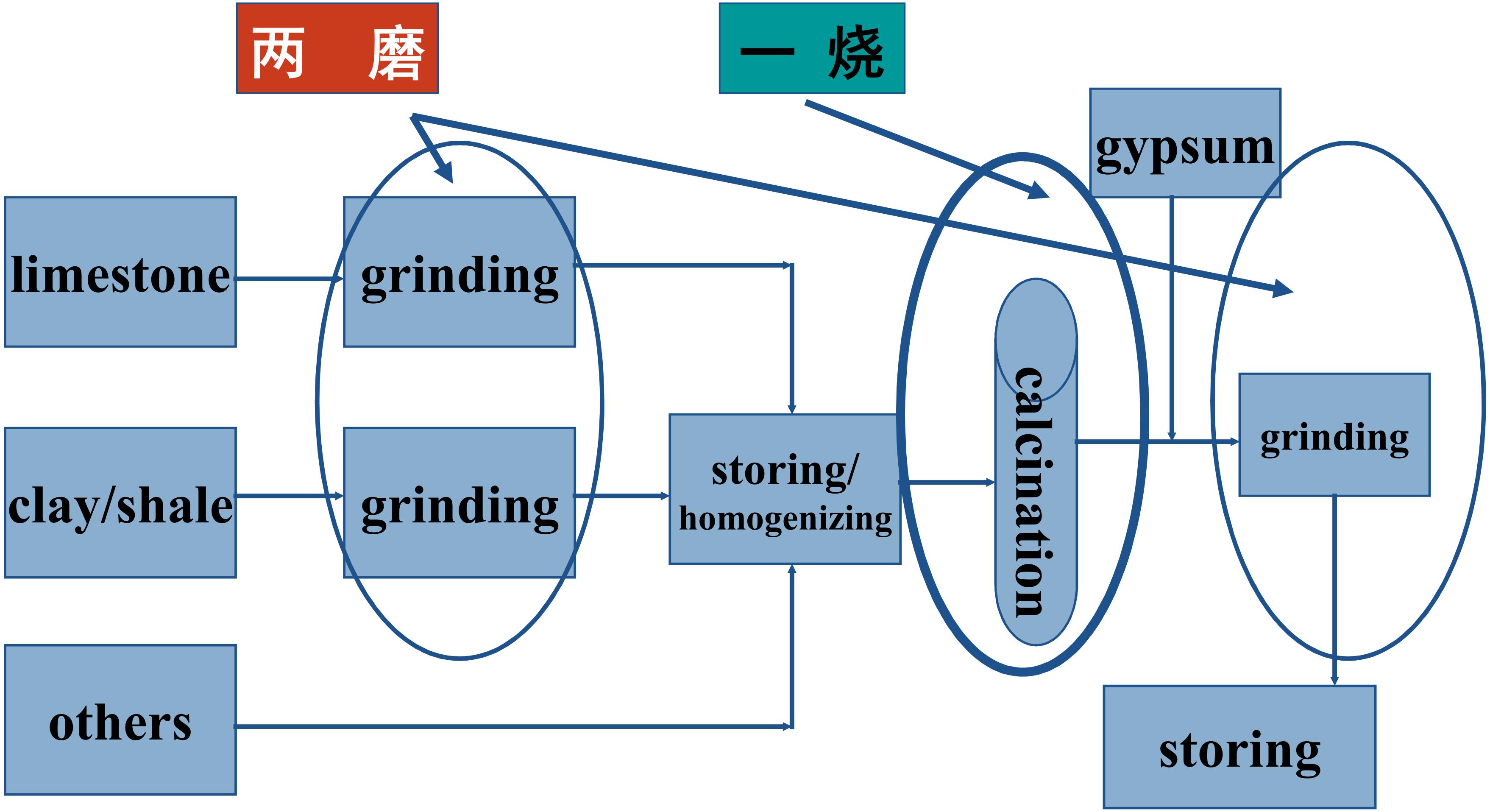
① **Limestone**

② **clay**

③ **gypsum**

④ **admixtures such as fly ash and slag**

硅酸盐水泥的生产



两 磨
一 烧
gypsum
limestone
grinding
clay/shale
grinding
storing/
homogenizing
calcination
grinding
others
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* modified in composition and crystal structure by ionic substitutions.

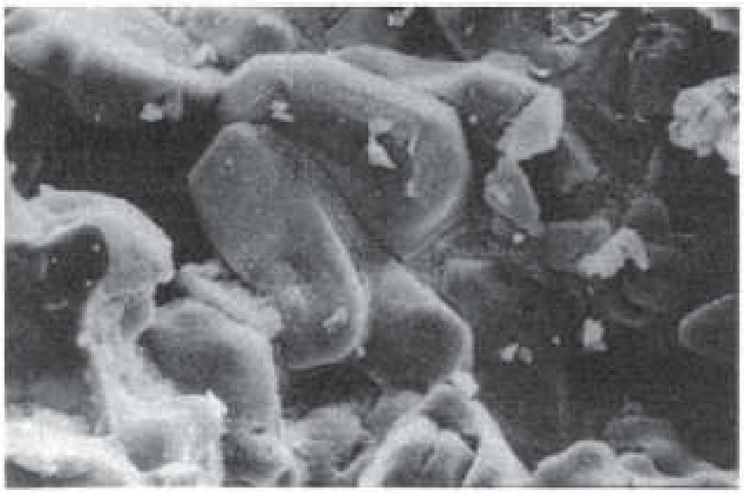


FIGURE 2.8 SEM micrograph of alite crystals separated by interstitial phase.

Belite

◆ **Belite constitutes 15%—30% of normal Portland cement clinkers, It is *dicalcium silicate* 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×).

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Aluminate

- **Aluminate constitutes 5%—10% of most normal Portland cement clinkers.**
- **It is *tricalcium aluminate* ($Ca_3Al_2O_6$), 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* (Ca_2AlFeO_5), 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.

2.3.1.3 Cement chemical nomenclature

Chemical formulae in cement chemistry are often expressed as sums of oxides, thus:

- tricalcium silicate, can be written as $3CaO{\cdot}SiO_2$. This does not imply that the constituent oxides have any separate existence within the structure.
- It is usual to abbreviate the formulae of the commoner oxides to single letters, such as C for CaO or S for SiO_2, thus becoming C_3S.

◆ 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—$4CaO+Al_2O_3+Fe_2O_3$

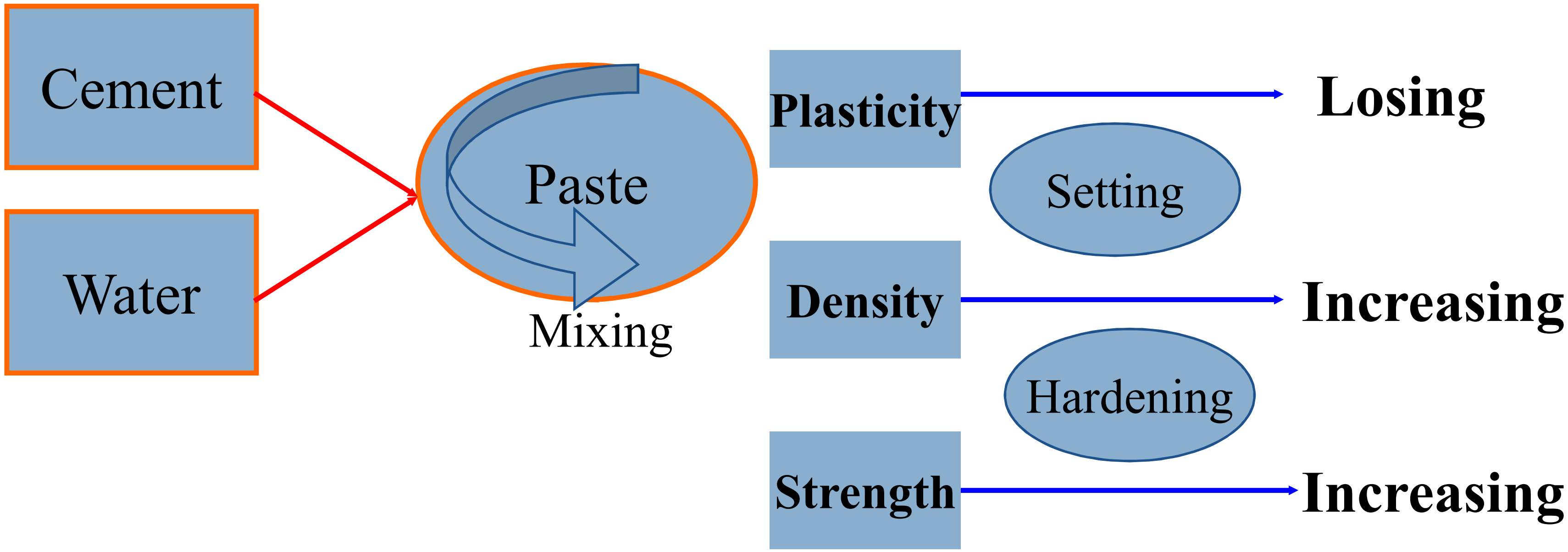
2.3.2 Hydration of Cement

- **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.**

The progress of hydration of cement can be determined by different means, such as the measurement of:

- **(a) the amount of $Ca(OH)_2$ in the paste;**
- **(b) the heat evolved by hydration;**
- **(c) the specific gravity of the paste;**
- **(d) the amount of chemically combined water;**
- **(e) the amount of unhydrated cement present (using X-ray quantitative analysis);**

- **(f) indirectly from the strength of the hydrated paste. Thermogravimetric techniques and continuous X-ray diffraction scanning of wet pastes undergoing hydration can be used in studying early reactions.**
- **(g) The microstructure of hydrated cement paste can also be studied by *back-scattered electron imaging* in a scanning electron microscope.**



塑性:Plasticity, permanent deformation capacity

凝结:Setting, bond stronger, particles gathering

硬化: Hardening, to be hard and stiffer

各水化阶段特征

初始反应：急剧反应，15分钟内结束；

诱导期（潜伏期）：反应十分缓慢，持续1~4小时，初凝时间相当于诱导期结束。

加速期：反应再次加快，出现第二放热峰，开始硬化。持续4~8小时。

减速期：持续12~24小时，扩散控制始。

稳定期：反应速率受扩散控制。

- **As the hydration of cement is an exothermic reaction, the rate of evolution of heat is an indication of the rate of hydration.**
- **This shows that there are three peaks in the rate of hydration in the first three days or so, from the time when the dry cement first comes into contact with water.**

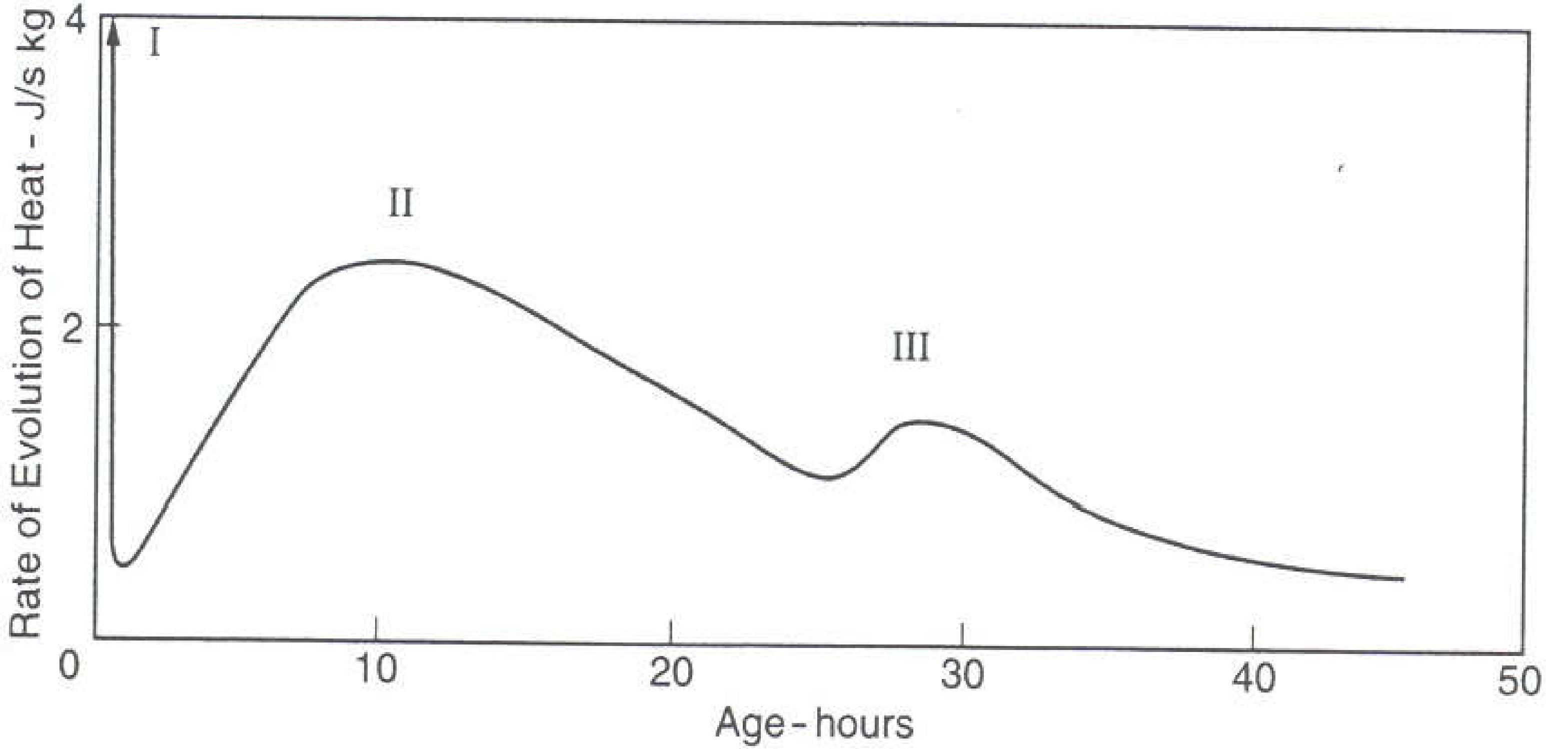


Figure 2.16 Rate of Evolution of Heat Portland Cement with a Water/Cement Ratio of 0.4

The first peak of 3200J /（s·kg） is off the diagram.

- Figure 2.16 shows a plot of the rate of evolution of heat against time.
- We can see the first peak, which is very high, and which corresponds to the initial hydration at the surface of the cement particles, largely involving C_3A.
- The duration of this high rate of hydration is very short, and there follows a so-called *dormant period*, sometimes called also an induction period, during which the rate is very low. This period lasts one or two hours during which the cement paste is workable.

- Eventually, the surface layer is broken down, possibly by an *osmotic mechanism* or by the growth of the crystals of calcium hydroxide.
- The rate of hydration (and therefore of heat evolution) increases fairly slowly and the hydration products of individual grains come into contact with one another, setting then occurs. The rate of heat evolution reaches a second peak, typically at the age of about 10 hours, but sometimes as early as 4 hours.

- **Following this peak, the rate of hydration slows down over a long period, the diffusion through the pores in the products of hydration becoming the controlling factor.**
- **With most, but not an, cements, there is a renewed increase in the rate of hydration up to a third, lower, peak at the age of between 18 and 30 hours. This peak is related to a renewed reaction of C_3A, following the exhaustion of gypsum.**

2.3.2.2 The Pozzolanic Reaction

With respect to the main C-S-H-forming reaction, a comparison between portland cement and portland-pozzolan cement is useful for the understanding the reasons for differences in their behavior:

- **Portland cement**

  $$C_3S + H \rightarrow C\text{-}S\text{-}H$$

- **Portland-pozzolan Cement**

  $$Pozzolan + CH + H \rightarrow C—S—H$$

- **The reaction between a pozzolan and calcium hydroxide is called the *pozzolanic reaction*.**
- **The technical advantage of using pozzolan cements and slag cements is derived mainly from three features of the pozzolanic reaction.**

- First, the reaction is slow; therefore, the rates of heat liberation and strength development will be accordingly slow.
- Second, the reaction is lime-consuming instead of lime-producing, which has an important bearing on the durability of the hydrated paste in acidic environments.
- Third, pore size distribution studies of hydrated IP and IS cements have shown that the reaction products are very efficient in filling up capillary, thus improving the strength and impermeability of the system.

2.3.2.3 Setting

- **This is the term used to describe the *stiffening* of the cement paste, although the definition of the stiffness of the paste which is considered that set is somewhat arbitrary.**
- **Broadly speaking, *setting* refers to a change from a fluid to a rigid stage.**

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

Quality of concrete

Affecting Factors

- 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.

Chapter 3 Metallic Materials

Types:

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

3.1.2 Nonferrous metals

Limitations of ferrous metals:

(1) a relatively high density

(2) a comparatively low electrical conductivity

(3) an inherent susceptibility to corrosion

Non-Ferrous metals:

copper – Cu aluminum – Al

magnesium – Mg titanium – Ti

the refractory metals, the superalloys, the noble metals, and miscellaneous alloys.

3.1.2.4 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

3.1.3 Phases

3.1.3.1 What is a phase?

A phase: is a state of aggregation of matter that has a distinctive structure.

相：化学成分和晶体结构相同，且有界面与其它部分分开的均匀组成部分。

Phase:

- **may be solid, liquid, or gaseous**
- **may be a pure material or a solution of several components**

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

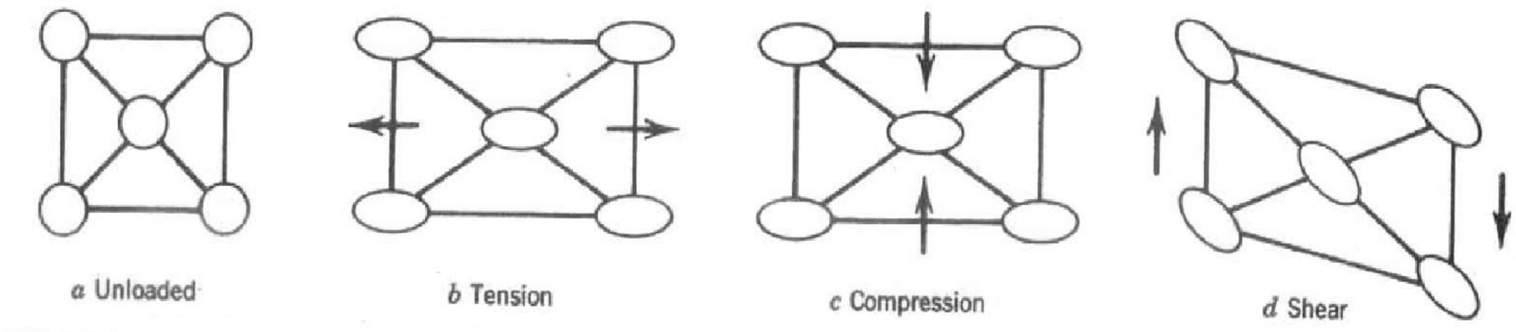
Stress: is the material's resistance to the applied load or force.

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 ~.

- **Elastic deformation: as soon as the stress is removed, the structure returns to its former shape.**

  A piece of metal will become thinner if it is stretched lengthwise.

- **Poisson's ratio: the ratio of movement at right angles to the applied force is called ~.**



(a) Unloaded **(b) tension** **(c) compression** **(d) Shear**

Distortion of crystal lattice with various kinds of stresses

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.

3.3.2.1 Mechanical Properties

Elasticity:

the relationship between stress and strain

An elastic material is one that can be deformed and then return to its original shape when the load is removed.

Elasticity is expressed by Hooke's law (δ/ε in the elastic region) as the degree to which an elastic body bends or stretches out of shape (strain), which is in direct proportion to the force (stress) acting upon it.

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

- **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**

Malleability: ability of metals to be deformed permanently when loaded in compression.

- **malleable metals: can be rolled, hammered, or pressed into flat pieces or sheets.**
- **Ductile metals: usually also malleable but there are some exceptions.**
  - **Lead: very malleable, not very ductile, cannot be drawn into wire very easily, but it can be extruded in wire or bar form.**
  - **Malleable metals: Au, Sn, Ag, Fe, Cu**

Hardness: the resistance to penetration or indentation(凹进，压痕).

It is related to:

- **elastic and plastic properties**
- **tensile strength**

  it can be assumed that hard steel is also strong and resistant to wear.

Chapter 4 Polymer Materials

第四章：高分子材料

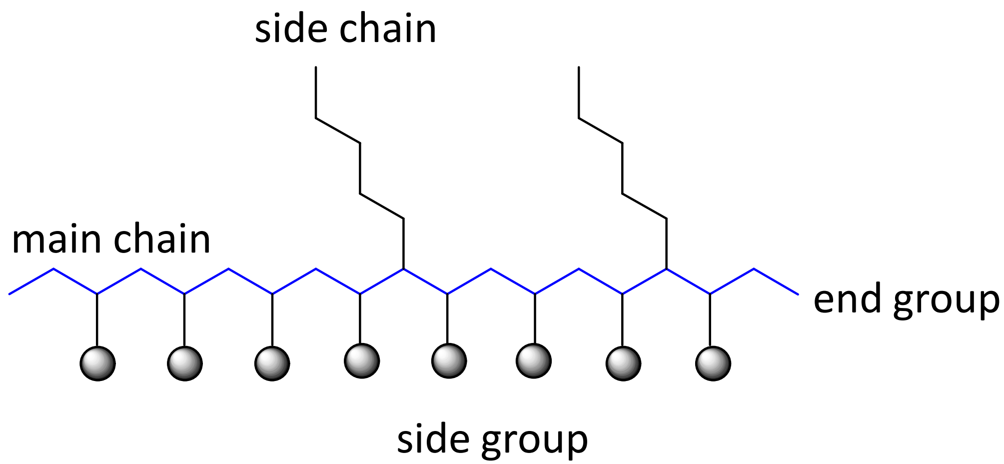
Contents

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.

molar masses ranging: several thousands to several millions

A side chain （支链） is a chemical group that is attached to a core part of the molecule called “main chain”.



An end-group （端基） is a unit that is an extremity of a macromolecule molecule. 主链两端的基团。

The main (backbone) chain（主链） of a polymer is the series of covalently bonded atoms that together create the continuous chain of the molecule. 贯穿于整个分子的链

4. Branched chain polymer: A polymer having extensions of polymer chain attached to the polymer backbone.

5. Chain-transfer: A reaction in which a free-radical abstracts an atom or group of atoms from a solvent, initiator, monomer or polymer.

6. Colligative properties: Properties of a solution which are dependent on the number of solute molecules present.

7. Condensation polymerization: The polymers are formed by various organic condensation reactions with the elimination of small molecules such as water.

8. Co-polymers（共聚物） A long chain polymer composed of at least two different monomers, joined together in an irregular sequence.

9. Cross-links（交联） Covalent bonds between two or more polymer chains.

10. Crystalline polymers（结晶聚合物）: A polymer with an ordered structure, which has been allowed to disentangle and form a crystal.

11.Crystalline melting point (T_m): This is the range of melting temperature of the crystalline domain of a polymer sample and is accompanied by change in polymer properties. It is also the first-phase transition when the solid and liquid phases are in equilibrium.

17. Inhibitor: An additive which reacts with a chain-forming radical to produce non-radical products or radicals of low reactivity, incapable of adding fresh monomer units.

18. Isostatic polymers: A polymer in which all the pendant groups are arranged on the same side of the polymer backbone.

19. Linear chain polymer: It consists of a linear polymer chain without any branching.

4.2.2.2 Relation between Tg and structure

- A highly flexible chain has a low T_g, which increases as the rigidity of the chain becomes greater.
- Strong intermolecular forces tend to raise T_g and also increase crystallinity.
- 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.
- Chain flexibility is the controlling factor on T_g .

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).

Chain initiate: $M_1 \rightarrow M_1\bullet$

Chain Propagate :

$$M_1\bullet + M \rightarrow M_2\bullet$$
$$M_2\bullet + M \rightarrow M_3\bullet$$
$$\text{---} \qquad \text{---}$$
$$M_{n-1}\bullet + M \rightarrow M_n\bullet$$

Chain termination :

$$M_n\bullet + M_m\bullet \rightarrow M_{n+m}$$
$$M_n\bullet + M_m\bullet \rightarrow M_n + M_m$$

Chain transfer :

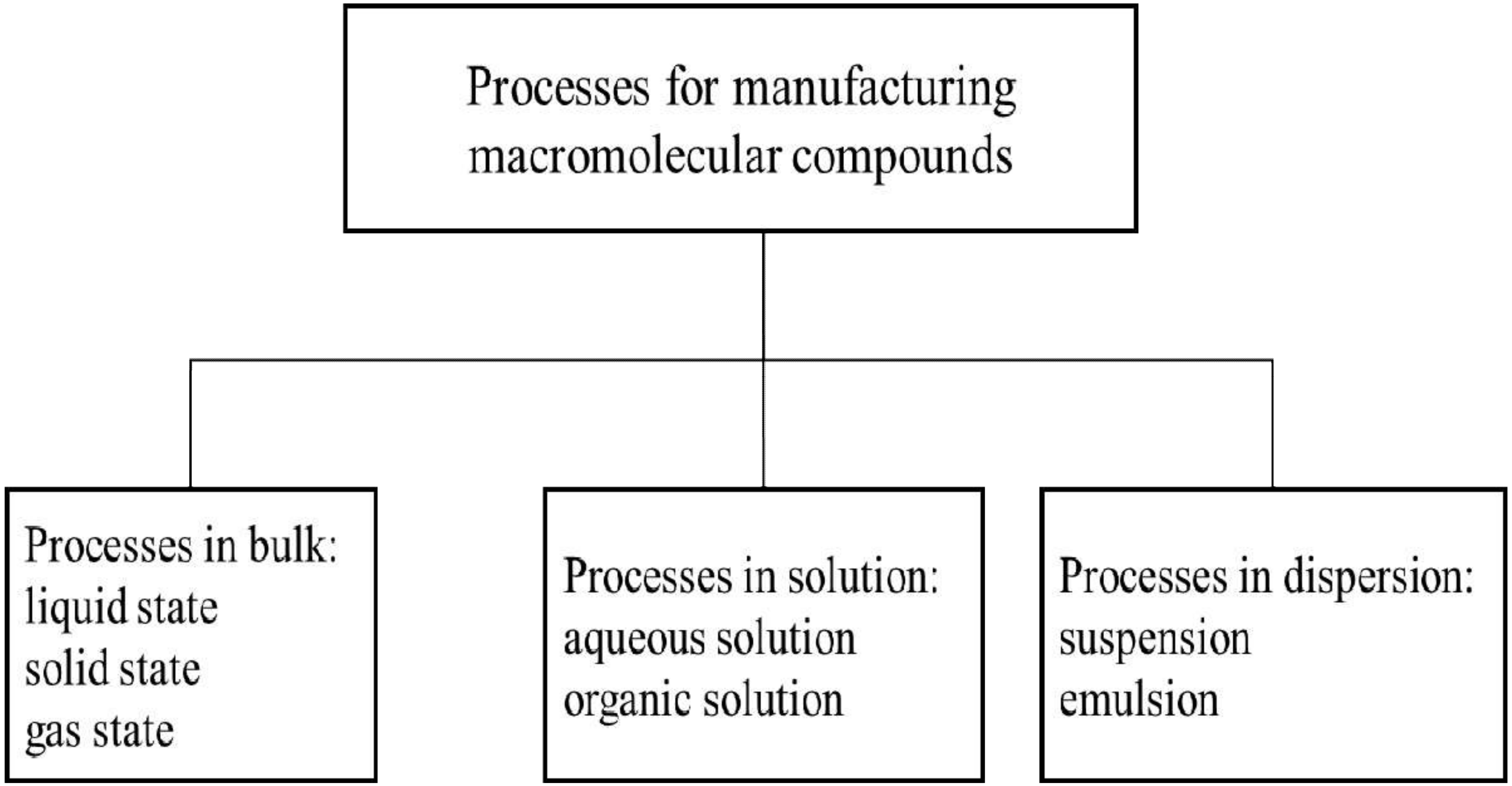
$$M_n\bullet + X - Y \rightarrow M_nY + X\bullet$$

(1) Initiation： This step begins when an initiator decomposes into free radicals in the presence of monomers.

(2) Propagation： After a synthesis reaction has been initiated, the propagation reaction takes over. In the propagation stage, the process of electron transfer and consequent motion of the active center down the chain proceeds.

(3) Termination： typically occurs in two ways: combination and disproportionate. Combination occurs when the polymer's growth is stopped by free electrons from two growing chains that join and form a single chain. Disproportionation halts the propagation reaction when a free radical strips a hydrogen atom from an active center.

4.4.2 Polymerization methods in industry



Polyreactions in Bulk(本体聚合)

Polyreactions in Solution

Polyreactions in Dispersion

Suspension polymerization悬浮聚合

Emulsion polymerization乳液聚合

Chapter 5 Composites
第五章：复合材料

Contents

课程学习目的

- **Constituents of Composite Materials**
- **Properties and Design of Composites**

Section 5.1: Introduction

5.1.2 Definition of Composite Material

A composite material is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent (on the microscopic level).

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 and reinforcement.

➢ 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.

➢ The reinforcement is stronger and stiffer, forming a sort of backbone, while the matrix keeps the reinforcement in a set place. The binder also protects the reinforcement, which may be brittle or breakable, as in the case of the long glass fibers used in conjunction with plastics to make fiberglass.

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)

- matrices
  - Polymer matrix materials
    - Thermosets
    - Thermoplastics
  - Metal matrix materials
  - Ceramic matrix materials
  - Carbon and graphic matrix materials

Figure 5.1 Classification of Matrices

5.2.1.1 Polymer Matrix

Characteristics

•the most common and least expensive;
•a low-density material;
•low processing temperatures, many organic reinforcements can be used.

The terms thermosets and thermoplastic are often used to identify a special property of many polymeric matrices.

5.2.1.2 Metal Matrix

Higher strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts.

5.2.1.3 Ceramic Matrix

Advantages:

•High melting points,

•good corrosion resistance,

•stability at elevated temperatures and high compressive strength

5.2.2 Reinforcement

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

The primary function of fibers or reinforcements is to carry load along the length of the fiber to provide strength and stiffness in one direction.Reinforcements can be both natural and man-made.

•Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular.
•Particles have no preferred orientation and so does their shape.
•Whiskers have a preferred shape but are small both in diameter and length as compared to fibers.

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.

5.3.1.1 Modulus of Elasticity

The modulus of elasticity describes the resistance to elastic deformation, which is reversible（可逆的）.

One common mechanism of elastic deformation under tension is bond stretching.When the load is released, the dimension returns to its original value.

The stress-strain curve （Figure 5.11）is linear in the elastic regime. This linear relation constitutes Hooke’s Law, which states that stress are proportional to strain, with the proportionality constant being the modulus.

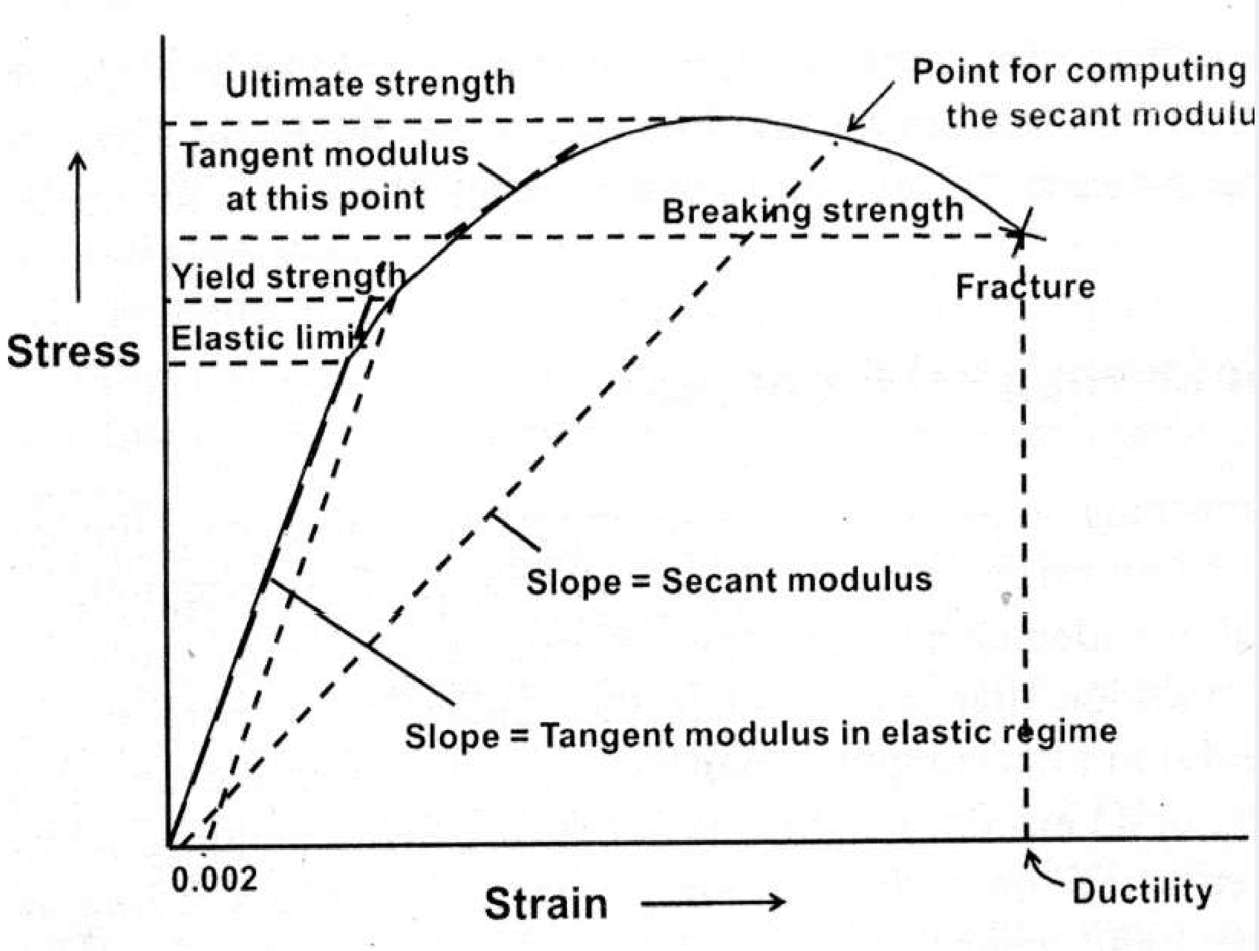


Figure 5.11 Stress-stain curves

Stress-stain curves illustrating the meaning of the tangent modulus, the secant modulus, the elastic limit, the 0.2% offset yield strength , the ultimate strength, and the breaking strength.

5.4 Fabrication of Composites

5.4.2 Polymeric Composites

processing techniques:

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)