Unit 1 Engineering Materials (I)

1.1 Introduction

For industrial purposes, materials can be divided into engineering materials and non-engineering materials. Engineering materials are those used in manufacturing and will become parts of products through definite processing. In generally, engineering materials may be further subdivided into metals, ceramics, composites and polymers.

Metals. Common metals are gold, silver, copper, iron, nickel, aluminum, magnesium and titanium, etc. Among these metals, gold and silver (also platinum) are precious metals; iron and nickel are magnetic materials (they are subject to the action of magnetic force); aluminum, magnesium and titanium are commonly called light metals. Of course, metal materials are seldom used in their pure states but in alloy states. Alloys contain more than one metallic element. Their properties can be modified by changing the element contents present in them. Examples of alloys include stainless steels which are alloys of Fe, Ni and Cr; and brass which is an alloy of Cu and Zn. In addition, metal materials can also be broadly divided into two groups, i.e. ferrous metals and nonferrous metals. Ferrous metals often refer to iron alloys (iron and steel materials) and nonferrous metals include all other metallic materials.

Ceramics. It seems that there hasn't been an exact and complete definition about advanced ceramics so far, but from a viewpoint of modern engineering and technology, advanced ceramics (differentiating from traditional household ceramics) may be defined as the new engineering materials composed of some special kinds of metallic oxides (e.g. alumina or corundum and zirconia) or carbides or nitrides of metallic and nonmetallic elements (e.g. tungsten carbide, silicon carbide, boron nitride, silicon nitride, etc.).[1] They have some unique properties such as high-temperature strength; hardness; inertness to chemicals, food, and environment; resistance to wear and corrosion; and low electrical and thermal conductivity. So they are widely used in turbine, automobile, aerospace components, heat exchangers, semiconductors and cutting tools.

Polymers. The word *polymer* was first used in 1866. In essence, they are organic macromolecular compounds. And in 1909, the word *plastics* was employed as a synonym for "polymers" . Plastic is from a Greek word *plastikos*, meaning "able to be molded and shaped". Plastics are one of numerous polymeric materials and have extremely large molecules. Because of their many unique and diverse properties, polymers have increasingly replaced metallic components in applications such as automobiles, civilian and military air craft, sporting goods, toys, appliances, and office equipment.

Composite materials. Among the major developments in materials in recent years are composite materials. In fact, composites are now one of the most important classes of engineered materials, because they offer several outstanding properties as compared with conventional materials. A composite material is a combination of two or more chemically distinct and insoluble phases; its properties and structural performance are superior to those of the constituents acting independently.[2]

Nanomaterials refer to those materials, at least one of whose three dimensions is at the nano-scale(1~100 nm) and hence we may have nano-powders, nano-fibers and nano-films.[3] They were first investigated in the early 1980s. However, we can not classify them in nature as distinct from other four common engineering materials, i.e. metals, ceramics, composite and macromolecular materials, because various nano-materials developed so far are all composed of one or combination of the above four materials.[4] Nevertheless, when the sizes of some common materials are reduced to the nano-scale, they will possess some special properties superior to traditional and commercially available materials. These properties can include strength, hardness, ductility, wear resistance and corrosion resistance suitable for structural (load-bearing) and nonstructural applications, in combination with unique electrical, magnetic, and optical properties. For example, nano-powders have very large specific surface area, up to hundreds even thousands of square meters per gram, making them become highly active adsorbents and catalysts with wide application prospect in organic synthesis and environmental protection.[5]

1.2 Ferrous Metals and Alloys

By virtue of their wide range of mechanical, physical, and chemical properties, ferrous metals and alloys are among the most useful of all metals. Ferrous metals and alloys contain iron as their base metal; the general categories are cast irons, carbon and alloy steels, stainless steels, tool and die steels.[6]

The term cast iron refers to a family of ferrous alloys composed of iron, carbon (ranging from 2.11% to about 4.5%), and silicon (up to about 3.5%). Cast irons are usually classified as follows:

1. Gray cast iron, or gray iron;
2. Ductile cast iron, nodular cast iron, or spherical graphite cast iron;
3. White cast iron;
4. Malleable iron;
5. Compacted graphite iron.

The equilibrium phase diagram relevant to cast irons is shown in Fig.1.1, in which the right boundary is 100% carbon, that is, pure graphite. The eutectic temperature is 1154 °C (2109 °F), and so cast irons are completely liquid at temperatures lower than those required for liquid steels. Consequently, iron with high carbon content can be cast at lower temperatures than can steels.

Carbon steels are generally classified by their proportion (by weight) of carbon content.

1. Low-carbon steel, also called mild steel, has less than 0.30% carbon. It is generally used for common industrial products, such as bolts, nuts, sheet, plate, and tubes, and for machine components that do not require high strength.

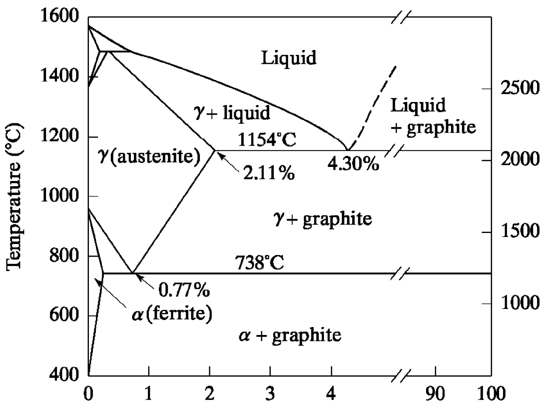

Fig.1.1 Composition graphite(%)

2. Medium-carbon steel has 0.30% to 0.60% carbon. It is generally used in applications requiring higher strength than is available in low-carbon steels, such as in machinery, in automotive and agricultural equipment parts (gears, axles, connecting rods, crankshafts), in railroad equipment, and in parts for metalworking machinery.
3. High-carbon steel has more than 0.60% carbon. It is generally used for parts requiring strength, hardness, and wear resistance, such as cutting tools, cable, music string, springs, and cutlery. After being manufactured into shapes, the parts are usually heat treated and tempered. The higher the carbon content of the steel, the higher is its hardness, strength, and wear resistance after heat treatment.

Alloy steels contain significant amounts of alloying elements. Structural-grade alloy steels, as identified by ASTM specifications, are used mainly in the construction and transportation industries, because of their high strength. Other alloy steels are used in applications where strength, hardness, creep and fatigue resistance, and toughness are required. These steels may also have been heat treated, in order to obtain the desired properties.

Stainless steels are characterized primarily by their corrosion resistance, high strength and ductility, and high chromium content. They are called *stainless* because in the presence of oxygen (air) they develop a thin, hard adherent film of chromium oxide that protects the metal from corrosion (*passivation*). This protective film builds up again in the event that the surface is scratched.[7] For passivation to occur, the minimum chromium content should be 10% to 12% by weight. In addition to chromium, other alloying elements in stainless steels typically are nickel, molybdenum, copper, titanium, silicon, manganese, columbium, aluminum, nitrogen, and sulfur.

Tool and die steels are specially alloyed steels. They are designed for high strength, impact toughness, and wear resistance at room and elevated temperatures. They are commonly used in forming and machining of metals.

High-speed steels (HSS) are the most highly alloyed tool and die steels. First developed in the early 1900s, they maintain their hardness and strength at elevated operating temperatures. There are two basic types of high-speed steels: the *molybdenum type* (M series) and the *tungsten type* (T series).

Hot-work steels are designed for use at elevated temperatures. They have high toughness as well as high resistance to wear and cracking. The alloying elements are generally tungsten, molybdenum, chromium, and vanadium.

Cold-work steels are used for cold-working operations. They generally have high resistance to wear and cracking. These steels are available as oil-hardening or air-hardening types.

Shock-resisting steels are designed for impact toughness and are used in applications such as header dies, punches, and chisels. Other properties of these steels depend on the particular composition.

1.3 Nonferrous Metals and Alloys

Nonferrous metals and alloys cover a wide range of materials, from common metals such as aluminum, copper, and magnesium to high-strength, high-temperature alloys, such as those of tungsten, tantalum, and molybdenum. Although generally more expensive than ferrous metals, nonferrous metals and alloys have important applications because of properties such as corrosion resistance, high thermal and electrical conductivity, low density, and ease of fabrication.

Aluminum (Al). Typical examples of the applications of nonferrous metals and alloys are aluminum for cooking utensils and aircraft bodies, copper wire for electricity, copper tubing for residential water supply, zinc for galvanized sheet metal for car bodies, titanium for jet-engine turbine blades and for orthopedic implants.

The principal uses of aluminum and its alloys are in containers and packaging (aluminum cans and foil), in buildings and other types of construction, in transportation (aircraft and aerospace applications, buses, automobiles), in electrical applications (economical and nonmagnetic electrical conductor), in consumer durables (appliances, cooking utensils, and furniture). Nearly all high-voltage transmission wiring is made of aluminum. In its structural (load-bearing) components, 82% of a Boeing 747 aircraft (and 79% of a Boeing 757 aircraft) is aluminum.

Porous Aluminum. Blocks of aluminum have recently been produced that are 37% lighter than solid aluminum and have uniform permeability (microporosity). This characteristic allows their use in applications where a vacuum or differential pressure has to be maintained. Examples are the vacuum holding of fixtures for assembly and automation and the vacuum forming or thermoforming of plastics.[8] These blocks are 70% to 90% aluminum powder; the rest is epoxy resin. They can be machined with relative ease and can be joined together using adhesives.

Magnesium (Mg) is the lightest engineering metal available, and it has good vibration-damping characteristics. Its alloys are used in structural and nonstructural applications wherever weight is of primary importance. Magnesium is also an alloying element in various nonferrous metals. A variety of magnesium alloys have good casting, forming, and machining characteristics.

Typical uses of magnesium alloys are in aircraft and missile components, material-handling equipment, portable power tools (such as drills and sanders), ladders, luggage, bicycles, sporting goods, and general lightweight components.

Copper (Cu), first produced in about 4000 B.C., and its alloys have properties somewhat similar to those of aluminum and its alloys. In addition, they are among the best conductors of electricity and heat, and they have good corrosion resistance. They can be processed easily by various forming, machining, casting, and joining techniques.

Copper alloys are often attractive for applications where a combination of electrical, mechanical, nonmagnetic, corrosion-resistant, thermally conductive, and wear-resistant qualities are required. Applications include electrical and electronic components; springs; cartridges for small arms; plumbing; heat exchangers; marine hardware, and consumer goods, such as cooking utensils, jewelry, and other decorative objects.

Titanium (Ti), named after the giant Greek god Titan, was discovered in 1791, but it was not produced commercially until the 1950s. Although it is expensive, its high strength-to-weight ratio and its corrosion resistance at room and elevated temperatures make it attractive for many applications including aircraft, jet-engine, racing-car, chemical, petrochemical, and marine components, submarine hulls, and biomaterials, such as orthopedic implants. Titanium alloys have been developed for service at 550°C (1000 °F) for long periods of time and at up to 750 °C (1400 °F) for shorter periods.

The properties and manufacturing characteristics of titanium alloys are extremely sensitive to small variations in both alloying and residual elements. These elements cause embrittlement of titanium and, consequently, reduce toughness and ductility.

Superalloys are important in high-temperature applications; hence, they are also known as heat-resistant or high-temperature alloys. Major applications of superalloys are in jet engines and gas turbines; other applications are in reciprocating engines, in rocket engines, in tools and dies for hot-working of metals, and in the nuclear, chemical, and petrochemical industries. Superalloys generally have good resistance to corrosion, to mechanical and thermal fatigue, to mechanical and thermal shock, to creep, and to erosion at elevated temperatures.

Most superalloys have a maximum service temperature of about 1000 °C (1800 °F) in structural applications. The temperatures can be as high as 1200 °C (2200 °F) and above and a major application for the superalloys of rapidly-solidified powders is consolidation into near-net shapes for parts used in aerospace engines.

Low-melting alloys are so named because of their relatively low melting points. The major metals in this category are lead, zinc, and tin and their alloys.

Lead (Pb) has properties of high density, resistance to corrosion (by virtue of the stable lead-oxide layer that forms to protect the surface), softness, low strength, ductility, and good workability. Lead is also used for damping sound and vibrations, in radiation shielding against x-rays, in ammunition, as weights, and in the chemical industry. An additional use of lead is as a solid lubricant for hot-metal forming operations. Because of its toxicity, however, environmental contamination by lead (causing lead poisoning) is a major concern.

Zinc (Zn), bluish-white in color, is the metal fourth most utilized industrially, coming after iron, aluminum, and copper. Zinc is also used as an alloying element. Brass, for example, is an alloy of copper and zinc. Major alloying elements in zinc-based alloys are aluminum, copper, and magnesium. Zinc-based alloys are used extensively in die casting, for making such products as fuel pumps and grills for automobiles, components for household appliances such as vacuum cleaners, washing machines, and kitchen equipment, and various machinery parts and photoengraving equipment.

Although used in small amounts, *tin* (Sn) is an important metal. The most extensive use of tin, a silvery-white, lustrous metal, is as a protective coating on the steel sheet (tin plate) that is used in making containers (tin cans) for food and for various other products. Unalloyed tin is used in such applications as lining material for water distillation plants and as a molten layer of metal over which plate glass (float glass) is made. Tin-based alloys (also called white metals) generally contain copper, antimony, and lead. The alloying elements impart hardness, strength, and corrosion resistance.

Precious Metals. Gold, silver, and platinum are the most important precious (that is, costly) metals; they are also called noble metals.

1. *Gold* (Au) is soft and ductile, and it has good corrosion resistance at any temperature.

Typical applications include jewelry, coinage, reflectors, dental work, electroplating, and electrical contacts and terminals.

2. *Silver* (Ag) is a ductile metal, and it has the highest electrical and thermal conductivity of any metal. It does, however, develop an oxide film that affects its surface characteristics and appearance. Typical applications for silver include tableware, jewelry, coinage, electroplating, photographic film, electrical contacts, solders, bearing linings, and food and chemical equipment.
3. *Platinum* (Pt) is a soft, ductile, grayish-white metal that has good corrosion resistance even at elevated temperatures. Platinum alloys are used as electrical contacts, for spark-plug electrodes, as catalysts for automobile pollution-control devices, in filaments, in nozzles, in dies for extruding glass fibers, in thermocouples, in the electrochemical industry, as jewelry, and in dental work.

Notes

[1] It seems that there hasn't been a exact and complete definition about advanced ceramics so far, but from a viewpoint of modern engineering and technology, advanced ceramics (differentiating from traditional household ceramics) may be defined as the new engineering materials composed of some special kinds of metallic oxides (e.g. alumina or corundum and zirconia) or carbides or nitrides of metallic and nonmetallic elements (e.g. tungsten carbide, silicon carbide, boron nitride, silicon nitride etc.).

句意：迄今为止，似乎还没有一个关于先进陶瓷材料的确切而完整的定义。但按照现代工程技术的观点，与传统的家用陶瓷材料不同的是，我们可以将先进陶瓷材料定义为由某些特殊金属氧化物［如氧化铝（或称为刚玉）和氧化锆］，或者金属和非金属元素的碳化物和氮化物（如碳化钨、碳化硅、氮化硼、氮化硅等）组成的一类新型工程材料。

[2] A composite material is a combination of two or more chemically distinct and insoluble phases; its properties and structural performance are superior to those of the constituents acting independently.

句意：复合材料是由两种以上化学性质完全不同，且互不相溶的所构成的，它的性质和结构特征要比各组成相单独作用时更加优越。

[3] Nanomaterials refer to those materials, at least one of whose three dimensions is at the nano-scale(1−100nm) and hence we may have nano-powders, nano-fibers and nano-films.

句意：纳米材料指的是这样一类材料：在它们的三维尺寸中至少有一维是在纳米尺度（1～100 nm）以内，因而有所谓的纳米粉、纳米纤维和纳米薄膜等。

[4] However, we can not classify them in nature as distinct from other four common engineering materials, i.e. metals, ceramics, composite and macromolecular materials because various nano-materials developed so far are all composed of one or combination of the above four materials.

句意：然而，我们却不能将它们在本质上与其他 4 种常用的工程材料即金属、陶瓷、复合材料和高分子材料区分开来，因为迄今为止所开发的各种纳米材料都不外乎是由以上 4 种工程材料中的一种或几种组合而成的。

[5] For example, nano-powders have very large specific surface area, up to hundreds even thousands of square meters per gram, making them become highly active adsorbents and catalysts with wide application prospect in organic synthesis and environmental protection.

句意：例如，纳米粉具有极大的比表面积，甚至可达每克数千平方米，使它们成为活性极高的吸附剂或催化剂，在有机合成和环境保护领域具有广阔的应用前景。

[6] ferrous metal 和 nonferrous metal 按英文原意是铁类（基）金属和非铁类（基）金属。现在工程界将其译成黑色金属和有色金属是错误的！英美工程界从来不承认金属分为黑色和有色，只认为金属分为铁基金属和非铁基金属。所以除钢铁材料外，所有其他一切金属统统是 nonferrous 金属！之所以发生这样的错译是 20 世纪 50 年代照搬苏联教科书的结果。当时俄语中将铁和常与铁形成共生矿的锰及铬归类为黑色金属 черный металл，而将其他金属归类为有色金属 цветной металл。所以我国的工程界也将铁、锰、铬作为黑色金属，其他金属则归类为有色金属。所以将英文的 ferrous 译成黑色，nonferrous 译成有色。现在如果查百度上的关键词“黑色金属”，就是如此解释的，它包括铁、锰和铬。

[7] Stainless steels are characterized primarily by their corrosion resistance, high strength and ductility, and high chromium content. They are called *stainless* because in the presence of oxygen (air) they develop a thin, hard adherent film of chromium oxide that protects the metal from corrosion (*passivation*). This protective film builds up again in the event that the surface is scratched.

句意：不锈钢的主要特点是它们具有很好的耐蚀性，强度高，延展性好，铬含量高。之所以被称为不锈钢，是因为在有氧环境下会生成一层牢牢附着在表面的氧化铬薄膜，从而保护其不被腐蚀（所谓钝化作用）。即使金属表面受到刮擦而破损，这层保护膜还会继续生成。

[8] Porous Aluminum Blocks of aluminum have recently been produced that are 37% lighter than solid aluminum and have uniform permeability (microporosity). This characteristic allows their use in applications where a vacuum or differential pressure has to be maintained. Examples are the vacuum holding of fixtures for assembly and automation and the vacuum forming or thermoforming of plastics.

句意：多孔铝是最近才生产出的新材料，因为含有均匀分布的细小微孔，所以它比实体铝

块轻 37%。这种特性使它们可在需要保持真空或压差的环境下得到应用（由于可通过微孔非常均匀和方便地抽成真空）。例如，用于装配和自动化操作的真空吸紧夹具，以及塑料的真空成形和热成形工艺。

Glossary

alumina [ə'lju:minə]　*n.* 氧化铝，刚玉

cartridge [kɑ:tridʒ]　*n.* 夹头，支架，支座

catalyst ['kætəlist]　*n.* 催化剂

compacted graphite iron　蠕墨铸铁

composite ['kɔmpəzit]　*n.* 复合材料

embrittlement [em'britlmənt]　*n.* 脆化

ferrous metal　铁类（基）金属（我国工程界译为黑色金属）

galvanizing [gælvə'naiziŋ]　*n.* 镀锌

hardenability [hɑ:dənə'biliti]　*n.* 可淬性

high-speed steel(HSS)　高速钢

luster ['lʌstə]　*n.* 光泽

macromolecular compound　大分子化合物

malleable iron　可锻铸铁

nanomaterial['nænomətiriəl]　*n.* 纳米材料

nonferrous metal　非铁类（基）金属（我国工程界译为有色金属）

passivation [pæsi'veiʃən]　*n.* 钝化

polymer ['pɔlimə]　*n.* 聚合物

porous aluminum　多孔铝材

precious metal(noble metal)　贵金属

solder ['sɔldə]　*n.* 焊料

specific surface　比表面积

superalloy [ˌsju:pə'ælɔi]　*n.* 超级合金，耐热合金

zirconia [z'kəuniə]　*n.* 氧化锆