普通高等学校材料科学与工程学科规划教材

Introduction to Materials

(2nd Edition)

材料概论（双语教学·第2版）

◎ **Editor Chief** Shui Zhonghe

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武汉理工大学出版社

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（双语教学·第2版）

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Brief Introduction

【内容简介】

Introduction to Materials (2nd Edition)，《材料概论》（第 2 版）是针对普通高等学校材料科学与工程类专业本科生开设“材料概论”双语教学课程而编写的教科书，是在参考了国外材料类流行教材、学术专著和学术论文的基础上编写而成的。全书内容共分为 7 章，主要包括：材料基础知识、无机非金属材料、金属材料、高分子材料、复合材料、功能材料和材料研究分析技术等。全书内容着力反映材料科学与工程领域的最新发展，与此同时，结合相关高等学校的教学要求，并兼顾了不同知识基础和英语程度的读者。本教材编写的内容，既具有较高的学术性和权威性，也具有一定的知识性、趣味性和可读性。

本书既可供高等学校材料类学科专业作为双语教学的课程教材，又可供从事材料科学研究与工程技术应用的专业人员作为了解专业知识、提高英语水平的阅读材料，还可作为高等职业技术院校相关专业的教学用书，以及材料类学科专业来华留学生的学习用书。

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Preface
前　言

《材料概论》（Introduction to Materials）作为双语教学课程教材，第1版自2005年正式出版发行以来，全国多所高等学校将其选作“材料概论”双语教学课程和“材料类专业英语”教学课程的教学用书，该书为推动我国高等学校材料科学与工程类专业的“双语教学”的开展发挥了一定的作用。与此同时，一些读者也来信，就教材的结构、内容和若干细节提出了不少意见和建议。

材料科技日新月异，教学内容也应与时俱进。武汉理工大学出版社早在三年前就建议编者编写新版教材，主编随即组织了由武汉理工大学11位教师组成的编写小组并开始了编写工作。但由于种种原因，迟至今日方才脱稿，我们实在有愧于各方的期待。尽管各位编者十分敬业，但难免存在疏漏，为此，恳请各位读者批评指正。

《材料概论》第2版与第1版相比较，教材的编写在结构上、内容上都有了很大的变化，主要表现在系统性更强，内容更全面，知识面更广，尤其是新增了“功能材料”和“材料分析”、“研究方法”的相关内容，可帮助学生更全面地掌握材料科学与工程的知识。

武汉理工大学水中和教授（硅酸盐建筑材料国家重点实验室）担任本书主编，负责全书的统稿工作，并负责编写第1章和第2章的“水泥与混凝土”部分；戴英教授（材料科学系）和雷丽文副教授（材料科学系）负责编写第2章的“陶瓷”部分，田培静副研究员（绿色建筑材料及制造教育部工程研究中心）负责编写第2章的“玻璃及其制品”部分；邢伟宏副教授（无机非金属材料工程系）负责编写第3章；陈万煜副教授（高分子与复合材料系）负责编写第4章；梅启林教授（高分子与复合材料系）和王翔副教授（高分子与复合材料系）负责编写第5章；陈伟[1]教授（无机非金属材料工程系）和陈伟[2]副教授（材料科学系）负责编写第6章；李秋博士（绿色建筑材料及制造教育部工程研究中心）负责编写第7章。材料科学与工程学院的高旭（硕士研究生）、张万如（硕士研究生）等参加了资料收集和整理工作，在此一并表示感谢。

编　者
2014年08月

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Chapter 1 Basic Knowledge on Materials

1.1 An Brief History of Materials

The survival and development of humankind are tightly associated with materials. Materials are probably more deep-seated in our culture than most of us realized. Transportation, housing, clothing, communication, recreation, and food production-virtually every segment of our everyday lives is influenced to one degree or another by materials. The designation of successive historical epochs as the Stone, Copper, Bronze and Iron Ages reflects the importance of materials. Human destiny and materials resources have been inextricably intertwined since the drawn of history; however, the association of a given material with the age or era that it defines is not only limited to antiquity. The present nuclear and information ages owe their existences to the exploitation of two remarkable elements, uranium and silicon, respectively. Even though modern materials ages are extremely time compressed relative to the ancient metal ages they share a number of common attributes. For one thing, these ages tended to define sharply the material limits of human existence. Stone, copper, bronze and iron meant successively higher standards of living through new or improved agricultural tools, food vessels and weapons. Passage from one age to another was frequently accompanied by revolutionary, rather than evolutionary, changes in technological endeavors.

For example, imagine that time is frozen at 1500 BC and we focus on the Middle East, perhaps the world's most intensively excavated region with respect to archaeological remains. In Asia Minor (Turkey) the ancient Hittites were already experimenting with iron, while close by to the east in Mesopotamia (Iraq), the Bronze Age was in flower. To the immediate north in Europe, the south in Palestine, and the west in Egypt, peoples were enjoying the benefits of the Copper and Early Bronze Ages. Halfway around the world to the east, the Chinese had already melted iron and demonstrated a remarkable genius for bronze, a copper-tin alloy that is stronger and easier to cast than pure copper. Further to the west on the Iberian Peninsula (Spain and Portugal), the Chalcolithic period, an overlapping Stone and Copper Age held sway, and in North Africa survivals of the Late Stone Age were in evidence. Across the Atlantic Ocean the peoples of the Americans had not yet discovered bronze, but like others around the globe, they fashioned beautiful work in gold, silver, and copper, which were found in nature in the free state (i.e., not combined in oxide, sulfide, or other ores). Figure 1.1 and Figure 1.2 show two outstanding ancient buildings which experienced thousands of years under the real environments, and kept relatively holonomic structures, demonstrating that application technology of durable materials approached a high level at the time.

The earliest humans had access to only a very limited number of materials, those that occur naturally: stone, wood, clay, skins, and so on. With time discovered techniques for producing materials included pottery and various metals. Furthermore, it was discovered that the properties of a material could be altered by heat treatments and by the addition of other substances. At this point, materials utilization was totally a selection process, that is, deciding from a given, rather limited set of materials the one that was best suited for an application by virtue of its characteristics. It was not until relatively recent times that scientists came to

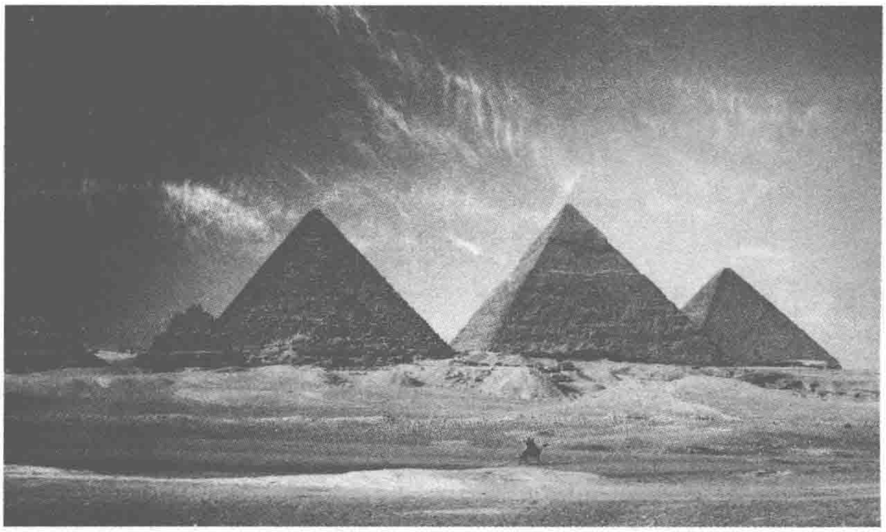

Figure 1.1 Pyramids Egypt

Figure 1.2 The Ancient Colosseum, Roma, Italy

understand the relationships between the structural elements of materials and their properties. This knowledge, acquired in the past 60 years or so, has empowered them to fashion, to a large degree, the characteristics of materials. Thus, tens of thousands of different materials have evolved with rather specialized characteristics that meet the needs of our modern and complex society; these include metals, plastics, ceramics and fibers. (See Figure 1.3, Figure 1.4)

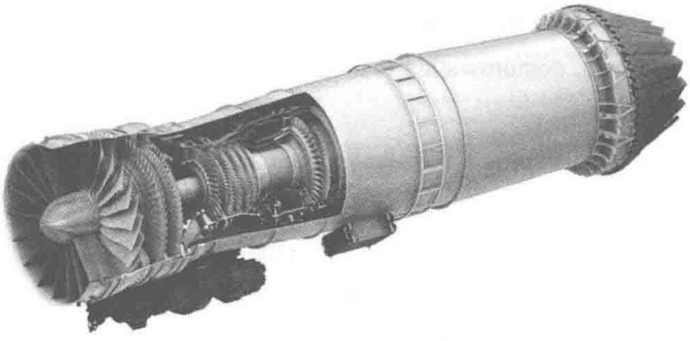

Figure 1.3 High Temperature Structural Ceramics Are Often Used in Advenced Aeroengine

Figure 1.4 Carbon Fiber Reinforced Composites Become Major Structural Material for Fighter Plane and Large Aircrafts

When the 20th century dawned the number of different materials controllably exploited had, surprisingly, not grown much beyond what was available 2000 years earlier. A notable exception was steel, which ushered in the Machine Age and revolutionized many facets of life. But then a period ensued in which there was an explosive increase in our understanding of the fundamental nature of materials. The result was the emergence of polymeric (plastic), nuclear, and electronic materials, new roles for metals and ceramics, and the development of reliable ways to process and manufacture useful products from them. Collectively, this modern Age of Materials has permeated the entire world and dwarfed the impact of previous ages.

Words and Terms

polymeric	*adj.*	聚合的；聚合物的
ceramics	*n.*	陶瓷
aramid	*n.*	芳香族聚酰酪；一种人造纤维
fiber	*n.*	纤维；光纤
composites	*n.*	复合材料
carbide	*n.*	碳化物
nitride	*n.*	氮化物
cubic	*adj.*	立方体的，立方的

1.2 Definition and Classification of Materials

1.2.1 Definition of Materials

The materials making up the surrounding world consist of discrete particles, having a submicroscopic size. Their behavior is determined by atomic theories. The states of organization of materials range from the complete

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disorder of atoms or molecules of a gas under weak pressure to the almost complete order of atoms in a monocrystal.

In this introductory work materials are defined as solids used by man to produce items which constitute the support for his living environment. The definition employed in this introductory work is limited to solid materials. It excludes liquids and gases, as well as solid combustibles.

Indeed, no object exists without materials. All sectors of human activity depend on materials, from the manufacture of an integrated circuit to the construction of a hydroelectric dam. They appear in our bodies to strengthen or replace our damaged biomaterials. Materials are also as indispensable to our society as food, energy and information. Their essential role is too often forgotten.

It is convenient to classify materials into broad categories for study. Many of the common characteristics of materials within a category arise from the lowest level of structure, the nature of the atomic bond that holds them together. The three main types of materials are metallic, polymeric and ceramic materials. Another type of materials that are very important for modern engineering technology is composite materials, combinations of two or more of the above three basic material classes. A brief explanation of these material types and representative characteristics is offered next.

1.2.2 Inorganic and Non-metallic Materials

In many countries, inorganic and non-metallic materials are called ceramics. Normally, ceramics includes glass, cement (concrete), pottery and porcelain, refractory, and so on, being of a big material family. Ceramic materials are inorganic materials that consist of metallic and nonmetallic elements chemically bonded together. Ceramic materials can be crystalline, noncrystalline or mixtures of both. Most ceramic materials have high hardness and high-temperature strength but tend to be brittle. Advantages of ceramic materials for engineering applications include light weight, high strength and hardness, good heat and wear resistance, reduced friction and insulative properties.

The insulative property along with high heat and wear resistance of many ceramics make them useful for furnace linings for heat treatment and melting of metals such as steel. An important aerospace application for ceramics is the use of ceramics tiles for the space shuttle. These ceramic materials thermally protect the aluminum internal structure of the space shuttle during ascent out of and reentry into the earth's atmosphere.

The ceramics and metals have a similar structure feature on the atomic scale: They are crystalline, which means that their constituent atoms are stacked together in a regular, repeating pattern. However, ceramics are not compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides and carbides. For example, some of the common ceramic materials include aluminum oxide (or alumina Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics—those composed of clay minerals (i.e., porçelain), as well as cement, and glass. With regard to mechanical behavior, ceramic materials are relatively stiff and string-stiffness and strengths are comparable to those of the metals (Figure 1.5 and Figure 1.6). In addition, ceramics are typically very hard. On the other hand, they are extremely brittle (lack ductility), and are highly susceptible to fracture . These materials are typically insulative to the passage of heat and electricity (i.e., have low electrical conductivities), and are more resistant to high temperatures and harsh environments than metals and polymers. With regard to optical characteristics, ceramics may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior.

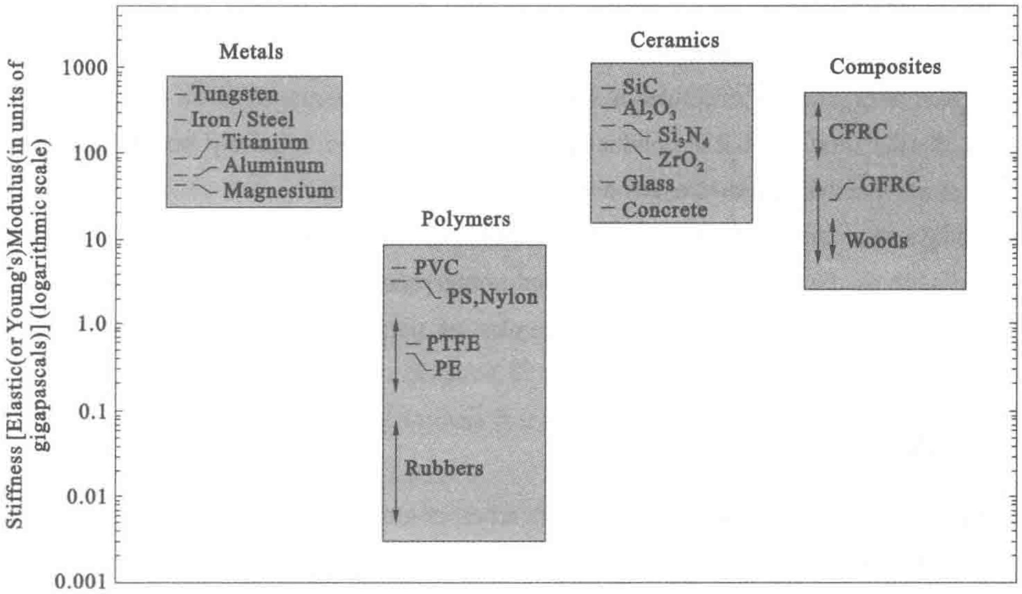

Figure 1.5 **Bar-chart of Room Temperature Stiffness (i.e., Elastic Modulus) Values for Various Metals, Ceramics, Polymers, and Composites Materials**

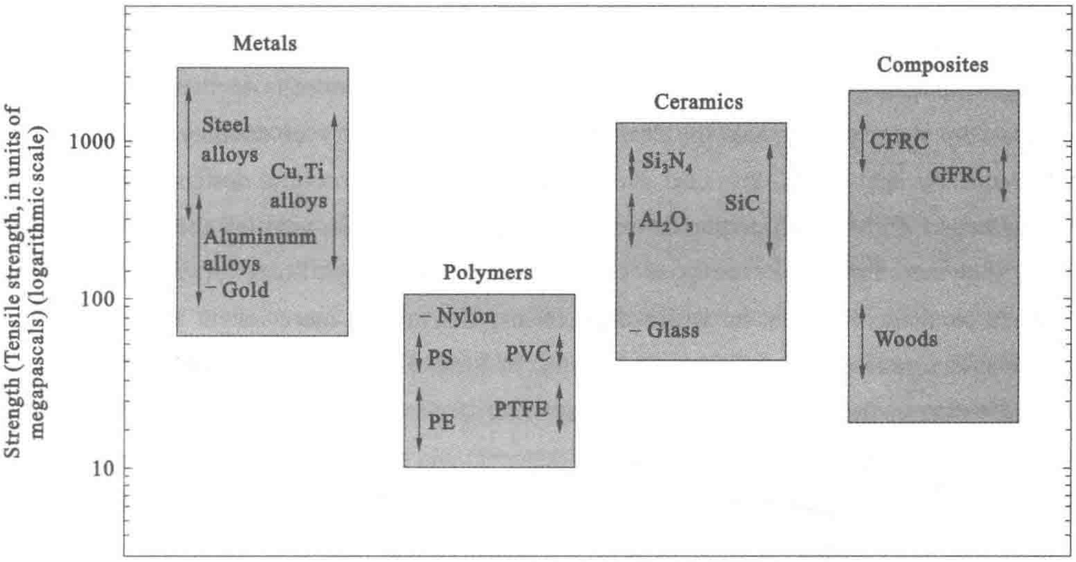

Figure 1.6 **Bar-chart of Room Temperature Strength (i.e., Tensile Strength) Values for Various Metals, Ceramics, Polymers, and Composites Materials**

1.2.3 Metallic Materials

Metallic materials are normally combinations of metallic elements. They have large number of nonlocalized electrons; that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. Metals are extremely good conductors of electricity and heat and are not transparent to visible light; a polished metal surface has a lustrous appearance. Furthermore, metals are quite strong, yet deformable, which accounts for their extensive use in structural applications. This is a large family indeed. The bases of the various engineering alloys include the irons and steels (from Fe), aluminum alloys (Al), magnesium alloys (Mg), Titanium alloys (Ti), Nickel alloys (Ni), zinc alloys (Zn), and copper alloys (Cu) including the brasses (Cu, Zn).

Metallic materials are inorganic substances that are composed of one or more metallic elements and may also contain some nonmetallic elements. Examples of metallic elements are iron, copper, aluminum, nickel and titanium etc. Nonmetallic elements such as carbon, nitrogen and oxygen may also be contained in metallic materials. Metals have a crystalline structure in which the atoms are arranged in an orderly manner. Metals in general are good thermal and electrical conductors. Many metals are relatively strong and ductile at room temperature, and many maintain good strength even at high temperatures.

Metals and alloys are commonly divided into two classes: ferrous metals and alloys that contain a large percentage of iron such as the steels and cast irons and nonferrous metals and alloys that do not contain iron or contain only a relatively small amount of iron. Examples of nonferrous metals are aluminum, copper, zinc, titanium and nickel etc.

1.2.4 Polymer Materials

Most polymeric materials consist of organic (carbon-containing) long molecular chains or networks. Structurally, most polymeric materials are noncrystalline, but some consist of mixtures of crystalline and noncrystalline regions. The "mer" in a polymer is a single hydrocarbon molecule such as ethylene (C_2H_4). Polymers are long-chain molecules composed of many mers bonded together. The most common commercial polymer is polyethylene $\leftarrow C_2H_4 \rightarrow_n$, where n can range from approximately 100 to 1000. Many important polymers (including polyethylene) are simply compounds of hydrogen and carbon. Others contain oxygen (e.g., acrylics), nitrogen (nylons), fluorine (fluoroplastics), and silicon (silicones). As the descriptive title implies, "plastics" commonly share with metals the desirable mechanical property of ductility. Unlike brittle ceramics, polymers are frequently lightweight, low-cost alternatives to metals in structural design applications.

The strength and ductility of polymeric materials vary greatly. Because of the nature of their internal structure, most polymeric materials are poor conductors of electricity. Some of these materials are good insulators and are used for electrical insulative applications. One of the more recent applications of polymeric materials has been in manufacture of digital video disks. In general, polymeric materials have low densities and relatively low softening or decomposition temperatures.

Polymers include the familiar plastic and rubber materials and so on. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements; furthermore, they have large molecular structures. These materials typically have low densities and may be extremely flexible.

1.2.5 Composite Materials

Composite materials are mixtures of two or more materials. Most composite materials consist of a selected filler or reinforcing material and a compatible resin binder to obtain the specific characteristics and properties desired. Usually, the composites do not dissolve in each other, and they can be physically identified by an interface between them. Composites can be of many types. Some of the predominant types are fibrous (composed of fibers in a matrix) and particulate (composed of particles in a matrix). Many different combinations of reinforcements and matrices are used to produce composite materials. Two outstanding types of modern composite materials used for engineering applications are fiberglass-reinforcing materials in a polyester or epoxy matrix and carbon fibers in an epoxy matrix.

A number of composite materials have been engineered that consist of more than one material type. Fiberglass reinforced plastics is a familiar example, in which glass fibers are embedded within a polymeric material. A composite is designed to display a combination of the best characteristics of each of the component materials. Fiberglass acquires strength from the glass and flexibility from the polymer. Many of the recent developments have involved composite materials.

Words and Terms

discrete	*adj.*	离散的；不连续的
submicroscopic	*adj.*	亚微观结构的
molecule	*n.*	分子
monocrystal	*n.*	单晶体
ferrous	*adj.*	亚铁的；铁的，含铁的
noncrystalline	*adj.*	非晶体的；非晶态的
matrix	*n.*	基体
polyester	*n.*	聚酯
epoxy	*adj.*	环氧的
epoxy resin	*n.*	环氧基树脂

1.3 Substances, Resources and Materials

In chemistry, a chemical substance is a form of matter that has constant chemical composition and characteristic properties. It cannot be separated into components by physical separation methods, i.e. without breaking chemical bonds. They can be solids, liquids or gases.

Chemical substances are often called 'pure' to set them apart from mixtures. A common example of a chemical substance is pure water; it has the same properties and the same ratio of hydrogen to oxygen whether it is isolated from a river or made in a laboratory. Other chemical substances commonly encountered in pure form are diamond (carbon), gold, table salt (sodium chloride) and refined sugar (sucrose). However, simple or seemingly pure substances found in nature can in fact be mixtures of chemical substances. For example, tap water may contain small amounts of dissolved sodium chloride and compounds containing iron, calcium and many other chemical substances.

Chemical substances exist as solids, liquids, gases, or plasma and may change between these phases of matter with changes in temperature or pressure. Chemical reactions convert one chemical substance into another.

Forms of energy, such as light and heat, are not considered to be matter, and thus they are not "substances" in this regard.

Natural resources occur naturally within environments that exist relatively undisturbed by mankind, in a natural form. A natural resource is often characterized by amounts of biodiversity and geodiversity existent in various ecosystems.

Natural resources are derived from the environment. Some of them are essential for our survival while most are used for satisfying our wants. Natural resources may be further classified in different ways.

Natural resources are materials and components (something that can be used) that can be found within the environment. Every man-made product is composed of natural resources (at its fundamental level). A natural resource may exist as a separate entity such as fresh water, and air, as well as a living organism such as a fish, or it may exist in an alternate form which must be processed to obtain the resource such as metal ores, oil, and most forms of energy.

There is much debate worldwide over natural resource allocations, this is partly due to increasing scarcity (depletion of resources) but also because the exportation of natural resources is the basis for many economies (particularly for developed nations such as Australia).

Some Natural resources can be found everywhere such as sunlight and air, when this is so the resource is known as an ubiquitous (existing or being everywhere) resource. However most resources are not ubiquitous. They only occur in small sporadic areas; these resources are referred to as localized resources. There are very few resources that are considered inexhaustible (will not run out in foreseeable future)—these are solar radiation, geothermal energy, and air (though access to clean air may not be). The vast majority of resources are however exhaustible, which means they have a finite quantity, and can be depleted if managed improperly. The natural resources are materials, which living organisms can take from nature for sustaining their life or any components of the natural environment that can be utilized by man to promote his welfare is considered as natural resources.

The materials making up the surrounding world consist of discrete particles, having a submicroscopic size. Their behavior is determined by atomic theories. The states of organization of materials range from the complete disorder of atoms or molecules of a gas under weak pressure to the almost complete order of atoms in a monocrystal.

In this introductory work materials are defined as solids used by man to produce items which constitute the support for his living environment.

Indeed, no object exists without materials. All sectors of human activity depend on materials, from the manufacture of an integrated circuit to the construction of a hydroelectric dam. They appear in our bodies to strengthen or replace our damaged biomaterials. Materials are also as indispensable to our society as food, energy and information. Their essential role is too often forgotten.

The definition employed in this introductory work is limited to solid materials. It excludes liquids and gases, as well as solid combustibles.

Words and Terms

biomaterials	*n.*	生物材料
biodiversity	*n.*	生物多样性
geodiversity	*n.*	地质多样性
ecosystems	*n.*	生态系统

1.4 Relationship between Structure, Properties and Processing of Materials

In materials, an underlying truth is: Material properties depend on the material microstructure, which in turn results from its compositions and processing.

Properties are a category that includes quite a few different things. Many engineers will be inclined to think first of mechanical strength, or ductility, or impact resistance. Sometimes, this includes such behavior under extremes of temperature or other external conditions, as well. But properties also includes electrical and thermal conductivity, optical properties, corrosion resistance, the ability of material to be fabricated into complex shapes and to be decorated or coated for appearance, and so forth. Properties, then, are the interface between the requirements of performance and the selection of material by the design engineer.

1.4.1 Property

We can consider the properties of a material in two categories—mechanical and physical.

The mechanical properties describe how the material responds to an applied force or stress. Stress is defined as the force divided by the cross-sectional area on which the force acts. The most common mechanical properties are the strength, ductility, and stiffness of the material. However, we are often interested in how the material behaves when it is exposed to a sudden intense blow (impact), continually cycled through an alternating force (fatigue), exposed to high temperatures (stability), or subjected to abrasive conditions (wear). The mechanical properties not only determine how well the material performs in service, but also determine the ease with which the material can be formed into a useful shape. A metal part formed by forging must withstand the rapid application of a force without breaking and have a high enough ductility to deform to the proper shape. Often small changes in the structure have a profound effect on the mechanical properties of the material.

Physical properties include electrical, magnetic, optical, thermal, elastic, and chemical behavior. The physical properties depend both on structure and processing of the material. Even tiny changes in the composition cause a profound change in the electrical conductivity of many semiconducting metals and ceramics.

High firing temperatures may greatly reduce the thermal insulation characteristics of ceramic brick. Small amounts of impurities change the color of a glass or polymer.

1.4.2 Structure

The structure of a material usually relates to the arrangement of its internal components. Subatomic structure involves electrons within the individual atoms and interactions with their nuclei. On an atomic level, structure encompasses the organization of atoms or molecules relative to one another. The next larger structural realm, which contains large groups of atoms that are normally agglomerated together, is termed “microscopic”, meaning that which is subject to direct observation using some type of microscope. Finally, structural elements that may be viewed with the naked eye are termed “macroscopic.”

1.4.3 Processing

The term synthesis refers to how materials are made from naturally occurring or man-made chemicals. The term processing means how materials are shaped into useful components to cause changes in the properties of different materials.

Materials processing produces the desired shape of a component from the initial formless material. Metals can be processed by pouring liquid metal into a mold (casting), joining individual pieces of metal (welding, brazing, soldering, adhesive bonding), forming the solid metal into useful shapes using high pressures (forging, drawing, extrusion, rolling, bending), compacting tiny metal powder particles into a solid mass (powder metallurgy), or removing excess materials (machining). Similarly, ceramic materials can be formed into shapes by related processes such as casting, forming, extrusion, or compaction, often while wet, and heat treatment at high temperatures to drive off the fluids and to bond the individual constituents together. Polymers are produced by injection of softened plastic into molds (much like casting), drawing and forming. Often a material is heat treated at some temperature below its melting temperature to effect a desired change in structure. The type of processing we use depends, at least partly, on the properties, and thus the structure, of the material.

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