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PART I INTRODUCTION TO MATERIALS SCIENCE AND ENGINEERING

Unit 1 Materials Science and Engineering

Materials are properly more deep-seated in our culture than most of us realize. Transportation, housing, clothing, communication, recreation and food production——virtually every segment of our everyday lives is influenced to one degree or another by materials. Historically, the development and advancement of societies have been intimately tied to the members' abilities to produce and manipulate materials to fill their needs. In fact, early civilizations have been designated by the level of their materials development (i. e. Stone Age, Bronze Age).

The earliest humans has access to only a very limited number of materials, those that occur naturally stone, wood, clay, skins, and so on. With time they discovered techniques for producing materials that had properties superior to those of the natural ones; these new 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 characteristic. It was not until relatively recent times that scientists came to 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.

The development of many technologies that make our existence so comfortable has been intimately associated with the accessibility of suitable materials. Advancement in the understanding of a material type is often the forerunner to the stepwise progression of a technology. For example, automobiles would not have been possible without the availability of inexpensive steel or some other comparable substitutes. In our contemporary era, sophisticated electronic devices rely on components that are made from what are called semiconducting materials.

Materials Science and Engineering

Materials science is an interdisciplinary study that combines chemistry, physics, metal-

lurgy, engineering and very recently life sciences. One aspect of materials science involves studying and designing materials to make them useful and reliable in the service of humankind. It strives for basic understanding of how structures and processes on the atomic scale result in the properties and functions familiar at the engineering level. Materials scientists are interested in physical and chemical phenomena acting across large magnitudes of space and time scales. In this regard it differs from physics or chemistry where the emphasis is more on explaining the properties of pure substances. In materials science there is also an emphasis on developing and using knowledge to understand how the properties of materials can be controllably designed by varying the compositions, structures, and the way in which the bulk and surface phase materials are processed.

In contrast, materials engineering is, on the basis of those structure properties correlations, designing or engineering the structure of a material to produce a predetermined set of properties. In other words, materials engineering mainly deals with the use of materials in design and how materials are manufactured.

"Structure" is a nebulous term that deserves some explanation. In brief, 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 large 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".

The notion of "property" deserves elaboration. While in service use, all materials are exposed to external stimuli that evoke some type of response. For example, a specimen subject to forces will experience deformation; or a polished metal surface will reflect light. Property is a material trait in terms of the kind and magnitude of response to a specific imposed stimulus. Generally, definitions of properties are made independent of material shape and size.

Virtually all important properties of solid materials may be grouped into six different categories: mechanical, electrical, thermal, magnetic, optical, and deteriorative. For each there is a characteristic type of stimulus capable of provoking different responses. Mechanical properties relate deformation to an applied load or force: examples include elastic modulus and strength. For electrical properties, such as electrical conductivity and dielectric constant, the stimulus is an electric filed. The thermal behavior of solids can be represented in terms of heat capacity and thermal conductivity. Magnetic properties demonstrate the response of a material to the application of a magnetic field. For optical properties, the stimulus is electromagnetic or light radiation: index of refraction and reflectivity are representative optical properties. Finally, deteriorative characteristics indicate the chemical reactivity of materials.

In addition to structure and properties, two other important components are involved in

the science and engineering of materials, namely "processing" and "performance". With regard to the relationships of these four components, the structure of a material will depend on how it is processed. Furthermore, a material's performance will be a function of its properties. Thus, the interrelationship between processing, structure, properties, and performance is linear as follows:

Processing→Structure→Properties→Performance

Why Study Materials Science and Engineering?

Why do we study materials? Many an applied scientists or engineers, whether mechanical, civil, chemical, or electrical, will be exposed to a design problem involving materials at one time or another. Examples might include a transmission gear, the superstructure for a building, an oil refinery component, or an integrated circuit chip. Of course, materials scientists and engineers are specialists who are totally involved in the investigation and design of materials.

Many times, a materials problem is to select the right material from many thousands available ones. There are several criteria on which the final decision is normally based. First of all, the in-service conditions must be characterized. On only rare occasion does a material possess the maximum or ideal combination of properties. Thus, it may be necessary to trade off one characteristic for another. The classic example involves strength and ductility; normally, a material having a high strength will have only a limited ductility. In such cases a reasonable compromise between two or more properties may be necessary.

A second selection consideration is any deterioration of material properties that may occur during service operation. For example, significant reductions in mechanical strength may result from exposure to elevated temperatures or corrosive environments.

Finally, probably the overriding consideration is economics. What will the finished product cost? A material may be found that has the ideal set of properties, but is prohibitively expensive. Here again, some compromise is inevitable. The cost of a finished piece also includes any expense incurred during fabrication.

The more familiar an engineer or scientist is with the various characteristics and structure-property relationships, as well as processing techniques of materials, the more proficient and confident he or she will be to make judicious materials choices based on these criteria.

(Selected from *Materials Science and Engineering: An Introduction*,

by William D Callister, 2002)

New Words and Expressions

pottery ['pɔtəri] *n.* 陶瓷

by virtue of 依靠（……力量），凭借，由于，因为

empower [im'pauə] *vt.* 授权，准许；使能够

empower sb. to do sth. 授权某人做某事

forerunner ['fɔːɪrʌnə] *n.* 先驱（者），传令官，预兆

stepwise ['stepwaiz] *a.* 逐步地，分阶段地

interdisciplinary [ˌintə'disiplinəri] *a.* 交叉学科的

metallurgy [me'tælədʒi] *n.* 冶金学

nebulous ['nebjuləs] *a.* 星云的，云雾状的，模糊的，朦胧的

agglomerate [ə'gləməreit] *n.* 大团，大块；*a.* 成块的，凝聚的

elaboration [iˌlæbə'reiʃən] *n.* 详尽的细节，解释，阐述

electrical conductivity 电导性，电导率

dielectric constant 介电常数

thermal conductivity 热导性，热导率

heat capacity 热容

refraction [ri'frækʃən] *n.* 衍射

reflectivity [ˌriflek'tiviti] *n.* 反射

ductility [dʌk'tiliti] *n.* 延展性

corrosive [kə'rəusiv] *a.* 腐蚀的，蚀坏的，腐蚀性的；*n.* 腐蚀物，腐蚀剂

overriding [ˌəuvə'raidiŋ] *a.* 最重要的；高于一切的

prohibitive [prə'hibitiv] *a.* 禁止的，抑制的

judicious [dʒuː'diʃəs] *a.* 明智的

criterion [krai'tiəriən] *n.* (*pl.* criteria) 标准，准则，尺度

Notes

① It was not until relatively recent times that scientists came to understand the relationships between the structural elements of materials and their properties. 这是一个强调句，强调时间。came to＋不定式，译为"终于……"，"开始……"。参考译文：直到最近，科学家才终于了解材料的结构要素与其特性之间的关系。

② The notion of "property" deserves elaboration. deserve，应受，值得；elaboration，详尽阐述。参考译文："property"一词的概念值得详细阐述。

③ Many an applied scientist or engineer,…, will at one time or another be exposed to a design problem involving materials. many a (an, another)＋单数名词，许多的，多的，一个接一个的，例如：many a person，许多人。be exposed to，暴露，面临，处于……境地。参考译文：许多应用科学家或工程师，……，在某个时候都将面临着涉及材料的设计问题。

④ On only rare occasion does a material possess the maximum or ideal combination of properties. 这是一个倒装强调句，其原句为：A material possesses the maximum or ideal combination of properties on only rare occasion. 句中的 possess 是"具有"的意思。

Exercises

1. Question for discussion

   (1) What is materials science? What is materials engineering?

   (2) Why do we study materials science and engineering?

(3) Give the important properties of solid materials.

2. Translate the following into Chinese

materials science	Stone Age
naked eye	Bronze age
optical property	integrated circuit
mechanical strength	thermal conductivity

- Materials science is an interdisciplinary study that combines chemistry, physics, metallurgy, engineering and very recently life sciences. One aspect of materials science involves studying and designing materials to make them useful and reliable in the service of human kind.

- Virtually all important properties of solid materials may be grouped into six different categories: mechanical, electrical, thermal, magnetic, optical, and deteriorative.

- In addition to structure and properties, two other important components are involved in the science and engineering of materials, namely "processing" and "performance".

- The more familiar an engineer or scientist is with the various characteristics and structure-property relationships, as well as processing techniques of materials, the more proficient and confident he or she will be to make judicious materials choices based on these criteria.

3. Translate the following into English

交叉学科	介电常数
固体材料	热容
力学性质	电磁辐射
材料加工	弹性系数 （模数）

Reading Material

Chemical Banding and Solid Materials

Solid materials are distinguished from the other states of matter (liquids and gases) by the fact that their constituent atoms are held together by strong interatomic forces. The electric and atomic structures, and almost all the physical properties, of solids depend on the nature and strength of primary interatomic bonds. Three difference types of strong of primary interatomic bonds are recognized: ionic, covalent, and metallic.

Ionic bonding: In the ionic bond, electron donor (metallic) atoms transfer one or more electrons to an electron acceptor (nonmetallic) atom. The two atoms then become a cation (e. g. ,metal) and an anion (e. g. ,nonmetal), which are strongly attracted by the electrostatic effect. This attraction of cations and anions constitutes the ionic bond.

In ionic solids composed of many ions, the ions are arranged so that each cation is surrounded by as many anions as possible to reduce the strong mutual repulsion of cations. This

packing further reduces the overall energy of the assembly and leads to a highly ordered arrangements called a crystal structure. The loosely bound electrons at the atoms are now tightly held in the locality of the ionic bond. Thus, the electron structure of the atom is changed by the creation of the ionic bond. In addition, the bound electrons are not available to serve as charge carriers and ionic solids are normally poor electrical conductors. Finally, the low overall energy state of these substances endows them with relatively low chemical reactivity. Sodium fluoride (NaF) and magnesium chloride ($MgCl_2$) are examples of ionic solids.

Covalent Bonding: Elements that fall along the boundary between metals and nonmetals, such as carbon and silicon, have atoms with four valence electrons and about equal tendencies to donate and accept electrons. For this reason, they do not form strong ionic bonds. Rather, stable electron structures are achieved by sharing valence electrons. For example, two carbon atoms can each contribute an electron to a shared pair. This shared pair of electrons constitutes the covalent bond.

If a central carbon atom participates in four of these covalent bonds (two electrons per bond), it has achieved a stable outer shell of right valence electrons. More carbon atoms can be added to the growing aggregate so that every atom has four nearest neighbors with which it shares one bond each. Thus, in a large grouping, every atom has a stable electron structure and four nearest neighbors. These neighbors often form a tetrahedron, and the tetrahedra in turn are assembled in an orderly repeating pattern (i. e. a crystal). This is the structure of both diamond and silicon. Diamond is the hardest of all materials, which shows that covalent bonds can be very strong. Once again, the bonding process results in a particular electronic structure (all electrons in pairs localized at the covalent bonds) and a particular atomic arrangement or crystal structure. As with ionic solids, localization of the valence electrons in the covalent bond renders these materials poor electrical conductors.

Metallic Bonding: The third and least understood of the strong bonds is the metallic bond. Metal atoms, being strong electron donors, do not bond by either ionic or covalent processes. Nevertheless, many metals are very strong (e. g. cobalt) and have high melting points (e. g. tungsten), suggesting that very strong interatomic bonds are at work here, too. The model that accounts for this bonding envisions the atoms arranged in an orderly, repeating three-dimensional pattern, with the valence electrons migrating between the atoms like a gas.

It is helpful to imagine a metal crystal composed of positive ion cores, atoms without their valence electron, about which the negative electrons circulate. On the average, all the electrical charges are neutralized throughout the crystal and bonding arises because the negative electrons act like a glue between the positive ion cores. This construct is called the free electron model of metallic bonding. Obviously, the bond strength increases as the ion cores and electron "gas" becomes more tightly packed (until the inner electron orbits of the ions begin to overlap). This leads to a condition of lowest energy when the ion cores are as close together as possible.

Once again, the bonding leads to a closely packed (atomic) crystal structure and a unique electronic configuration. In particular, the non-localized bonds within metal crystals permit plastic deformation (which strictly speaking does not occur in any nonmetals), and the electron gas accounts for the chemical reactivity and high electrical and thermal conductivity of metallic systems.

Weak Bonding: In addition to the three strong bonds, there are several weak secondary bonds that significantly influence the properties of some solid materials, especially polymers. The most important of these are van der Waals bonding and hydrogen bonding, which have strengths $3\% \sim 10\%$ that of the primary C—C covalent bond.

Atomic Structure: The three-dimensional arrangement of atoms or ions in solid materials is one of the most important structural features that derive from the nature of the solid-state bond. In the majority of solid materials, this arrangement constitutes a crystal. A crystal is a solid whose atoms or ions are arranged in an orderly repeating patterns in three dimensions. These patterns allow the atoms to be closely packed (i. e. ,have the maximum possible number of near or contacting neighbors) so that the number of primary bonds is maximized and the energy of the aggregate is minimized.

Crystal structures are often represented by repeating electrons or subdivisions of the crystal called unit cells. Unit cells have all the geometric properties of the whole crystal. A model of the whole crystal can be generated by simply stacking up unit cells like blocks or hexagonal tiles.

Materials

The technical materials used to build most structures are divided into three classes, metals, ceramics (including glasses), and polymers. These classes may be identified only roughly with the three types of interatomic bonding.

Metals: Materials that exhibit metallic bonding in the solid state are metals. Mixtures or solutions of different metals are alloys.

About 85% of all metals have a crystal structure. In both face-centered cubic (FCC) and hexagonal close-packed (HCP) structures, every atom or ion is surrounded by twelve touching neighbors, which is the closest packing possible for spheres of uniform size. In any enclosure filled with close-packed spheres, 74% of the volume will be occupied by the spheres. In the body-centered cubic (BCC) structure, each atom or ion has eight touching neighbors or eightfold coordination. Surprisingly, the density of packing is only reduced to 68% so that the BCC structure is nearly as densely packed as the FCC and HCP structure.

Ceramics: Ceramic materials are usually solid inorganic compounds with various combination of ionic or covalent bonding. They also have tightly packed structure, but with special requirements for bonding such as fourfold coordination for covalent solids and charge neutrality for ionic solids (i. e. ,each unit cell must be electrically neutral). As might be expected, these additional requirement lead to more open and complex crystal structures.

Carbon is often included with ceramics because of its much ceramic like properties, even

though it is not a compound and conducts electrons in its graphitic form. Carbon is an interesting material since it occurs with two different crystal structures. In the diamond form, the four valence electrons of carbon lead to four nearest neighbors in tetrahedral coordination. This gives rise to the diamond cubic structure. An interesting variant on this structure occurs when the tetrahedral arrangement is distorted into a nearly flat sheet. The carbon atoms in the sheet have a hexagonal arrangement and stacking of the sheets gives rise to the graphite form of carbon. The (covalent) bonding within the sheets is much stronger than the bonding between sheets.

The existence of an element with two different crystal structures provides a striking opportunity to see how physical properties depend on atomic and electronic structure.

Inorganic Glasses: Some ceramic materials can be melted and upon cooling do not develop a crystal structure. The individual atoms have nearly the ideal number of nearest neighbors, but an orderly repeating arrangement is not maintained over long distances throughout the three-dimensional aggregates of atoms. Such noncrystals are called glasses or, more accurately, inorganic glasses and are said to be in the amorphous state. Silicates and phosphates, the two most common glass formers, have random three-dimensional network structures.

Polymers: The third category of solid materials includes all the polymers. The constituent atoms of classic polymers are usually carbon and are joined in a linear chairlike structure by covalent bonds. The bonds within the chain require two of the valence electrons of each atom, leaving the other two bonds available for adding a great variety of atoms (e. g. , hydrogen), molecules, functional groups, and so on.

Based on the organization of these chains, there are two classes of polymers. In the first, the basic chains have little or no branching. Such "straight" chain polymers can be melted and remelted without a basic change in structure (an advantage in fabrication) and are called thermoplastic polymers. If side chains are present and actually form (covalent) links between chains, a three-dimensional network structure is formed. Such structures are often strong, but once formed by heating will not melt uniformly on reheating. These are thermosetting polymers.

Usually both thermoplastic and thermosetting polymers have intertwined chains so that the resulting structures are quite random and are also said to be amorphous like glass, although only the thermoset polymers have sufficient cross linking to form a three-dimensional network with covalent bonds. In amorphous thermoplastic polymers, many atoms in a chain are in close proximity to the atoms of adjacent chains, and van der Waals and hydrogen bonding holds the chains together. It is these interchain bonds that are responsible for binding the substance together as a solid. Since these bonds are relatively weak, the resulting solid is relatively weak. Thermoplastic polymers generally have lower strengths and melting points than thermosetting polymers.

(Selected from *Materials Science and Engineering: An Introduction*, by William D Callister, 2002)

New Words and Expressions

ionic ［ai'ɔnik］ *a.* 离子的，离子键的

covalent ［kəu'veilənt］ *a.* 共价的，共价键的

metallic ［mi'tælik］ *a.* 金属的，金属键的

cation ［'kætaiən］ *n.* 阳离子

anion ［'ænaiən］ *n.* 阴离子

electrostatic ［iˌlektrəu'stætik］ *a.* 静电的，静电学的

repulsion ［ri'pʌlʃən］ *n.* 推斥，排斥

arrangement ［ə'reindʒmənt］ *n.* 排列

sodium ［'səudiəm］ *n.* 钠

fluoride ［'flu(:)əraid］ *n.* 氟化物

face-centered (cubic) *a.* 面心（立方）的

close-packed *a.* 紧密堆积的

body-centered *a.* 体心的

coordination ［kəuˌɔːdi'neiʃən］ *n.* 配位，配位体

graphite ［'græfait］ *n.* 石墨

valence ［'veiləns］ *n.* （化合）价，（原子）价

amorphous ［ə'mɔːfəs］ *a.* 无定向的，无晶形的，隐晶质的

silicate ［'silikit］ *n.* 硅酸盐

phosphate ［'fɔsfeit］ *n.* 磷酸盐

thermoplastic ［'θəːməu'plæstik］ *a.* 热塑性的；*n.* 热塑性塑料

tetrahedron ［'tetrə'hedrən］ *n.* 四面体

tungsten ［'tʌŋstən］ *n.* 钨

thermosetting ［ˌθəːməu'setiŋ］ *a.* 热固性的（材料受热可能分解，但不软化）

intertwine ［ˌintə(:)'twain］ *v.* （使）纠缠，（使）缠绕

Notes

① In the ionic bond, electron donor (metallic) atoms transfer one or more electrons to an electron acceptor (nonmetallic) atom. electron donor (metallic) atoms，给予（失去）电子的原子（金属原子）；electron acceptor (nonmetallic) atom，接受（获得）电子的原子（非金属原子）。参考译文：在离子键中，给予电子的原子（金属原子）将一个或多个电子传递给接受电子的原子（非金属原子）。

② In ionic solids composed of many ions, the ions are arranged so that each cation is surrounded by as many anions as possible to reduce the strong mutual repulsion of cations. composed of，由……组成；as many anions as，相同数量的阴离子，一样多的阴离子；mutual repulsion，相互排斥。参考译文：在由许多离子组成的离子固体中，离子尽可能排列成每个阳离子周围有相同数量的阴离子，以削弱阳离子间强烈的相互排斥力。

③ Obviously, the bond strength increases as the ion cores and electron "gas" becomes more tightly packed. electron gas，电子云；packed 是对晶体结构的一种描述，意思是"紧密

的"，下文的 "close-packed" 和 "tightly packed" 的意思均为 "紧密堆积的"。参考译文：很明显，（金属）键的强度随着离子核与电子云堆积的紧密程度的增加而增加。

④ Crystal structures are often represented by repeating electrons or subdivisions of the crystal called unit cells. crystal structure，晶体结构；unit cell，单位晶胞。

Unit 2　Classification of Materials

Basic Classifications and Engineering Materials

Solid materials have been conveniently grouped into three basic classifications: metals, ceramics and polymers. This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another, although there are some intermediates. In addition, there are three other groups of important engineering materials—composites, semiconductor, and biomaterials. Composites consist of combinations of two or more different materials, whereas semiconductors are utilized because of their unusual electrical characteristics; biomaterials are implanted into the human body. A brief explanation of the material types and representative characteristics is offered next.

Metals: Metallic materials are normally combinations of metallic elements. They have large numbers 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.

Ceramics: Ceramics are compounds between metallic and nonmetallic elements: they are most frequently oxides, nitrides, and carbides. The wide range of materials that falls within this classification includes ceramics that are composed of clay minerals, cement, and glass. These materials are typically insulative to the passage of electricity and heat, and are more resistant to high temperatures and harsh environments than metals and polymers. With regard to mechanical behavior, ceramics are hard but very brittle.

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

Composites: A number of composite materials have been engineered that consist of more than one material type. Fiberglass 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 material developments have involved composite materials.

Semiconductors: Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators. Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, which concentrations may be controlled over very small spatial regions. The semiconductors

have made possible the advent of integrated circuitry that has totally revolutionized the electronics and computer industries over the past two decades.

Biomaterials: Biomaterials are employed in components implanted into the human body for replacement of diseased or damaged body parts. These materials must not produce toxic substances and must be compatible with body tissue (i. e. must not cause adverse biological reactions). All of the above materials—metals, ceramics, polymers, composites and semiconductors—may be used as biomaterials. For example, some of the biomaterials such as CF/C (carbon fibers/carbon) and CF/PS (polysulfone) are utilized in artificial hip replacements.

Advanced Materials

Materials that are utilized in high-technology (or high-tech) applications are sometimes termed advanced materials. By high technology we mean a device or product that operates or functions using relatively intricate and sophisticated principles; examples include electronic equipment (VCRs, CD players, etc.), computers, fiberoptic systems, spacecraft, aircraft, and military rocketry. These advanced materials are typically either traditional materials whose properties have been enhanced or newly developed, high-performance materials. Furthermore. they may be of all material types (e. g. metals, ceramics, polymers), and are normally relatively expensive.

Modern Materials Needs

In spite of the tremendous progress that has been made in the discipline of materials science and engineering within the past few years, there still remain technological challenges, including the development of even more sophisticated and specialized materials, as well as consideration of the environmental impact of materials production. Some comment is appropriate relative to these issues so as to round out this perspective.

Nuclear energy holds some promise, but the solutions to the many problems that remain will necessarily involve materials from fuels to containment structures and facilities for the disposal of radioactive waste.

Significant quantities of energy are involved in transportation. Reducing the weight of transportation vehicles (automobiles, aircraft, trains, etc.), as well as increasing engine operating temperatures, will enhance fuel efficiency. New high strength, low-density structural materials remain to be developed, as well as materials that have higher-temperature capabilities, for use in engine components.

Furthermore, there is a recognized need to find new, economical sources of energy, and to use the present resources more efficiently. Materials will undoubtedly play a significant role in these developments. For example, the direct conversion of solar energy into electrical energy uses silicon materials. To ensure a viable technology, materials that are highly efficient in this conversion process yet less costly must be developed.

Additionally, environmental quality depends on our ability to control air and water pol-

lution. Pollution control techniques employ various materials. In addition, materials processing and refinement methods need to be improved so that they produce less environmental degradation, that is, less pollution and less despoilage of the landscape from mining of raw materials. Also, in some materials manufacturing processes, toxic substances are produced, and the ecological impact of their disposal must be considered.

Many materials that we use are derived from resources that are nonrenewable, that is, not capable of being regenerated. These include polymers, for which the prime raw material is oil, and some metals. These nonrenewable resources are gradually becoming depleted, which necessitates : (1) the discovery of additional reserves, (2) the development of new materials having comparable properties with less adverse environmental impact, and/or (3) increased recycling efforts and the development of new recycling technologies. As a consequence of economics of not only production but also environmental impact and ecological factors, it is becoming increasingly important to consider the "cradle-to-grave" life cycle of materials relative to the overall manufacturing process.

(Selected from *Materials Science and Engineering : An Introduction*,

by William D Callister, 2002)

New Words and Expressions

intermediate [ˌintəˈmiːdjət] *a.* 中间的；*n.* 媒介，中间品

ceramic [siˈræmik] *n.* 陶瓷，陶瓷制品

polymer [ˈpɔlimə] *n.* 聚合物，聚合体，聚合材料

composite [ˈkɔmpəzit] *n.* 复合物，复合体，复合材料

semiconductor [ˌsemikənˈdʌktə] *n.* 半导体，半导体材料

biomaterial [ˌbaiəuməˈtiəriəl] *n.* 生物材料

implant [imˈplɑːnt] *n.* 移植，植入

oxide [ˈɔksaid] *n.* 氧化物

nitride [ˈnaitraid] *n.* 氮化物

carbide [ˈkɑːbaid] *n.* 碳化物

brittle [ˈbritl] *a.* 脆的，易碎的

recycle [ˌriːˈsaikl] *n. & vt.* （使）再循环，再利用，回收

transparent [trænsˈpærənt] *a.* 透明的，显然的，明晰的

lustrous [ˈlʌstrəs] *a.* 有光泽的，光辉的

impurity [imˈpjuəriti] *n.* 杂质，混杂物，不洁，不纯

circuitry [ˈsəːkitri] *n.* 电路，线路

despoil [disˈpɔil] *vt.* 夺取，掠夺

renewable [riˈnju(ː)əbl] *a.* 可更新的，可恢复的

Notes

① This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another, although there are some intermediates.

This scheme 指上一句中材料的分类方案；chemical makeup，化学组成（构成）；inter-mediates，指材料分类方案中的过渡类型（处于某两类之间）。

② These advanced materials are typically either traditional materials whose properties have been enhanced or newly developed，high-performance materials. 注意式中 either...or... 的并列关系，只有 whose properties have been enhanced 修饰 traditional materials，句中 newly developed 是修饰 high-performance materials。

Exercises

1. Question for discussion
    (1) Give the basic classifications of materials based on chemical makeup and atomic structure.
    (2) What are advanced materials? Please give some examples.
    (3) What do you think about the environmental impact of materials production?
    (4) What are renewable resources? Which types of materials are nonrenewable?

2. Translate the following into Chinese

    composite materials   organic compound
    advanced materials   nuclear energy
    transportation vehicles   raw materials
    nonrenewable resources   recycling technology

    - Metals are extremely good conductors of electricity and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance.
    - Ceramics are typically insulative to the passage of electricity and heat, and are more resistant to high temperatures and harsh environments than metals and polymers.
    - Materials processing and refinement methods need to be improved so that they produce less environmental degradation, that is, less pollution and less despoilage of the landscape from mining of raw materials.

3. Translate the following into English

    工程材料   黏土矿物
    可见光   玻璃纤维
    非金属元素   移植
    杂质   材料加工
    高科技   环境质量

Reading Material

How Does the Structure of Metals and Alloys Differ from that of Ceramics or Polymers?

The three basic classes of engineering materials are ⅰ) metals and their alloys, ⅱ)

man-made polymers and (iii) ceramic materials. Metals and ceramics are quite distinct from each other, but have more in common with each other than with polymers.

Consider first the differences between metals and ceramics. Whereas metals have free electrons, ceramics are ionically or covalently bonded compounds and the electrons are held rigidly in well-defined positions. Consequently, with the exception of graphite, which has an unusual structure that leaves some of the electrons mobile, ceramics tend to be good electrical insulators. In many ceramics, the bonding is stronger than in metals and so ceramics tend, for example, to have higher melting points than metals (although some very strongly bonded metals, such as tungsten, have very high melting points).

An important feature that metals share in common with ionic compounds is that neither of these forms molecules. In contrast, polymers are made up of distinct molecules (in polymers, these molecules can be very large). This difference is significant in terms of the properties of metals or ceramics versus those of polymers. For example, suppose that you wanted to melt a metal, a ceramic and a polymer. In the case of the metal, one must put in enough energy (in the form of heat) to break strong bonds between metal atoms. In contrast, in many polymers, what are known as "thermoplastic" polymers, the bonds between molecules ("intermolecular bonds") are very weak and all that need happen for melting to occur is that the weak intermolecular bonds are broken. In such cases, there is no need to disassemble the molecules themselves to cause melting. Since only very weak intermolecular bonds need be broken, thermoplastic polymers have much lower melting points than most metals or ceramics.

In "thermosetting" polymers, the different molecules are cross-linked to each other. For example, many adhesives harden by a curing process induced by heat, atmospheric exposure and/or a hardening additive. During curing, cross-linking occurs and this causes a gooey liquid to transform to a strong, rigid solid. Once cross-linking of the polymer chains has occurred, melting would require breaking up of the relatively strong bonds within the polymer chains. Consequently, thermosetting polymers have much higher melting points than do thermoplastics and, if heated in air, thermosetting polymers usually burn before they melt.

The polar bonding within polymer molecules ("intramolecular bonds") is typically far weaker than that of metals or ionic ceramics. This is a feature of the bonds involved in forming polymers, rather than an intrinsic feature of covalent bonding. For example, diamond is very strongly bonded by covalent bonds! This makes diamond very stiff and hard. Thus, a cutting wheel coated with an abrasive grit made up of small (say 10 to 100μm diameter) diamond particles will readily cut glass, for example.

What about semiconductors? In an atom, the outer (valence) electrons normally sit in the valence energy level (the "valence band"). These electrons are only free to move if sufficient energy is given to them to move the electrons to a higher energy level (called the "conduction band"). The difference in energy between the valence and conduction bands is called the "band gap" and the larger the band gap the more difficult it will be to allow elec-

trons to move. Electrons either have enough energy to jump from the valence to the conduction band, in which case electrical conduction becomes possible, or they don't, in which case the material will behave as an electrical insulator. Electrons can not sit somewhere in between the valence and the conduction bands. In the case of a metal, there is no band gap and the electrons are free to move and the metal conducts electricity, even at very low temperatures. In the case of a "typical" ceramic, say alumina for example, the band gap is very large and so even if a large amount of energy is made available (for example by heating the ceramic) electrons can not jump from the valence to the conduction band. Hence, alumina is a good electrical insulator even when hot and is widely used as such. The band gap for a semiconductor is smaller than that for an insulator, but is not zero, as in the case of a metal. Consequently, semiconductors like silicon can be made to conduct electricity if sufficient (e. g. thermal) energy is provided. Each electron carries a single negative charge, so that electrons promoted to the conduction band act as carriers of negative charges, while the "holes" left in the valence band by electrons promoted to the conduction band effectively act as if they had a positive charge (because a negative charge has been removed).

Left on their own, electrons tend to drop back from the conduction band into the valence band, thus removing both a negative charge in the conduction band and an effective positive charge in the valence band. Pure silicon (an "intrinsic" semiconductor) has exactly the same number of conduction band electrons and valence band holes, since the promotion of one electron from the valence band to the conduction band produces one hole in the valence band. Thus, pure silicon is electrically neutral overall. However, by chemically doping silicon with elements that either donate electrons to the silicon or accept electrons from the silicon, the balance between electrons and holes can be altered so that semiconductors can act as if they conduct electricity by the flow of either negative ("n-type") or positive ("p-type") charges. The transistors that form the basis of computer chips depend on putting n- and p-type semiconductors next to each other.

If ionic compounds are usually insulators, how come adding salt to water increases the conductivity of the water? Solid sodium chloride is an electrical insulator, because the band gap is too large for electrons to serve as conductors of electrical charge. Therefore, solid $NaCl$ can not be an electronic conductor. Also, although the Na^+ and Cl^- ions are charged, these are not free to move, so that the ions themselves can not serve as ionic conductors. However, dissolving sodium chloride in water allows the charged Na^+ and Cl^- ions to move freely. Likewise melting a metal salt (such as sodium chloride) can have the same effect. A material that allows conduction by the flow of ionic charges is referred to as an electrolyte. In most ceramics, this requires melting of the ceramic, however there are some ceramics ("solid electrolytes") that allow weak ionic conduction at high-temperatures in the solid-state. Solid electrolytes form the basis of many sensors (for example the oxygen sensor in the exhaust system of your car).

(Selected from *Materials Science and Engineering: An Introduction*, by William D Callister, 2002)

New Words and Expressions

ionic [ai'ɔnik]　*a.* 离子的

covalent [kəu'veilənt]　*a.* 共有原子价的，共价的

adhesive [əd'hi:siv]　*a.* 带黏性的，胶黏；*n.* 黏合剂

cure [kjuə]　*v.* 固化；*n.* 固化；加工处理

atmospheric [ˌætmɔs'ferik]　*a.* 大气的

gooey ['gu:i]　*a.* 胶黏的；*n.* 胶黏物

abrasive [ə'breisiv]　*n.* 研磨剂；*a.* 研磨的

grit [grit]　*n.* 粗砂；*v.* 研磨，在……上铺砂砾

band [bænd]　*n.* 键；*v.* 键合，成键

donate ['dəuneit]　*v.* 捐赠，赠予，给予，贡献

transistor [træn'sistə]　*n.* 晶体管

sodium ['səudjəm]　*n.* 钠

electrolyte [i'lektrəulait]　*n.* 电解，电解液

Notes

① An important feature that metals share in common with ionic compounds is that neither of these forms molecules. share with，与……共享。参考译文：金属与离子化合物都具有一个重要性质，那就是它们都不形成分子。

② The polar bonding within polymer molecules is far weaker than that of metals or ionic ceramics. polar bonding，极性键。聚合体分子中的极性键比金属和离子型陶瓷材料中的要弱得多。

Unit 3 Structure-Property Relationships of Materials

Today's materials can be classified as metals and alloys, as polymers or plastics, as ceramics, or as composites; composites, most of which are man-made, actually are combinations of different materials. Applications of these materials depend on their properties; therefore, we need to know what properties are required by the application and to be able to relate those specifications to the material. For example, a ladder must withstand a design load, the weight of a person using the ladder. However, the material property that can be measured is strength, which is affected by the load and design dimension. Strength values must therefore be applied to determine the ladder dimensions to ensure safe use. Therefore, in general, the structures of metallic materials have effects on their properties.

Stress and Strain

In a "tensile test" a sample is gradually elongated to failure and the tensile force required to elongate the sample is measured using a load cell throughout the test. The result is a plot of tensile force versus elongation. The problem is that the load required to elongate the sample by a certain extent depends upon the dimensions of the sample. This would be a big problem if, for example, mechanical property data were to be used to design a bridge, since it is clearly impossible to test an entire bridge. Thus, what is clearly needed is to make the data from the tensile test independent of the size of the sample. To achieve this end, we use "stress" and "strain".

The "true" stress (σ) is defined as: $\sigma = F/A$, where F = force applied to the sample at any given instant and A = current cross-sectional area of the sample.

The "true" strain (ε) is defined as: $\varepsilon = \ln(l_1/l_0)$, where l_1 is the current gauge length and l_0 the original gauge length of the sample.

True stress and true strain provide the most accurate description of what actually happens to the material during testing and so are widely used in materials science. For engineering design, however, there are two problems. Firstly, true stress requires knowledge of the value of A throughout the test, whereas in real world applications the designer of structures chooses an initial cross sectional area (A_0). Secondly true strain is not very easy to visualize. Consequently for engineering applications an "engineering" stress (s) and strain (e) are used in place of true stress and true strain:

$$s = F/A_0 \quad \text{and} \quad e = (l_1 - l_0)/l_0$$

Stress has a unit of Pa (i. e. N $\cdot$ m^{-2}) and strain is dimensionless. The concept of a stress is clearly closely related to that of pressure. Using the definitions of stress and strain given above, the load versus elongation curve produced by the tensile test can be converted into true stress-strain or engineering stress-strain curves. Using these curves, it is now pos-

sible to describe the mechanical properties of metals and alloys.

Stiffness, Strength, Ductility, Hardness and Toughness

In true and engineering stress-strain relationships for a "typical" metal, linear portion of the stress-strain curves the material is deforming elastically at the initial. In other words, if the load were removed the material will return to its initial, undeformed condition. In the linear elastic region, the "stiffness" or "elastic modulus" is the amount of stress required to produce a given amount of strain. For a tensile test, stiffness is described by Young's modulus (E), which is given by:

$$E = \sigma/\varepsilon \quad \text{or} \quad E = s/e$$

The greater the value of the stiffness, the more difficult it will be to produce elastic deformation. Thus, for example, in selecting a material for the springs of a vehicle, stiffness would be a key engineering design criterion.

On exceeding a certain stress, known as the "yield stress" or "yield strength"(σ_y or s_y in true and engineering stress respectively), the stress-strain curve ceases to be linear and the material begins to undergo permanent "plastic" deformation. In the plastic region of the stress-strain curve, it is apparent that the stress required to continue plastic deformation is higher than that required to make the material yield. This phenomenon is called "work hardening" or "strain hardening". In the true stress-strain curve, it can be seen that work hardening actually continues right up until failure at the failure stress σ_f. In contrast the engineering stress strain curve shows a maximum stress, the "ultimate tensile stress"(UTS), prior to final failure. During final failure, the sample starts to "neck" down to failure and this is not accounted for when A_0, rather than A, is used to calculate a stress. Nonetheless, for a design engineer, the UTS is a very useful datum and the UTS (rather than σ_f) is normally used as the measure of the "tensile strength" of a material.

"Ductile" materials are those that can undergo plastic deformation and so the greater the extent of plastic deformation, the higher the "ductility". The engineering strain to failure is a common measure of ductility. Note that if l is measured after the sample has failed, then the elastic portion of the sample's elongation will be removed, since the applied load is removed when the sample fails. Thus only plastic and not elastic deformation will contribute to an l_1 measured after failure.

The "hardness" of a material is a measure of the resistance to plastic deformation. Hardness is measured by determining the depth or projected area of an indentation produced by a standard indentor. The higher the hardness of the material, the shallower the indentation for a given load and the smaller the projected area. Hardness is an important property in many applications. Consider, as an example, a material intended to serve as the liner for a bearing supporting a rotating shaft. Many bearing alloys consist of a hard phase in a soft phase. The purpose of the hard phase is to resist abrasion as the shaft turns. The soft phase serves both to bind the hard phase into place and allows wear debris to become embedded, thus preventing the debris from damaging the shaft.

The "toughness" of a material is a measure of how much energy can be absorbed by the material before failure. Toughness is determined by subjecting the material to an impact from a swinging hammer and measuring the amount of energy absorbed from the swing. Energy is absorbed by plastic deformation and hence ductile materials show a high toughness. In contrast, brittle materials can have a high strength, but have negligible toughness. For example, it is preferable for the crumple zones in your car to absorb as much of an impact as possible through extensive plastic deformation than to have your bones undergo brittle failure. Likewise, a concrete guard rail is good for protecting construction workers, because the kinetic energy of an oncoming vehicle is absorbed by deformation of the vehicle. In contrast, a steel guard rail protects drivers because plastic deformation of this absorbs energy efficiently in the event of an impact, but is not so good at protecting construction workers because the vehicle is not brought to a sudden halt. So do what the signs say and slow down for construction!

In addition to the properties discussed above, other mechanical properties are very important. These include resistance to "fatigue" failure due to cyclic loading and to thermally assisted, time-dependent "creep" deformation and failure.

An Example of a Processing, Structure-Property Relationship

There are many possible examples of the relationship between processing, structure and properties. However, the following example is chosen because it illustrates a number of the features discussed in materials science.

Nickel-boron alloys form the basis of brazes used to join many nickel-base alloys, especially in aerospace. A eutectic forms between nickel and the nickel boride Ni_3B and so a nickel boron braze can melt and flow without melting the nickel-base materials to be joined. However, boron diffuses as an interstitial in nickel and can diffuse rapidly away into the substrates. Dispersing the boron removes the liquid (which was only there because, by forming an eutectic, boron depresses the melting-point of nickel) and this allows components to operate at high temperatures without these melting in service.

A problem with using boron-containing brazes is that Ni_3B is very brittle and this means that these brazes can not be produced as a sheet by conventional means, such as rolling. Thus, these types of brazes are often used as a powder which is inconvenient to handle and oxide from the surface of the powder particles can reduce the strength of joints. As an alternative, a molten nickel-boron alloy can be sprayed onto the surface of a rapidly spinning copper wheel, which carries heat away very efficiently. This process is called "melt-spinning". Given the very high cooling rate, the liquid can not crystallize and a metallic glass is formed. Thus, no borides are formed and the resulting foil is quite ductile and can easily be placed into position in the joint. During heating to the bonding temperature, as soon as the temperature becomes hot enough for diffusion to occur, the metallic glass crystallizes. Crystallization takes place far below the equilibrium melting temperature and the result is lots and lots of nucleation and very little growth so that a very fine grain size is produced. Ni_3B is precipi-

tated during crystallization and this does make the foil brittle, but this doesn't matter at this stage since the foil is about to be melted for the brazing operation.

(Selected from *An Introduction to Metallic Materials*, by William F. Gale, 2002)

New Words and Expressions

stress [stres] *n.* 应力

strain [strein] *n.* 应变

gauge [geidʒ] *n.* 标准尺，规格，量规，量表；*v.* 测量

datum ['deitəm] *n.* 数据，资料

indentor [in'dentə] *n.* 压锥，压头，挤入体

stiffness ['stifnis] *n.* 刚度，刚性

strength [streŋθ] *n.* 强度

ductility [dʌk'tiliti] *n.* 延展性，韧性

hardness ['hɑːdnis] *n.* 硬度，坚固

toughness [tʌfnis] *n.* 韧度，韧性

shaft [ʃɑːft] *n.* 轴，杆状物

debris ['debriː] *n.* 碎片，残骸

swing [swiŋ] *v.* 摇摆，摆动，回转，旋转；*n.* 秋千，摇摆，摆动

crumple ['krʌmpl] *v.* 弄皱，压皱，变皱，崩溃，垮台

kinetic [kai'netik] *a.* （运）动的，动力（学）的

braze [breiz] *vt.* 铜焊；*vt.* 用黄铜镀或制造

eutectic [juː'tektik] *a.* 易熔的，在最低温度可融化的，共熔的；*n.* 共晶

spray [sprei] *n.* 喷雾，飞沫；*vt.* 喷射，喷溅

boride ['bɔːraid] *n.* 硼化物

nucleation [ˌnjuːkli'eiʃən] *n.* 成核现象，晶核形成

Notes

① The "true" stress (σ) is defined as: $\sigma = F/A$, where F = force applied to the sample at any given instant and A = current cross-sectional area of the sample. 描述公式时，一般用 where 或 in which 引导定语从句对公式中的内容进行解释。

② Consequently for engineering applications an "engineering" stress (s) and strain (e) are used in place of true stress and true strain. engineering stress and strain，工程应力与应变；true stress and true strain，纯应力和纯应变；in place of，取代。

③ Stress has a unit of Pa (i.e. N · m^{-2}) and strain is dimensionless. 参考译文：应力的单位是 Pa（即 N · m^{-2}），应变是无量纲的。

④ In other words, if the load were removed the material will return to its initial, undeformed condition. its initial, undeformed condition，指材料未变形的初始状态。参考译文：换句话说，如果将加载的负荷去掉，材料将回到其未变形的初始状态。

⑤ This phenomenon is called "work hardening" or "strain hardening". work hardening，加工硬化（金属晶体结构永久变形所致），加工强化；strain hardening，应变硬化。

Exercises

1. Question for discussion
   (1) Explain the following notions: stress, strain, stiffness, strength, ductility, hardness and toughness of materials.
   (2) Please give an example to explain the relationship between structure and property of materials.
   (3) What are the differences between engineering stress-strain curves and true stress-strain curves?

2. Translate the following into Chinese

tensile test	plastic deformation
load cell	gauge length
cross-sectional area	fatigue failure
elastic modulus	yield strain

   - Applications of these materials depend on their properties; therefore, we need to know what properties are required by the application and to be able to relate those specifications to the material.
   - True stress and true strain provide the most accurate description of what actually happens to the material during testing and so are widely used in materials science.
   - "Ductile" materials are those that can undergo plastic deformation and so the greater the extent of plastic deformation, the higher the "ductility".

3. Translate the following into English

张力	应力-应变曲线
无量纲的	弹性变形
动能	熔点
镍铜合金	共熔温度
极限抗拉强度	蠕变

Reading Material

Fracture Mechanisms of Elastic and Plastic Deformation for Materials

The science of "fracture mechanics" deals with how fracture occurs and how this can be prevented. Prior to fracture mechanics, designers had little guidance and the results could be most unfortunate. Two examples of this were the Liberty Ships and the Comet airliner. The Liberty Ships were supply ships built in large numbers, for the US Navy, during World War II. There was a great need for transportation and so these ships had to be constructed very quickly. The traditional method of riveting the hulls of ships is slow and so

these ships used welded hulls (as is the standard today). Unfortunately, at that time, little was understood about either welding metallurgy or fracture mechanics and the Liberty Ships had a bad habit of breaking in two, even in harbor! Likewise, the Comet led the way into pressurized cabin, jet airliners, but several were lost in mysterious circumstances. Only by testing whole aircraft to destruction was a problem with fatigue failure diagnosed. Recent studies of the loss of the Titanic suggest that limited control of the microstructure of the hull may have exacerbated the damage done when this ship hit an iceberg. These kinds of details might not make a Hollywood blockbuster, but had a big effect on those with the misfortune to be a member of the crew or a passenger on the Titanic.

Elastic Deformation

Elastic deformation involves stretching, rather than breaking, bonds between atoms. Consequently, when the applied load is removed, the material can revert to its original undeformed condition. In contrast, plastic deformation involves the breaking of bonds and the making of new bonds, and is therefore permanent. Elastic deformation is a "cohesive" property that depends on the bonding of the material. Consequently, stiffness is not dependent on the microstructure of the material. For example, all steels have about the same elastic modulus. In contrast, the yield and ultimate tensile strengths of metals and alloys are extremely sensitive to microstructure.

To understand the practical significance of this difference, consider building a scaffolding tower from an aluminum alloy. The low density of aluminum makes aluminum scaffolding light and so easy to erect and the high corrosion-resistance of aluminum alloys very useful for outdoor applications. Unfortunately, pure aluminum has both a very low yield stress and a low stiffness. By alloying and appropriate processing, the yield stress of aluminum can be increased to the point where the scaffolding tower will not plastically deform during normal use. In contrast, aluminum alloys suffer from the same low modulus as pure aluminum and consequently an aluminum scaffolding tower sags alarmingly when somebody climbs this.

A student working part-time in a bike shop mentioned that they considered aluminum bicycle frames to be "stiffer" than steel frames and wondered about the apparent contradiction between this and the much lower stiffness of aluminum alloys than steels. Here the key point is that the low density of aluminum allows the use of designs that employ stiff shapes. Likewise, the "radiator" in modern cars is made from very thin gauge aluminum strip, but this is fabricated into a honeycomb structure that is both stiff and very light. These are examples of how, with good mechanical design, even undesirable characteristics of materials can be accommodated. Alternatively, another way of dealing with the low stiffness of aluminum alloys is to form a composite with an aluminum matrix reinforced with a stiff material such as silicon carbide (SiC).

However, designers don't always make correct use of the stiffness of the materials they build with, especially when a new and creative design is attempted. For example, the Mil-

lennium Bridge across the River Thames in London uses a revolutionary new design, that has been widely praised for its aesthetics. Unfortunately, when first opened, the bridge tended to sway from side to side to an extent that proved very disconcerting for users of the bridge. This was not really a safety problem (the motion was on a much smaller scale which led to the failure of the famous Tacoma Narrows bridge in Washington State), but the Millennium Bridge was closed temporarily for dampers to be fitted.

The Role of Dislocations in Plastic Deformation

The mechanism of plastic deformation involves sliding layers of atoms over each other. This is a shearing process and occurs as close as possible to the plane of maximum shear stress (which is at 45 degrees to the tensile axis). Generally, the more closely packed together the atoms are, the easier the layers of atoms will be to slide. Hence, shearing takes place in the close-packed plane and along the close packed direction that are nearest to the location of maximum shear stress.

If every bond between layers of atoms had to be broken at once, then the stress required would be more than that needed to cause fracture. In such a case, metals and alloys would be completely brittle (i. e. metals would have mechanical properties like those of rock and human beings would be stuck in the Stone Age!). Fortunately, defects called "dislocations" exist in the structure of metal crystals. Dislocations are a localized imperfection in the alignment of the layers of atoms in the lattice. These can consist of a) layers being twisted with respect to each other (the result looks like a screw thread and so these are called "screw" dislocations), b) an extra half plane of atoms (this is an "edge" dislocation) or c) a combination of these two.

Dislocations can serve as a means of producing the shearing involved in plastic deformation. The key point is that dislocations can be moved through the material with only localized making and breaking of bonds and so reduce the yield stress to a manageable level. The existence of dislocations alone does not guarantee ductility. Ceramic materials do have dislocations. However, the crystallography of ceramics makes these immobile and so ceramics are brittle.

Strain Hardening and Annealing

As was noted by scientists, metals and alloys undergo work hardening. This phenomenon is associated with the formation of new dislocations, during plastic deformation. Some dislocations are present, as random growth defects, in undeformed metals and alloys. During plastic deformation, however, many new dislocations are formed. The more dislocations that are trying to move at once, the greater the probability of dislocations becoming entangled. The result is dislocation pile-ups that make further plastic deformation more difficult. Hence, the stress required to produce further deformation is increased and work hardening occurs. Without work hardening, the yield and ultimate tensile stresses would be exactly the same.

Unlike plastic deformation itself, strain hardening is reversible. By heating to a sufficiently high temperature (an example of an "annealing" treatment) the dislocations are able to re-orient themselves into networks, in a process called "recovery". Further heating actually allows the growth of new grains with a low dislocation density. This is called "recrystallization". Both recovery and especially recrystallization remove dislocation pile-ups and hence reduce the hardness of the material. The driving force is that, just as an interface (basically a defect that covers an area) has an associated energy, so does a dislocation (a line defect). Hence, removing dislocations (via a thermally activated process) reduces the energy of the material.

If a material is cooled immediately after recrystallization, the new grains will be quite small. With prolonged heating, grain growth will occur as big grains cannibalize their smaller neighbors. Grain growth reduces the total grain boundary area and this process is driven by the material's desire to reduce its total interfacial energy. Grain size is very important in plastic deformation, because there is an inverse relationship (the Hall-Petch relationship) between grain size (d) and yield stress:

$$\sigma_y = \sigma_0 + k_y (d^{-0.5})$$

where k_y and σ_0 are constants. For a single crystal d is large and so $\sigma_y = \sigma_0$.

The neat thing about a fine grain size is that not only does this make the material stronger, but this also enhances toughness (unlike other methods of strengthening that reduce ductility). The only time that a fine grain size is not desirable is for high-temperature service, because the presence of grain boundaries enhances creep.

Strain hardening is used to strengthen metallic materials (at the price of reduced ductility) by using forming treatments (e. g. rolling) at temperatures that are too low for recovery to occur. These types of treatments is known as "cold working". In contrast, materials "hot worked" at high temperatures will recrystallize dynamically during working, so that strain hardening is continually removed. Thus, hot work is used to reduce to manageable levels the loads required to form large components.

Yield-Point Effects

In pure metals and many alloys, yielding is a gradual ("continuous") process, as those dislocations that are most favorably situated will move at a lower applied stress than others.

In steels, a distinctive sharp ("discontinuous") yield point is produced. This is the result of the presence of interstitial carbon in the steel. Carbon is somewhat too large for the interstitial sites in α-Fe. Hence, the dilation of the lattice produced by the tensile portion of the strain field around a dislocation improves the fit of the carbon atoms into the lattice. Thus, carbon tends to diffuse to dislocations forming what is known as an "atmosphere". Once an atmosphere forms, carbon is reluctant to be separated from the dislocation and this increases the yield stress. A sharp yield point is produced when the applied stress becomes high enough to unzip the dislocations from their carbon atmospheres.

If a steel is loaded beyond yield, and then immediately unloaded, gradual yielding will

occur on the second loading cycle. The reason for the occurrence of gradual yielding is that the first round of yielding separated the dislocations from their atmospheres. In contrast, if the steel is allowed to sit for a while between the first and second loading cycle, then discontinuous yielding is observed on the second cycle. The return of this sharp yield point is known as "strain aging" and is due to carbon atoms having time to diffuse back to the dislocations and re-form the atmospheres.

Brittle Versus Ductile Failure

In brittle materials, final failure generally initiates at pre-existing defects such as cracks (originating, for example, from fatigue), or notches. The cross-sectional area is lower in the region with a crack than in uncracked regions. Hence, for a given applied load, the stress is higher in regions with cracks than without. If the load is increased and/or the cracks are made larger, then a point will be reached at which this stress can no longer be borne and the material will cleave into two pieces. Cleavage cracks like this can move very quickly (around the speed of sound) and cleavage failure provides little advanced warning. Hence non-destructive examination to detect cracks that are close to the critical size is very important in, for example, the aerospace industry. Cleavage failure involves pulling the material apart and hence brittle cracks grow perpendicular to the tensile axis.

Face-centered cubic metals (FCC) and alloys are usually ductile at all temperatures. In contrast, body-centered cubic (BCC) materials tend to become brittle at low temperatures. The reason for this difference is that the atoms in FCC metals are closely packed, whereas those in BCC metals are somewhat less close packed. Close packing makes the layers of atoms easier to slide over each other and hence makes plastic deformation easier. Also, materials that are normally ductile can be embrittled by contaminants; for example hydrogen originating from moisture in the atmosphere can induce brittle failure of welds in otherwise ductile steels, so it is vital for example to keep welding rods in a dry atmosphere.

In a ductile material, plastic deformation tends to blunt cracks and cleavage failure does not occur. Instead, final failure is induced by the formation of microvoids after extensive plastic deformation. These microvoids form usually due to decohesion between precipitates (e. g. manganese sulfide, MnS, in steels) and the matrix, or fracture of precipitates. As deformation continues, the microvoids eventually coalesce and final failure occurs. Since microvoid formation and coalescence is the result of plastic deformation, failure occurs at in the plane of maximum plastic deformation. This is the plane of maximum shear stress and is at 45 degrees to the tensile axis.

In addition, the microstructure of a material has a huge effect on plastic deformation, involving a large number of different mechanisms.

(Selected from *An Introduction to Metallic Materials*, by William F. Gale, 2002)

New Words and Expressions

rivet ['rivit] *n.* 铆钉; *v.* 固定

hull ［hʌl］ *n.* 外壳，船体

exacerbate ［eks'æsə(:)beit］ *vt.* 恶化，增剧，激怒，使加剧，使烦恼

blockbuster ［'blɔkˌbʌstə］ *n.* （破坏力极大的）巨型炸弹，一鸣惊人者

tensile ［'tensail］ *a.* 可拉长的，可伸长的；张力的，拉力的

sag ［sæg］ *v.* 松弛，下陷，下垂，漂流；*n.* 下垂，下陷，物价下跌，随风漂流，垂度

honeycomb ［'hʌnikəum］ *n.* 蜂房，蜂巢

sway ［swei］ *v.* 摇摆，摇动

disconcert ［ˌdiskən'səːt］ *vt.* 使惊惶，使仓皇失措，破坏

damper ［'dæmpə］ *n.* 起抑制作用的因素，节气闸

cannibalize ［'kænibəlaiz］ *vt.* & *vi.* 拆用配件，调拨人员

dilation ［dai'leiʃən］ *n.* 膨胀，扩张，扩大

cleavage ［'kliːvidʒ］ *n.* 劈开，分裂

perpendicular ［ˌpəːpən'dikjulə］ *a.* 垂直的，正交的；*n.* 垂线

coalesce ［ˌkəuə'les］ *v.* 接合

Notes

① The science of "fracture mechanics" deals with how fracture occurs and how this can be prevented. fracture mechanics，断裂力学。参考译文：断裂力学主要研究断裂是怎样产生的和怎样防止断裂。

② In contrast，the yield and ultimate tensile strengths of metals and alloys are extremely sensitive to microstructure. 注意句中的 strengths 是复数形式，其修饰词为 yield 和 ultimate tensile；be sensitive to，对……灵敏。参考译文：相反，金属与合金的屈服强度和极限抗拉强度对显微结构极其灵敏。

③ A student working part-time in a bike shop mentioned that they considered aluminum bicycle frames to be "stiffer" than steel frames and wondered about the apparent contradiction between this and the much lower stiffness of aluminum alloys than steels. 参考译文：一个在自行车商店兼职工作的学生提到，他们认为铝自行车框架比钢架的刚性更强，但铝合金的刚性较钢的刚性要低得多，因此很想知道这两者之间为什么会存在如此明显的矛盾。

④ If a material is cooled immediately after recrystallization，the new grains will be quite small. With prolonged heating，grain growth will occur as big grains cannibalize their smaller neighbors. recrystallization，重结晶作用；grain，晶粒（结晶形成的颗粒）；big grains cannibalize their smaller neighbors，大晶粒吞噬其相临的较小晶粒。

Unit 4 Chemistry and Advanced Materials

Chemistry of Advanced Materials

Stone, bronze, iron: civilization has always been defined by Man's relationship with materials. Nowadays, materials have become such an integral part of our society, that they are often either underappreciated or even overlooked. But much of the technological progress is directly or indirectly dependent on the availability of advanced materials with improved functions. It is often forgotten that there is much chemistry behind these investigations!

Being closely related to materials science, chemistry focuses on the atomic or molecular level, and materials science deals with macroscopic properties, however both together provide a proper understanding of how chemical composition, structure, and bonding of materials are related to the particular properties. In the earlier days of civilization, especially in the production of metals, chemistry was only used empirically for the processing of materials, far from any understanding of the basic concepts. But many arising problems like pollution of the environment or the toxicity of different materials nowadays clearly reveal the need of a better understanding of the basic chemistry. It is becoming widely recognized that no new method for extracting or processing a material can be considered without good understanding of the real costs as well as its fate after its lifetime. A number of important aspects have to be investigated for example whether the required properties can be achieved and maintained during the use of a material, whether the material is compatible with other parts of an assembly, whether a material can be easily recycled, whether a material causes environmental problems, and whether a material can be produced economically. Taking the fact into account that most of the processes during the life-cycle of a product are typically chemical reactions, it becomes obvious, that the solution of fundamental materials science problems is intimately interconnected with our knowledge in chemistry. Only a better understanding of the chemical concepts involved in materials life-cycle leads to substantial improvements in materials technologies. The understanding of the nano-structure of materials will be an essential part of such an enterprise. But the complexity and interdisciplinary nature of material science and engineering requires effective cooperation between scientists and engineers from various disciplines.

Solid State Chemistry and Nanochemistry

In general, research in solid state chemistry is concerned with investigations of syntheses, structures and properties of solids. The most important motivation is to understand, to predict, and to design the properties of solids with respect to both, chemical composition and their crystal and electronic structures. Of course, the first step is the synthesis of the required material. Three different categories of solid state synthesis can be distinguished de-

pending on the motivation:

i) preparation of known compounds to investigate a specific property;

ii) synthesis of unknown members in a structurally related family in order to extend structure-property relations;

iii) synthesis of new classes of solids.

Thus, solid state chemistry is mainly concerned with the development of new synthesis methods, new ways of identifying and characterizing materials and of describing their structure. In the last few years, the key direction of solid state chemistry lay in the search for new strategies of tailor-making materials with desired and controllable properties. Although there have been major advances in the synthesis of solid materials due to many new chemical methods, we are still far away from a tailor-making of solid materials with specified structures/properties. Most of the discoveries of new solids still have been made by chance! Therefore, rational design and synthesis of novel materials have remained important objectives. The control over the composition is often possible, but still then there must be a way of producing materials in any required micro- and nanoscopic shape or form. At the same time, the characterization of materials is a critical ingredient to progress, because it provides guidance for further research efforts.

In the last few years, solid state chemists started to exploit a combination of covalent and non-covalent interactions, i. e. they started to connect molecular chemistry, the chemistry of the covalent bond, with supramolecular chemistry, based on non-covalent, intermolecular forces (electrostatic interactions, hydrogen bonding, van der Waals forces). Molecular chemistry is concerned with uncovering and mastering the rules that govern the structures, properties, and transformations of molecular species, whereas the supramolecular chemistry is covering the structures and functions of organized entities of higher complexity formed by association of two or more chemical species held together by intermolecular forces. These polymolecular assemblies may lead to supramolecular devices, defined as structurally organized and functionally integrated chemical systems built on supramolecular architectures.

From molecular to supramolecular chemistry, nanochemistry is the pursuit of this development of bottom-up synthesis of complex objects. The nanochemist's future goal is to built and organize nanoscale objects under mild and controlled conditions finally of one cluster of atoms or even one atom at a time instead of manipulating the bulk, thus, providing a reproducible method of preparing materials that are perfect in size and shape. Nowadays, one would call this directed self-assembly. At present, nanochemistry is concerned with the development of novel methods for the synthesis and characterization of chemical systems within the size range of about 1 nm to 100 nm.

The interest in nanoscale objects is due to the exhibition of novel electronic, optical, magnetic, transport, photochemical, electrochemical, catalytic and mechanical behaviors, depending on composition, size, and shape of the particles. The physical properties of nanoparticles neither correspond to those of the free atoms or molecules making up the particle

nor to those of the bulk solids with identical chemical composition. It is astonishing, that many relevant phenomena at nanoscale are caused by the tiny size of the organized structure and by interactions at their predominant and complex interfaces. When the chemists are able to gain control over size and shape of the particles, further enhancement of material properties and device functions will surely be possible. Each change in both, composition or size can lead to different physical and chemical properties, providing a large number of new materials. Interestingly, it is true that the products of nanochemistry exhibit new and useful properties, but at the same time it is not necessarily a need for new starting materials; new applications and properties are rather a result of tailoring matter and subsequently arranging the components by means of chemical interactions, so, ideally, new properties can arise from a combination of inexpensive and environmentally harmless components.

At present the field of nanochemistry includes (ⅰ) nanoparticles, (ⅱ) nanocrystalline materials and (ⅲ) nanodevices. The most important aspect is still the development of new strategies for the synthesis of nanomaterials, particularly soft chemical routes.

But the chemist not only has to be able to synthesize perfect, i. e. ,monodispersed and shape-defined objects having nanometer dimensions, but also may have to position these objects in appropriately organized arrays. This may be tackled either by using lithographic techniques or templating methods (molecular and supramolecular assembly processes, or deposition inside the void spaces of nanoporous host materials). However, the templating methods may become the most favorable in the far run towards directed self-assembly. All this reflects the desire of the chemists to deliberately control, to design, the synthesis of a particular solid-state structure.

(Selected from *Synthesis and Characterization of Novel Micro-and Nanostructured Material*, by Markus Josen Niederberger, 2001)

New Words and Expressions

nano-structure　['nænəu'strʌktʃə]　*n.* 纳米结构
covalent　[kəu'veilənt]　*a.* 共有原子价的，共价的
supramolecular　['sjuːprəmə'lekjulə]　*a.* 超分子的
nanochemistry　['nænou'kemistri]　*n.* 纳米化学
self-assembly　['self-ə'sembli]　*n.* 自组装
template　['templit]　*n.* (＝templet) 模板
lithographic　[ˌliθə'græfik]　*a.* 平版印刷的，平版的

Notes

① ..., they started to connect molecular chemistry, the chemistry of the covalent bond, with supramolecular chemistry, based on non-covalent, intermolecular forces. 本句结构是 they started to connect... with..., 他们开始将……与……结合在一起。the chemistry of the covalent bond 是对 molecular chemistry 的说明；同样，based on non-covalent, intermolecular forces 是对 supramolecular chemistry 的解释。

② The most important aspect is still the development of new strategies for the synthesis of nanomaterials, particularly soft chemical routes. soft chemical routes，可直译为"软化学路线"，实质上是指纳米材料合成的化学技术路线。

Exercises

1. Question for discussion
   (1) What are the relations between chemistry and materials?
   (2) Explain solid state chemistry and nanochemistry.
2. Translate the following into Chinese

   materials life cycle   supramolecular chemistry

   solid state chemistry   nano-structure

   nanocrystalline materials   non-covalent interaction

   - Being closely related to materials science, chemistry focuses on the atomic or molecular level, and materials science deals with macroscopic properties, however both together provide a proper understanding of how chemical composition, structure, and bonding of materials are related to the particular properties.
   - Molecular chemistry is concerned with uncovering and mastering the rules that govern the structures, properties, and transformations of molecular species, whereas the supramolecular chemistry is covering the structures and functions of organized entities of higher complexity formed by association of two or more chemical species held together by intermolecular forces.
   - At present the field of nanochemistry includes (ⅰ) nanoparticles, (ⅱ) nanocrystalline materials and (ⅲ) nanodevices. The most important aspect is still the development of new strategies for the synthesis of nanomaterials, particularly soft chemical routes.
3. Translate the following into English

   化学反应   固态化学

   分子化学   分子间力

   超分子结构   自组织

   纳米材料   氢键

Reading Material

Chemistry and the Synthesis of Novel Materials

Introduction: Chemistry and Materials

All the solids around us, natural and man-made, are materials and the science of materials is the effort to understand the relationships between structure and properties so that structures can be selected and constructed to have the properties desired. The properties in

question are nearly always physical: chemical reactions, on or within solids, are the subject matter of chemistry proper, though perhaps an exception could be made in the case of ionic migration.

Chemistry has impacted on the science of materials in two ways. First, it has brought new methods to the synthesis of solids. Traditional methods of making ceramics, glasses, and so on were optimized largely by empirical means, some going back hundreds or even thousands of years: "heat it and beat it" is a phrase encapsulating the older ceramics industry, for example. Recent study of the reaction mechanisms involved in forming solid phases from precursors has made it possible to use much lower temperatures to make ceramics which, with sol-gel processing, has revolutionized production of these materials. Similarly, to deposit thin (not just in the semiconductor industry but in anti-abrasion surface hardening and optical coating) decomposing organo-metallic molecules has proved a notable advance over the "engineering" approach of flinging atoms at a cold surface in an ultra high vacuum.

The second way that chemistry has widened the perspectives of materials science will, in the long run, certainly prove more influential even than the control of synthesis. It lies at the core of the whole discipline of chemistry, and in enlarging the range of the possible by synthesizing new lattices of atoms and molecules not previously found in the natural or man-made worlds. Such lattices are much more complex than hitherto, providing unit cells bordering on the mesoscopic, and give access to properties not previously observed. One aspect of this novelty is the concept of self-assembly.

Long And Short Range Order

Solids can be classified by the degree of order in the structures through the concept of a correlation function, and can be defined by the average value of the product of two vectors, representing the position or orientation of the contents of a given unit cell and the other the corresponding arrangement at a given distance from the first. If the positions and orientations of the contents of the remote region map completely on to that of the reference cell the average value of the vector product is unity, while if there is no correlation between them the correlation function is zero. We can define both short and long range correlation functions and classify solids by the length scale over which correlation exists. Thus amorphous solids show correlation between atom positions over short range but not long. Glasses (which may be formed by polyhedral SiO_4 and PO_4 sharing vertices, or even by random atomic distributions in metals) are isotropic on length scales much larger than interatomic. However, other classes of solid may be disordered in more complicated ways. Liquid crystals, for example, show long range structural correlation in one or two dimensions simultaneously with only short range correlation in the third. Solid polymers, too, having covalent backbones, show anisotropic atom-atom correlations which lead to unusual dynamical behavior.

Infinite correlation lengths in three dimensions characterize the crystalline state where, the infinitely repeating units can be not only single atoms but also molecules. In a continu-

ous lattice solid like SiO_2 or Al_2O_3 no molecular units can be distinguished, but a molecular crystal like CO_2 or naphthalene dissolves or vaporizes into molecules rather than atoms. A particularly interesting class of crystals, which have become more and more important in recent years, combines the characteristics of continuous and molecular in the same lattice, for example continuous layers interleaved by molecular units, as in the layer perovskite salts $(C_nH_{2n+1}NH_3)_2 MX_4$. A final category of solid is the "composite", strictly speaking a two-phase material in which exceptional mechanical properties are conferred by small particles of one kind of material within the matrix of another on a mesoscopic scale, that is, in the range $10 \sim 100$ nm. Thus we have metal-matrix or polymer-matrix composites, for instance incorporating carbon fibers.

Simple and Composite Chemical Bonding

In real solids the classical paradigms of ionic, covalent, metallic and van der Waals bonding are augmented by many other more interesting possibilities. There are a number of cases where two distinct bonding modes coexist in the same crystal lattice. For instance in a crystal of C_{60} intramolecular C—C bonds are certainly covalent but the interaction between C_{60} is of van der Waals type although at low temperature more specific interaction develops between C—C double bonds on one C_{60} and the C_5 rings on its neighbors. These differences are relevant to the dynamics of the C_{60} crystal: free rotation of the molecules at high temperature is replaced by finite jumps at the temperature, inducing a series of structural phase transitions.

When C_{60} forms superconducting K_3C_{60}, ionic interactions are added to the covalent and van der Waals ones. More unusual are cases such as $K_2Pt(CN)_4Br_{0.30} \cdot 2H_2O$ (commonly called KCP) where metallic bonding in one dimension is combined with ionic bonding in directions orthogonal to the chain of metal atoms. Even more peculiar are the superconducting molecular charge transfer salts like $(BEDT-TTF)_2X$ where BEDT-TTF is bisethylenedithio-tetrathiafulvalene, a quasi-planar organo-sulfur molecule, and X is an inorganic anion such as I_3^-, $AuBr_2^-$, $Cu(NCS)_2^-$. The metallic character arises from overlap of frontier molecular orbitals on neighboring molecules which, however, are charged and so interact primarily by Coulomb forces with the polyatomic anions.

Physical Properties and Their Combinations

The physical properties of solids are rarely the sum of properties attributable to the individual components. For example, in a molecular superconductor the superconductivity of one molecule is a nonsense—the property is a collective one, belonging to the aggregate. One could make the analogy with extrinsic and intrinsic thermodynamic properties, e. g. temperature cannot be ascribed separately to each unit in a solid ensemble.

The properties of interest to chemists are often the ones studied in simple prototypical solids many years ago by the physicists, though with the proviso that new properties or combinations may arise that challenge the simple paradigms. Properties are redivided into

those which arise from the cohesive forces binding the crystal and those classed as "electronic". Among the former are thermal properties such as specific heat, and mechanical properties like compressibility. It might appear that hardness would also come into the same category, but in practice it is rarely an intrinsic property, being determined more by isolated and extended defects and dislocations. Chemists have not thought much about mechanical properties, certainly not with a view to designing such properties into the structure. However, matching the observed compressibility (and its pressure dependence) is a sensitive method of calibrating the interionic and intermolecular potentials used in the structure simulations.

Just as that many of the most interesting solids have more than one mode of chemical bonding in their lattices, so many interesting properties arise not alone but by combining physical phenomena. For example, thermally induced phase transformations combine with differences in optical behavior in two phases to give the property of thermochromism. Stress, too, influences other physical properties, leading to the technologically important properties of ferroelectricity, ferroelasticity and magnetostriction. Likewise photon absorption gives rise to photochromism or photoconductivity, and even changes in magnetism, though photomagnetic effects are less well known. Finally electrical conductivity can be influenced by magnetic fields, most spectacularly in the so-called "giant magnetoresistance" effects in $La_x Sr_{1-x} MnO_3$.

The remainder of this survey exemplifies some of the points made above by considering two special topics. One is the special features associated with the less well developed field of molecular materials, and the other is the diverse materials that can exhibit a single property; some examples are given from the field of superconductivity.

Molecular Solids: A New Horizon for Solid State Chemistry

The paradigms of physical behavior in the solid state are based on prototypes with simple crystal structures, containing only one to three atoms in the chemical unit cell. Such is the variety of electronic structure accessible by permuting of 90 stable elements in the periodic table, that all the bonding types are already available even in this limited subset. Conductivity is a property that spans the largest number of orders of magnitude of any in the universe: 28 from the most conducting metal to the most insulating solid substance.

Given that so many fascinating and useful properties arise from continuous lattice solids, you may ask why one should bother with these much more complex ones. Several convincing answers can be given. First, they are prepared in quite different ways from conventional metals and ceramics, at or close to room temperature, and usually from solution. Thus they give the solid state chemist access to the wider world inhabited by the coordination, organometallic and organic chemists. The implication is that contemporary synthetic virtuosity can be harnessed to the solid state.

A second obvious feature distinguishing molecular arrays is orientational order: either whole molecules or their side chains, can change their relative orientation as a function of

temperature, pressure, stress, applied fields and so on, bringing about phase transitions that cause macroscopic changes in physical properties. One has only to think of liquid crystal displays to see the implications. Allied to orientation is the issue of anisotropy; low-dimensional conductivity, and deposition of oriented thin films are examples.

Superconductivity: The Role of Chemistry

From its discovery in 1910 up to the 1980s, superconductivity was not of much interest to chemists. The materials concerned were firmly in the realm of the metallurgist and the materials scientist, while the theory was couched in terms of wave vectors and phonons that made it accessible only to physicists. Even the theoretical prediction that one needed to maximize the electronic density of states at the Fermi surface and increase the electron-phonon coupling was scarcely a recipe for action by a synthetic chemist. Since then, of course, superconductivity has entered chemistry in a big way: an object lesson in materials chemistry. For example, After the epoch making discovery of superconductivity in a phase mixture containing La, Ba, Cu and O, many solid state physicists converged on the problem with the result that many physical properties were measured on distinctly ill characterized samples. Only with preparative solid state chemistry methods could single phase samples of $La_{2-x}Ba_xCuO_{4-\delta}$ and $YBa_2Cu_3O_{7-\delta}$ be prepared, so that the structures and properties could be studied in a definitive way.

Conclusion

The foregoing discussion shows how closely chemistry has become woven into the science of materials. The superconductors bear the same message. Similar examples could be given from other classes of physical property, especially from the burgeoning category of materials based on molecular building blocks. The conclusion is that "materials chemistry" is now firmly of age.

(Selected from *Pure Applied Chemistry*, by Peter Day, 1999)

New Words and Expression

organometallic [ˌɔːgənəumiˈtælik] *a.* 有机金属的

vector [ˈvektə] *n.* 向量，矢量

vertex [ˈvəːteks] (*pl.* vertices) *n.* 顶点，至高点

isotropic [ˌaisəuˈtrɔpik] *a.* 各向同性的

anisotropic [ˌænaisəˈtrɔpik] *a.* 各向异性的

naphthalene [ˈnæfθəliːn] *n.* 萘（球），卫生球

interleave [ˌintə(ː)ˈliːv] *vt.* 插入纸，使隔行，使交织

perovskite [pəˈrɔvzˌkait] *n.* 钙钛矿

confer [kənˈfəː] *vt.* 赠与，使……具有性能

paradigm [ˈpærədaim] *n.* 范例

coexist [ˈkəuigˈzist] *vi.* 共存

orthogonal [ɔːˈθɔgənəl] *a.* 直角的，直交的

orbital [ˈɔːbitl] *a.* 轨道的

superconductivity [ˈsjuːpəˌkɔndʌkˈtiviti] *n.* 超导性，超导率

collective [kəˈlektiv] *a.* 集体的；*n.* 集体

aggregate [ˈægrigeit] *n.* 集合体

extrinsic [eksˈtrinsik] *a.* 外在的，外表的，外来的

thermodynamic [ˈθəːməudaiˈnæmik] *a.* 热力学的，热动力学的

ensemble [ɑːnˈsɑːmbl] *n.* 全体，整体，系统，组，束

prototype [ˈprəutətaip] *n.* 原型

proviso [prəˈvaizəu] *n.* 限制性条款，附文，附带条件

compressibility [kəmˌpresiˈbiliti] *n.* 可压缩性

calibrate [ˈkælibreit] *v.* 校准

interionic [ˌintəaiˈɔnik] *a.* 离子间的

thermochromism [ˌθəːməˈkrəumism] *n.* 热致变色现象

photochromism [ˌfoutəˈkroumism] *n.* 光致变色现象

ferroelectricity [ˌferouiˈlektrisiti] *n.* 铁电性

ferroelasticity [ˌferouelæsˈtisiti] *n.* 铁弹性

magnetostriction [mægˌniːtəuˈstrikʃən] *n.* 磁缩性

photomagnetic [ˌfoutoumægˈnetik] *a.* 光磁的

photomagnetic effect 光磁效应

permute [pə(ː)ˈmjuːt] *v.* 序列改变

virtuosity [ˌvəːtjuˈɔsiti] *n.* 艺术鉴别力

phonon [ˈfəunɔn] *n.* 声子

burgeon [ˈbəːdʒən] *n.* 嫩芽；*v.* 萌芽

Notes

① ... chemical reactions, on or within solids, are the subject matter of chemistry proper,... 当 proper 置于名词之后时，意思是"纯的"、"严格意义上的"；因此本句中 chemistry proper 是指"纯化学"。又如：Beijing proper，北京市（不包括北京郊区）。

② Solids can be classified by the degree of order in the structures through the concept of a correlation function, and.... the degree of order in the structures，结构有序度，下文的 orientational order 则指方向有序性；correlation function，相关函数。

③ Liquid crystals, for example, show long range structural correlation in one or two dimensions simultaneously with only short range correlation in the third. 参考译文：例如，液晶在一维或二维空间表现为长程结构相关，同时在第三维空间仅表现为短程相关。

④ ... free rotation of the molecules at high temperature is replaced by finite jumps as the temperature is reduced, inducing a series of structural phase transitions. 参考译文：随着温度的降低，高温下分子的自由旋转变为有限跃迁，导致一些列过渡相结构的形成。

⑤ For example, in a molecular superconductor the superconductivity of one molecule is a nonsense——the property is a collective one, belonging to the aggregate. Aggregate，集

合体。本句主要解释：一个分子的性质不能决定一种材料的性质，材料的特性取决于分子集合体的性质。参考译文：例如，在某个分子超导体中，一个分子的超导性毫无意义；该性质是一个集体特性，属于材料的集合体。

⑥ Conductivity is a property that spans the largest number of orders of magnitude of any in the universe. orders of magnitude，数量级；spans the largest number of orders of magnitude，所跨的数量级最大。

Unit 5　Materials Research: Today and Future (Part Ⅰ)

The future of the business in polymeric materials is influenced to a large extent by three factors: macro-trends in society, developments in science and technology and the outcome of the present turmoil in the chemical industry. Looking at the future needs of the society, it is expected that an increasing pressure will be exerted in the next decades by the society at large on the chemical industry, to come to a higher level of sustainability. The development of really sustainable products and processes will become more and more important. On the other hand, the most striking development in material science and technology is an ever increasing control on the molecular and the supramolecular level, up to the nano length scale. The interest of polymer scientists has shifted from new monomers and their (co)polymers towards functional and smart materials, resulting from the mimicking of the perfect control of macromolecular structure and function as found in nature. It is expected that these developments will provide the solutions for more sustainable products and processes. The third factor is a thorough reshuffling of the activities in the chemical industry. The position of the 'advanced materials' in this redistribution is not clear. It might even happen that a substantial part of this business disappears from the chemical industry towards for instance the electronic industry.

Traditionally, industrial research tried to establish the link between three elements (Fig. 1. 1): the running business, the future needs of society and the developments in science and technology.
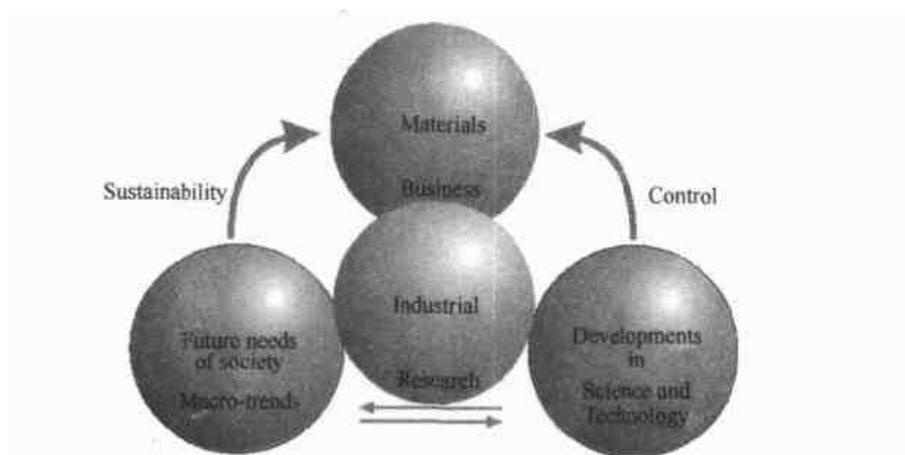

Fig. 1. 1　Driving forces for the business in polymeric materials

At this moment, changes happen in all three spheres, which are so fundamental that industrial polymer research has to adapt in a dramatic way to a completely new situation.

The changing society

The evolution of our society can be illustrated with a series of S-curves, reflecting life

cycles of eras (Fig. 1. 2). After having lived in an agricultural society for ages, we turned into an industrial society at the end of the 18 th century. A couple of centuries later, after the second world war, we again entered a new era, triggered by the development of computers. Now, after just some decades, we are at the point to make a new jump into an era, characterized by an almost unlimited access to knowledge and information via the worldwide web, but also characterized by down scaling and miniaturization, thanks to smart materials and functional materials. This will be the outcome of the integration of the natural and the synthetic approach to materials, the integration of Biotechnology and advanced Material Science. R. W. Oliver labeled it "the Bioterials age".
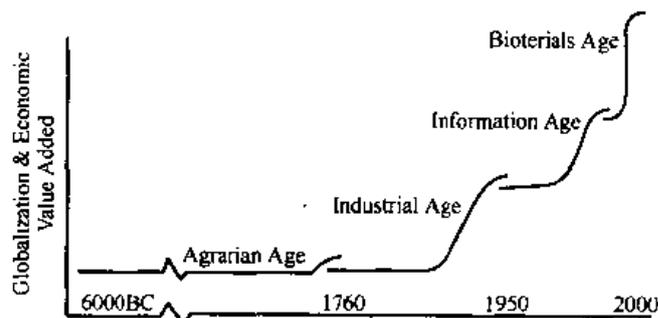
Fig. 1. 2   Technology waves create economic eras

Major changes in society are almost always brought about by technological revolutions. In this respect, I remember Sir George Porter stating that James Watt had liberated more slaves from slavery than any politician ever did, just by inventing the steam engine. In fact, by his invention, James Watt initiated the industrial era.

Which are the major technologies that lie at the basis of the present transformation?

In a study performed by the Study Centre for Technology Trends in the Netherlands, but also in many other studies, it was concluded that, at this turn of the centuries, three major waves of technology are affecting society: the silicon technology, the biotechnology and the nanotechnology. Silicon technology took off in the fifties and in fact brought about the former jump. One can say that it changed the world completely in 50 years. It is expected to level off now and even decline, because further developments will be taken over partly by a new technology: nanotechnology (Fig. 1. 3).
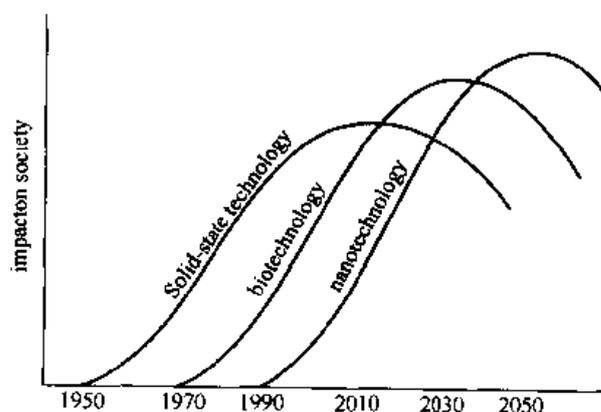
Fig. 1. 3   Waves of technology affecting society

In the mean time, another technology developed: biotechnology. Started in the 1970's, it is now in its fast growing phase. The next wave is the nanotechnology, only in its embryonic phase at this moment. It is the combination or the integration of the latter two technology waves that will bring about the next change.

It is hard to predict what the needs of this changing society will be. But, as far as materials are concerned, one can foresee that functional or smart materials for 'communication hardware' and materials for medical applications will certainly boom.

Changes in science and technology

The integration of biotechnology and nanotechnology can best be illustrated by a picture that I borrowed from Jean-Marie Lehn. I have taken the liberty to adapt it slightly. In the last chapter of his book on 'Supramolecular Chemistry', Jean-Marie Lehn compares 'natural' and 'synthetic' compounds in a very nice picture in which he puts 'controlled complexity' against 'diversity' and puts forward that nature reached a tremendous level of control and complexity with a limited number of chemical systems. In synthetic chemistry on the contrary, we can synthesize an unlimited number of monomers, building blocks and backbones but, until recently, with very limited control and complexity (Fig. 1.4).
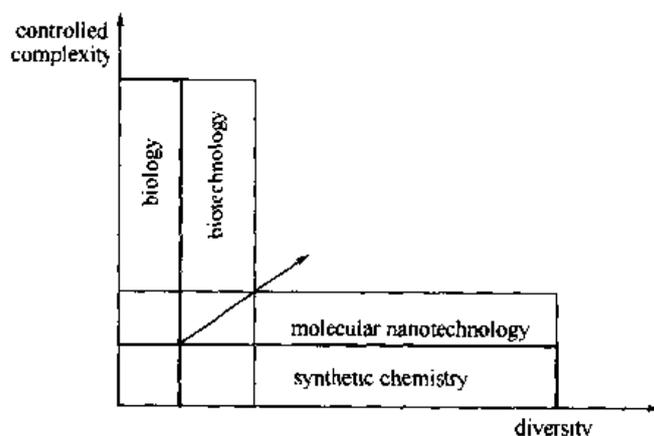
Fig. 1.4 Natural and synthetic chemistry

In recent years progress has been made in two ways. The diversity in molecules synthesized by living organisms is increased by biotechnology. On the other hand a substantial jump has been made in synthetic chemistry towards more control and complexity, the so-called molecular nanotechnology or nanochemistry.

J. M. Lehn drew an arrow in the diagram and said that progress would be made in that direction. This means that continuous mutual interaction between the two fields——biotechnology and molecular nanotechnology——could offer countless opportunities for new concepts.

Time & technology

Looking at the developments in science and technology, it is clear that the fields of 'life

sciences' and 'materials sciences' are growing closer and closer together. For instance, it is striking that nature succeeds, despite the limited number of building blocks, in getting adequate structural properties anyway. Nature is able to do so by complete control on the molecular level (molecular weight, molecular weight distribution, sequence, tacticity), by ordering on the nano-level and by perfect macroscopic design. In this respect we can learn a lot from nature, as well for structural applications of synthetic materials, as for functional applications or a combination of the two.

(Selected from *Industrial research*, *which way to go*, by Joseph Put, 2002)

New Words and Expressions

miniaturization [miniətʃərai'zeiʃən] *n.* 小型化

synthetic [sin'θetik] *a.* 合成的，人造的

biotechnology [ˌbaiəutek'nɔlədʒi] *n.* 生物技术，生物工艺学

nanotechnology [ˌnænəutek'nɔlədʒi] *n.* 纳米技术

sequence ['si:kwəns] *n.* （分子的）序列结构

tacticity [tæk'tisəti] *n.* 立构规整度

life cycle 寿命周期，使用寿命

down scaling 减小尺度

smart material 智能材料

functional material 功能材料

supramolecular chemistry 超分子化学

molecular weight 分子量

molecular weight distribution 分子量分布

Exercises

1. List the tree major waves of technology that had significant influence on our society.

2. Do the following statements agree with the views of the writer in the above passage? Write:

   YES   if the statement agrees with the writer

   NO   if the statement contradicts the writer.

(1) Polymer scientists are devoting themselves to the synthesis of new monomers and their (co)polymers.

(2) In recent years, the diversity in molecules synthesized by living organisms is increased by biotechnology.

(3) Thanks to the efforts of chemists, we can now perfectly control the macromolecular structure and function of polymers.

(4) The fields of 'life science' and 'material sciences' are growing closer and closer.

Material Research: Today and Future (Part Ⅱ)

Nanotechnology, a Breakthrough Field

'Molecular nanotechnology' is still considered by many people as a buzz word and a hype. In fact it is simply the logical next step in the development of synthetic chemistry, in this way closing the gap with biology.

Several phenomena in the scientific environment gave birth to this important new direction. On the one hand there was the development of the new microscopies, which made it possible to determine and characterize structures on the nano length scale. On the other hand, there was the synthesis of completely new architectures with carbon compounds: fullerenes, nanotubes and all kinds of dendritic and hyperbranched structures.

A lot of effort is given at the moment to the large scale synthesis of fullerenes and nanotubes. Applications of these molecules in nano-electronics look very promising. Also the dendrimers, although they didn't reach a commercial breakthrough yet, formed a milestone in synthetic chemistry for several reasons.

With the dendrimers, scientists were able for the first time to obtain synthetic macromolecules with a well-defined structure. Furthermore, a completely new molecular architecture and a really multifunctional macromolecule with a high density. of functions on the outside was built up. A process for large scale synthesis of dendrimers was developed by DSM.

Embroidering further on this theme and combining it with non-covalent supramolecular interactions, enormously improved synthetic skills were realized together with an increasing understanding of hierarchical organization in soft matter. This combination led to the controlled synthesis of complex molecular and supramolecular systems, in this way mimicking nature. This creates new possibilities that were simply not there before. As Jean-Marie Lehn said: 'The novel features that appear at a higher level of complexity do not and even cannot conceptually exist at the level below'.

Concerted research efforts are needed to realize the potential of nanotechnology as a key technology for the 21st century, surpassing solid-state technology and biotechnology. The increasing control over the arrangement of atoms will create new possibilities for manufacturing in all areas, including sustainable as well as military products. Many materials, electronics and medical applications will enter the market within 20 years. Fancier products such as self-cleaning textiles can be expected to appear in the mid term. In the long term, nanotechnology might even modify the concept of life, invoking ethical objections resembling those against biotechnology. The question is which industry will be able to pick up these new developments. Is the chemical industry and more precisely, the polymer industry ready to go into smart materials and functional materials?

The Changing Chemical Industry

At this moment, a thorough reshuffling of the chemical industry is taking place. This implies more than just mergers or fusions. It is a complete regrouping of chemical activities by splitting up, exchanging parts of businesses, merging etc. It looks as if the structure of the chemical industry is at the end of a life cycle and a jump to a new S-curve, with a completely new structure, is going on (Fig. 1.5).
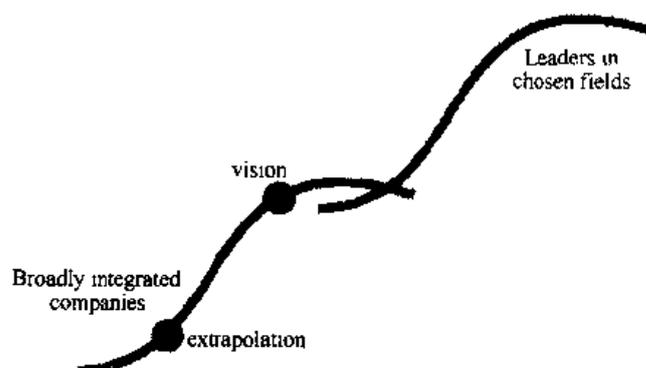
Fig. 1.5   The structure of the chemical industry seems to be at the end of a life cycle

At the beginning of an S-curve, one can predict what will happen by extrapolating. At the end of a life cycle one needs vision, as things are changing into something completely new.

The chemical industry seems to move from broadly integrated companies that cover almost the entire field from crackers up to pharmaceuticals, towards leaders in chosen fields.

The position of 'advanced materials', and especially 'smart' and 'functional' materials in this whole rearrangement of the industry is not clear. Producers of advanced materials for the automotive industry, the electric and electronic industry, the medical devices industry, etc. are 'solution providers' and in this way they do not fit within the mindset of the producers of bulk polymers. Do they fit within a company focussed on life science products? Some people do not see any synergy. Others are convinced that there is a lot of synergy in the technologies and even in the market approach.

We are convinced that a lot of synergy is possible between the two important knowledge fields: material sciences and life sciences. Companies that master both fields might have a competitive advantage. We think we are only at the beginning of a completely new development in the field of synthetic materials. A bright future is waiting for this new polymer and material science, combining principles out of biology and out of synthetic chemistry.

However, it remains to be seen whether this will be reflected in the reshuffling of the mentioned spin-off companies. At this moment the chemical industry and the materials industry seem not to be able to pick up the new developments in nanoscience. Electronic industries are a lot more active in that field. Chemical industry focuses largely on biotechnology and life sciences.

A New Approach in Industrial Research

As the environment of industrial research is changing so drastically, this activity itself

has to change dramatically, to adapt to the new situation. The essence of this change is a much more pronounced external focus. This external orientation is necessary with respect to the knowledge infrastructure as well as with respect to the partners in the business chain and even with respect to the competitors.

The new concepts in the materials field that are discovered at universities and research institutes are scarcely picked up by the polymeric materials industry, because these developments are too far away from their focus field or too far away from commercialisation. Furthermore, application development has to be done by an industry that is familiar with the end market, so co-operation is necessary with a partner situated further down the business column, like electronic industry, medical materials industry etc. ...

Often these new developments are picked up by small 'start-up' companies with an intense focus on that one concept that they want to bring to commercialisation and making use of venture capital. Many larger chemical companies react to this new phenomenon with 'corporate venturing'. This is in fact a way of company innovation with an external focus, making maximum use of the possibilities outside the company.

These companies start to invest in venture capital funds or start to act with venture capital themselves. They take direct or indirect participations in these start-up companies. Contrary to the 'normal' venture capital funds, their selection is not only based on financial criteria but is highly influenced by strategic and technological arguments. If the start-up performs well, sooner or later the company will spin it in before it goes public. An increased entrepreneurial spirit at universities and research institutes is needed for this approach.

Parallel to this, new developments that arise within a company are treated in an analogous way and can grow into a separate business unit, or can be spun out if the fit with the strategy turns out to be unsatisfactory. This is also value creation for the parent company. Correct and early valuation of knowledge and of technology is crucial in these approaches.

It is clear that a new kind of industrial research is needed to support these activities, with a focus on searching and evaluating external activities.

(Selected from *Industrial research, which way to go*, by Joseph Put, 2002)

New Words and Expressions

dendritic [den'dritik] *a.* 树枝状的
reshuffle [riː'ʃʌfl] *vt. n.* 重新洗牌，重组，改组
merger ['məːdʒə] *n.* 合并，归并
extrapolate [eks'træpəleit] *v.* 推断，外推
pharmaceutical [ˌfɑːmə'sjuːtikl] *a.* 制药的；药学的
synergy ['sinədʒi] *n.* 合力，协力，协同作用
infrastructure ['infrəˌstrʌktʃə] *n.* 基础结构
entrepreneurial [ˌɔntrəprə'nəːriəl] *a.* 企业家的
fullerene ['fjuːləriːn] *n.* 富勒烯
nanotube [ˌnænəu'tjuːb] *n.* 纳米管

hyperbranched   *a.* 超支化的

dendrimer   *n.* 树枝状单体

non-covalent   *a.* 非共价键的

mindset   ['maindˌset]   *n.* 固定的习惯

venture capital   *n.* 风险投资

Notes

'Molecular nanotechnology' is still considered by many people as a buzz word and a hype. buzz Word：与某一特定领域或组织相关，听起来重要的单词或短语，主要用于宣传目的或给外行人加深印象；hype：骗局，天花乱坠的广告宣传。

PART II METALLIC MATERIALS AND ALLOYS

Unit 6 An Introduction to Metallic Materials

What is a Metal?

The key feature that distinguishes metals from non-metals is their bonding. Metallic materials have free electrons. In the case of pure metals, the outermost layer of electrons is not bound to any given atom, instead these electrons are free to roam from atom to atom. Thus, the structure of metallic material can be thought of a consisting of positive centers (or ions) sitting in a "gas" of free-electrons.

The existence of this free electron gas has a number of profound consequences for the properties of metallic materials. For example, one of the most important features of metallic materials is that freely moving electrons can conduct electricity and so metallic materials tend to be good electrical conductors. Some metals more closely resemble the idealized picture of free electrons than others. Consequently, some metals are better conductors of electricity than others; for example, copper is a more efficient electrical conductor than tin.

Electrical conductivity is such an important characteristic of metals that conductivity is sometimes used to distinguish metals from non-metals. The problem with using conductivity to distinguish metals from non-metals is that this approach is somewhat arbitrary. For example, graphite is a form of carbon which has quite a high electrical conductivity, but the bonding of carbon atoms in graphite is very different from that of atoms in a metal. Therefore, it would be quite misleading to describe graphite as a metal. Note: the way in which atoms are arranged in a structure is just as important as the nature of the atoms themselves in determining the extent of electrical conductivity. Both diamond and graphite are made up of pure carbon, but diamond is a very good electrical insulator, rather than an electrical conductor like graphite.

What is an Alloy?

An alloy consists of a mixture of a pure metal and one or more other elements. Often, these other elements will be metals. For example, brass is an alloy of copper and zinc. In other cases, a metal will be alloyed with a non-metal. The most important example of alloying involving addition of a non-metal would be (plain-carbon) steels, which consist of iron alloyed with carbon.

Alloys are usually less malleable and ductile than pure metals and the tend to have lower melting points. They do, however, have other properties which make them more useful than pure metals. An alloy is made by melting the different metals in the alloy together.

The amounts of each metal are usually quite important.

Solid Solutions and Intermetallic Compounds

In many cases, metals are quite soluble in other metals. For example, solid copper and solid nickel are fully soluble in each other. This type of perfect solid solubility is a side effect of having free electrons. Since the electrons are free to move, the exact number of valence electrons possessed by any given atom shouldn't matter. Thus a metal should be able to dissolve another metal and produce a "solid-solution" in which one metal serves as the solvent and the other as the solute, although in a case like copper and nickel where these are mutually soluble at all compositions the terms solvent and solute can be a little misleading.

In practice, however, not all metals are soluble in other metals. Thus, instead of a solid-solution a new phase, an "intermetallic compound", with a structure different from that of any of its constituent metals can be produced. For example, nickel will dissolve some aluminum, so that at low aluminum contents a solid solution is produced. However, if larger amounts of aluminum are added, then a series of intermetallic compounds (for example Ni_3Al and $NiAl$) are produced. Some of these compounds (called "line compounds") have a very well defined composition (for example Ni_3Al invariably has almost exactly three nickel atoms for each aluminum atom). In contrast, other compounds have quite a wide range of composition (for example "$NiAl$" covers quite a wide range of nickel to aluminum ratios and there isn't necessarily exactly one nickel atom for every aluminum atom).

The formation of intermetallic compounds seems strange, given the comment above about above free electrons promoting solid-solubility. However, there are three types of circumstances in which intermetallic compounds form, instead of solid-solutions (these are called the "Hume-Rothery rules"). The first of these circumstances is when the size difference between the solvent and solute atoms is such that these do not fit very well together (the result is a "size factor" compound). Consequently only a limited amount of the solute can be dissolved in the solvent. The second circumstance is when there is a large difference in electronegativity between the solvent and a solute, in which case the result is more like ionic than metallic bonding. The final circumstance is related to certain ratios of the number of valence electrons to the number of atoms in a structure (the result is an "electron" compound). This is a consequence of some metallic systems only approximating the free electron model of metallic bonding.

Given that many of the compounds formed in alloys are size factor or electron compounds, these do not follow the rules of valency. In other words, whereas the chemical formula of an ionic compound, like $NaCl$ or Al_2O_3 can be predicted easily from the compound's position in the periodic table, this is not the case for many intermetallic compounds. Thus, knowing from their position in the periodic table that Na wants to form Na^+ ions and chlorine wants to form Cl^- ions explains why an ionic compound with a formula $NaCl$ is observed. In contrast, this doesn't explain why a carbide with a formula $Cr_{23}C_6$ is formed in stainless steels. The precipitation of $Cr_{23}C_6$ is a big problem when stainless steels are welded. $Cr_{23}C_6$

forms in the "heat affected zone" around the weld (this region is heated but not melted during welding). The formation of this chromium-rich phase pulls chromium out of solution in the surrounding iron. This, in turn, prevents the formation of a protective layer of Cr_2O_3 on the surface of the stainless steel and so the stainless steel is no longer stainless, but instead suffers from catastrophic localized corrosion.

Consider a different example. NiAl is an electron compound which forms due to having a "magic" 1.5 valence electrons per atom (this magic number isn't really magic, but is a results of deviations from the free electron model). There is one nickel atom and one aluminum atom in NiAl and the valency of nickel is two and that of aluminum is three. Given that $(2+3)/2=2.5$ this doesn't seem like 1.5 valence electrons per atom. However, as a transition metal, nickel is able to act as if it does not have a valency by "hiding" electrons in the empty states in the shells below the outer shell. Thus, effectively, there are $(0+3)/2=1.5$ valence electrons per atom in NiAl.

Even in cases where intermetallic formation does not occur, there may not be perfect solid-solubility. If two metals have different crystal structures then at some intermediate composition there will have to be a change from the crystal structure of one metal to that of the other. In such a case the result would be, on gradually changing the composition of an alloy from pure metal A (forming the α-phase) to pure metal B (forming the β-phase):

- single-phase α solid-solution;
- two-phase mixture of α solid-solution and β solid-solution;
- single-phase β solid-solution.

(Selected from *An Introduction to Metallic Materials*, by William F. Gale, 2002)

New Words and Expressions

roam [rəum] *v.* 漫游，闲逛，徜徉；*n.* 漫步，漫游，徘徊

graphite ['græfait] *n.* 石墨

malleable ['mæliəbl] *a.* 有延展性的，可锻的

ductile ['dʌktail] *a.* 易延展的，易教导的，柔软的

soluble ['sɔljubl] *a.* 可溶的，可溶解的

chromium ['krəumjəm] *n.* 铬

transition [træn'siʒən] *n.* 转换，跃迁，过渡

shell [ʃel] *n.* 壳，外壳

Exercises

1. Question for discussion
   (1) What is a metal? What is an alloy? What are the differences between their properties?
   (2) Give examples to explain solid solution and intermetallic compound.
2. Translate the following into Chinese
   the outmost layer of electrons   free electron gas

electrical conductivity

plain-carbon steel

solid solution

intermetallic compound

- In the case of pure metals, the outermost layer of electrons is not bound to any given atom, instead these electrons are free to roam from atom to atom.
- Alloys are usually less malleable and ductile than pure metals and the tend to have lower melting points.
- The formation of intermetallic compounds seems strange, given the comment above about above free electrons promoting solid-solubility.
- If two metals have different crystal structures then at some intermediate composition there will have to be a change from the crystal structure of one metal to that of the other.

3. Translate the following into English

金属材料   不锈钢

溶质   元素周期表

溶剂   电负性

过渡金属   晶体结构

Reading Material

Structures of Metals and Alloys

What is a Phase?

The word "phase" has different meanings in different sciences and even in different aspects of materials science. In the present paper, a phase is used to indicate a state of matter with a distinct structure and hence properties. The most familiar phases are solid, liquid, vapor (gas) and plasma. However, within the solid-state for example, there can be a number of different solid phases within a system. For example on heating between room-temperature and its melting-point, pure iron goes through three different phases. These phase are known as α-Fe ("ferrite"), γ-Fe ("austenite") and δ-Fe ("delta-ferrite"). Each of these phases has its own distinctive structure and properties, although all three are made up of iron atoms.

Crystal Structures

A phase has a distinct structure. What might this involve? Consider for example the α- and β-phases in pure iron. In both of these phases, the iron atoms are the same, but are arranged in a different pattern. In each case, the pattern (or "lattice") is made up of a repeating unit (the "unit cell"). Although in both α- and β-iron the unit cell is a cube, the length of the sides of the cube (the "lattice parameter", a_0) is different and the atoms are arranged differently within the cube. In both cases, iron atoms sit at the corners of the

cube. However, in α-Fe there is also an iron atom at the center of the cube. Consequently, this crystal structure is referred to as the "body-centered cubic" (BCC) structure. In the case of α-Fe, iron atoms are present at the centers of each of the faces of the cube and the resulting structure is known as "face centered cubic" (FCC).

Thus far, the examples given have been for pure metals. What about solid-solutions and intermetallic compounds? The nature of solid-solutions depends on the size of the solute atoms, relative to that of the solvent. When the solute atoms are much smaller than those of the solvent, carbon in α- or γ-Fe for example, the solute will sit in such empty spaces ("interstices") as are available between the solvent atoms. This is called an "interstitial solid solution". The interstitial sites are smaller in α- than in γ-Fe and so carbon fits better into γ-Fe than into α-Fe. Consequently, the carbon solubility in γ-Fe is far larger than in α-Fe. Thus, on transforming a steel from γ-Fe to α-Fe carbon is precipitated out from the iron in the form of a carbide Fe_3C (known as "cementite"). Controlling this process is one of the metallurgist's most important tools.

When the solute atom is fairly similar in size to that of the solvent, for example chromium dissolved in either α- or γ-Fe iron, then solute atoms will substitute for some of the solvent atoms and the result is called a "substitutional solid-solution". It is important that in both substitutional and interstitial solid-solutions the sites occupied by specific atoms are random, consequently adding the solute does not change the crystal structure. In contrast, in an intermetallic compound, such as NiAl, the different atoms sit on specific sites. NiAl, for example, is a cubic structure in which nickel atoms sit at the cube corners and aluminum at the body center. Since each cube corner side is shared by eight unit cells and each body center site is entirely within a unit cell, this produces:

- 8 corner sites/8 unit cells sharing each site = 1 nickel atom per unit cell
- 1 body center site/1 unit cell containing the site = 1 aluminum atom per unit cell

This gives a nickel atom to aluminum atom ratio of 1 : 1 and hence a chemical formula of NiAl.

This structure is nothing like that of either a substitutional solid solution of aluminum in nickel, which is FCC, or of nickel in aluminum, which is also FCC, although with a different lattice parameter. It might seem tempting at first sight to describe the structure of NiAl as BCC. However, this is not the case, since the nickel and aluminum atoms have their own distinctive sites. Try covering up either the nickel or the aluminum atoms and it will be apparent that the structure is simply a cube and this is an example of what is known as a "simple cubic" or "primitive cubic" structure.

Not all unit cells are cubic. For example, the unit cell of the carbide Fe_3C is in the shape of a cuboid with three sides of different lengths (a, b and c) and is an example of an "orthorhombic" structure. The structure of α-Fe can become distorted in steels subjected to special treatments, such that instead of a BCC structure (which is cubic with three sides of length a_0) a "body centered tetragonal" structure in which two of the sides have length a and one side has a length c with $c > a$ is produced.

The science of crystal structures and the methods by which they are determined experimentally makes up the subject of "crystallography".

Crystalline and Amorphous Metals

In a material that is "crystalline" a long range structure exists in which atoms are arranged into unit cells and the unit cells repeat in a regular pattern, forming a lattice. If the lattice extends right out to the edges of a piece of material, the result is a large "single crystal". The most familiar example of this would be a gemstone, such as a diamond. However, the nickel-base alloy turbine blades used in aero gas-turbine engines (what are popularly known as jet engines) can also be produced as single crystals. To produce a solid single crystal from a liquid requires that the lattice forms in a uniform fashion. In most cases, however, solidification begins from multiple sites, each of which can produce a different orientation. The result is a "polycrystalline" material consisting of many small crystals (also known as "grains") each of which has the same lattice, but with a misorientation from grain to grain.

In three dimensions, the grains in a polycrystal are usually found to be polygonal. The interfaces between the grains ("grain boundaries") have an associated energy, just as do other interfaces (for example the outer surface of a liquid or a solid). For any given type of interface, there will be a certain interfacial energy per unit area of interface. Hence, since matter tries to adopt the lowest energy condition possible, there is a driving force to minimize the total interfacial area, as this reduces the total interfacial energy of the sample. Spherical grains would give the lowest surface area to volume ratio, but packing spheres together can not completely fill space (in other words a sample that solidified by forming spheres would inevitably leave some liquid behind). Hence, the grains do the next best thing and grow as polygons, which have almost as low a surface area to volume ratio as spheres, but unlike spheres can stack together to fill space.

If a material is cooled very rapidly from the liquid state there is not enough time for the material to arrange the solid into a lattice. Instead, a random "amorphous" arrangement is produced and the result is a non-crystalline material. The best known amorphous material is window glass and hence amorphous materials are often referred to as glasses. Metals are usually able to crystallize even at very high cooling rates, but under extreme conditions metallic glasses can be produced in some alloys. Note: metallic glasses are not transparent. Nonetheless, the lack of a long range structure in metallic glasses does produce some unusual properties and these are employed in specialist applications. For example, Fe-Si-B metallic-glass alloys are used as magnetically soft-iron for high performance transformer cores, since the lack of long range structure prevents the processes that lead to the production of a permanent "hard" magnet.

Perhaps the most important current application of amorphous metals is in read-write compact discs (CD-RW). All compact discs (CDs) depend on changing the extent to which the disc reflects light from a laser to store information (e. g. music or computer data). Con-

ventional CDs control reflection using small pits that are produced mechanically in a factory and so standard CDs are read-only. In contrast, recordable CDs (CD-R) discs contain a dye layer within the disc. This dye undergoes a color change when heated. CD-R discs store information by using a laser to heat a small region of the CD, producing a localized color change that, in turn, modifies the reflectivity of the disc. Hence the term "burning a CD". CD-R discs are very cheap to produce, but suffer from the disadvantage that the color change is permanent, so that the disc is write-once-read-many (WORM). Thus, a single mistake when burning the CD and the result is only fit for use as a coaster. CD-RW discs work in a different fashion. Within the disc is a metallic layer. When this is heated locally by a laser, at a fairly high power, a small region of the metallic layer melts. The rest of the disc makes an efficient heat sink and so the small molten region cools extremely quickly and is unable to crystallize. The resulting amorphous region reflects light differently from its crystalline surroundings and so can do the same job as the pits in a conventional CD or the dye in a CD-R. The key difference is that, if the amorphous region is reheated, but with a lower laser power than before, the amorphous region becomes hot enough to allow crystallization to take place, but not so hot that the region re-melts. This erases the original information, making the CD-RW disc re-writable.

If one visits a store selling fancy glassware, one will see the phrase "crystal glassware". This is a contradiction in terms, as any given phase is either crystalline or glassy. Thus a material can be crystalline (most metals), glassy (many polymers), or a mixture of separate crystalline and glassy phases (some polymers and the class of materials called "glass ceramics").

The structure of an amorphous material is more like that of a very viscous liquid than a solid. Indeed, if one visits a very old building (say a stately home in Europe) one can see clearly that, over the course of hundreds of years, window glass will flow at room temperature!

(Selected from *An Introduction to Metallic Materials*, by William F. Gale, 2002)

New Words and Expressions

phase [feiz] *n.* 相

plasma ['plæzmə] *n.* 等离子体，等离子区

precipitate [pri'sipiteit] *n.* 沉淀物；*vt.* 使沉淀，析出，凝结

ferrite ['ferait] *n.* （正）铁酸盐，（冶）铁素体

austenite ['ɔːstəˌnait] *n.* 体，奥氏体，碳丙铁

lattice ['lætis] *n.* 格子

interstitial [ˌintə(ː)'stiʃəl] *a.* 空隙的，裂缝的，形成空隙的，裂缝间的

cuboid ['kjuːbɔid] *a.* 立方体的，立方形的，三次方的，立方的

orthorhombic [ˌɔːθə'rɔmbik] *a.* 正交晶的，斜方晶的

tetragonal [te'trægənl] *a.* 正方晶的，四方晶的

crystallography [ˌkristə'lɔgrəfi] *n.* 结晶学，晶体学

turbine ['təːbin, 'təːbain] *n.* 涡轮

blade [bleid] *n.* 刀刃，刀片

polygonal [pə'ligənl] *a.* 多角形的，多边形的

gemstone [dʒem,stəun] *n.* 宝石

spherical ['sferikəl] *a.* 球的，球形的

amorphous [ə'mɔːfəs] *a.* 无定形的，无组织的，无晶形的

transparent [træns'pærənt] *a.* 透明的

pit [pit] *n.* 坑，槽

coaster ['kəustə] *n.* 垫子，银盘

viscous ['viskəs] *a.* 黏性的，黏滞的，胶黏的

interfacial [,intə(:)'feiʃəl] *a.* 界面的，分界面的，面间的

Notes

① Although in both α- and β-iron the unit cell is a cube, the length of the sides of the cube (the "lattice parameter", a_0) is different and the atoms are arranged differently within the cube. unit cell，单位晶胞；the length of the side，边长；lattice parameter，晶胞参数。参考译文：尽管在 α-Fe、β-Fe 中单位晶胞都是立方体，但立方体的边长（晶胞参数 a_0）并不相同，立方体内原子的排列也不相同。

② The result is a "polycrystalline" material consisting of many small crystals (also known as "grains") each of which has the same lattice, but with a misorientation from grain to grain. 参考译文：其结果是形成一种多晶材料，这种多晶材料由许多小晶体（也称"晶粒"）组成，每个小晶体具有相同的晶格，但晶粒与晶粒之间具有不同的生长方向。

③ If a material is cooled very rapidly from the liquid state there is not enough time for the material to arrange the solid into a lattice. Instead, a random "amorphous" arrangement is produced and the result is a non-crystalline material. amorphous，无定向的，无定形的，隐晶质的；non-crystalline，非晶质的，非结晶的。参考译文：如果一种材料从液态快速冷却，那么对材料来说没有足够的时间使其结晶颗粒排列成晶格；此时将产生随机无定向排列，其结果是形成非晶质材料（即形成隐晶质材料）。

④ The structure of an amorphous material is more like that of a very viscous liquid than a solid. that 代词，代 structure。参考译文：隐晶质材料的结构更像非常黏稠的液体的结构，而与固体的结构相差甚远。

⑤ Indeed, if one visits a very old building (say a stately home in Europe) one can see clearly that, over the course of hundreds of years, window glass will flow at room temperature! stately，豪华的。参考译文：实际上，如果你去参观一座非常古老的建筑，比方说欧洲的豪华古宅，你可清楚地看到，经历了几百年以后，窗户上的玻璃在室温下会发生流动。

Unit 7 Applying Powder Metallurgy to Gear Manufacturing

Powder Metallurgy (PM) is a well-established manufacturing process which has undergone substantial growth in recent years in terms of allowable loads. This is due to the use of detailed stress analysis which can define the best process parameters, the availability of highly compressed powders, and the accurate design of compacting equipment.

PM gears have several advantages:

- Economy in production of medium-to-large batches.
- The ability to obtain complex shapes which could be very difficult or even impossible to produce by machining.
- The ability to combine functions and eliminate assemblies.
- Self-lubrication properties.
- Very good surface finish.

It is possible to produce helical, bevel, internal and external gears. Consequently, materials scrap losses are eliminated. Internal and frontal configurations are formed simultaneously with the gear profile. Thereby eliminating subsequent machining operations. Slots, grooves, blind holes, and recesses of varied depths are also obtainable. The PM process provides close dimensional tolerances, minimal machining, good surface finish, and excellent part-to-part reproducibility.

Powder Metallurgy Technology

Powder metallurgy encompasses a wide range of processing techniques applicable to net and near-net shape components manufacturing. It is a well-established technology, especially in the power transmission field and specifically in the automotive industry.

The PM process uses powder as a raw material which, in the case of gears, is primarily an atomized iron-based powder. This type of metal powder provides the highest density possible. The metal particles are compacted in dies using mechanical or hydraulic presses. These dies have the desired part reproduced in the negative. During the compacting process, the metal particles are brought into contact with one another and plastically deformed along the joints.

After pressing, the parts are put into special furnaces with protective atmosphere at temperatures between 1100 ℃ and 1300 ℃. This phase, called sintering, causes diffusion of the alloy elements present in the powder and solid aggregation among the particles of the compacted part occurs. During the maximum temperature phase, new crystallites form and grow at the contact points. The edges of the original metal particles disappear. After sintering, there may be additional processes such as sizing, a second sintering, and/or heat

treatment to improve the mechanical characteristics of the product.

By means of tight process control of variables involved in the PM process, limited dimensional tolerance can be obtained. Powder metallurgy technology offers a series of distinct advantages when compared with other traditional technologies.

- Economic advantage due to the low costs of process.
- The possibility of manufacturing parts with complex forms without additional machine work.
- The PM manufacturing process can be considered condensed when compared to machining a similar part that requires multiple operations.
- Good process capability and surface finishes without additional operations.
- PM is a continuously developing technology with a large potential for significant improvements in product performance.

Gears and Powder Metallurgy

The full advantages of PM gears can only be realized by combining knowledge of the sintering process with gear designing and manufacturing. The best performances of a PM gear can be only achieved with cooperation between the gear designer and PM specialist. This cooperation overcomes the limiting factors of the PM process and incorporates as many different gear functions in only one part. For example, axial projections usually can be formed using powder metallurgy, but the permissible size depends on whether the powder will flow into the die recesses. Tooling with thin sections or sharp inside corners should be avoided. PM limits the number of multiple axial projections that can be formed. Undercuts and cross holes cannot be molded and, therefore, must be machined after sintering.

A PM shop must have both compacting and sintering equipment as well as the conventional hobbing and milling machines. The PM department should be equipped with a series of mechanical and hydraulic presses, ranging from 45 to 500 tons, sintering furnaces and heat treatment furnaces, and induction-hardening machines.

Besides the advantages already mentioned, PM gears have other advantages. The wear resistance of PM gears is higher than that of machined steels in the absence of external lubrication. Since oil is impregnated into the piece in a vacuum vessel after sintering or heat treatment, the porosity of the sintered gear acts as reservoir for the oil. This oil protects against corrosion and provides self-lubrication during operation. The vibrations of PM gears are dampened when compared with steels. The PM material's porosity absorbs vibrations, resulting in decreased noise of the running gear.

(Selected from *Appliance Engineer*, by Pierluigi Zingale, Gianni

Bonetti and Andrea Navazio, 1999)

New Words and Expressions

batches [bætʃis] *n.* 一次生产量，批量

assembly [ə'sembli] *n.* 组合，装配，集合，会议

lubrication ［ljuːbriˈkeiʃən］ *n.* 润滑

helical ［ˈhelikəl］ *a.* 螺线，螺旋状的

bevel ［ˈbevəl］ *a.* 斜角，倾斜，倾斜的

scrap ［skræp］ *n.* 碎片，断片，废品

slot ［slɔt］ *n.* 缝，槽

groove ［gruːv］ *n.* 切口，（凹，空心）槽

encompass ［inˈkʌmpəs］ *v.* 包围，拥有，围（环）绕

atomize ［ˈætəmaiz］ *vt.* 使雾化，喷雾，散布

hydraulic ［haiˈdrɔːlik］ *a.* 水力学的，液力的

metallurgy ［meˈtælədʒi］ *n.* 冶金（学）

sintering ［ˈsintəriŋ］ *n.* 烧结

hobbing ［ˈhɔbiŋ］ *n.* 滚刀（切，铣）

absence ［ˈæbsəns］ *n.* 缺少（席，少），没有，不存在

impregnate ［ˈimpregneit］ *v.* 注入，充满，灌注

recess ［riˈses］ *n.* 凹口

Notes

① This is due to the use of detailed stress analysis which can define the best process parameters, the availability of highly compressed powders, and the accurate design of compacting equipment. 这是因为使用了可以确定加工参数的详细的应力分析技术，具有高压缩性粉体的采用和成型设备的精确设计。

② The ability to combine functions and eliminate assemblies. 多功能和减少组装工序的能力。

③ near-net shape，近净尺寸。

④ power transmission field，功率传输领域。

⑤ The PM process provides close dimensional tolerances, minimal machining, good surface finish, and excellent part-to-part reproducibility. 粉末冶金能够提供最小的公差尺寸，最少的机加工，好的表面质量和优异的工件重复性。

⑥ This phase, called sintering, causes diffusion of the alloy elements present in the powder and solid aggregation among the particles of the compacted part occurs. 这个叫烧结的阶段使粉体中的合金成分扩散，同时坯体中的颗粒开始产生聚集。

Exercises

1. Reading comprehension

    (1) What are the advantages of powder metallurgy method for gear component manufacture?

    (2) Please describe the fabrication process for gears using powder metallurgy.

2. Translate the following into Chinese

    compacting equipment   raw material

    mechanical characteristics   product performance

heat treatment furnace   self-lubrication

- The PM process uses powder as a raw material which, in the case of gears, is primarily an atomized iron-based powder. This type of metal powder provides the highest density possible. The metal particles are compacted in dies using mechanical or hydraulic presses. These dies have the desired part reproduced in the negative. During the compacting process, the metal particles are brought into contact with one another and plastically deformed along the joints.
- PM limits the number of multiple axial projections that can be formed. Undercuts and cross holes cannot be molded and, therefore, must be machined after sintering.

3. Translate the following into English

应力分析   加工参数
润滑   烧结

Reading Material

Powder Metallurgy Innovations

To gear makers today, the phrase calls up images of low power applications in non-critical systems. As powder metal technology advances, as the materials increase in density and strength, such opinions are changing. It is an ongoing, evolutionary process and one that will continue for some time. According to Donald G. White, the executive director of the Metal Powder Industries Federation, in his State-of-the-P/M Industry——1999 report, "The P/M world is changing rapidly and P/M needs to be recognized as a world-class process——national, continental and even human barriers and prejudices must be eliminated——we must join forces as a world process——unified in approach and goals."

According to Todd Olson, marketing manager for Burgess-Norton Manufacturing Co., this kind of unification is already happening. "Overall, the powder metal industry is moving toward consolidation. Historically, the industry has been very fragmented. However, the late 1990s have witnessed a wave of mergers and acquisitions, which is allowing major powder metal players to optimize economics of scale and provide customers with a full rage of products and services."

There is a greater use of powder metal in gear manufacturing, on both the tooling side and the workpiece side, today than ever before. In fact, a number of gear applications won awards in the 1999 P/M Design Competition. Major automakers are increasing the amount of powder metal they use in their transmissions and engines, and many of these gears are being made with new high-speed steel alloy cutting tools. Part of the credit for this goes to new alloys being developed, while the rest goes to the new powder metal processing methods, which are designed to increase the material density to improve its mechanical qualities.

According to Philip Drupp, president of P/M Drupp Technologies, Inc., this drive to-

ward heavier density in powder metal parts is of great importance to the powder metal industry because, as he said, "They've done all that can be reasonably achieved with varying chemistry and heat treatment, and higher density is pretty much all that is left."

According to Krupp, "Current P/M gear capabilities are very good in regard to shape complexity and tolerances, but fall short on high strength and hardness. For that, higher densities will be needed." This need for higher densities has led to the development of processing methods that promise near-fully dense powder metal products. Near-fully dense means that the part has less than 1% residual porosity. These processes also use different compacting methods, enhanced sintering techniques and work primarily with high alloy materials. Four of the most promising processes are powder forging, isostatic pressing, metal injection molding and spray forming.

Powder Forging. This method begins with the creation of a "green compact" (a workpiece that has been pressed into shape at room temperature) called a "preform." The preform is then sintered as usual, producing a near-net shape workpiece. This workpiece is then placed in the forge and restruck until the final density is reached. Powder forging is currently used in the mass production of powder metal steel parts with wrought steel properties. These parts are primarily used by the automotive industry and include gears, transmission parts and engine parts.

Isostatic Pressing. This method is primarily used to produce powder metal parts to near-net sizes and shapes of varying complexity. The biggest difference between isostatic pressing and other methods of compaction is that isostatic pressing is performed in a pressurized fluid. The powder mass is contained in a flexible, sealed container, which provides a pressure differential between the powder and the pressurizing fluid.

There are two types of isostatic pressing-hot and cold. Hot isostatic pressing is carried out using an inert gaseous atmosphere, usually argon or helium, contained within the pressure vessel. Usually, both the pressurized atmosphere and the part to be pressed are heated by a furnace within the vessel.

The powder being processed is hermetically vacuum-sealed within a shaped mold that will deform plastically at high temperatures. The powder metal is then simultaneously pressed and sintered within the heated vessel. Common pressure levels reach 15000 psi (pounds per square inch) at temperatures as high as 2300°F. The mold is then removed from the finished near-net shaped part by chemical leaching, machining or some other mechanical method. Hot isostatic pressing allows densities in the 7.2~7.4 g/cm³ rage. While this is a notable improvement over the results of other methods, it is still not dense enough for many gear applications.

According to Krupp, "The tolerances are roughly equivalent to those of investment casting. It is suitable for more complex shapes that have the economic room for finishing operations to bring dimensions into line."

Cold isostatic pressing is carried out at room temperature and uses a liquid pressure medium rather than a gas. The pressures in this method often reach 6000 psi. Packed into

complex shaped rubber or elastomeric molds, the powder metal achieves a higher and more uniform density than could be obtained from regular cold die compaction. The resulting green perform is then sintered.

Metal Injection Molding. This method allows for the mass production of complex powder metal parts. Here, fine metal powders are mixed with thermoplastics, waxes or other ingredients, which serve as binding materials. The resulting feedstock is then fed into a conventional injection molding machine. Once the green preform is made, most of the binding material is removed either thermally or chemically, or by some combination of the two. The precise method is based on the binding material being used. The part is then sintered at temperatures that normally exceed 2300°F, eliminating the remaining binding material. This process offers final relative densities in excess of 96% with interconnected porosity being less than 0.2%. A wide variety of alloys can be processed with this method including alloy and stainless steel, soft magnetic alloys and tungsten carbide.

Spray Forming. This is not a process used to create a single workpiece. Rather, its is used to create billets, tubes and sheet/plate that are then used to make other products. The spray forming process consists of sequential stages of liquid metal atomization and droplet consolidation at deposition rates from 0.5 to 50 pounds per second. This produces a near-net shaped product that is close to full density with a fine, even grain structure and mechanical properties that meet or exceed those of ingot processed alloys.

(Selected from *Gear Technology*, September/October, by Charles M. Cooper, 1999)

New Words and Expressions

prejudice ['predʒudis] *n.* 偏见，歧视

fragment ['frægmənt] *n.* 碎片；*vt.* （使）成碎片，分裂

merger ['mə:dʒə] *n.* 合并，联合

acquisition [ækwi'ziʃən] *n.* 获得，收获，探测，发现

hardness ['hɑ:dnis] *n.* 硬（刚）度，难度

forging ['fɔ:dʒiŋ] *n.* 锻造

preform ['pri:'fɔ:m] *n.*, & *vt.* 预制件，预制

wrought [rɔ:t] *a.* 锻（制）的，可锻造的，精致的

inert [i'nə:t] *a.* 惰性的，不活泼的，无效的

hermetically [hə:'metikəli] *ad.* 密封地，气密地

leaching ['li:tʃiŋ] *n.* 浸出，浸析

investment [in'vestmənt] *n.* 投资，投入，包围，熔模（蜡模）制造

elastomeric [iˌlæstə'merik] *a.* 弹性的

feedstock ['fi:dstɔk] *n.* 原料

billet ['bilit] *n.* 钢坯

ingot ['iŋgət] *n.* （铸）块，浇锭

spray forming 喷溅成型

relative densities 相对密度

green compact 生坯，未经高温烧结的坯体

Notes

① There is a greater use of powder metal in gear manufacturing，on both the tooling side and the workpiece side，today than ever before. 粉末金属在齿轮和制造齿轮的工具方面的使用，今天比过去的任何时候都要多。

② high-speed steel alloy cutting tools，高速切割合金钢。

③ This drive toward heavier density in powder metal parts is of great importance to the powder metal industry. 这种使粉末金属工件向更高密度发展的努力对粉末金属工业非常重要。

④ interconnected porosity，互通气孔率。

⑤ cold isostatic pressing，冷态等静压。

⑥ metal injection molding，金属注射成型。

Unit 8 Metal-Matrix Composites: Challenges and Opportunities

Scope and Definitions

A metal-matrix composite (MMC) combines into a single material a metallic base with a reinforcing constituent, which is usually non-metallic and is commonly a ceramic. By definition, MMCs are produced by means of processes other than conventional metal alloying. Like their polymer-matrix counterparts, these composites are often produced by combining two pre-existing constituents (e. g. a metal and a ceramic fibre). Processes commonly used include powder metallurgy, diffusion bonding, liquid phase sintering, squeeze-infiltration and stir-casting. Alternatively, the typically high reactivity of metals at processing temperatures can be exploited to form the reinforcement and/or the matrix *in situ*, i. e. by chemical reaction within a precursor of the composite.

There are several reasons why MMCs have generated considerable interest within the materials community for nearly 30 years.

(1) The "composite" approach to metallurgical processing is the only pathway for the production of entire classes of metallic materials. Only in this way can aluminium, copper, or magnesium be combined with significant volume fractions of carbide, oxide or nitride phases because, unlike iron, the solubility of carbon, nitrogen or oxygen in the molten metal is (with the exception of O in Cu) far too low.

(2) The approach facilitates significant alterations in the physical properties of metallic materials. Composites offer scope for exceeding the specific elastic modulus value of about 26 J • kg $^{-1}$, which is exhibited by all the main engineering metals. Composites also offer the only path-way for producing materials with tailored physical property combinations; an example is that of low thermal expansivity combined with high thermal conductivity, a combination of importance for electronic packaging.

(3) MMCs offer significant improvements over their polymer matrix counterparts with regard to several properties, including tolerance of high temperature, transverse strength, chemical inertness, hardness and wear resistance, while significantly outperforming ceramic matrix composites in terms of toughness and ductility.

(4) Exceptional properties can be obtained in some cases. An example is that of 3M's Nextel-reinforced aluminium composites, which exhibit along the fibre direction a tensile strength of 1. 5 GPa, a compressive strength of 3 GPa and a transverse strength above 200 MPa, in a material of density only slightly above 3 g • cm $^{-3}$.

MMCs come in several distinct classes, generally defined with reference to the shape of their reinforcement.

Particle-reinforced metals (PRMs) contain approximately equiaxed reinforcements,

with an aspect less than about 5. These are generally ceramic (SiC, Al₂O₃, etc.). PRMs commonly contain below 25 vol. % ceramic reinforcement when used for structural applications, but can have as much as 80 vol. % ceramic when used for electronic packaging. In general, PRMs are at least approximately isotropic. They are produced using both solid state (powder metallurgy) and liquid metal techniques (stir casting, infiltration). Their mechanical properties, while often inferior to those of fibre-reinforced metals, are more or less isotropic and often represent, at moderate cost, significant improvements over those of corresponding unreinforced metals.

Short fibre- and whisker-reinforced metals These contain reinforcements with an aspect ratio of greater than 5, but are not continuous. These composites are commonly produced by squeeze infiltration. They often form part of a locally reinforced component, generally produced to net or near-net shape. Their use in automotive engines is now well established.

Continuous fibre-reinforced metals contain continuous fibres (of alumina, SiC, carbon, etc.) with a diameter below about 20μm. The fibres can either be parallel, or pre-woven before production of the composite; this is generally achieved by squeeze infiltration.

Monofilament-reinforced metals contain fibres that are relatively large in diameter (typically around 100μm), available as individual elements. Due to their thickness, the bending flexibility of monofilaments is low, which limits the range of shapes that can be produced. Monofilament-reinforced metals can be produced by solid state processes requiring diffusion bonding; they are commonly based on titanium alloy matrices, which are well-suited to such techniques.

Interpenetrating phase composites are ones in which the metal is reinforced with a three-dimensionally percolating phase, for example ceramic foam.

Liquid phase sintered metallic materials, include the cemented carbides, in which carbide particles are bonded together by a metal such as cobalt, and the tungsten heavy alloys.

State of the Art

MMCs have been extensively studied. SiC monofilament-reinforced titanium has been the subject of many investigations, as have aluminium alloys containing up to 25 vol. % SiC and Al₂O₃ particles. These materials have been produced by industry (including Alcan, Textron, Alcoa, AMC, BP, and 3M) in relatively large quantities, such that they have been made available for testing at research laboratories and universities. Their novelty, and their interesting mechanical behavior (at both micro- and microscopic levels), have led to many publications, exploring many features of their microstructure, deformation, and fracture behavior. Many mechanisms responsible for their mechanical characteristics are now well understood, including the roles of damage development, internal stresses, reinforcement clustering, interfacial bond strength and the effects of the presence of the reinforcement on aging of the matrix. However, much work remains to be done before required property combinations can be systematically achieved via micro-structural design.

The processing of MMCs has also generated much interest. Many publications have ap-

peared over the past decades on this subject. Commonly, such studies have presented novel composite materials or processes, without advancing the underlying science concerning the transport phenomena involved or their relationship with micro-structural features of the product. For example the rate of solid state consolidation of a mixture of two different powders is not yet predictable, nor is the rate of liquid phase sintering of metal bonded carbides.

With regard to industrial applications, MMCs now have a proven track record as successful "high-tech" materials in a range of applications, bringing significant benefits (in terms of energy savings, or component lifetime) and having documented engineering viability. These often relate to niche applications, where achievable property combinations (e. g. high specific stiffness and weldability; high thermal conductivity and low thermal expansion, or high wear resistance and low weight and high thermal conductivity) are attractive for the component concerned. Many such niches, ranging from diesel engine pistons to automotive engine cylinder liners, are of considerable industrial significance. Barriers to their wider exploitation include price (which is, of course, inter-related with global and specific usage levels), shortage of property data and design guidelines and (perceived) limitations to their ductility and toughness.

Challenges and Opportunities

Several challenges must be overcome in order to enhance the engineering usage of MMCs. Research efforts required to overcome these challenges span the spectrum from basic, fundamentals-oriented research, to more applied engineering projects.

(1) There is a need to advance our understanding of processing fundamentals, particularly concerning established processes such as squeeze infiltration, liquid phase sintering, and powder metallurgy. Progress in this area is required, both to drive innovation and to enable quantitative process simulation, optimization, and control. In particular, progress in this area is critical for controlling internal defects—an important goal with these materials, given that they are more brittle than unreinforced metals.

(2) Property improvements must be sought, particularly in ductility and toughness. Systematic investigations are required of the fundamental links between microstructure and properties. Much work to date has focused on only a few commercial or near-commercial materials, which have been characterized in detail, but do not provide full insight into basic microstructure-property relations, such as the link between particle size or spatial distribution and mechanical properties.

(3) There is clearly scope for improvements in the properties of reinforcements. Substantial advances in fibres for MMCs have been achieved at the 3M company: in terms of strength, for example, the performance of alumina fibre-reinforced aluminium has doubled over the past decade. Recent work has also shown that significant differences exist between ceramic particles that can be used as reinforcements for aluminium. Research on the economical production of high strength, low-cost, ceramics for the reinforcement of metals would be very timely.

(4) An important issue concerns secondary processing. Operations such as welding and machining, and also the definition of recycling strategies, are challenging when applied to MMCs. Research in this area is critical for certain applications and for the life-cycle engineering of these materials.

(5) Much work to date has focused on aluminium matrix composites, but copper, magnesium, and iron-based matrix composites do offer promise in specific applications. These include electronic applications for copper-matrix composites, and chemical processing environments for steel matrix composites. These systems deserve exploration, again with emphasis on fundamentals, rather than the development of this or that specific composite.

These windows of opportunity in research are ones which, in large part, call for partnerships between different laboratories and researchers. For instance, a capability for controlled processing of these materials is needed for the generation of samples and microstructures that can be used in the exploration of microstructure-property relations. Unlike unreinforced alloys, in which the micro-structure can be varied using conventional and well-established deformation and heat-treatment processes, the processing of MMCs requires specialized equipment and know-how. The establishment of a European centre of excellence in MMC research, able to cover the entire spectrum from processing to performance, and providing a hub for such a coordinated effort, would be highly opportune.

(Selected from *Materials Synthesis and Processing*, by A. Mortensen and T. W. Clyne, 2002)

New Words and Expressions

matrix ['meitriks] *n.* 基质，基体

composite ['kɔmpəzit] *a.* 合成的，复合的；*n.* 合成物，复合材料

polymer ['pɔlimə] *n.* 聚合体，聚合物，聚合材料

diffusion [di'fju:ʒən] *n.* 扩散

sinter ['sintə] *n.* 泉华，烧结物，熔渣；*vt.* 使烧结

squeeze [skwi:z] *v.* 压，压缩，挤

infiltration [ˌinfil'treiʃən] *n.* 渗透，渗入，渗透物

carbide ['kɑ:baid] *n.* 碳化物，碳化钙

oxide ['ɔksaid] *n.* 氧化物

facilitate [fə'siliteit] *vt.* 使容易，使便利，推动，促进

elastic modulus 弹性模数，弹性组件，弹性计量单位

tailored ['teiləd] *a.* 剪裁讲究的，特制的，特定的

packaging ['pækidʒiŋ] *n.* 包装，包装术，包装业

transverse strength 抗挠强度，横向强度

inertness [i'nə:tnis] *n.* 不活泼，没有生气

ductility [dʌk'tiliti] *n.* 展延性，柔软性，顺从

tensile ['tensail] *a.* 可拉长的，可伸长的；张力的，拉力的

equiaxed ['i:kwiækst] *a.* 各方等大的，由等轴晶粒组成的

isotropic ［ˌaisəuˈtrɔpik］ *a.* 等方性的，各向同性的

flexibility ［ˌfleksəˈbiliti］ *n.* 弹性，适应性，机动性，挠性

monofilament ［ˌmɔnəˈfiləmənt］ *n.* 单（根长）丝，单纤（维）丝

titanium ［taiˈteinjəm］ *n.* 钛

percolate ［ˈpəːkəleit］ *n.* 滤过之液体，滤液；*v.* 过滤

cement ［siˈment］ *n.* 水泥，接合剂；*vt.* 接合，用水泥涂，巩固；*vi.* 粘牢

underlie ［ˌʌndəˈlai］ *vt.* 位于……之下，成为……的基础

consolidation ［kənˌsɔliˈdeiʃən］ *n.* 巩固，合并

track ［træk］ *n.* 轨迹，途径；*vt.* 循路而行，追踪，通过

niche ［nitʃ］ *n.* 小生境，墙壁的凹入处，壁龛

diesel ［ˈdiːzəl］ *n.* 柴油机，内燃机

piston ［ˈpistən］ *n.* 活塞

cylinder ［ˈsilində］ *n.* 圆筒，圆柱体，汽缸，柱面

liner ［ˈlainə］ *n.* 衬垫，底垫

cylinder liner 汽缸衬垫，垫圈

optimization ［ˌɔptimaiˈzeiʃən］ *n.* 最佳化，最优化

simulation ［ˌsimjuˈleiʃən］ *n.* 仿真，模拟，模拟实验

spatial ［ˈspeiʃəl］ *a.* 空间的

substantial ［səbˈstænʃəl］ *a.* 坚固的，实质的，真实的，充实的

welding ［ˈweldiŋ］ *n.* 焊接法，定位焊接

hub ［hʌb］ *n.* 毂，木片，中心；*n.* 网络集线器，网络中心

Notes

① Like their polymer-matrix counterparts, these composites are often produced by combining two pre-existing constituents (e. g. a metal and a ceramic fibre). counterparts，对应的人或事物，此处指 composites；these composites 指 metal-matrix composites。

② Only in this way can aluminum, copper, or magnesium be combined with significant volume fractions of.... 这是一个强调句，强调 in this way。以 Only 开头的句子，其助动词应置于主语之前，本句助动词为 can，在句中置于主语 aluminum, copper, or magnesium 之前。

Exercises

1. Question for discussion
   (1) What are metal-matrix composites? According to the shape of their reinforcement, which classes can MMCs be divided into?
   (2) Please state the advancement of MMC researches.
   (3) In study MMCs, which challenges do research efforts require to overcome?
2. Translate the following into Chinese

metal-matrix composite   metallurgical processing

chemical inertness   wear resistance

particle-reinforced metals   powder metallurgy

- Their mechanical properties, while often inferior to those of fibre-reinforced metals, are more or less isotropic and often represent, at moderate cost, significant improvements over those of corresponding unreinforced metals.
- Many mechanisms responsible for their mechanical characteristics are now well understood, including the roles of damage development, internal stresses, reinforcement clustering, interfacial bond strength and the effects of the presence of the reinforcement on aging of the matrix.
- Much work to date has focused on only a few commercial or near-commercial materials, which have been characterized in detail, but do not provide full insight into basic microstructure-property relations, such as the link between particle size or spatial distribution and mechanical properties.
- Unlike unreinforced alloys, in which the micro-structure can be varied using conventional and well-established deformation and heat-treatment processes, the processing of MMCs requires specialized equipment and know-how.

3. Translate the following into English

抗挠强度   力学行为

挤压渗透   晶须加强型金属

单丝状加强型材料   内渗透相复合材料

液相焙烧金属材料   持续纤维加强型材料

Reading Material

Materials Science in Space

Introduction

Materials science in space is a small but challenging sector in the field of materials science. The environment of reduced gravity existing in space puts fundamental research in the field of materials processing within our reach. Under microgravity, the buoyancy convection in a melt is significantly reduced and sedimentation effects are suppressed. This enables the investigation of crystallization and solidification mechanisms with no interference from convective heat and mass transport in the liquid.

In this way, the reduced gravity level existing in space provides an important tool for fundamental research projects in materials science. Performing demanding experiments in a microgravity environment can therefore be regarded as a revolutionary approach in materials science.

State of the Art

Materials science experiments have been carried out in space for more than two decades.

Solidification or crystallization processes are sensitive to melt flow or sedimentation effects. This implies that the experiments need at least some minutes of low gravity and therefore can only be carried out during sounding rocket flights, during space shuttle missions or at a space station. As a consequence, opportunities for materials science in space are very few and far between. Each experiment needs years of intensive preparation and can be regarded as a 'single shot' experiment with a high risk of failure. In this sense, the kind of ongoing experimental programme, familiar in materials science on earth, does not exist for materials science in space.

Nevertheless, previous microgravity experiments have shown a series of important scientific results. In the following some relevant examples are mentioned.

- In relation to microstructure formation during columnar alloy growth no comprehensive and systematic study exists and the data available is only limited. Using a binary transparent alloy acting as a model substance for non-faceting solidification, earth experiments show deformed interfaces and do not allow quantitative pattern evaluation. In contrast, the space growth sample shows an undisturbed and rather regular hexagonal pattern with fewer defects. Directional dendritic solidification under conditions of purely diffusive heat and mass transport conditions in space show significantly regular patterns consisting of larger dendrites in the space experiments.

- First experiments in of equiaxed growth confirm an environment free of sedimentation. The resulting grain structure is much more regular than on earth and will provide a starting point for a better understanding of grain growth mechanisms. Sedimentation-free solidification is also important in the case of peritectic systems which exist for many multicomponent alloys. Solid peritectic phases grow in the melt and behave like *in situ* particles. The diffusive growth conditions obtaining in space allow undisturbed observation of such technically important phenomena.

- The principal objective in relation to crystal growth of semiconductor materials is to study the origin of chemical heterogeneities, both on the macroscopic and microscopic level. Space experiments using InSb and doped Ge in Bridgman-type facilities show almost striation-free crystals and therefore much better homogeneity. For crystal growth without contact to the wall the floating-zone technique is used. Space experiments using Si show that surface tension-driven Marangoni convection also impacts in a microgravitational environment and restricts achievable homogeneity. On the other hand, using compound semiconductors, such as GaAs or GaSb, crystals in sizes not attainable on earth have been processed.

- Containerless processing in space allows determination of the thermophysical properties of the melt, e. g. viscosity, thermal conductivity, diffusivity, surface tension or enthalpy. In particular for glass-forming or highly reactive alloys, these space experiments provide unique data for thermodynamic modelling.

Expected Breakthroughs and Future Visions

Materials science in space is expected to make a crucial contribution both to the fundamental understanding of materials processes and in enhancing materials properties. Sophisticated experiments in a microgravity environment allow crystal growth or alloy solidification under purely diffusive heat and mass transport conditions. In addition, containerless sample processing available in space allows the measurement of properties of the melt such as viscosity, thermal conductivity, diffusivity or surface tension. This is why convection-free or containerless processing of this kind provides a unique database for enhancing the accuracy of numerical models of microstructure formation.

Fundamental investigations of this kind may result in the enhancement of industrial products. At present, there is a rather large gap between simplified scientific experiments and complex technical processes. To improve the transfer of knowledge, closer interaction between science and industry is absolutely necessary. This means greater transparency in scientific results for industry, as well as specification of specific problems as an input for scientific research using microgravity.

Two essential boundary conditions make the achievement of such a breakthrough within the next decade a realistic possibility. Firstly, within the next few years the International Space Station ISS will be providing a platform for carry out ongoing experiments in microgravity. Secondly, future activities in space will be joint experiments by groups of scientists from different countries defining a common scientific programme. Within the scope of this Microgravity Applications Promotion (MAP) programme of ESA, industrial partners are directly involved in order to define materials science research in space. In this sense, the concept of "learning for earth in space" can be realized.

Research Potential and Priorities

Research potential for materials science in space can be identified in areas in which buoyancy effects in the melt and sedimentation effects on earth play an important role. Space experiments allow a diffusive growth condition. Three main topics can be defined as follows.

(a) Solidification of metallic alloys   During directional solidification processes on earth, convection in the melt significantly impacts the growth structure of the solid-liquid interface. In the case of metallic alloys, the main future goal is reliable determination of fundamental relationships at microscopic scales. The strategy is based on a joint approach using well-defined space experiments and theoretical and numerical modelling. Progress is mainly required in two topics: (1) In columnar growth, our understanding of the formation of non-planar solid-liquid interface patterns is nowhere near complete. In particular, understanding the stability and dynamics of dendritic or mushy interface structures, impacted by melt flow and freckle formations, is essentially important to most industrial casting processes. Benchmark experiments in microgravity allow much more ordered cellular or dendritic morphologies as a basis for a better fundamental understanding. (2) Equiaxed growth often occurs in casting processes. The development of equiaxed grains in the undercooled melt can be stud-

ied extremely well through space experiments without superposed settlement of nuclei. In particular, lightweight metallic alloys, as applied in the automotive industry, should be used for future well-defined benchmark experiments. The results obtained in such experiments will provide a database for numerical modeling and will be an aid in improving technical processes.

(b) Solidification of semiconductor materials   In the case of semiconductor crystal growth in space the main objective is to understand the role of the basic transport mechanisms in the melt, i. e. buoyancy and Marangoni convection. This is the prerequisite to producing larger-sized crystals with a greater degree of homogeneity and fewer defects than on earth. Key topics in the field of crystal growth may be wall-free growth from the melt (CdTe and compounds of Si and Ge), growth from the vapour phase (HgI_2), and research into chemical segregation in highly concentrated alloys.

(c) Determination of thermophysical properties   Most technically relevant materials consist of more than two components. During solidification, a very broad range of different phases may occur, either enhancing or drastically deteriorating the properties of the materials. Understanding and predicting the structure of multi-component alloys demands determination of thermophysical properties and knowledge as to how stable or metastable phases are formed. Space experiments using a containerless processing technique may be able to measure relevant thermophysical data such as viscosity, thermal conductivity, diffusivity or surface tension in a highly accurate way. This data is necessary input to enhancing numerical modeling of industrially relevant solidification processes.

To sum up, in the above-mentioned topics, materials science in space is expected to be of great benefit in the future, both by achieving better fundamental understanding of solidification processes and by enhancing casting technologies.

(Selected from *Materials: Science and Application*, by P. R. Sahm and G. Zimmermann, 2002)

New Words and Expressions

dendritic [den'dritik] *a.* 树枝状的
equiaxed ['i:kwiækst] *a.* 各方等大的，由等轴晶粒组成的
peritectic [,peri'tektik] *a.* 包晶的，转熔的
heterogeneity [,hetərəudʒi'ni:iti] *n.* 非均一性；异种，异质，不同成分
striation [strai'eiʃən] *n.* 条痕，条纹状
diffusivity [,difju:'siviti] *n.* 扩散能力，扩散率
enthalpy [en'θælpi] *n.* 焓，热函
buoyancy ['bɔiənsi] *n.* 浮性，浮力，轻快
benchmark ['bentʃmɑ:k] *n.* 基准

Notes

① As a consequence, opportunities for materials science in space are very few and far be-

tween. few and far between 是固定用法，意思是"极其稀少"、"极为罕见"。

② At present，there is a rather large gap between simplified scientific experiments and complex technical processes. gap，差距。参考译文：目前，在简化的科学实验与复杂的工艺过程之间存在着相当大的差距。

③ Understanding and predicting the structure of multi-component alloys demands determination of thermophysical properties and knowledge as to how stable or metastable phases are formed. thermophysical property，**热物理特性（性质）**；metastable phase，**亚稳相**。demands 有两个宾语，一个是 determination，另一个是 knowledge。

PART III CERAMICS

Unit 9　Introduction to Ceramics（Ⅰ）

Definition

The word ceramic, derives its name from the Greek *keramos*, meaning "pottery", which in turn is derived from an older Sanskrit root, meaning "to burn". The Greeks used the term to mean "burnt stuff" or "burned earth". Thus the word was used to refer to a product obtained through the action of fire upon earthy materials.

Ceramics make up one of three large classes of solid materials. The other material classes include metals and polymers. The combination of two or more of these materials together to produce a new material whose properties would not be attainable by conventional means is called a composite. Examples of composites include steel reinforced concrete, steel belted tyres, glass or carbon fibre-reinforced plastics (so called fibre-glass resins) used for boats, tennis rackets, skis, and racing bikes.

Ceramics can be defined as inorganic, non-metallic materials that are typically produced using clays and other minerals from the earth or chemically processed powders. Ceramics are typically crystalline in nature and are compounds formed between metallic and non-metallic elements such as aluminium and oxygen (alumina, Al_2O_3), silicon and nitrogen (silicon nitride, Si_3N_4) and silicon and carbon (silicon carbide, SiC). Glass is often considered a subset of ceramics. Glass is somewhat different from ceramics in that it is amorphous, or has no long range crystalline order.

Most people, when they hear the word ceramics, think of art, dinnerware, pottery, tiles, brick and toilets. The above mentioned products are commonly referred to as traditional or silicate-based ceramics. While these traditional products have been, and continue to be, important to society, a new class of ceramics has emerged that most people are unaware of. These advanced or technical ceramics are being used for applications such as space shuttle tile, engine components, artificial bones and teeth, computers and other electronic components, and cutting tools, just to name a few.

History and Impact on Society

Archaeologists have uncovered man-made ceramics that date back to at least 24000 BC. These ceramics were found in what was formerly Czechoslovakia and were in the form of animal and human figurines, slabs, and balls. These ceramics were made of animal fat and bone mixed with bone ash and a fine clay-like material. After forming, the ceramics were fired at temperatures between 500~800℃ in domed and horseshoe shaped kilns partial-

ly dug into the ground with loess walls. While it is not clear what these ceramics were used for, it is not thought to have been a utilitarian one.

The first use of functional pottery vessels is thought to be in 9,000 BC. These vessels were most likely used to hold and store grain and other foods. Ancient glass manufacture is thought to be closely related to pottery making, which flourished in Upper Egypt about 8,000 BC. While firing pottery, the presence of calcium oxide (CaO) containing sand combined with soda and the overheating of the pottery kiln may have resulted in a coloured glaze on the ceramic pot. It is thought that it was not until 1,500 BC that glass was produced independently of ceramics and fashioned into separate items.

Since these ancient times, the technology and applications of ceramics (including glass) has steadily increased. We often take for granted the major role that ceramics have played in the progress of humankind. Let us look at a few examples of the importance of ceramics in our lives. Modern iron and steel and non-ferrous metal production would not be possible without the use of sophisticated refractory materials that are used to line high temperature furnaces, troughs and ladles. Metals make automobiles, machinery, planes, buildings, and thousands of other useful things possible. Refractory ceramics are enabling materials for other industries as well. The chemical, petroleum, energy conversion, glass and other ceramic industries all rely on refractory materials.

Much of the construction industry depends on the use of ceramic materials. This includes brick, cement, tile, and glass. Cement is used to make concrete which in turn is used for roadways, dams, buildings, and bridges. Uses of glass in the construction industry include various types of windows, glass block, and fibres for use in insulation, ceiling panels and roofing tiles. Brick is used for homes and commercial buildings because of its strength, durability, and beauty. Brick is the only building product that will not burn, melt, dent, peel, warp, rot, rust or be eaten by termites. Tile is used in applications such as flooring, walls, countertops, and fireplaces. Tile is also a very durable and hygienic construction product that adds beauty to any application.

An important invention that changed the lives of millions of people was the incandescent light bulb. This important invention by Thomas Edison in 1879 would not be possible without the use of glass. Glass's properties of hardness, transparency, and its ability to withstand high temperatures and hold a vacuum at the same time made the light bulb a reality. The evolution of lighting technology since this time has been characterized by the invention of increasingly brighter and more efficient light sources. By the middle of twentieth century, methods of lighting seemed well established——with filament and fluorescent lamps for interiors, neon lamps for exterior advertising and signs, and sodium discharge lamps for streets. Since this time, light-emitting diode (LED) technology has been developed with applications in watches, instrument panel indicators, telecommunications (optical fibre networks), data storage (CD technology), and document production (laser printers).

The electronic industry would not exist without ceramics. Ceramics can be excellent insulators, semiconductors, superconductors, and magnets. It's hard to imagine not having

mobile phones, computers, television, and other consumer electronic products. Ceramic spark plugs, which are electrical insulators, have had a large impact on society. They were first invented in 1860 to ignite fuel for internal combustion engines and are still being used for this purpose today. Applications include automobiles, boat engines, lawnmowers, and the like. High voltage insulators make it possible to safely carry electricity to houses and businesses.

The optical fibres have provided a technological breakthrough in the area of telecommunications. Information that was once carried electrically through hundreds of copper wires is now being carried through high-quality transparent silica (glass) fibres. Using this technology has increased the speed and volume of information that can be carried by orders of magnitude over that which is possible using copper cable. The reliability of the transmitted information is also greatly improved with fibre optic fibres. In addition to these benefits, the negative effects of copper mining on the environment are reduced with the use of silica fibres.

Ceramics play an important role in addressing various environmental needs. Ceramics help decrease pollution, capture toxic materials and encapsulate nuclear waste. Today's catalytic converters in vehicles are made of cellular ceramics and help convert noxious hydrocarbons and carbon monoxide gases into non-toxic carbon dioxide and water. Advanced ceramic components are starting to be used in diesel and automotive engines. Ceramics' light weight and high-temperature and wear resistant properties, results in more efficient combustion and significant fuel savings.

Reusable, lightweight ceramic tile make NASA's space shuttle program possible. These thermal barrier tile protect the astronauts and the shuttle's aluminium frame from the extreme temperatures (up to approximately 1600℃) encountered upon re-entry into the earth's atmosphere.

(Selected from *Journal of the American Ceramic Society*, by Greg Geiger, 1999)

New Words and Expressions

pottery ['pɔtəri] *n.* 陶器

sanskrit ['sænskrit] *a.* 梵语的

racket ['rækit] *n.* 球拍

alumina [ə'lju:minə] *n.* 氧化铝

tile [tail] *n.* 瓦片，瓷砖

archaeologist [ɑ:ki'ɔlədʒist] *n.* 考古学家

figurine ['figjuri:n] *n.* 小雕像

glaze [gleiz] *n.* 釉料，釉面

refractory [ri'fræktəri] *a.*, *n.* 难熔的，耐火材料

cement [si'ment] *n.* 水泥，结合剂

incandescent [inkæn'desnt] *a.* 遇热发光的，白炽的

fluorescent ［fluə'resnt］ *a.* 荧光的

diode ［'daiəud］ *n.* 二极管

encapsulate ［in'kæpsjuleit］ *vt.* 装入胶囊，包裹

hygienic ［hai'dʒiːnik］ *a.* 卫生的

neon ［'niːɔn］ *n.* 氖

noxious ［'nɔkʃəs］ *a.* 有害的

trough ［trɔf］ *n.* 出钢水口

ladle ［'leidl］ *n.* 钢水包

termite ［'təːmait］ *n.* 白蚁

silicon nitride 氮化硅

Notes

① The word ceramic, derives its name from the Greek *keramos*, meaning "pottery", which in turn is derived from an older Sanskrit root, meaning "to burn". 陶瓷这个词是由希腊的 *keramos* 得来的，意思是"陶器"，而 *keramos* 这个词又是起源于更古老的梵语，意思是"烧"。

② earthy materials，泥土料。

③ steel reinforced concrete，钢筋混凝土。

④ steel belted tyres，钢丝轮胎。

⑤ silicate-based，硅酸盐的。

⑥ non-ferrous metal，非铁类金属。

⑦ light-emitting diode，发光二极管。

⑧ ceramic spark plugs，陶瓷火花塞。

Exercises

1. Reading comprehensions
   (1) What kinds of materials are generally classified as ceramics?
   (2) Please give the basic properties of ceramic materials.
   (3) Please give some application examples of ceramic materials.

2. Translate the following into Chinese

   amorphous materials   refractory materials

   electrical insulator   silica fibre

   thermal barrier tile

   - Ceramics can be defined as inorganic, non-metallic materials that are typically produced using clays and other minerals from the earth or chemically processed powders. Ceramics are typically crystalline in nature and are compounds formed between metallic and non-metallic elements such as aluminium and oxygen (alumina, Al_2O_3), silicon and nitrogen (silicon nitride, Si_3N_4) and silicon and carbon (silicon carbide, SiC). Glass is often considered a subset of ceramics. Glass is somewhat different than ceramics in that it is amorphous, or has no long range crystalline order.

- Ceramics play an important role in addressing various environmental needs. Ceramics help decrease pollution, capture toxic materials and encapsulate nuclear waste.

3. Translate the following into English

碳纤维   非金属材料

类似黏土的材料   高温炉

混凝土

Reading Material

Introduction to Ceramics （Ⅱ）

Advanced Ceramics

Advanced ceramics, also known as engineering or technical ceramics, refer to materials which exhibit superior mechanical properties, corrosion/oxidation resistance, and thermal, electrical, optical or magnetic properties. Advanced ceramics are generally broken down into the following segments:

- structural ceramics;
- electrical and electronic ceramics;
- ceramics coatings;
- chemical processing & environmental ceramics.

Structural ceramics include applications such as industrial wear parts, bioceramics, cutting tools, and engine components. Electronic ceramics, which has the largest share of the advanced ceramic market includes capacitors, insulators, substrates, integrated circuits packages, piezoelectrics, magnets and superconductors. Ceramic coatings find application in engine components, cutting tools, and industrial wear parts. The applications under chemical processing and environmental ceramics include filters, membranes, catalysts, and catalyst supports.

The beginning of the advanced ceramics era has been said to have started approximately 50 years ago with the expanding use of chemically prepared powders. For example, the Bayer process for the production of alumina powders initially grew from spark plug production. While these powders would be considered relatively low grade by today's standards, they were more pure and offered more control over the composition, microstructure, and crystal structure over minerals-based ceramics.

Today, the market for advanced ceramics is large and growing as they continue to replace more traditional materials in many applications while providing the only material solution in other applications. In many cases, ceramics are used with other materials to make up only part of an overall system. This is especially true in the electronics field.

The future success of both the traditional advanced ceramic markets and developing non-traditional U.S. markets depends on factors such as increasing the quality and reliability of

the finished products, improving the cost/benefit ratio of ceramic components, increasing applied research and development, increased supply of domestic, high-quality raw materials, and overcoming designer and end-user reluctance to use ceramics.

Improvements are occurring however, in areas such as powder processing, shape forming, non-destructive evaluation, machining, standardization and the development of a materials property database. In order to reduce manufacturing expenses, researchers are looking toward innovative, "near-net-shape" forming methods such as gelcasting, freezecasting, injection moulding, and rapid prototyping. These methods will reduce machining cost, which can be as much as 50% of the total manufacturing cost.

NASA Lewis Research Centre and the two leading aircraft engine manufacturers, General Electric Aircraft Engines (GE) and Pratt & Whitney (P&W), are developing the technology for an environmentally safe propulsion system for a High Speed Civil Transport (HSCT). This type of supersonic airliner would transport more than 300 passengers in a three-class arrangement over 5,000 nautical miles at Mach 2.4 cruise. Because of its high speed, a trip from Los Angeles to Tokyo, for example, would take just over 4 hours instead of 10 hours on subsonic aeroplanes.

What the Future May Hold for Advanced Ceramics

Imagine a car that has a fuel efficiency of 80 mpg (miles per gallon), a range of 500 miles, emits no pollutants, and runs on many different fuels such as gasoline, diesel or alcohol. Chrysler Corp. hopes to have a family car with this technology available by 2010, and the cost will be the same as that of a standard petrol-engined car. This type of vehicle is made possible by fuel cell technology. Fuel cells work like batteries, but are better because they won't run down. These fuels cell would not be possible however if not for the use of ceramic materials.

Another interesting area of research is the so called "smart" ceramics. These ceramic systems provide the necessary life functions of sensing, actuating, control, and intelligence. Some examples of smart systems include: medical systems that treat diabetes with blood sugar sensors and water purification systems that sense and remove noxious pollutants; and houses that have electrochromic windows that control the flow of heat and light in response to weather changes and human activity. A major ski manufacturer now offers a "smart" ski that makes use of ceramics piezoelectric properties. When skiing at high speeds, skis tend to vibrate, lessening the contact area between the ski edge and snow surface. This results in reduced stability and control and decreases the skiers speed. The piezoceramic embedded in the ski converts the unwanted vibrations into electrical energy, thus keeping the skis on the snow.

Ceramic, or high-temperature superconductors are now being developed for commercial applications and appear to be a sure bet to enter more commercial markets over the next few years. Electric wires made from these materials carry electricity with little or no resistance losses. In the utility power industry, these wires can be used to produce super efficient

coils, magnets, conductors, and machines and power components. The use of high temperature superconductors in these applications could save billions of dollars in energy costs and help the environment at the same time.

Circuits using high-temperature superconducting materials could boost the processing speed of computers, reduce resistance losses in motor controllers, and enhance the ability of magnetic resonance imaging (MRI) scanners and other non-destructive examination devices to sense minute changes in magnetic fields. Even the processes of getting to work and traveling between major cities could be changed by high-temperature superconductors. Research is being conducted to use this material for magnetic levitation (maglev) trains. These trains would travel efficiently at high speeds by floating on a frictionless magnetic cushion. Prototype maglev trains already operate in Japan and Germany and researchers are now looking for a new generation of ceramic superconducting magnets for this application.

Another growth area for advanced ceramics is in the medical field. Surgeons are already using bioceramic materials for repair and replacement of human hips, knees, shoulders, fingers, eyes and wrists. Ceramics are also being used to replace diseased heart valves. Dentists are using ceramics for tooth replacement implants and for brackets for braces.

(Selected from *Journal of the American Ceramic Society*, by Greg Geiger, 1999)

New Words and Expressions

bioceramics [ˌbaiəusiˈræmiks] *n.* 生物陶瓷

piezoelectrics [paiˈiːzəuiˈlektriks] *n.* 压电体

nautical [ˈnɔːtikəl] *a.* 船员的，船舶的，海上的，航海的

combustor [kəmˈbʌstə] *n.* 喷射引擎之燃烧室

cathode [ˈkæθəud] *n.* 阴极

cermet [ˈsəːmet] *n.* 金属陶瓷，含陶合金

actuate [ˈæktjueit] *vt.* 开动，促使

diabetes [ˌdaiəˈbiːtiːz] *n.* 糖尿病，多尿症

superconductor [ˌsjuːpəkənˈdʌktə] *n.* 超导（电）体

magnetic [mægˈnetik] *a.* 磁的，有磁性的，有吸引力的

levitation [leviˈteiʃən] *n.* 轻轻浮起，升在空中

maglev [mæglev] *n. & a.* 磁力悬浮火车（的）

bracket [ˈbrækit] *n.* 括弧，支架

brace [breis] *n.* 支柱，带子；*vt.* 振作精神

structural ceramics 结构陶瓷

yttrium oxide 氧化铱

zirconium dioxide 氧化锆

Notes

① magnetic properties，磁学性能。

② integrated circuits packages，集成电路包装。

③ ceramic coating，陶瓷涂层。

④ near-net-shape，近净尺寸。

⑤ rapid prototyping，快速原形（样品）制造。

⑥ high-temperature superconductors，高温超导体。

Unit 10 Advanced Ceramics on the Battlefield

The recent use of NATO military force in the former Federal Republic of Yugoslavia has once again focused the world's attention on the advanced and awesome technology that is arrayed on the modern battlefield—— one of the most severe and hostile environments on earth. Given the combinations of properties available with advanced ceramics, it is not surprising that there are many unique military applications for these materials.

Ceramic Armor

Protection of personnel and critical equipment against hostile fire is a high priority for modern military forces. The high hardness exhibited by many advanced ceramics enables them to shatter hard, armor piercing projectiles. When a hard projectile hits a ceramic target, the energy transferred from the projectile to the ceramic induces an elastic shock wave, which reflects from the back face of the ceramic, travels back across the ceramic and reenters the projectile as an elastic tensile wave that shatters the projectile. As the ceramic is defeating the projectile, it is undergoing fracture itself. To contain the residual fragments and kinetic energy of the projectile and ceramic rubble, a backup layer of polymer is used to strengthen the structure. This configuration is known as composite ceramic armor.

During the Vietnam conflict it became necessary to protect helicopter crews from armor piercing small arms fire. At the time it was demonstrated that boron carbide-faced composite armor could provide such protection at about half the weight of steel armor. Rapid scale-up and fielding of boron carbide composite seats and chest plates for aircrews saved many lives during that conflict. Since then, boron carbide composite armor has been considerably improved with more efficient backup materials such as Kevlar or Spectra. These composites remain the most weight-efficient armor versus small arms fire, and virtually all Western combat helicopters use it for seats and critical component protection. In cases where weight can be traded for reduced cost, silicon carbide or alumina-faced armors have also been used. Modular ceramic armor, which can be rapidly installed and removed as missions change, was used to protect C-17 aircraft flying relief missions into Bosnia in the mid-90s. It has also been used to protect light vehicles in peacekeeping operations.

Missile Guidance

Radar is widely used to identify and acquire targets. When most of us think of radar antennas, we think of the rotating dishes seen at airports. The radar beam is "steered" by the rotation of the dish. An alternative method is to use stationary, flat phased array radar transmitters where the radar beam can be steered electronically, which is much faster. Military radar systems such as the Patriot ground-based or Aegis sea-based radars use the latter.

A phase shifter in each element of the array is used to "steer" the beam. In early versions of the Patriot system, each unit contained over 5000 ceramic phase shifter elements, which were polycrystalline ceramics of a garnet composition. Development of phase shifters tends to favor ferroelectrics, often with compositions in the barium strontium titanate family of materials.

When the ground-based radar identifies an aircraft as hostile, a surface-to-air missile is launched. At some point in the missile's flight, its onboard radar homes in and guides the missile to the target. The radome is at the front of the missile through which radar is transmitted and received. Radomes for ground-launched supersonic missiles not only have to maintain outstanding "transparency" for radar transmission, this transparency must be maintained as the radome heats up. Moreover, ground-launched missiles often have to fly through clouds. This means that the radome must be thermal shock resistant, as a very hot radome entering the cloud will be sprayed with water at 0℃.

If the missile survives the thermal shock it must then deal with rain erosion. When we walk through a spring shower we think of rain as benign. However, rain drops become like machine gun bullets at supersonic speeds. This can completely destroy many materials, and will certainly degrade the radar transparency properties of most. Thus, a successful radome material must possess thermal shock and rain erosion resistance in addition to low dielectric loss and preferably a low dielectric constant. Slip cast fused silica has demonstrated this combination of properties and is the radome material on the Patriot missile. Future surface-to-air missile may use silicon nitride-based materials for enhanced performance.

Many missile are infrared (IR) guided——they home in on the IR signal generated by the target itself. Thus, IR domes must be transparent in one or more portions of the IR spectra, so that the incoming thermal signal can be analyzed by detectors mounted behind the dome. A frequently used wavelength range is 3 to 5 microns. Many current IR dome materials operate in this range, for example MgF_2 and sapphire. The excellent abrasion resistance and strength of sapphire have made it a leading candidate dome material for several next-generation missile systems. AlON, which shares most mechanical and many physical properties with sapphire, is a polycrystalline ceramic that is more easily shape formed than sapphire. It is also likely to be used in future IR dome applications. Thin polycrystalline diamond domes have been demonstrated, and may be used for future IR dome applications.

The above are just several of many military applications of ceramics. Others include sonar, IR countermeasure devices, and thermal barrier coatings on jet engine blades. The proven success of advanced ceramic components on the battlefield should encourage ceramic developers and design engineers in their quest to address ever more challenging peacetime applications.

(Selected from *Ceramic Industry* 149, by R. Nathan Katz, 1999)

Words and Expressions

awesome ['ɔːsəm] *a.* 令人敬畏的

armor ['ɑːmə] *n.* 装甲

projectile ['prɔdʒiktail] *n.* 抛射体．枪弹

rubble ['rʌbl] *n.* 碎石

versus ['vəːsəs] *prep.* 反对，与……比较

patriot ['pætriət] *n.* 爱国者

garnet ['gɑːnit] *n.* 石榴石

radome ['reidəum] *n.* 雷达天线罩

erosion [i'rəuʒən] *n.* 磨损，风化

benign [bi'nain] *a.* 有益健康的，温和的，良好的

dielectric [daii'lektrik] *a.* 不导电的；*n.* 介质，介电材料

infrared ['infrə'red] *a.* 红外线的

sapphire ['sæfaiə] *n.* 蓝宝石

abrasion [ə'breiʒən] *n.* 擦伤，磨损

quest [kwest] *n. v.* 追求，寻求，调查

hostile environments 敌对环境

advanced ceramics 高级陶瓷，先进技术陶瓷

Notes

① To contain the residual fragments and kinetic energy of the projectile and ceramic rubble, a backup layer of polymer is used to strengthen the structure. 为了防止陶瓷碎片飞溅和吸收枪弹的动能，在装甲背部加了一种由聚合物制做的加强层。

② armor piercing small arms fire，小型穿甲火力（枪弹）。

③ elastic shock wave．弹性冲击波。

④ An alternative method is to use stationary, flat phased array radar transmitters where the radar beam can be steered electronically, which is much faster. 另外一种方法是使用静止，平的相控阵雷达发射器。这种发射器采用电子转向机构使雷达波转向更为迅速。

⑤ ground-launched missiles，陆基导弹。

⑥ Thus, a successful radome material must possess thermal shock and rain erosion resistance in addition to low dielectric loss and preferably a low dielectric constant. 这样一来，成功的雷达罩材料除了具有低的介质损耗和介电常数外，还必须具有抗热震性和耐雨水腐蚀性。

⑦ Kevlar and Spectra，两种材料的品牌。

⑧ AlON，aluminum oxynitride，氮氧化铝。

Exercises

1. Reading comprehension
   (1) How does the ceramic armor works?
   (2) What are the basic property requirements for the materials used as radome?
2. Translate the following into Chinese
   advanced technology   weight-efficient armor

modular ceramic armor

polycrystalline ceramics

ferroelectrics

dielectric loss

abrasion resistance

thermal barrier coating

- In cases where weight can be traded for reduced cost, silicon carbide or alumina-faced armors have also been used. Modular ceramic armor, which can be rapidly installed and removed as missions change, was used to protect C-17 aircraft flying relief missions into Bosnia in the mid-90s. It has also been used to protect light vehicles in peacekeeping operations.
- This means that the radome must be thermal shock resistant, as a very hot radome entering the cloud will be sprayed with water at $0°C$.

3. Translate the following into English

动能

钢质装甲

碳化硼复合材料

碳化硅

热冲击

介电损耗

Reading Material

Advance Ceramics to Continue Growth into the Millennium

Advanced ceramics in the U. S. have been growing steadily in the 1990s, despite the fact that the cuts in the U. S. military programs affected some of the anticipated demand in this decade. Electronic ceramics still constitutes a major segment with a mature market, and some of its segments are still growing very strongly. Further growth is predicted for ICs, capacitors, piezoelectric ceramics and ceramic magnetic materials. The new high temperature ceramic superconductor also offers a very high future potential market. Electronic ceramics growth is likely to continue until the early part of the next century.

The demand for ceramic coatings for military engines has declined in the 1990s. However, wear-resistant and other industrial applications have picked up, enabling overall market growth. Due to the new regulations for emissions from automobiles and hot industrial gases, ceramic automotive catalyst supports and ceramic filters are being increasingly used to reduce pollutants. These, along with ceramic membranes, are growing rapidly. In the structural ceramic area, cutting tools, wear-resistant parts and bioceramics have been growing.

Business Communications Co. , Inc. recently updated the various advanced ceramic market segments and applications in each segment in a report, *High Tech Ceramics Review* '98. According to this study, advanced ceramics are expected to continue their growth into the next century. Electronic ceramics will not only continue to hold the largest share of the market, but will also lead in the growth rate. Structural ceramics will be a close second in the growth rate. The total value of the U. S. advanced ceramic components market for 1998 is estimated to be $ 7. 4 billion. This will increase to $ 10. 9 billion by 2003, with an annu-

al average growth rate of 7.9%.

In terms of market share, electronics constituted 65.2% of the market in 1998. With increased use of ICs and capacitors in computers and telecommunication applications, the electronic market share will increase to 67.7% by the year 2003.

While structural ceramics will slightly increase market share, ceramic coatings and ceramics used for chemical processing applications will decrease their share by the year 2003. Ceramics used in environment-related applications are expected to grow at a rate above the overall growth rate of advanced ceramics.

Although there are technical and economic issues to be resolved, structural ceramics are being increasingly commercialized. The U.S. advanced structural ceramics market is expected to grow from $425 million in 1998 to $640 million in 2003. Structural ceramics will have the second largest average annual growth rate (8.5%) in the next five years, just behind electronic ceramics.

Mature markets for advanced ceramics in the electronics industry include insulators, substrates, capacitors, integrated circuit packages, magnetic ferrites and piezoelectric ceramics. The new revolutionary electronic ceramic materials are high superconductor ceramics, consisting of mixed oxides containing rare earth oxides and copper oxides. The total U.S. consumption of electronic ceramic components in 1998 was estimated at $4.878 billion. The market will further increase to $7.414 billion by the year 2003. The average annual growth rate for electronic ceramics is estimated to be 8.7% from 1998 to the year 2003.

Although the high-performance ceramic coating market was estimated to have a high growth rate in the 1990s, the market showed less growth because of the decline in the military aircraft engine market. However, many new industrial applications have compensated for that decline. Another recently completed study from BCC, titled *High-Performance Ceramic Coatings*, provides new market numbers.

Business Communications Co., Inc. has estimated the 1998 high-performance ceramic coating service market to be $757 million. This includes thermal spray, CVD and PVD. This market is expected to grow 6.9% annually to reach $1.056 billion by the year 2003.

The market segments grouped under chemical processing and environmental-related applications are ceramic membranes, filters, catalysts and catalyst supports. Of all the large commercial ceramic market segments, ceramic membranes have the largest growth rate — — as much as 15% from 1998 to 2003. Ceramic catalysts and catalyst supports constitute the largest market segment outside electronic ceramics——over $1 billion.

The combined chemical processing and environmental-related ceramics market is estimated at $1.42 billion in 1998. This will increase to $1.84 billion by the year 2003, with an average annual growth rate of 5.3%.

<div align="right">(Selected from *Ceramic Industry* 149, by Thomas Abraham, 1999)</div>

New Words and Expressions

piezoelectric [pai'i:zəui'lektrik]   *a.* 压电的

bioceramics ［ˌbaiəusiˈræmiks］ n. 生物陶瓷

magnetic ［mægˈnetik］ a. 磁性的，磁铁的

emission ［iˈmiʃən］ n. 发（放，辐）射，散发，传播

catalyst ［ˈkætəlist］ n. 催化剂

membrane ［ˈmembrein］ n. （薄）膜

capacitor ［kəˈpæsitə］ n. 电容器

substrate ［ˈsʌbstreit］ n. 基片，衬基

ferrite ［ˈferait］ n. 铁氧体

spray ［sprei］ n. 浪花，喷雾，喷涂

electronic ceramics 电子陶瓷

magnetic ferrites 磁性铁氧体

Notes

① ceramic magnetic materials，陶瓷磁性材料。

② catalyst supports，催化剂载体。

③ However, wear-resistant and other industrial applications have picked up, enabling overall market growth. 参考译文：然而，抗磨损和其他工业方面的应用已经兴起，并且使得市场得到全面的增长。

④ The new revolutionary electronic ceramic materials are high superconductor ceramics, consisting of mixed oxides containing rare earth oxides and copper oxides. 参考译文：最新的具有革命性的电子陶瓷材料是高温超导陶瓷。它是由含有稀土和铜氧化物的几种氧化物组成的。

⑤ High-Performance Ceramic Coatings，高性能陶瓷涂层。

⑥ integrated circuit packages，集成电路包装。

Unit 11 Ceramic Processing Methods

Present methods of manufacturing ceramic green bodies of a complicated shape on an industrial level include dry-pressing with subsequent machining, slip casting, pressure casting, and injection molding. Tape casting is used to produce thin sheets, mainly for the electronics industry. All these forming methods start with a suspension where the ceramic particles (powders, whiskers, etc.) are mixed with a liquid or a polymer melt, proper dispersant, and possibly further additives such as binders, plasticizers, and antifoaming agents so that a well-dispersed, nonagglomerated ceramic slurry can be made.

With the growing awareness of the detrimental effects of different types of heterogeneities on the materials properties of mainly structural ceramics, a concept called colloidal processing has been introduced as a useful approach for flaw minimization. Examples of colloidal processing include removal of large, hard agglomerates in the starting powder through sedimentation or filtration of well-dispersed suspensions and the development of designed, ordered mixtures of several components through the manipulation of the interparticle forces. These concepts apply to most conventional processing methods, and they also can be used for the development of new processing techniques.

Dry pressing and cold isostatic pressing (CIPing) are probably the most important forming techniques for industrial production of ceramic materials. Green bodies are formed by pressing granules in a die. The free-flowing granules are formed from a suspension using a granulation technique, e. g. ,spray drying or freeze granulating. Pressing is an established forming technique that has existed for decades and has been used for many applications, ranging from dinnerware to insulators and spark plugs. However, there are developments in the field involving high-pressure CIPing and cyclic CIPing that can produce green bodies of higher density. The major advantage of dry pressing is productivity; modem presses can produce as many as 20 parts per minute. This makes pressing the method of choice for most industrial ceramic operations despite the problems associated with density gradients, inhomogeneous microstructures, and the need to machine complex-shaped objects.

All the drain-casting techniques e. g. ,slip casting, pressure casting, and centrifugal casting involve a solid-liquid separation process to form a dense green body. The liquid flow is driven by either an external pressure gradient (slip casting, pressure casting) or a body force in a centrifugal force field (centrifugal casting). Slip casting is a low-pressure filtration method where capillary suction provides the driving force (on the order of 0. 1~0. 2 MPa) for liquid removal and formation of a cast layer at a mold surface. Slip casting is generally a slow process, because the casting rate decreases parabolically with thickness of the cast layer. Pressure casting which is an established forming technique in fabrication of traditional clay-based ceramic materials, such as pottery and sanitary porcelain——and pressure filtration are modifications of slip casting that have been developed

to accelerate the consolidation stage and to obtain a higher green density. In these methods, an external pressure (<4 MPa) substantially higher than the capillary suction pressure is applied to the ceramic suspension.

The traditional drain-casting methods are plagued by some genetic problems. The liquid flow affects the suspension microstructure and tends to orient nonspherical constituents, such as whiskers. The stress gradient may also lead to nonuniform densities of the green body and cause mass segregation because of differences in particle size and density.

Undrained, or constant volume, forming methods, such as injection molding, have the potential to avoid the aforementioned problems. Injection molding is capable of producing parts of complex shape with high precision at relatively high production rates. This commonly used forming technique is based on mixing of the ceramic powder with a binder system (usually a mixture of polymers) to create a viscous feedstock and forming the part by injecting the powder/binder mixture into an impermeable mold, where the binder is solidified, usually by a temperature gradient. Injection molding has proved to be an excellent forming technique for smaller objects although there are potential problems related to the die-filling process. Abrasive wear of screw-driven injectors for high-pressure injection molding can also lead to metallic inclusions and poor reliability.

The major problem confronting injection molding is the removal of the binder. Binder burnout must proceed at a slow rate (taking up to several days) to avoid problems with slumping and crack formation. The polymer removal time increases drastically when the size of the green body increases, making it difficult, if not impossible, to produce parts with thick cross sections. New systems with catalytic degradation of the polymer have been developed that have the potential to reduce many of the problems stated above through depolymerization and sublimation of the monomer at low temperatures. Using this catalytic degradation approach, the problems associated with the thermal expansion of the polymer, capillary forces, and particle migration due to liquid flow can be avoided. However, because of the high cost of the polymers used, this approach has found limited use.

The drying process has a major influence on green microstructure and production rate. Drying is a critical operation, which has to be controlled to avoid cracking and warping. Drying is a coupled heat-and mass-transfer problem for which mathematical representations have been available for years. The desired end in ceramic part production is fast drying; however, fast drying causes cracks. Tape-casting studies have shown that decreasing drying rates results in increasing green densities, and binder additives strongly affect stress history. Cracking is inhibited by strengthening the solids network, increasing pore size, and reducing capillary pressure. During drying, transport of evaporating dispersing media can cause binder and small particle migration to the surface. This can lead to additional problems during burnout and sintering. These problems can be minimized or avoided when the binder content is low or the dispersing media is sublimated.

(Selected from *Journal of the American Ceramic Society*, by W. M. Sigmund, N. S. Bell and L. Bergström, 2000)

New Words and Expressions

whisker ['hwiskə] *n.* 须，晶须

agglomerate [ə'glɔməreit] *v.* （使）聚集，成团，团聚；*n.* 大块，大堆，聚集

suspension [səs'penʃən] *n.* 悬浊液

dispersant [di'spəːsənt] *n.* 分散剂

heterogeneity ['hetərəudʒi'niːiti] *n.* 不均匀性，多相性，杂质，不同性质

granule ['grænjuːl] *n.* 小（颗，细）粒

plug [plʌg] *n.* 塞，栓，插头

pottery ['pɔtəri] *n.* 陶器

sanitary ['sænitəri] *a.* （环境）卫生的，清洁的，保健的

viscous ['viskəs] *a.* 黏（性、稠）的

capillary [kə'piləri] *n.*；*a.* 毛细管（的）

abrasive [ə'breisiv] *n.*；*a.* （研）磨料，摩擦力，磨料的，磨损的

slump [slʌmp] *n.*；*vi.* 衰退，滑动，坍塌，落下

degradation [degrə'deiʃən] *n.* 降低，下降，降解

sublimation [ˌsʌbli'meiʃən] *n.* 升华，提纯，纯化

slip casting 注浆成型

pressure casting 压力注浆成型

centrifugal casting 离心成型

injection molding 注模成型

Notes

① drain casting，是指浆体在多孔模具表面沉积一定时间后，将未沉积的浆体倒出模具的成型方法。主要指注浆成型，压力注浆成型。

② All these forming methods start with a suspension where the ceramic particles （powders，whiskers，etc.）are mixed with a liquid or a polymer melt，proper dispersant，and possibly further additives such as binders，plasticizers，and antifoaming agents so that a well-dispersed，nonagglomerated ceramic slurry can be made. 参考译文：所有这些方法都是从制备悬浮液开始的。陶瓷颗粒（粉末，晶须）和水或熔化的聚合物，分散剂以及可能需要的添加剂如：黏合剂、塑化剂，去泡剂相混合来获得分散良好，没有团聚的浆体。

③ Slip casting is a low-pressure filtration method where capillary suction provides the driving force （on the order of 0.1~0.2 MPa）for liquid removal and formation of a cast layer at a mold surface. 参考译文：注浆成型是一个低压过滤的过程。在这个过程中，毛细管的吸力把液体从浆体中吸出从而在模具表面形成一个沉积层。

Exercises

1. Reading comprehension

    (1) Describe the process of making a suspension for slip casting.

    (2) What the awareness should be addressed during drying process?

(3) What are the drawbacks of drying pressing?

(4) How could be the green structure improved by isostatic pressing?

2. Translate the following into Chinese

detrimental effects   colloidal processing

isostatic pressing   spray drying

- The traditional drain-casting methods are plagued by some genetic problems. The liquid flow affects the suspension microstructure and tends to orient nonspherical constituents, such as whiskers. The stress gradient may also lead to nonuniform densities of the green body and cause mass segregation because of differences in particle size and density.

- During drying, transport of evaporating dispersing media can cause binder and small particle migration to the surface.

3. Translate the following into English

陶瓷生坯   干压成型

陶瓷粉体   塑化剂

等静压   裂纹

Reading Material

Novel Ceramic Processing Method——Direct Casting

During the past decade, an increasing number of novel near-net-shape-forming techniques have been presented to the ceramic community. One class of these new methods, the direct-casting methods, uses some of the inherent properties of dense suspensions to transform a fluid suspension to a stiff gel. The general concept is to retain the homogeneous state of the dense slurry during the green-body formation step. By minimizing the disturbance to the slurry during gelation, introduction of larger heterogeneities can be avoided and density gradients minimized. The physical or chemical processes responsible for the formation of a solid green body may vary, but all methods require a well-dispersed suspension with (very) high solids loading of reasonably low viscosity to facilitate the mold-filling process. Hence, maximizing the solids loading by tailoring the range and magnitude of the interparticle repulsion and optimizing the particle-size distribution become very important issues.

To ensure high reliability and reproducibility of sintered parts, the dense slurries must be homogeneous with respect to the ceramic particles and organic processing additives. Gradients of any type should be avoided. Hence, a thorough mixing or milling step is common to the preparation of the starting slurries. The slurries also have to be deaired to avoid defects caused by trapped air bubbles. Heterogeneities (hard agglomerates, organic inclusions) are commonly removed by filtration before casting.

The underlying mechanisms for most of the direct-casting methods are related to the for-

mation of either physical or chemical bonds between either the particles or some species in the dispersion. The division between physical and chemical gels is somewhat arbitrary, differing mainly in the strength of the green body; chemical gels are substantially stronger than physical gels. Physical particle gels rely on the formation of a physical bond between the particles in dense suspensions. This is mainly achieved by manipulating the interparticle forces to become attractive. In electrostatically stabilized slurries, this can be achieved by changing pH or increasing salt content, whereas sterically stabilized systems can be flocculated by changing the solvency of the adsorbed polymer layers. At high solids loading, parti cle gels can develop a sufficient strength to support their own weight and, thus, be handled without shape distortion. However, because no permanent bonds between the particles are formed, particles can rearrange because of thermal fluctuations or gravity. Hence, a physical particle gel, sometimes referred to as a transient gel, may undergo a slow densification with time.

The formation of strong gels is commonly accompanied by the formation of permanent chemical bonds between either the particles or some species in the dispersion. Typical examples are the formation of a percolating polymer network by polymerizing a monomer in the slurry and the gelation of dissolved polymers. We also include methods that use a phase transition of the continuous media, e. g. ,freezing of water, in this category.

The direct-casting methods are organized according to fundamental physical and chemical principles of their dispersing mechanism and gelling reaction. Some of the direct-casting methods use more than one physical or chemical principle for dispersion and gelling. These are categorized according to the dominating principles, and, where necessary, the specific chemistry and physics are discussed with each method. First, we describe processes that manipulate interparticle potentials and create physical gels via a percolating network of particles. Second, we describe percolating networks formed by additives in the dispersing media using physical or chemical processes

A concentrated Al_2O_3 suspension can be transformed from a dispersed, fluid state into a flocculated, rigid state by either changing pH toward the isoelectric point (or pzc) or by increasing the salt content to compress the electric double layer. Such changes can be induced by adding acid, base, or salt. However, there is a large risk that the simultaneous mixing and gelation may result in large inhomogeneities in the dense suspension. A better approach is to use a reaction that produces the desired pH or salt change in situ. Examples of such reactions are thermally activated decomposition of urea which change the pH from acidic toward neutral by slowly forming NH_3 at $60 \sim 80°C$. Hydrolysis of esters or lactones yields carboxylic acids, thus changing pH from alkaline toward neutral. An increase in salt concentration also can be achieved by the decomposition of urea. It has been found that flocculating a suspension by the addition of salt allows the particle network to deform plastically. This claylike behavior is attributed to an additional short-range repulsive force coming from chemically grafted molecules or strongly adsorbed ions on the particle surface. Depending on the thickness and density of the steric layers as well as the number of particle-particle con-

tacts, a yield stress can be achieved that is large enough to retain the shape of a molded body. These claylike saturated bodies deform under applied pressures greater than the yield stress. Claylike forming allows complex shaping without the concern of density gradients and eliminates the problem of stress-induced cracking due to the release of forming pressures.

New Words and Expressions

gel [dʒel] *n.* 凝胶，冻胶

homogeneous [hɔmə'dʒiːnjəs] *a.* 同（族，质，性，种）的，一致性的

slurry ['sləːri] *n.* 稀（泥，沙）浆，悬浮体

gelation [dʒi'leiʃən] *n.* 冻（凝，胶）结，胶凝体

arbitrary ['aːbitrəri] *a.* 任（随）意的，任选的，随机的

sterically ['sterikəli] *ad.* 空间（上）地

flocculate [flɔkju'leit] *v.* 絮凝，沉淀

potential [pə'tenʃəl] *a.* 潜在的，可能的，电位的；*n.* 可能，电位

urea ['juəriə] *n.* 尿素

ester ['estə] *n.* 酯

graft [graːft] *n.*，*v.* 接枝，嫁接，（使）接合，移植

yield [jiːld] *v. n.* 产生，发生，提供，产量，输出，流动性，塑流

direct-casting 直接成型法

Interparticle repulsion 颗粒间相互斥力

Isoelectric point 等静电点

Notes

① Hence, maximizing the solids loading by tailoring the range and magnitude of the interparticle repulsion and optimizing the particle-size distribution become very important issues. 参考译文：这样一来，非常重要的问题就是通过调整颗粒间的相互排斥力和优化颗粒大小的分布来获得尽可能大的固体含量。

② In electrostatically stabilized slurries, this can be achieved by changing pH or increasing salt content, whereas sterically stabilized systems can be flocculated by changing the solvency of the adsorbed polymer layers. 参考译文：对由表面静电稳定的浆体，絮凝可以通过改变 pH 和增加盐含量来得到，而对由空间结构稳定的浆体，改变吸附的聚合物的溶解度可以使它絮凝。

③ This claylike behavior is attributed to an additional short-range repulsive force coming from chemically grafted molecules or strongly adsorbed ions on the particle surface. 参考译文：这种像黏土的性质是由于在颗粒表面由化学键连接的分子或牢固吸附的离子产生的一种附加的短距离排斥力造成的。

Unit 12　Advanced Ceramic Materials:
Basic Research Viewpoint (I)

Since production and engineering of materials and components are increasingly knowledge-based, the technology itself reveals gaps in the basic understanding of materials. Such gaps limit the degree to which materials technology can be competitive with other technologies. Therefore, the continued pursuit of additional knowledge will always be necessary. Some technological trends are important to follow as present and future directions of basic and applied research. The most significant of these are:

- Increasing materials complexity because of increased functionality;
- Integration of different materials into multifunctional components;
- Miniaturization of devices;
- Exploitation of nanosized effects;
- Theoretical treatment and modeling of materials and components development.

In addition to these trends, present environmental regulations and awareness and the recycling of materials will affect the use of materials and require less expensive production processes.

Traditional materials-oriented research is now complemented by more interdisciplinary and method-linking works. The research activities extend from the structures at the atomic and molecular level to macroscopic features of components and devices. One fundamental area of research to pursue is the development of a unified description of deformation and fracture in order to design microstructures for improved mechanical reliability of ceramic parts. This would decrease the material's susceptibility to environmental stresses and facilitate integration of ceramics into whole engineered system. In addition, as these tasks become more and more interdisciplinary, advances in ceramic materials will benefit increasingly from closer cooperation among materials scientist, physicists, chemists, engineers, and especially, biologist.

Needs for Future Basic Research

Following technological trends, the needs for future basic research in the field of ceramics can be divided into four major areas. (a) materials and materials properties research in order to widen the area's scope and match its needs for future applications. (b) research to increase the knowledge of economical and ecological production processes for materials, components, and devices. (c) miniaturization and integration. (d) modeling and numerical simulation, which would complement or even act as a substitute for present areas of experimental work, thus not only directing research to defined questions, but also reducing practical work and time periods typically combined with product development. The identified

four areas of future basic research will be discussed in the following.

Ceramics now cover an extensive area of functionality. Hardly any other class of materials offers such a variety of properties useful for applications. Promising technical developments emerge from the discovery of new compounds, and new materials with specific functions have recently appeared on the horizon. These materials include high temperature superconductors, single crystal piezoelectrics, high-frequency dielectrics. Detailed basic research in solid state chemistry and solid state physics will continue to widen the scope of materials, resulting in the optimization of existing materials' functionalities and the likely enhancement of ceramics with new physical behaviours. Since both result in complex materials, there will be a continuous need for the comprehensive evaluation of the underlying materials. Therefore, extended investigations of physical, chemical, and mechanical properties will be necessary in order to evaluate the potential of the materials for practical applications.

In the area of ceramic materials, ferroelectric ceramics are technically the most important. They are known for their unique properties, such as high dielectric permittivity as well as high piezoelectric constants, and are used in multilayer capacitors or as microwave devices within wireless communication systems. Besides that, they will very likely play a key role in the future of information technology as a basis for low-cost, low power energy consumption, high density storage, and fast readout of information. Most of the inorganic materials for linear and nonlinear optics are also ferroelectric. Infrared absorption and electro-optical modulation are optimized in ferroelectrics because of their strong linear and nonlinear polarizabilities. However, the increasing power and speed of today's lasers has a large effect on the crystalline quality and defect content of ferroelectrics. This is even more crucial in the case of integrated devices for which optical density, electric fields, thermal gradients, and mechanical stresses are increased by the limited size of wave guides.

Presently, piezoelectric ceramics certainly show the broadest range of individual applications, including sonar, ultrasonic cleaners, buzzers, accelerometers, hydrophones, piezotransformers, ultra-precision positioners, and many other sensors requiring a wide field of interdisciplinary research for further evaluation.

Magnetoresistive materials, which change their electrical resistivity upon application of magnetic fields, have also received attention for magnetic reading heads. Ceramics, such as doped rare-earth manganites exhibit extremely high values for this effect, even superior to that of giant magnetoresistant metals presently in use.

Ion conduction also provides great technological benefits. It is a basis for energy and information technology systems such as batteries, fuel cells, chemical sensors, and chemical filters providing efficient and cleaner energy transformation, chemical control, and environmental protection. Apart from the functional aspect, the application of these materials requires the simultaneous fulfillment of many properties. These include thermal, chemical, mechanical, and electrical stabilities. Examples of the devices are stable proton conductors, interfacially controlled ionic conductors, and chemical sensors for acid/base active gases.

In the field of high-temperature superconductivity, important progress has been

achieved over the last few years regarding both energy applications as well as electronics. Large-sized demonstration prototypes of superconducting cables, transformers have been fabricated and successfully tested.

(Selected from *European White Book on Fundamental Research in Materials Science*, by F. Aldinger, J. F. Baumard, 2000)

New Words and Expressions

macroscopic [mækrou'skɔpik] *a.* 肉眼可见的，巨观的

susceptibility [səsepti'biliti] *n.* 易感性，感受性，感情；磁化系数

biologist [bai'ɔlədʒist] *n.* 生物学家

ecological [ˌekə'lɔdʒikəl] *a.* 生态学的，社会生态学的

complement ['kɔmplimənt] *vt.* 补充，配套

ferroelectric [ferəui'lektrik] *n.* 铁电物质；*a.* 铁电的

permittivity [pəːmi'tiviti] *n.* 介电常数，电容率

polarizability [pəuləraizə'biliti] *n.* 极化性，极化率

magnetoresistive [mæg'nitəu'rizistiv] *a.* 磁（致电）阻的

manganite ['mæŋɡənait] *n.* 水锰矿；亚锰酸盐

piezotransformers [pai'iːzouˌtræns'fɔːmə] *n.* 压电能量转换器

Notes

① multifunctional components，多功能组件。

② environmental regulations，环境法规。

③ the material's susceptibility to environmental stresses，材料的环境影响。

④ to widen the area's scope，扩展这个领域的范围。

⑤ a unified description of deformation and fracture，对形变和断裂的统一解释。

⑥ modeling and numerical simulation，建模和数值模拟。

⑦ high-frequency dielectrics，高频介电性。

⑧ electro-optical modulation，光电转换模数。

⑨ the comprehensive evaluation of the underlying materials，潜在材料的综合评价。

⑩ fuel cells，燃料电池。

⑪ ultra-precision positioners，高精度定位装置。

Exercises

1. Reading comprehension

    (1) What areas should be addressed for future researches on ceramic materials?

    (2) Why should we continue to carry out basic research on ceramic materials?

    (3) Please give some application examples of piezoelectric ceramic materials and the benefits we get from the advancement of ceramic materials.

2. Translate the following into Chinese

    solid state physics   ferroelectric ceramics

dielectric permittivity   linear and nonlinear polarizabilities

mechanical stresses   thermal stability

- Magnetoresistive materials, which change their electrical resistivity upon application of magnetic fields, have also received attention for magnetic reading heads. Ceramics, such as doped rare-earth manganites exhibit extremely high values for this effect, even superior to that of giant magnetoresistant metals presently in use.

- In the field of high-temperature superconductivity, important progress has been achieved over the last few years regarding both energy applications as well as electronics. Large-sized demonstration prototypes of superconducting cables, transformers have been fabricated and successfully tested.

3. Translate the following into English

仪器小型化   微观结构

机械可靠性   材料性能

高温超导体   压电性

固体化学

Reading Material

Advanced Ceramic Materials: Basic Research Viewpoint (II)

Processing and microstructure design

Ceramic are synthesized into glasses, polycrystals, single crystals, and many forms dictated by their use, including fine powders, fibres, thin films, thick films, coatings, monoliths, and composites. Polycrystalline components are conventionally produced by powder synthesis and forming processes followed sintering at high temperature. The performances of ceramic materials are determined not only by the structure and composition, but also by defects (such as pores), second phases (which can be deliberately added to facilitate processing), and interfaces. Thus, one of the primary limitations of current ceramic processing technologies is that they are an art as well as a science. This situation is changing progressively. For instance, in order to meet the requirements of miniaturization and integration, these techniques have to be supplemented by deposition techniques, such as physical vapor deposition (PVD), pulsed-laser deposition (PLD), chemical solution deposition (CSD), and chemical vapor deposition (CVD). During these processes, the materials are synthesized on a microscopic scale without powder processing as an intermediate step, usually at temperatures much below the typical sintering temperature of bulk materials. Not only can ceramic materials of small dimensions be deposited, but their ceramic compositions and structures can also be designed much more flexibly. The understanding and mastering of phenomena at the microscopic and, more importantly, at the nanoscopic scales clearly need further basic research. A specific example can be found in thin films of ferroelectrics, where

dielectric properties are dominated by interfacial effects rather than by the bulk capacitance.

A great challenge is the architecture of ceramic materials in atomic dimensions, not only in thin films but also in thick films and bulk materials. The ceramic materials will open up novel classes of materials with properties still unknown with respect to conventionally processed materials. One possibility for research is the thermally induced transformation of pre-ceramic compounds by solid state thermolysis. By tailoring the composition and molecular structure of precursors by means of advanced chemical syntheses, and by controlling thermolysis, the composition, structure, and microstructure of ceramic materials can be designed. The characteristics of precursor thermolysis, and the relative ease with which various geometries can be processed at the preceramic stage using standard polymer processing techniques, makes them highly applicable for the production of fibre-reinforced composites, oxidation-resistant coatings, wear-resistant materials, and many others.

Another growing field of research with an attractive technical potential is the production of materials inspired by biomineralization. Oxidic depositions from aqueous solutions on organically modified surfaces, for example, provide a synthesis route for ceramics at ambient conditions. Such template-induced and self-assembled materials using biomimetic techniques provides low cost routes to get new metastable materials that possess original microstructures as layered polymer-ceramic composites and cannot be obtained by conventional high-temperature routes. Therefore, the investigation of interactions between organic and inorganic phases, as well as nucleation and growth phenomena, is a promising area of basic research.

Nevertheless, conventional processes will continue to offer breakthroughs. A deeper understanding of the surface chemistry of powders will lead to a better control of the interaction between particles during colloidal powder processing, thus providing a means for controlling powder consolidation and defect-free microstructure. New methods for net-shape forming based on the control of interparticle forces in dense suspensions of powders have been proposed recently. There is no doubt that possibilities offered by surface chemistry are far from being fully exploited, especially in the case of non-oxide ceramics. The challenge for future years is the development of processing technique for the production of finer powders, which could lead to new applications resulting from different green-state architectures.

Direct and indirect cost savings by process-cost reductions and product improvements, respectively, are necessary in the field of advanced properties of ceramics. Cost savings are typically achieved by a better understanding of the fundamentals of the underlying processes. Savings could also be obtained by new types of low-cost processes, component design changes or simplifications by using proper joining techniques, or product-development time reductions. In essence, processing science remains a priority, but in the case of ceramics, it now extends far beyond the simple processing of powders.

Modeling and numerical simulation

Modeling and simulating have been used for a long time in the development and improve-

ment of materials. Fundamental theories exist for many physical phenomena (e. g. elasticity, plasticity, fracture, thermodynamics, electricity, magnetism), all of which improved enormously the understanding of materials. There have been developed a variety of chemical continuum concepts and macroscopic finite element methods to simulate the behavior of materials and compounds. Both areas have created much progress in materials science and technology. However, in order to achieve a real breakthrough in designing new materials and tailoring their properties, there is a need to bridge both areas. The most desirable breakthrough would be to outline the structural and functional performance of a material directly from its elemental composition, structure, and morphology.

(Selected from *European White Book on Fundamental Research in Materials Science*, by F. Aldinger, J. F. Baumard, 2000)

New Words and Expressions

monolith ['mɔnəuliθ] *n.* 独石

miniaturization [minjətʃərɑi'zeiʃən] *n.* 小型化

supplement ['sʌpliment] *n.* 补遗，补充，附录，增刊；*v.* 补充

dominate ['dɔmineit] *v.* 支配，占优势

thermolysis [θə'mɔlisis] *n.* 热（分）解（作用）；散热（作用）

geometry [dʒi'ɔmitri] *n.* 几何学

mimetic [mi'metik] *a.* 模仿的，好模仿的

metastable [metə'steibl] *a.* 亚稳的

magnetism ['mægnitizəm] *n.* 磁，磁力，吸引力，磁学

powder synthesis 粉体合成

biomineralization 生物矿化，生物成矿作用

Notes

① nanoscopic scales，纳米尺寸。

② pulsed-laser deposition，激光沉积。

③ the composition and molecular structure of precursor，前驱体的成分和分子结构。

④ biomimetic techniques，生物仿生技术。

⑤ defect-free microstructure，无缺陷的微观结构。

⑥ green-state architectures，生坯结构。

PART IV POLYMERS

Unit 13 Polymer Synthesis

Polymers are a large class of materials consisting of many small molecules (called monomers) that can be linked together to form long chains, thus they are known as macromolecules. The picture at the top of the page is a short section of such a chain. A typical polymer may include tens of thousands of monomers. Because of their large size, polymers are classified as macromolecules.

Humans have taken advantage of the versatility of polymers for centuries in the form of oils, tars, resins, and gums. However, it was not until the industrial revolution that the modern polymer industry began to develop. In the late 1830s, Charles Goodyear succeeded in producing a useful form of natural rubber through a process known as "vulcanization." Some 40 years later, Celluloid (a hard plastic formed from nitrocellulose) was successfully commercialized. Despite these advances, progress in polymer science was slow until the 1930s, when materials such as vinyl, neoprene, polystyrene, and nylon were developed. The introduction of these revolutionary materials began an explosion in polymer research that is still going on today.

Unmatched in the diversity of their properties, polymers such as cotton, wool, rubber, Teflon (tm), and all plastics are used in nearly every industry. Natural and synthetic polymers can be produced with a wide range of stiffness, strength, heat resistance, density, and even price. With continued research into the science and applications of polymers, they are playing an ever increasing role in society. The following sections provide an introduction to the science of macromolecules.

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

Addition Polymerization

The most common type of addition polymerization is free radical polymerization. A free radical is simply a molecule with an unpaired electron. The tendency for this free radical to gain an additional electron in order to form a pair makes it highly reactive so that it breaks the bond on another molecule by stealing an electron, leaving that molecule with an unpaired election (which is another free radical). Free radicals are often created by the division of a molecule (known as an initiator) into two fragments along a single bond. The following di-

agram shows the formation of a radical from its initiator, in this case benzoyl peroxide.
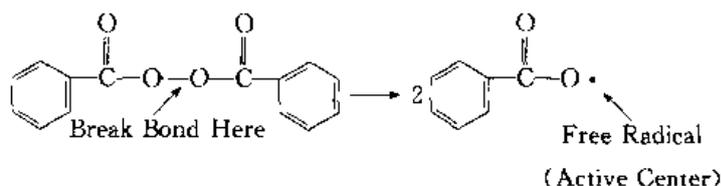
The stability of a radical refers to the molecule's tendency to react with other compounds. An unstable radical will readily combine with many different molecules. However a stable radical will not easily interact with other chemical substances. The stability of free radicals can vary widely depending on the properties of the molecule. The active center is the location of the unpaired electron on the radical because this is where the reaction takes place. In free radical polymerization, the radical attacks one monomer, and the electron migrates to another part of the molecule. This newly formed radical attacks another monomer and the process is repeated. Thus the active center moves down the chain as the polymerization occurs.

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

Initiation Reaction

The first step in producing polymers by free radical polymerization is initiation. This step begins when an initiator decomposes into free radicals in the presence of monomers. The instability of carbon-carbon double bonds in the monomer makes them susceptible to reaction with the unpaired electrons in the radical. In this reaction, the active center of the radical "grabs" one of the electrons from the double bond of the monomer, leaving an unpaired electron to appear as a new active center at the end of the chain. Addition can occur at either end of the monomer.

In a typical synthesis, between 60% and 100% of the free radicals undergo an initiation reaction with a monomer. The remaining radicals may join with each other or with an impurity instead of with a monomer. "Self destruction" of free radicals is a major hindrance to the initiation reaction. By controlling the monomer to radical ratio, this problem can be reduced.

Propagation Reaction

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. In this diagram, (chain) refers to a chain of connected monomers, and X refers to a substituent group (a molecular fragment) specific to the monomer. For example, if X were a methyl group, the monomer would be propylene and the polymer, polypropylene.
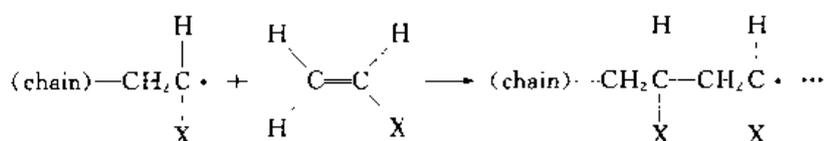
In free radical polymerization, the entire propagation reaction usually takes place within a fraction of a second. Thousands of monomers are added to the chain within this time. The entire process stops when the termination reaction occurs.

Termination Reaction

In theory, the propagation reaction could continue until the supply of monomers is exhausted. However, this outcome is very unlikely. Most often the growth of a polymer chain is halted by the termination reaction. Termination typically occurs in two ways: combination and disproportionation.

Combination occurs when the polymer's growth is stopped by free electrons from two growing chains that join and form a single chain. The following diagram depicts combination, with the symbol (R) representing the rest of the chain.
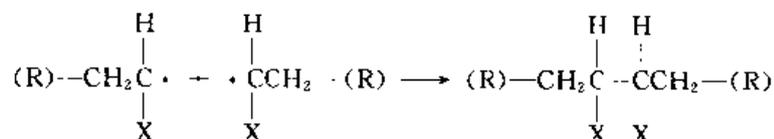
Disproportionation halts the propagation reaction when a free radical strips a hydrogen atom from an active chain. A carbon-carbon double bond takes the place of the missing hydrogen. Termination by disproportionation is shown in the diagram.
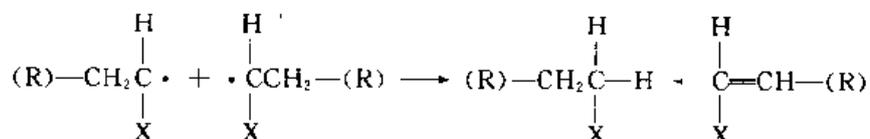
Disproportionation can also occur when the radical reacts with an impurity. This is why it is so important that polymerization be carried out under very clean conditions.

Living Polymerization

There exists a type of addition polymerization that does not undergo a termination reaction. This so-called "living polymerization" continues until the monomer supply has been exhausted. When this happens, the free radicals become less active due to interactions with solvent molecules. If more monomers are added to the solution, the polymerization will resume.

Uniform molecular weights (low polydispersity) are characteristic of living polymerization. Because the supply of monomers is controlled, the chain length can be manipulated to serve the needs of a specific application. This assumes that the initiator is 100% efficient.

(Selected from *Polymers and Liquid Crystals*, by, Case Western Reserve University PLC Team, 1998)

New Words and Expressions

polymer ['pɔlimə]　*n.*　聚合体

monomer ['mɔnəmə] *n.* 单体

macromolecule [ˌmækrə'mɔlikjuːl] *n.* 巨大分子，高分子

vulcanization [vʌlkənai'zeiʃən] *n.* 橡胶的硬化，硫化

nitrocellulose [naitrə'seljələus] *n.* 硝化纤维素

vinyl ['vainil] *n.* 乙烯基，乙烯树脂

neoprene ['niːəpriːn] *n.* 氯丁橡胶

polystyrene [pɔli'stairiːn] *n.* 聚苯乙烯

celluloid ['seljulɔid] *n.* 赛璐珞

initiation [iniʃi'eiʃən] *n.* 引发

propagation ['prɔpə'geiʃən] *n.* 增长

termination ['təːmi'neiʃən] *n.* 终止

initiator [i'niʃieitə] *n.* 引发剂

methyl ['meθil] *n.* 甲基

propylene ['prəupəliːn] *n.* 丙烯

polypropylene [pɔli'prəupiliːn] *n.* 聚丙烯

combination [ˌkɔmbi'neiʃən] *n.* 偶合（终止）

disproportionation [ˌdisprəˌpɔːʃə'neiʃən] *n.* 歧化（终止）

polydispersity [ˌpɔlidis'pɔːsəti] *n.* 多分散性；聚合度多分散性

addition polymerization 加成聚合

free radical 自由基

unpaired electron 未成对电子

benzoyl peroxide 过氧化苯甲酰

active center 活性中心

substituent group 取代基团

living polymerization 活性聚合

Notes

The tendency for this free radical to gain an additional electron in order to form a pair makes it highly reactive so that it breaks the bond on another molecule by stealing an electron, leaving that molecule with an unpaired electron (which is another free radical). 这是一个由主句和 so that 引导的结果状语从句组成的复合句。主句的主要成分是：the tendency makes it highly reactive. 参考译文：自由基要得到另外一个电子以形成电子对的倾向使得它高度活泼，因此它通过夺得一个电子而破坏另一个分子的价键，使它成为孤对电子（另一个自由基）。

Exercises

1. Complete the notes below with one or two words.

   (1) _____ are a large class of materials consisting of many small molecules that can be linked together to form long chains.

(2) Natural and synthetic polymers can be produced with a wide range of _____,

_____, _____, _____, and even price.

(3) A _____ is simply a molecule with an unpaired electron.

(4) The _____ is the location of the unpaired electron on the radical because this is where the reaction takes place.

2. Answer the following questions according to the text

(1) Give a brief explanation to the 3 main steps of addition polymerization.

(2) What is the difference between the two ways of termination: combination and disproportionation?

Reading Material

Chemistry Basics

Molecules may be represented in two dimensions by a structural diagram.
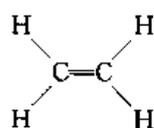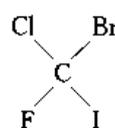

Ethylene   Bromo-Chloro-Fluoro-Iodo-Methane

While this representation allows for the derivation of the three dimensional structure of the left molecule, the right molecule requires further description.

Molecules may be represented in three dimensions by a ball and stick configuration like this. This allows examination of the molecule's configuration, in this case an sp3 hybridized central carbon with 4 different atoms attached.

Another method used to describe atoms and their bonding is through the location of the electrons in their outermost shell. Because there is no exact location of where the electron may be found, probability distributions (commonly called orbitals) based on quantum mechanical calculations are sketched showing where the electron is most likely to be found. A few of these representations are presented here to illustrate this approach. The first three types of orbitals for individual atoms are:
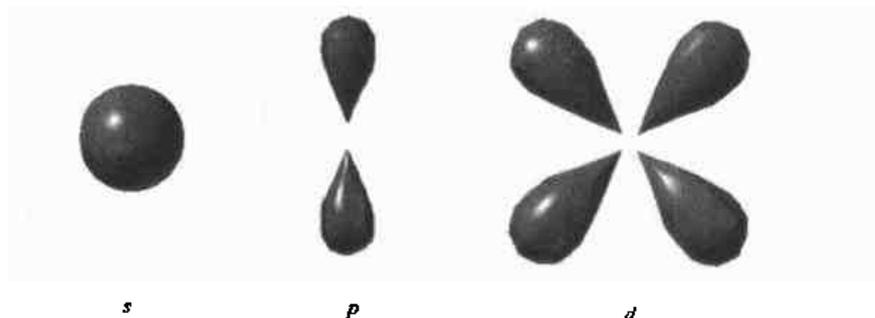

s   *p*   *d*

The *p* and *d* orbitals actually change according to how many electrons are in the outer shell. A full *p* orbital is customarily indicated as shown below:
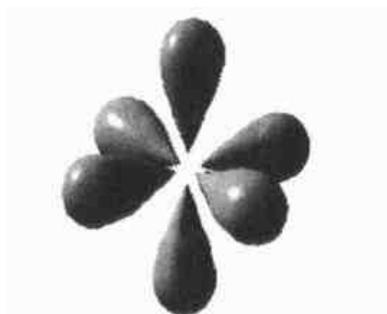
When two or more atoms are bounded to form a molecule, the orbitals from each atom may be combined into hybrid atomic orbitals, which are useful in describing molecular structural properties such as geometry. A few examples are illustrated below. The hybrid sp combination yields the linear geometry of CO_2; sp^2 describes the trigonal planar geometry of BF_3; and the sp^3 combination fits the familiar tetrahedral geometry of CH_4.

sp	sp^2	sp^3
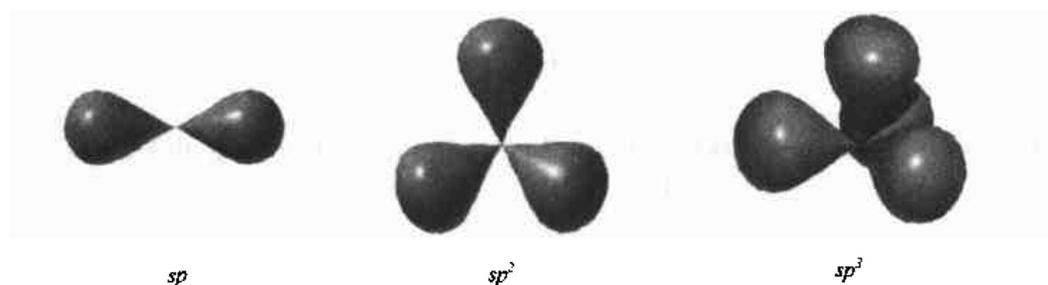
Hybrid atomic orbitals are also useful in describing double bond formation. We illustrate this for the case of ethylene, which will be used in the polymer synthesis section as an example of free radical formation in connection with addition polymerization. After the sp^2 orbitals with the hydrogen are occupied, two electrons in carbon $2s$ states interact to form a sigma bond along the C—C centerline and the single electron remaining in each of the unhybridized $2p$ orbitals interact to form a pi bond (a "combined" p orbital appearance). For a more complete discussion of these topics see any recent college chemistry text.

Chirality

The ability of carbon to form four bonds allows for the possibility of two configurations using the same molecular formula. Particularly, a configuration about the central carbon and its mirror image is possible. The mirror image is not superimposible upon the original configuration; thus it represents a new form of the molecule.

Such molecules are said to be chiral, and the central atom known as the chiral center. One of the configurations about the chiral center is designated S and the other R. The pair of molecule configurations due to chirality are known as enantiomers. Enantiomers have identical chemical properties except towards optically active reagents, and identical physical properties except for the direction of rotation of the plane of polarized light. A mixture of equal amounts of both enantiomers is known as a racemic mixture and is not optically active. It is possible for a molecule to contain two chiral centers and thus four possible configurations may result. This may result in chiral molecules which are not mirror images of each other.

Such molecules are known as diastereomers, and have similar chemical properties but may have vastly different physical properties.

Geometric Isomers
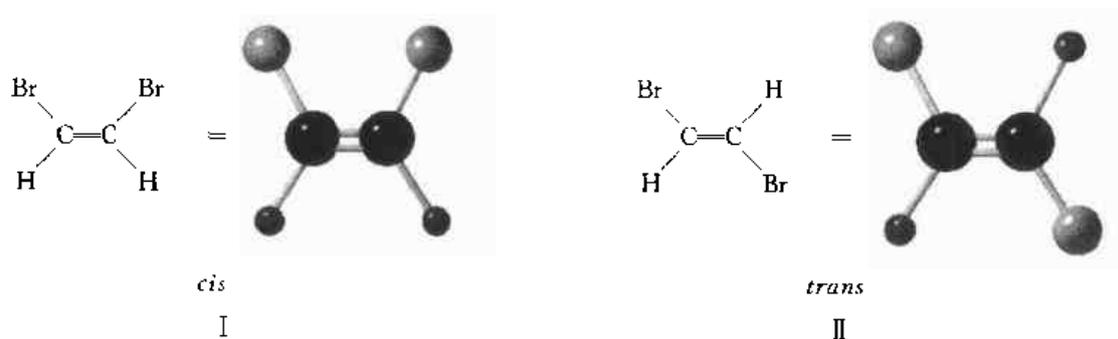
Examination of the two molecules above reveals they share the same molecular formula (BrCHCHBr) as well as the location of the double bond. Thus they are isomers; both represent 2-ethylene but their physical properties differ. The difference between the two isomers is hinted by their two dimensional representation but becomes more clear when the examined in three dimensions.

The difference lies in the way the atoms are oriented in space. They are not mirror images of each other, and thus they are termed diastereomers. However, because the rotation about the carbon carbon double bond is hindered (since it would break the pi bond), they are classified as geometric isomers. The two configurations are named by inserting the prefix "*cis*"(Latin: on this side) for I and "*trans*"(Latin: across) for II which indicate the location of the bromo groups each on the same or opposite sides of the molecule. Thus, the proper name for I is *cis*-1,2-dibromo-ethene and II *trans*-1,2-dibromo-ethene.

Nomenclature

Naming large molecules can be a complex task. The IUPAC Nomenclature Committee has established conventions that eliminate confusion. In general, a polymer with an unspecified number of monomers is named by adding the prefix "poly" to the constitutional repeating unit (CRU). Otherwise, the Greek prefix corresponding to the number of monomers is added to the name of the CRU.

Number	Prefix	Number	Prefix
1	Meth	7	Hept
2	Eth	8	Oct
3	Prop	9	Non
4	But	10	Dec
5	Pent	11	Undec
6	Hex		

The name of the CRU is formed by naming each of the subunits. If a polymer contains only one subunit, the prefix "poly" is added to the name of the subunit. For example, if a polymer is formed from a combination of ethylene monomers, its name would be polyethy-

lene. Polymers containing more than one subunit are named based on the largest subunits, and are set off from the prefix "poly" with parentheses.

The naming of the subunits is the most difficult part. The subunits are named by the main constituent of the subunit with smaller molecules added on as prefixes. The best way to demonstrate this nomenclature is to use examples. For example, the monomer:

$$- OCHCH_2 —$$
$$|$$
$$F$$
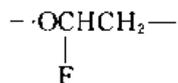
would be called oxy (1-fluoroethylene). To start, we see that there is an oxygen atom attached to a larger subunit. Therefore, the name will have the prefix oxy-. The rest of the monomer can be seen to be an ethylene molecule with a fluorine atom attached. Since the fluorine atom is attached to the first carbon atom, the name of this part of the monomer is 1-fluoroethylene. Thus the name of the complete monomer is oxy (1-fluoroethylene), and the name of the polymer formed from this monomer would be poly [oxy (1-fluoroethylene)].

For monomers with branched chains, the monomer is named for the longest continuous chain. For example:

$$CH_3$$
$$|$$
$$CH_3—CH—CH—CH_2—CH_3$$
$$|$$
$$CH_3$$
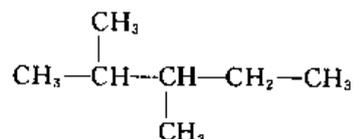
The molecule above is named for pentane, since the longest continuous chain is five carbons long. However, there are also two extra methyl groups attached to the 2nd and 3rd carbons in the chain. Therefore, this monomer is called 2,3 dimethylpentene, and the name of the polymer formed from these monomers is called poly (2,3 dimethylpentane). It may be tempting to label this 3,4 dimethylpentane, but convention mandates that you use the name with the smallest numbers possible.

(Selected from *Polymers and Liquid Crystals*, by, Case Western Reserve University PLC Team, 1998)

New Words and Expressions

ethylene ['eθəli:n] *n.* 乙烯
derivation [ˌderi'veiʃən] *n.* 衍生物
configuration [kənˌfigju'reiʃən] *n.* 构型
hybridize ['haibridaiz] *v.* （使）杂化
trigonal ['trigənl] *a.* 三角的，三角形的
planar ['pleinə] *a.* 平面的，二维的
tetrahedral [tetrə'hedrəl] *a.* 四面体的
chirality ['tʃirəliti] *n.* 手征对称性；手征性
isomer ['aisəmə] *n.* 异构体
cis- 顺式
trans- 反式

nomenclature ['nəumənkleitʃə] *n.* 命名法，专门语，术语

methane ['meθein] *n.* 甲烷，沼气

superimposible *a.* 可叠合的

enantiomer [i'næntiəumə] *n.* 对映（结构）体

diastereomer [ˌdaiə'stiəriəumə] *n.* 非对映异构体

bromo- 溴代

chloro- 氯代

fluoro- 氟代

iodo- 碘代

oxy- 氧代，含氧的

structural diagram 结构图

quantum mechanical calculations 量子力学计算

hybrid atomic orbital 杂化原子轨道

Notes

While this representation allows for the derivation of the three dimensional structure of the left molecule, the right molecule requires further description. 这是一个由 while 引导的弱语气的让步状语从句。可译成"尽管"，"虽然"。

Unit 14　Polymer Structure

Although the fundamental property of bulk polymers is the degree of polymerization, the physical structure of the chain is also an important factor that determines the macroscopic properties.

The terms configuration and conformation are used to describe the geometric structure of a polymer and are often confused. Configuration refers to the order that is determined by chemical bonds. The configuration of a polymer cannot be altered unless chemical bonds are broken and reformed. Conformation refers to order that arises from the rotation of molecules about the single bonds. These two structures are studied below.

Configuration

The two types of polymer configurations are *cis* and *trans*. These structures can not be changed by physical means (e. g. rotation). The *cis* configuration arises when substituent groups are on the same side of a carbon-carbon double bond. *Trans* refers to the substituents on opposite sides of the double bond.

Stereoregularity is the term used to describe the configuration of polymer chains. Three distinct structures can be obtained. Isotactic is an arrangement where all substituents are on the same side of the polymer chain. A syndiotactic polymer chain is composed of alternating groups and atactic is a random combination of the groups. The following diagram shows two of the three stereoisomers of polymer chain.

Isotactic　　　　　　　　　Syndiotactic
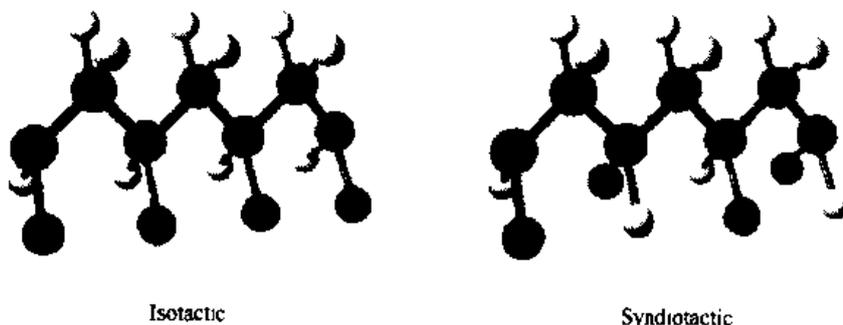
Conformation

If two atoms are joined by a single bond then rotation about that bond is possible since, unlike a double bond, it does not require breaking the bond.

The ability of an atom to rotate this way relative to the atoms which it joins is known as

an adjustment of the torsional angle. If the two atoms have other atoms or groups attached to them then configurations which vary in torsional angle are known as conformations. Since different conformations represent varying distances between the atoms or groups rotating about the bond, and these distances determine the amount and type of interaction between adjacent atoms or groups, different conformation may represent different potential energies of the molecule. There several possible generalized conformations: Anti (*Trans*), Eclipsed (*Cis*), and Gauche (+ or −).

Other Chain Structures

The geometric arrangement of the bonds is not the only way the structure of a polymer can vary. A branched polymer is formed when there are "side chains" attached to a main chain. A simple example of a branched polymer is shown in the following diagram.
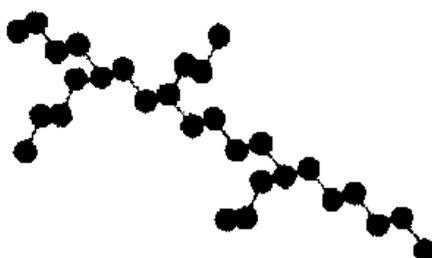
There are, however, many ways a branched polymer can be arranged. One of these types is called "star-branching". Star branching results when a polymerization starts with a single monomer and has branches radially outward from this point. Polymers with a high degree of branching are called dendrimers. Often in these molecules, branches themselves have branches. This tends to give the molecule an overall spherical shape in three dimensions.

A separate kind of chain structure arises when more that one type of monomer is involved in the synthesis reaction. These polymers that incorporate more than one kind of monomer into their chain are called copolymers. There are three important types of copolymers. A random copolymer contains a random arrangement of the multiple monomers. A block copolymer contains blocks of monomers of the same type. Finally, a graft copolymer contains a main chain polymer consisting of one type of monomer with branches made up of other monomers. The following diagram displays the different types of copolymers.

Block Copolymer   Graft Copolymer   Random Copolymer
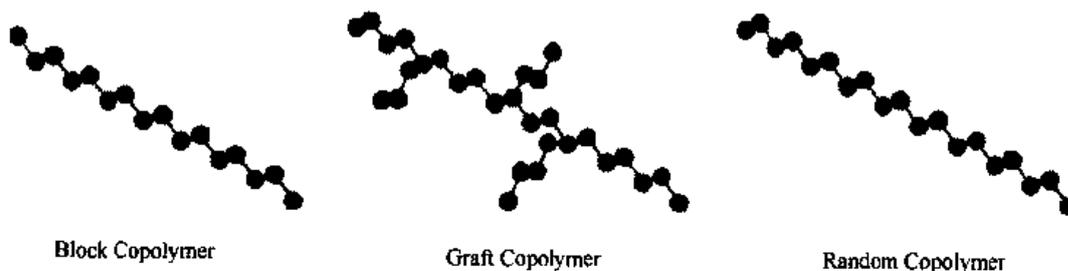
An example of a common copolymer is Nylon. Nylon is an alternating copolymer with 2 monomers, a 6 carbon diacid and a 6 carbon diamine. The following picture shows one monomer of the diacid combined with one monomer of the diamine:

$$
\begin{array}{ccc}
\overset{\displaystyle O}{\underset{\displaystyle \parallel}{}} & & \overset{\displaystyle O}{\underset{\displaystyle \parallel}{}} \\
\end{array}
$$

$$-C-(CH_2)_4-C-NH-(CH_2)_6-NH-$$

|←————Diacid————→|←————Diamine————→|
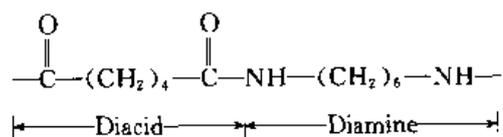
Cross-Linking

In addition to the bonds which hold monomers together in a polymer chain, many polymers form bonds between neighboring chains. These bonds can be formed directly between the neighboring chains, or two chains may bond to a third common molecule. Though not as strong or rigid as the bonds within the chain, these cross-links have an important effect on the polymer. Polymers with a high enough degree of cross-linking have "memory." When the polymer is stretched, the cross-links prevent the individual chains from sliding past each other. The chains may straighten out, but once the stress is removed they return to their original position and the object returns to its original shape.

One example of cross-linking is vulcanization. In vulcanization, a series of cross-links are introduced into an elastomer to give it strength. This technique is commonly used to strengthen rubber.

Classes of Polymers

Polymer science is a broad field that includes many types of materials which incorporate long chain structure of many repeat units as discussed above. The two major polymer classes are described here.

Elastomers, or rubbery materials, have a loose cross-linked structure. This type of chain structure causes elastomers to possess memory. Typically, about 1 in 100 molecules are cross-linked on average. When the average number of cross-links rises to about 1 in 30 the material becomes more rigid and brittle. Natural and synthetic rubbers are both common examples of elastomers. Plastics are polymers which, under appropriate conditions of temperature and pressure, can be molded or shaped (such as blowing to form a film). In contrast to elastomers, plastics have a greater stiffness and lack reversible elasticity. All plastics are polymers but not all polymers are plastics. Cellulose is an example of a polymeric material which must be substantially modified before processing with the usual methods used for plastics. Some plastics, such as nylon and cellulose acetate, are formed into fibers (which are regarded by some as a separate class of polymers in spite of a considerable overlap with plastics). As we shall see in the section on liquid crystals, some of the main chain polymer liquid crystals also are the constituents of important fibers. Every day plastics such as polyethylene and poly (vinyl chloride) have replaced traditional materials like paper and copper for a wide variety of applications. The section on Polymer Applications will go into greater detail about the special properties of the many types of polymers.

(Selected from *Polymers and Liquid Crystals*, by Case Western Reserve
University PLC Team, 1998)

New Words and Expressions

configuration   [kənfigju'reiʃən]   *n.* 构形

conformation   [kɔnfɔː'meiʃən]   *n.* 构象

stereoregularity   [ˌstiəriəˌregju'læriti]   *n.* 立构规整性

isotactic   [ˌaisəu'tæktik]   *n.* 全同立构

syndiotactic   [ˌsindiəu'tæktik]   *n.* 间同立构

atactic   [ɔi'tæktik]   *n.* 无规立构

stereoisomer   [ˌstiəriəu'aisəmə]   *n.* 立体异构体

gauche   [gəuʃ]   *a.* 非对称的

dendrimer   树枝状单体

diacid   [dai'æsid]   *n.* 二酸

diamine   ['daiəmiːn, dai'æmiːn]   *n.* 二胺

crosslink   ['krɔsliŋk]   *n.* 交联

elastomer   [i'læstəmə]   *n.* 弹性体；合成橡胶

plastic   ['plæstik]   *n.* 塑料

torsional angle   扭转角

potential energies   势能

branched polymer   支化聚合物

star-branching   星形支化

random copolymer   无规共聚

block copolymer   嵌段共聚

graft copolymer   接枝共聚

Exercises

1. Explain the difference and similarity between Configuration and Conformation.

2. Give a brief explanation to the following terms and concepts.

     a. isotactic polymer   b. syndiotactic polymer

     c. random copolymer   d. block copolymer

     e. graft copolymer

3. Complete the notes below with words taken from the text above.

     (1) _____ results when a polymerization starts with a single monomer and has branches radially outward from this point. Polymers with a high degree of branching are called _____. Often in these molecules, branches themselves have branches. This tends to give the molecule an overall _____ shape in three dimensions.

     (2) _____, or rubbery materials, have a loose cross-linked structure. _____ are polymers which, under appropriate conditions of temperature and pressure, can be molded or shaped. In contrast to the former, the later group has a greater _____ and lack reversible _____.

Polymer Morphology

Molecular shape and the way molecules are arranged in a solid are important factors in determining the properties of polymers. From polymers that crumble to the touch to those used in bullet proof vests, the molecular structure, conformation and orientation of the poly ~ mers can have a major effect on the macroscopic properties of the material. The general concept of self-assembly enters into the organization of molecules on the micro and macro-scopic scale as they aggregate into more ordered structures. Crystallization, discussed below, is an example of the self-assembly process as is the orientational organization of liquid crystals to be discussed later.

Crystallinity

We need to distinguish here, between crystalline and amorphous materials and then show how these forms coexist in polymers. Consider a comparison between glass, an amorphous material, and ice which is crystalline. Despite their common appearance as hard, clear material, capable of being melted, a difference is apparent when viewed between crossed polarizers, as illustrated below:

The highly ordered crystalline structure of ice changes the apparent properties of the polarized light, and the ice appears bright. Glass and water, lacking that highly ordered structure, both appear dark.

The amorphous morphology of glass leads to very different properties from crystalline solids. This is illustrated in the heating process where the application of heat to glass turns it from a brittle solid-like material at room temperature to a viscous liquid. In contrast, the application of heat to ice turns it from solid to liquid. Crystalline melting leads to striking changes in optical properties during the melting process when observed through crossed polarizers. Note that the entire process occurs over a very narrow temperature range.

The reasons for the differing behaviors lie mainly in the structure of the solids. Crystalline materials have their molecules arranged in repeating patterns. Table salt has one of the

simplest atomic structures with its component atoms, Na⁻ and Cl⁻, arranged in alternating rows and the structure of a small cube. Salt, sugar, ice and most metals are crystalline materials. As such, they all tend to have highly ordered and regular structures. Amorphous materials, by contrast, have their molecules arranged randomly and in long chains which twist and curve around one-another, making large regions of highly structured morphology unlikely.

The morphology of most polymers is semi-crystalline. That is, they form mixtures of small crystals and amorphous material and melt over a range of temperature instead of at a single melting point. The crystalline material shows a high degree of order formed by folding and stacking of the polymer chains. The amorphous or glass-like structure shows no long range order, and the chains are tangled as illustrated below.

Crystalline   Amorphous
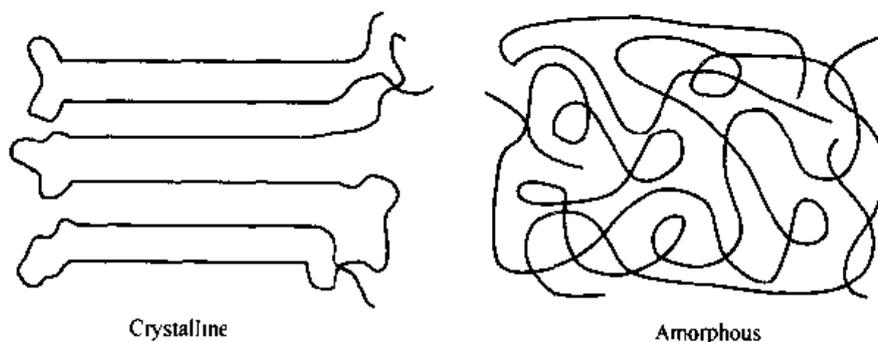
There are some polymers that are completely amorphous, but most are a combination with the tangled and disordered regions surrounding the crystalline areas. Such a combination is shown in the following diagram.

An amorphous solid is formed when the chains have little orientation throughout the bulk polymer. The glass transition temperature is the point at which the polymer hardens into an amorphous solid. This term is used because the amorphous solid has properties similar to glass.

In the crystallization process, it has been observed that relatively short chains organize themselves into crystalline structures more readily than longer molecules. Therefore, the degree of polymerization (DP) is an important factor in determining the crystallinity of a polymer. Polymers with a high DP have difficulty organizing into layers because they tend to become tangled.

The cooling rate also influences the amount of crystallinity. Slow cooling provides time for greater amounts of crystallization to occur. Fast rates, on the other hand, such as rapid

quenches, yield highly amorphous materials. For a more complete discussion, see the section on thermal properties. Subsequent annealing (heating and holding at an appropriate temperature below the crystalline melting point, followed by slow cooling) will produce a significant increase in crystallinity in most polymers, as well as relieving stresses.

Low molecular weight polymers (short chains) are generally weaker in strength. Although they are crystalline, only weak van der Waals forces hold the lattice together. This allows the crystalline layers to slip past one another causing a break in the material. High DP (amorphous) polymers, however, have greater strength because the molecules become tangled between layers. For uses and examples of high and low DP polymers, see the section on Polymer Applications. In the case of fibers, stretching to 3 or more times their original length when in a semi-crystalline state produces increased chain alignment, crystallinity and strength.

In most polymers, the combination of crystalline and amorphous structures forms a material with advantageous properties of strength and stiffness.

Also influencing the polymer morphology is the size and shape of the monomer's substituent groups. If the monomers are large and irregular, it is difficult for the polymer chains to arrange themselves in an ordered manner, resulting in a more amorphous solid. Likewise, smaller monomers, and monomers that have a very regular structure (e. g. rod-like) will form more crystalline polymers.

(Selected from *Polymers and Liquid Crystals*, by Case Western
Reserve University PLC Team, 1998)

New Words and Expressions

orientation ['ɔːrien'teiʃən] n. 定向，取向
macroscopic ['mækrəu'skɔpik] a. 宏观的，肉眼可见的
crystallization [ˌkristəlai'zeiʃən] n. 晶化，结晶
crystalline ['kristəlain] a. 结晶的，结晶性的
amorphous [ə'mɔːfəs] a. 无定形的
polarizer ['pəuləraizə] n. 偏光器，起偏镜
annealing [ə'niːliŋ] n. 退火
self-assembly 自组装
semi-crystalline 半结晶的
glass transition temperature (T_g) 玻璃化转变温度
degree of polymerization (DP) 聚合度

Unit 15 Polymer Liquid Crystals

Introduction

Polymer liquid crystals (PLCs) are a class of materials that combine the properties of polymers with those of liquid crystals. These "hybrids" show the same mesophases characteristic of ordinary liquid crystals, yet retain many of the useful and versatile properties of polymers.

In order for normally flexible polymers to display liquid crystal characteristics, rod-like or disk-like elements (called mesogens) must be incorporated into their chains. The placement of the mesogens plays a large role in determining the type of PLC that is formed. Main-chain polymer liquid crystals or MC-PLCs are formed when the mesogens are themselves part of the main chain of a polymer. Conversely, side chain polymer liquid crystals or SC-PLCs are formed when the mesogens are connected as side chains to the polymer by a flexible "bridge"(called the spacer.)
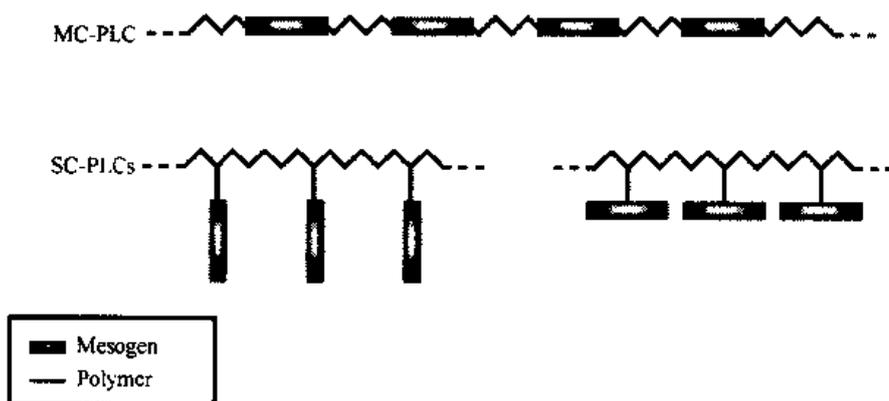
Other factors influencing the mesomorphic behavior of polymers include the presence of long flexible spacers, a low molecular weight, and regular alternation of rigid and flexible units along the main chain.

The following sections will go into greater detail about the structure, phases, and applications of polymer liquid crystals.

Main Chain Polymer Liquid Crystals

Main chain polymer liquid crystals are formed when rigid elements are incorporated into the backbone of normally flexible polymers. These stiff regions along the chain allow the polymer to orient in a manner similar to ordinary liquid crystals, and thus display liquid crystal characteristics. There are two distinct groups of MC-PLCs, differentiated by the manner in which the stiff regions are formed.

The first group of main chain polymer liquid crystals is characterized by stiff, rod-like monomers. These monomers are typically made up of several aromatic rings which provide

the necessary size. The following diagram shows an example of this kind of MC-PLC.

PHNA poly [hydroxynapthoic acid]
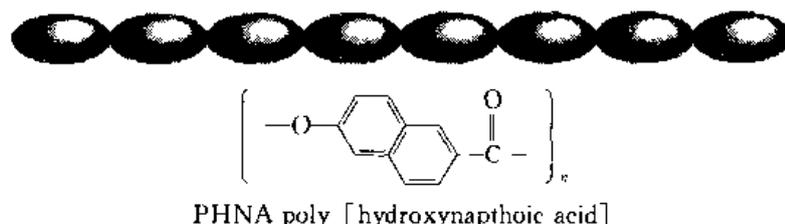
The second and more prevalent group of main chain polymer liquid crystals is different because it incorporates a mesogen directly into the chain. The mesogen acts just like the stiff areas in the first group. Generally, the mesogenic units are made up of two or more aromatic rings which provide the necessary restriction on movement that allow the polymer to display liquid crystal properties. The stiffness necessary for liquid crystallinity results from restrictions on rotation caused by steric hindrance and resonance. Another characteristic of the mesogen is its axial ratio. The axial ratio is defined to be the length of the molecule divided by the diameter ($x = L/d$). Experimental results have concluded that these molecules must be at least three times long as they are wide. Otherwise, the molecules are not rod-like enough to display the characteristics of liquid crystals.

This group is different from the first in that the mesogens are separated or "decoupled" by a flexible bridge called a spacer. Decoupling of the mesogens provides for independent movement of the molecules which facilitates proper alignment. The following is a diagram of this type of main chain polymer liquid crystal. Notice the flexible spacer (methylene groups) and the stiff mesogen (aromatic ring and double bonds).

PET poly [*p*-phenyleneterephthalate]
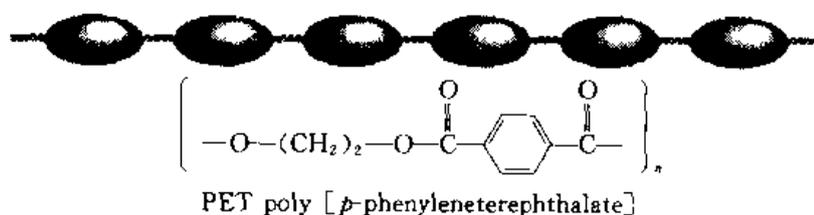
Temperature Range Problems

It is difficult to create polymer liquid crystals that show mesogenic behavior over temperature ranges which are convenient to work with. In fact, many times the temperature of the liquid crystalline behavior is actually above the point where the polymer begins to decompose. This problem can be avoided in one or more of the following ways.

The first method of lowering polymer melting temperatures involves the arrangement of the monomers in the chain. If the molecules are put together in random orientation (head-to-tail, head-to-head, etc.), interactions between successive chains are minimized. This allows for a lower melting temperature.

Another method to bring the temperature down to a useful range involves copolymerization. If a random copolymer can be created, the regularity of the chains is greatly reduced.

This will help to minimize the interactions between the chains by breaking up the symmetry, which in turn will lower polymer melting temperature. The following picture shows how the irregularity of polymer substituents can lead to decreased interactions.

Finally, defects can be introduced into the chain structure which lower the polymer melting temperature. This method creates 120 degree "kinks" in the chain which disrupt the ability for neighboring polymers to line up. Unfortunately, this also decreases the effective persistence length so too many kinks can destroy any liquid crystal behavior.

Side Chain Polymer Liquid Crystals

It has been demonstrated that main chain polymer liquid crystals often cannot show mesogenic behavior over a wide temperature range (see Main Chain Polymer Liquid Crystals). Side chain polymer liquid crystals, however, are able to expand this scale. These materials are formed when mesogenic units are attached to the polymer as side chains.
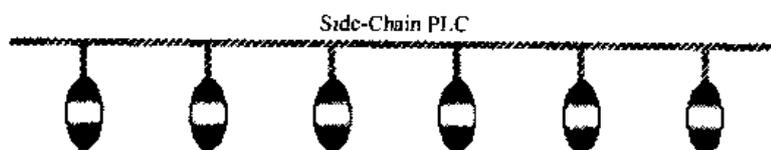
Side-Chain PLC

Side chain polymer liquid crystals have three major structural components: the backbone, the spacer, and the mesogen. The versatility of SC-PLCs arises because these structures can be varied in a number of ways.

The Backbone

The backbone of a side chain polymer liquid crystal is the element that the side chains are attached to. The structure of the backbone can be very important in determining if the polymer shows liquid crystal behavior. Polymers with rigid backbones typically have high glass transition temperatures, and thus liquid crystal behavior is often difficult to observe. In order to lower this temperature, the polymer backbone can be made more flexible.

The Mesogen

Perhaps the most important part of a side chain polymer liquid crystal is the mesogen. It is the alignment of these groups that causes the liquid crystal behavior. Usually, the mesogen is made up of a rigid core of two or more aromatic rings joined together by a functional group. The following diagram is a typical repeating unit in a side chain polymer liquid crystal. Notice the spacer of methylene units and the mesogen of aromatic rings.

$$\left[CH_2-CH\right]_n$$

$$O=C$$

$$O-(CH_2)_{11}-O-\bigcirc-CH=N-\bigcirc-CN$$
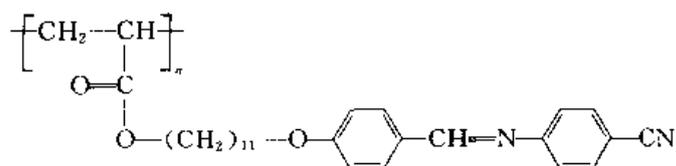
The Spacer

Like their main chain counterparts, mesogens attached as side groups on the backbone of side chain polymer liquid crystals are able to orient because the spacer allows for independent movement. Notice in the following diagram that even though the polymer may be in a tangled conformation, orientation of the mesogens is still possible because of the decoupling action of the spacer.
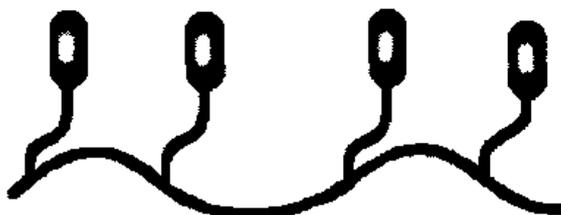
The structure of the spacer is an important determining factor in side chain polymer liquid crystals. Generally, the spacer consists of two to four methylene (CH_2) groups attached together in a line. Accordingly, the spacer length has a profound effect on the temperature and type of phase transitions. Usually, the glass transition temperature decreases with increasing spacer length. Short spacers tend to lead to nematic phases, while longer spacers lead to smectic phases.

(Selected from *Polymers and Liquid Crystals*, by Case Western
Reserve University PLC Team, 1998)

New Words and Expressions

mesophase ['mesəufeiz] *n.* 中间相，介晶相

mesogen 致晶链节

spacer ['speisə] *n.* （柔性的）间隔链节

mesomorphic [mesə'mɔːfik] *a.* 介晶的

aromatic [ˌærəu'mætik] *a.* 芳香族的

resonance ['resənəns] *n.* 共振，谐振

methylene ['meθiliːn] *n.* 亚甲基

kink [kiŋk] *n.* 纽结，蜷缩

steric hindrance 空间位阻

nematic phases 向列相

smectic phases 近晶相

Exercises

1. Complete the notes blow with words taken from the text above.

(1) Generally, the mesogenic units are made up of two or more _____ which provide the necessary _____ on movement that allow the polymer to display liquid crystal properties. The _____ necessary for liquid crystallinity results from restrictions on rotation caused by _____ and _____. Another characteristic of the mesogen is its _____.

(2) Perhaps the most important part of a side chain polymer liquid crystal is the _____. It is the _____ of these groups that causes the liquid crystal behavior.

2. Put the following into Chinese:

(1) main-chain polymer liquid crystals   (2) side-chain polymer liquid crystal

(3) glass transition temperature

3. List at least two methods of lowering polymer melting temperature.

Reading Material

PLCs' Phases and Their Applications

Polymer liquid crystals form the same mesophases as ordinary liquid crystals. Understanding the ways in which the molecules line up is important in understanding their properties.

Side chain polymer liquid crystals show a tendency to separate the backbone from the mesogenic side groups. This is achieved in the smectic phase where the mesogenic groups and backbone chains form individual layers.
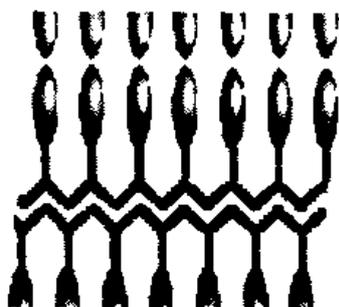
Many side chain polymer liquid crystals form what is known as the "double comb" con-

figuration. This structure is formed when side chains point away from the backbone in an alternating fashion. The double comb configuration allows the polymers to form layers characteristic of the smectic phase.
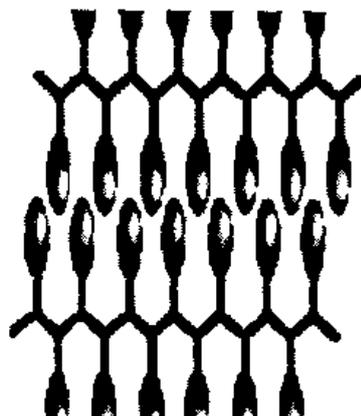
Atactic polymers in addition to copolymers cannot form this structure because the side chains are connected to the backbone in random directions.

Applications of Polymer Liquid Crystals

Polymer liquid crystals will most certainly become more important as research into this field progresses. Applications for these materials range from the production of high-strength materials to their use in optical devices. The following is an introduction to some of these applications.

High-Strength Fibers

An application of polymer liquid crystals that has been successfully developed for industry is the area of high strength fibers. Kevlar, which is used to make such things as helmets and bullet-proof vests, is just one example of the use of polymer liquid crystals in applications calling for strong, light weight materials.

Ordinary polymers have never been able to demonstrate the stiffness necessary to compete against traditional materials like steel. It has been observed that polymers with long straight chains are significantly stronger than their tangled counterparts. Main chain liquid crystal polymers are well-suited to ordering processes. For example, the polymer can be oriented in the desired liquid crystal phase and then quenched to create a highly ordered, strong solid. As these technologies continue to develop, an increasing variety of new materials with strong and light-weight properties will become available.

Optical Applications

The use of polymer liquid crystals in the display industry is an exciting area of research. At this time, PLC's demonstrate relatively slow "response times" to electric fields. That is, when a field is applied, the molecules take a long time to align along it. This is not a good property for use in displays where the screen must be able to change rapidly from one view to another. Researchers are working to overcome this problem because the manipulation of polymers is often much easier than traditional liquid crystals.

In applications for which response time is not a factor (or in the future, after response times have improved), a twisted nematic polymer liquid crystal cell can be used to make energy efficient displays. A laser is used to selectively melt portions of the display into the liquid crystal phase. The orientation of the cell is then chosen by applying a field across it, just as in an ordinary twisted nematic liquid crystal cell. When the polymer cools down and hardens into a glass, the mesogens will be locked in that configuration and the field can be turned off.

Side chain polymer liquid crystals exhibit good properties for applications in optically

nonlinear devices including optical waveguides and electro-optic modulators in poled polymeric slab waveguides. More devices are expected to be fabricated from PLCs in the future: optically-addressed spatial light modulators, tunable notch filters, optical amplifiers, and laser beam deflectors. The properties of ferroelectric chiral smectic C phases make this material useful for films with applications in nonlinear optics.

(Selected from *Polymers and Liquid Crystals*, by Case Western

Reserve University PLC Team, 1998)

New Words and Expressions

counterpart ['kauntəpaːt] *n.* 对应物，配对物

quench [kwentʃ] *v.* 冷浸，淬火

nonlinear [nɔn'liniəl] *a.* 非线性的

modulator ['mɔdjuleitə] *n.* 调制器

waveguide ['weivgaid] *n.* 波导

fabricate ['fæbrikeit] *vt.* 制造，建造，装配，伪造

deflector [di'flektə] *n.* 偏转器

ferroelectric [ˌferəui'lektrik] *n.* 铁电

amplifier ['æmplifaiə] *n.* 放大器

fabricate ['fæbrikeit] *vt.* 制造，建造

bullet-proof vest 防弹背心

optical waveguide 光学波导（波导管，波导器）

electro-optic modulator 电-光调制器

optically-addressed spatial light modulator 光寻址空间光调制器

notch filter 陷波滤波器

optical amplifier 光学放大器

laser beam 激光束

Unit 16 Applications of Polymers

Macromolecular science has had a major impact on the way we live. It is difficult to find an aspect of our lives that is not affected by polymers. Just 50 years ago, materials we now take for granted were non-existent. With further advances in the understanding of polymers, and with new applications being researched, there is no reason to believe that the revolution will stop any time soon.

This section presents some common applications of the polymer classes introduced in the section on Polymer Structure. These are by no means all of the applications, but a cross section of the ways polymers are used in industry.

Elastomers

Rubber is the most important of all elastomers. Natural rubber is a polymer whose repeating unit is isoprene. This material, obtained from the bark of the rubber tree, has been used by humans for many centuries. It was not until 1823, however, that rubber became the valuable material we know today. In that year, Charles Goodyear succeeded in "vulcanizing" natural rubber by heating it with sulfur. In this process, sulfur chain fragments attack the polymer chains and lead to cross-linking. The term vulcanization is often used now to describe the cross-linking of all elastomers.

Much of the rubber used in the United States today is a synthetic variety called styrene-butadiene rubber (SBR). Initial attempts to produce synthetic rubber revolved around isoprene because of its presence in natural rubber. Researchers eventually found success using butadiene and styrene with sodium metal as the initiator. This rubber was called Buna-S—— "Bu" from butadiene, "na" from the symbol for sodium, and "S" from styrene. During World War II, hundreds of thousands of tons of synthetic rubber were produced in government controlled factories. After the war, private industry took over and changed the name to styrene-butadiene rubber. Today, the United States consumes on the order of a million tons of SBR each year. Natural and other synthetic rubber materials are quite important.

Plastics

Americans consume approximately 60 billion pounds of plastics each year. The two main types of plastics are thermoplastics and thermosets. Thermoplastics soften on heating and harden on cooling while thermoset, on heating, flow and cross-link to form rigid material

which does not soften on future heating. Thermoplastics account for the majority of commercial usage.

Among the most important and versatile of the hundreds of commercial plastics is polyethylene. Polyethylene is used in a wide variety of applications because, based on its structure, it can be produced in many different forms. The first type to be commercially exploited was called low density polyethylene (LDPE) or branched polyethylene. This polymer is characterized by a large degree of branching, forcing the molecules to be packed rather loosely forming a low density material. LDPE is soft and pliable and has applications ranging from plastic bags, containers, textiles, and electrical insulation, to coatings for packaging materials.

Another form of polyethylene differing from LDPE only in structure is high density polyethylene (HDPE) or linear polyethylene. This form demonstrates little or no branching, enabling the molecules to be tightly packed. HDPE is much more rigid than branched polyethylene and is used in applications where rigidity is important. Major uses of HDPE are plastic tubing, bottles, and bottle caps.

Other forms of this material include high and ultra-high molecular weight polyethylenes. HMW and UHMW, as they are known. These are used in applications where extremely tough and resilient materials are needed.

Fibers

Fibers represent a very important application of polymeric materials, including many examples from the categories of plastics and elastomers.

Natural fibers such as cotton, wool, and silk have been used by humans for many centuries. In 1885, artificial silk was patented and launched the modern fiber industry. Man-made fibers include materials such as nylon, polyester, rayon, and acrylic. The combination of strength, weight, and durability have made these materials very important in modern industry.

Generally speaking, fibers are at least 100 times longer than they are wide. Typical natural and artificial fibers can have axial ratios (ratio of length to diameter) of 3000 or more.

Synthetic polymers have been developed that possess desirable characteristics, such as a high softening point to allow for ironing, high tensile strength, adequate stiffness, and desirable fabric qualities. These polymers are then formed into fibers with various characteristics.

Nylon (a generic term for polyamides) was developed in the 1930's and used for parachutes in World War II. This synthetic fiber, known for its strength, elasticity, toughness, and resistance to abrasion, has commercial applications including clothing and carpeting. Nylon has special properties which distinguish it from other materials. One such property is the elasticity. Nylon is very elastic, however after elastic limit has been exceeded the material will not return to its original shape. Like other synthetic fibers, Nylon has a large electrical resistance. This is the cause for the build-up of static charges in some articles of clothing and carpets.

From textiles to bullet-proof vests, fibers have become very important in modern life. As the technology of fiber processing expands, new generations of strong and light

weight materials will be produced.

Processing Polymers

Once a polymer with the right properties is produced, it must be manipulated into some useful shape or object. Various methods are used in industry to do this. **Injection molding** and **extrusion** are widely used to process plastics while **spinning** is the process used to produce fibers.

Injection Molding

One of the most widely used forms of plastic processing is injection molding. Basically, a plastic is heated above its glass transition temperature (enough so that it will flow) and then is forced under high pressure to fill the contents of a mold. The molten plastic in usually "squeezed" into the mold by a ram or a reciprocating screw. The plastic is allowed to cool and is then removed from the mold in its final form. The advantage of injection molding is speed; this process can be performed many times each second.

Extrusion

Extrusion is similar to injection molding except that the plastic is forced through a die rather than into a mold. However, the disadvantage of extrusion is that the objects made must have the same cross-sectional shape. Plastic tubing and hose is produced in this manner.

Spinning

The process of producing fibers is called spinning. There are three main types of spinning: melt, dry, and wet. Melt spinning is used for polymers that can be melted easily. Dry spinning involves dissolving the polymer into a solution that can be evaporated. Wet spinning is used when the solvent cannot be evaporated and must be removed by chemical means. All types of spinning use the same principle, so it is convenient to just describe just one. In melt spinning, a mass of polymer is heated until it will flow. The molten polymer is pumped to the face of a metal disk containing many small holes, called the spinneret. Tiny streams of polymer that emerge from these holes (called filaments) are wound together as they solidify, forming a long fiber. Speeds of up to 2500 feet/minute can be employed in spinning.

Following the spinning process, as noted in the section on Polymer Morphology, fibers are stretched substantially-from 3 to 8 or more times their original length to produce increased chain alignment and enhanced crystallinity in order to yield improved strength.

New Words and Expressions

isoprene ['aisəpri:n] *n.* 异戊二烯
sulfur ['sʌlfə] *n.* 硫磺
styrene ['stairi:n] *n.* 苯乙烯

butadiene [ˌbjuːtə'daiiːn] *n.* 丁二烯

thermoplastic [θəːmou'plæstik] *a.* 热塑性的；*n.* 热塑性塑料

thermoset [θəːmouset] *a.* 热固性；*n.* 热固性材料

linear ['liniə] *a.* 线性的，直线的

ironing ['aiəniŋ] *n.* 熨平

extrusion [eks'truːʒən] *n.* 挤出，压出

spinning ['spiniŋ] *n.* 纺丝，纺织

ram [ræm] *n.* 撞锤，水压机活塞

filament ['filəmənt] *n.* 细丝，细线

styrene-butadiene rubber 丁苯橡胶

low density polyethylene 低密度聚乙烯

high density polyethylene 高密度聚乙烯

ultra-high molecular weight polyethylene 超高分子量聚乙烯

axial ratios 轴向比率（长径比）

tensile strength 拉伸强度

synthetic fiber 合成纤维

injection molding 注塑成型，注塑

reciprocating screw 往复式螺杆

Exercises

1. Compare the differences among elastomers, plastics, and fibers in terms of properties and performances.
2. List the most widely used processing methods for polymers.
3. Give the full names and Chinese translations for the following acronyms.
   (1) SBR   (2) LDPE   (3) HDPE
   (4) HMW   (5) UHMW
4. Fill in the blanks with words "thermoplastics" and "thermosets".

   The two main types of plastics are _____ and _____ . _____ soften on heating and harden on cooling while _____ . on heating, flow and cross-link to form rigid material which does not soften on future heating. _____ account for the majority of commercial usage.

Reading Material

Thermal Properties of Polymers

Polymer Glass Transition

In the study of polymers and their applications, it is important to understand the concept of the glass transition temperature, T_g. As the temperature of a polymer drops below

T_g, it behaves in an increasingly brittle manner. As the temperature rises above the T_g, the polymer becomes more rubber-like. Thus, knowledge of T_g is essential in the selection of materials for various applications. In general, values of T_g well below room temperature define the domain of elastomers and values above room temperature define rigid, structural polymers.

This behavior can be understood in terms of the structure of glassy materials which are formed typically by substances containing long chains, networks of linked atoms or those that possess a complex molecular structure. Normally such materials have a high viscosity in the liquid state. When rapid cooling occurs to a temperature at which the crystalline state is expected to be the more stable, molecular movement is too sluggish or the geometry too awkward to take up a crystalline conformation. Therefore the random arrangement characteristic of the liquid persists down to temperatures at which the viscosity is so high that the material is considered to be solid. The term glassy has come to be synonymous with a persistent non-equilibrium state. In fact, a path to the state of lowest energy might not be available.
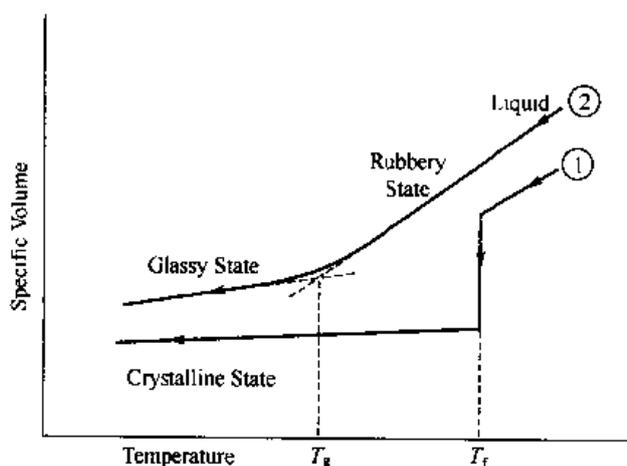
To become more quantitative about the characterization of the liquid-glass transition phenomenon and T_g, we note that in cooling an amorphous material from the liquid state, there is no abrupt change in volume such as occurs in the case of cooling of a crystalline material through its freezing point, T_f. Instead, at the glass transition temperature, T_g, there is a change in slope of the curve of specific volume vs. temperature, moving from a low value in the glassy state to a higher value in the rubbery state over a range of temperatures. This comparison between a crystalline material ① and an amorphous material ② is illustrated in the figure below. Note that the intersections of the two straight line segments of curve ② defines the quantity T_g.

The specific volume measurements shown here, made on an amorphous polymer ②, are carried out in a dilatometer at a slow heating rate. In this apparatus, a sample is placed in a glass bulb and a confining liquid, usually mercury, is introduced into the bulb so that the liquid surrounds the sample and extends partway up a narrow bore glass capillary tube. A capillary tube is used so that relatively small changes in polymer volume caused by changing the temperature produce easily measured changes in the height of the mercury in the capillary.

The determination of T_g for amorphous materials, including polymers as mentioned above, by dilatometric methods (as well as by other methods) are found to be rate dependent. This is schematically illustrated in the figure below, again representing an amorphous polymer, where the higher value, T_{g_2}, is obtained with a substantially higher cooling rate than for T_{g_1}.

We can understand this rate dependence in terms of intermolecular relaxation processes. Since a glass is not an equilibrium phase, its properties will exhibit a time dependence, or physical aging. The primary portion of the relaxation behavior governing the glass transition in polymers can be related to their tangled chain structure where cooperative molecular motion is required for internal readjustments. At temperatures well above T_g, 10 to 50 repeat units of the polymer backbone are relatively free to move in cooperative thermal motion to provide conformational rearrangement of the backbone. Below T_g, the motion of these individual chains segments becomes frozen with only small scale molecular motion remaining, involving individual or small groups of atoms. Thus a rapid cooling rate or "quench" takes rubbery material into glassy behavior at higher temperatures (higher T_g).

While the dilatometer method is the more precise method of determining the glass transition temperature, it is a rather tedious experimental procedure and measurements of T_g are often made in a differential scanning calorimeter (DSC). In this instrument, the heat flow into or out of a small (10~20 mg) sample is measured as the sample is subjected to a programmed linear temperature change. This will be discussed in the next section. There are other methods of measurement such as density, dielectric constant and elastic modulus which are treated in texts on polymers. These methods are, of course, also rate dependent.
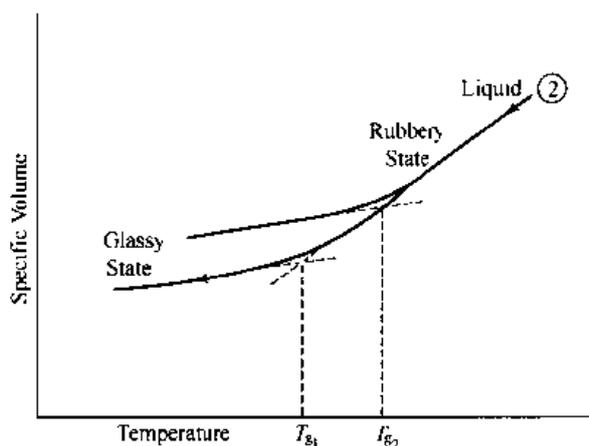
T_g and Mechanical Properties

Another important property of polymers, also strongly dependent on their temperatures, is their response to the application of a force, as indicated by two main types of behavior: elastic and plastic. Elastic materials will return to their original shape once the force is removed. Plastic materials will not regain their shape. In plastic materials, flow is occurring, much like a highly viscous liquid. Most materials demonstrate a combination of elastic and plastic behavior, showing plastic behavior after the elastic limit has been exceeded.

Glass is one of the few completely elastic materials while it is below its T_g. It will remain elastic until it reaches its breaking point. The T_g of glass occurs between 510 and 560 degrees C, meaning that it will always be a brittle solid at room temperature. In comparison, polyvinyl chloride (PVC) has a T_g of 83 degrees C, making it good, for example, for cold water pipes, but unsuitable for hot water. PVC also will always be a brittle solid at room temperature.

Adding a small amount of plasticizer to PVC can lower the T_g to $-40°C$. This addition renders the PVC a soft, flexible material at room temperature, ideal for applications such as garden hoses. A plasticized PVC hose can, however, become stiff and brittle in winter. In this case, as in any other, the relation of the T_g to the ambient temperature is what deter-

mines the choice of a given material in a particular application.

A striking example of the rate dependence of these viscoelastic properties is furnished by Silly Putty. Slowly pulling on two parts of the Silly Putty stretches it apart until it very slowly separates. Placing the Silly Putty on a table and hitting it with a hammer will shatter it.
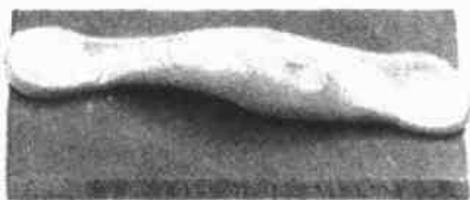
Slowly Deformed

Rapidly Deformed

The above images are representative of the behavior of a material above and below its glass transition temperature. The image on the (left) is Silly Putty that has been slowly stretched. The image on the (right) is Silly Putty which has been hit with a hammer. The speed of the hammer raised the rate of the application of the force and in turn raised the T_g. This caused the Silly Putty to react as if it were below its T_g and to shatter. Even though both reactions took place at the same ambient temperature, one reaction appeared to be above the effective T_g and the other appeared to be below.

Our focus has been on amorphous polymers in the preceding discussion but we have hardly touched on their mechanical properties. A further complication arises in dealing with general polymers from their semi-crystalline morphology in which amorphous regions and crystalline regions are intermingled. This gives rise to a mixed behavior depending on the percent crystallinity and on their temperature, relative to T_g of the amorphous regions. You are referred to texts on polymer science for basic discussion of these topic but the inhomogeneity of the material and its characteristics presents interesting analytical challenges.

(Selected from *Polymers and Liquid Crystals*, by Case
Western Reserve University PLC Team, 1998)

New Words and Expressions

intersection [intə'sekʃən]   n. 交叉点
dilatometer [dailə'tɔmitə]   n. 膨胀计
capillary [kə'piləri]   n. 毛细管; a. 毛细管状的
quench [kwentʃ]   v. & n. 淬火
plasticizer ['plæstisaizə]   n. 增塑剂
ambient ['æmbiənt]   a. 周围的
viscoelastic [ˌviskəui'læstik]   a. 黏弹性的
Glass Transition   玻璃化转变
non-equilibrium state   非平衡态
specific volume   比容
differential scanning calorimeter (DSC)   差示扫描量热仪

PART V COMPOSITES

Unit 17 Polymeric Composite Materials

Introduction

Principal advantage of composite materials resides in the possibility of combining physical properties of the constituents to obtain new structural or functional properties. Composite materials appeared very early in human technology, the "structural" properties of straw were combined with a clay matrix to produce the first construction material and, more recently, steel reinforcement opened the way to the ferroconcrete that is the last century dominant material in civil engineering. As a matter of fact, the modern development of polymeric materials and high modulus fibres (carbon, aramidic) introduced a new generation of composites. The most relevant benefit has been the possibility of energetically convenient manufacturing associated with the low weight features. Due to the possibility of designing properties, composite materials have been widely used, in the recent past, when stiffness/weight, strength/weight, ability to tailor structural performances and thermal expansion, corrosion resistance and fatigue resistance are required. Polymeric composites were mainly developed for aerospace applications where the reduction of the weight was the principal objective, irrespective of the cost. The scientific efforts in this field were therefore focused to the comprehension and optimization of the structural performances of these materials. Structural composite materials have also been used in other fields such as automotive, naval transportation and civil engineering but the high cost still limits their applications. A continuous task has been making composite components economically attractive. The effort to produce economic attractive composite components has resulted in several innovative manufacturing techniques currently being used in the composite industry.

State of the Art

Nowadays, technology is devoted to the development of new materials able to satisfy specific requirements in terms of both structural and functional performances. The need of exploring new markets in the field of polymeric composites has recently driven the research in Europe towards the development of new products and technologies. In particular, activities on thermoplastic based composites and on composites based on natural occurring materials (environmentally friendly, biodegradable systems) have been of relevant interest in many European countries.

Since the beginning of the 1990s, U. S. and Japan have recognized the need of expanding composite applications. In the field of materials, Japan put more emphasis than U. S.

on thermoplastic and high temperature resins. Moreover, due to the large extent of the textile industry in Japan, textile preforming is significantly more advanced than in U. S, and this could lead to the development of cost-efficient automated computer-controlled looms for complex textile shapes. In contrast to the U. S. approach of developing computational models to better understand manufacturing processes, Japanese manufacturing science appears to reside in experienced workers who develop understanding of the process over long period of time. However, Japanese process and product development methods are based on concurrent engineering methodology, which is based on the integration of product and process design.

Biomedical is another important field where composites are applied. Materials, able to simulate the complex structural properties of the natural tissues, which are composite in nature, have been developed but there are still few applications. This is due to the delay in the technology transfer from different areas (composite industry and biomedical) and to the lack of cross-disciplinary strategies. In this field, U. S. maintain a leadership role but major centres exist in EU and Japan. Japan recognized the necessity of establishing a "National Institute for Advanced Interdisciplinary Research" which is devoted to research on subjects combining elements from various fields that cannot be adequately treated within the bounds of traditional divisions of science. Among other topics, soft and hard tissue engineering are considered of relevant interests. Tissue engineering activities are growing, as well and strong R&D programmes are present in EU and Japan, even though U. S. have a leadership role in the field.

Trends

The main trends in the structural composite field are related to the reduction of the cost which cannot only be related to the improvement in the manufacturing technology, but needs an integration between design, material, process, tooling, quality assurance, manufacturing. Moreover, the high-tech industry, such as telecommunication, where specific functional properties are the principal requirements, will take advantages by the composite approach in the next future. The control of the filler size, shape and surface chemical nature has a fundamental role in the development of materials that can be utilized to develop devices, sensors and actuators based on the tailoring of functional properties such as optical, chemical and physical, magneto-elastic etc. Finally, a future technological challenge will be the development of a new class of smart composite materials whose elasto-dynamic response can be adapted in real time in order to significantly enhance the performance of structural and mechanical systems under a diverse range of operating conditions.

Over the long period term, U. S. and Japan believe that advances in the materials area would prompt new breakthroughs in the area of composites. In fact, the current emphasis is on "fourth-generation" materials, i. e. those that are designed by controlling the behavior of atoms and electrons, and which provide carefully tailored functional gradients.

Expectation and Needs for the Next 10 Years

The composite materials market is expected to expand in areas where costs are today a strong limitation. The improvement of the mature manufacturing technologies will benefit from integrated approach where product and process requirements are set at design level. The expected reduction of manufacturing costs of the structural composites will expand applications of such materials to large-scale markets such as civil and goods. Among the paramount needs are large-scale sponsored demonstration project; large scale and long-duration tests programmes; development and support of product certification and specification protocols. In particular, it is demanding to expand basic and applied research in the fields of materials systems for homes, more durable materials to replace aging pipelines and transmission systems, enhanced safety systems for lighter automobiles made from composites, as well as research into even more rapid manufacturing processes, improvements in material handling and storage, and better, more durable and ever more benign resins.

Significant breakthroughs are expected in new composite materials especially in those applications, such as electronic, optic and biomedical, where functionality is the most relevant technical need. Relevant development will be expected in the area of nanophase material synthesis and nanocomposite manufacturing technology. However, further optimization studies are required to implement large-scale production.

Particular emphasis should be devoted to the R&D of composite materials able to respond to dynamic variation of the operative conditions. Smart materials will provide the nervous systems, the brains and the muscles for the existing advanced materials and structure that, at the moment, are a mere skeleton compared with the anatomy forecasted in a near future. Applications are expected in fields of sensors, actuators, and biomedical.

The quality of human life would be greatly improved by the availability of artificial prostheses (bone, muscles, cartilage, and soft tissues) and organs able to restore, repair or replace structural and functional performances of the natural tissues. The composite structure of the natural systems with its intrinsic complexity needs to be reproduced. Tissue Engineering is one of the major focuses of biotechnological research today, with the expectation that this type of biohybrid technology will ultimately transform the practice of restorative clinics. The approach combines the principles of biology, material science and engineering to culture cells, also heterogeneous groups of cells, using polymeric biodegradable scaffolds as delivery vehicles for cell transplantation to obtain complex three-dimensional cellular constructs. Composite materials should be properly designed to provide anisotropic and/or active scaffolds able to control the cell growth in the reconstruction of complex natural structures.

The expected development of the aforementioned fields needs a serious interdisciplinary approach. As already recognized by U. S. and Japan, significant advancement in the next 10 years in the field of a) functional and structural composites through nanotechnologies, b) smart materials and c) composite for biomedical applications requires cross-disciplinary strategies that should be addressed by combining various scientific disciplines. The available huge

amount of human and economic resources, spread all over Europe, should be better coordinated by the creation of new interdisciplinary European research centers that could face the world scientific and technological challenge in these strategic fields.

Conclusions

Research activities, aimed to expand the applications in composite industry, must be addressed to improve manufacturing composite technology, through a better integration of product and process design; to develop new constituent materials with better performances and/or for the tailoring of structural and functional properties for special applications and for the development of new processes and new manufacturing technologies.

Expected breakthroughs are related to the development of multi-component materials with anisotropic and non-linear properties, able to impart unique structural and functional properties. Applications include smart systems, able to recognize and to adapt to external stimuli, as well as anisotropic and active composite systems to be used as scaffold for tissue engineering and other biomedical applications.

<div align="right">

(Selected from *Materials Synthesis and Processing*,

by M. Giordano, S. Iannace and L. Nicolais. 2002)

</div>

New Words and Expressions

ferroconcrete ['ferəu'kɔŋkriːt] *n.* 钢筋混凝土，钢骨水泥

energetically [ˌenə'dʒetikəli] *ad.* 精力充沛地，积极地

fatigue resistance 耐疲劳性，抗疲劳强度

textile ['tekstail] *n.* 纺织品；*a.* 纺织的

loom [luːm] *n.* 织布机，织机；*v.* 隐现，迫近

integration [ˌinti'greiʃən] *n.* 综合

cross-disciplinary *n.* 交叉学科

filler [filə] *n.* 装填者，补白，装填物，填料，掺入物

magneto-elastic *a.* 磁致弹性的

elasto-dynamics *n.* 弹性动力学

paramount ['pærəmaunt] *a.* 极为重要的

protocol ['prəutəkɔl] *n.* 科学实验报告

benign [bi'nain] *a.* （病）良性的，（气候）良好的，仁慈的，和蔼的

implement ['implimənt] *n.* 工具，器具；*vt.* 贯彻，实现；*v.* 执行

skeleton ['skelitn] *n.* （动物之）骨架，骨骼，格架

anatomy [ə'nætəmi] *n.* 剖析，解剖学

prosthesis ['prɔsθisis] *n.* (*pl.* -ses) 修复术，弥补术；修补物，假体

biohybrid [ˌbaiəu'haibrid] *n.* 生物杂交种，混合物

scaffold ['skæfəld] *n.* 脚手架

heterogeneous ['hetərəu'dʒiːnjəs] *a.* 不同种类的，异类的

anisotropic [ˌænaisə'trɔpik] *a.* 各向异性的

non-linear   *a.* 非线性的

Notes

① In particular, activities on thermoplastic based composites and on composites based on natural occurring materials (environmentally friendly, biodegradable systems) have been of relevant interest in many European countries. 注意，本句 activities on 后面有两个词组做介词 on 的宾语，一个是 thermoplastic based composites，另一个是 composites based on natural occurring materials。

② Moreover, the high-tech industry, such as telecommunication, where specific functional properties are the principal requirements, will take advantages by the composite approach in the next future. 本句中 where specific functional properties are the principal requirements 是修饰主语 the high-tech industry，句子的谓语是 will take advantages by... 。

Exercises

1. Question for discussion

    (1) What are polymeric composite materials?

    (2) What limits the applications of the structural composite materials?

    (3) According to the passage, what should we do to expand the applications in composite industry?

2. Translate the following into Chinese

polymeric composites	steel reinforcement
civil enhineering	cost-efficient automated computer-controlled looms
corrosion resistance	smart materials

   • Composite materials appeared very early in human technology, the "structural" properties of straw were combined with a clay matrix to produce the first construction material and, more recently, steel reinforcement opened the way to the ferroconcrete that is the last century dominant material in civil engineering.

   • The main trends in the structural composite field are related to the reduction of the cost which cannot only be related to the improvement in the manufacturing technology, but needs an integration between design, material, process, tooling, quality assurance, manufacturing.

   • Significant breakthroughs are expected in new composite materials especially in those applications, such as electronic, optic and biomedical, where functionality is the most relevant technical need.

3. Translate the following into English

环境友好的	生物可降解体系
纺织业	无线电通讯
弹性动力学	重要进展
非线性的	耐(抗)疲劳强度

Ceramic Matrix Composites

Introduction

Ceramic matrix composites (CMCs) have been developed to overcome the intrinsic brittleness and lack of reliability of monolithic ceramics, with a view to introduce ceramics in structural parts used in severe environments, such as rocket and jet engines, gas turbines for power plants, heat shields for space vehicles, fusion reactor first wall, aircraft brakes, heat treatment furnaces, etc. It is generally admitted that the use of CMCs in advanced engines will allow an increase of the temperature at which the engine can be operated and eventually the elimination of the cooling fluids, both resulting in an increase of yield. Further, the use of light CMCs in place of heavy superalloys is expected to yield significant weight saving. Although CMCs are promising thermostructural materials, their applications are still limited by the lack of suitable reinforcements, processing difficulties, sound material data bases, lifetime and cost.

Ceramic Matrix Composite Spectrum

A given ceramic matrix can be reinforced with either discontinuous reinforcements, such as particles, whiskers or chopped fibres, or with continuous fibres. In the first case, the enhancement of the mechanical properties, in terms of failure strength and toughness, is relatively limited but it can be significant enough for specific applications, a well known example being the use of ceramics reinforced with short fibres in the field of the cutting tools (SiC_w/Si_3N_4 composites). Among the discontinuous reinforcements, whiskers are by far the most attractive in terms of mechanical properties. Unfortunately, their use raises important health problems both during processing and in service. Conversely, continuous reinforcements, such as fibre yarns, are much more efficient, from a mechanical stand-point, but they are more expensive and more difficult to use in a ceramic matrix in terms of material design and processing.

There is a wide spectrum of CMCs depending on the chemical composition of the matrix and reinforcement. **Non-oxide CMCs** are by far those which have been the most studied. Such a choice could appear surprising since the atmosphere in service is often oxidizing. That choice could be explained as follows. The most performant fibres, in terms of stiffness, failure strength, refractoriness and density are non-oxide fibres, i. e. carbon and silicon carbide fibres. Further, carbon fibres are extensively used in volume production of polymer-matrix composites. As a result, they are much cheaper than all the other fibres (glass fibres excepted). Second, in order to avoid compatibility problems, which are crucial oxide fibres are preferably embedded in non-oxide matrices. Hence, the first non-oxide CMCs have been carbon/carbon (C/C) composites. They have been initially designed and produced for use in

rocket engines and re-entry heat shields, i. e. under extremely severe service conditions but short lifetimes. In a second step, C/SiC and SiC/SiC composites were developed in order to increase the oxidation resistance of the materials and hence their lifetimes in oxidizing atmospheres. Silicon nitride was also used as matrix although it is less stable at high temperatures than silicon carbide.

Oxide-CMCs would obviously be the best choice, from a thermodynamic standpoint, for long term applications in oxidizing atmospheres. Unfortunately, oxide fibres, although they are refractory, tend to undergo grain growth at high temperatures, (which results in a fibre strength degradation) and exhibit a poor creep resistance. Further, they display much higher densities than say carbon fibres (4 g/cm^3 for alumina versus 2 for carbon). Attempts have been made to improve the high temperature properties of oxide fibres with limited success. Despite these disadvantages, Al_2O_3/Al_2O_3 and derived CMCs have been, and are still, extensively studied.

State of the Art in CMC Processing

CMCs can be produced according to either gas phase routes or liquid phase routes, each of them having advantages and drawbacks.

In gas phase routes, i. e. the so-called chemical vapor infiltration (CVI) processes, the reinforcements (usually as a multidirectional preform) is densified by the matrix deposited from a gaseous precursor, e. g. a hydrocarbon for carbon or a mixture of methyltrichlorosilane and hydrogen for silicon carbide. It is now well established that a fibre coating, referred to as the interphase, has to be deposited on the fibre prior to the infiltration of the matrix in order to control the fibre-matrix (FM) bonding and the mechanical behavior of the composite. Pyrocarbon (PyC), boron nitride or $(PyC-SiC)_n$ and $(BN-PyC)_n$ multilayers, with an overall thickness ranging from about 0.1 μm to about 1 μm, displaying a layered crystal structure (PyC, BN) or a layered microstructure (multilayers), are the most common interphase materials in non-oxide CMCs. The main role of the interphase is to deflect the microcracks which form in the matrix under loading and hence to protect the fibre form notch effect (mechanical fuse function).

There are several versions of the CVI-process. The most commonly studied and used version is isothermal/isobaric CVI (or I-CVI). It is a relatively slow process since mass transfer in the preform is mainly by diffusion and it yields some residual porosity and density gradient. Conversely, I-CVI is a clean and flexible process (it can be used to densify simultaneously a large number of preforms, eventually of different shapes). For these reasons, it is the preferred process at the plant level. It is well suited to the fabrication of relatively thin parts.

In order to increase the densification rate and hence to reduce the processing times, temperature or/and pressure gradients can be applied to the preform. In temperature gradient CVI (TG-CVI), or forced CVI (F-CVI), the processing time can be reduced by one order of magnitude with respect to I-CVI. A similar processing time lowering has also been

reported for the film-boiling (or calefaction) process, in which the heated fibre preform is directly immersed in a liquid matrix precursor.

Finally, pressure pulsed-CVI (P-CVI) has been recently presented as a way to engineer, at the micrometre (or even nanometre) scale, either the interphase or the matrix. Based on this technique, multilayered self-healing inter-phases and matrices (combining crack arrester layers and glass former layers) have been designed and produced, through a proper selection of chemical composition of the layers.

In the liquid phase routes, the fibres first coated with an interphase (e. g. by I -CVI) are embedded in a liquid pre-cursor of the matrix. In the reactive melt infiltration (RMI) processes, a fibre preform is impregnated by capillary forces with a liquid which reacts either with a solid phase used to consolidate the fibre preform (SiC-Si matrices formed through liquid silicon infiltration of a carbon-consolidated preform) or with the atmosphere (Al_2O_3-Al matrices formed through liquid aluminium infiltration and chemical reaction with an oxidizing atmosphere). Among other advantages, the RMI-processes are fast and can be applied to thick preforms. They also yield materials of low residual porosities and high thermal conductivities.

In the polymer impregnation and pyrolysis (PIP) processes, the fibres are embedded in a polymeric precursor of the matrix, such as a thermosetting resin or a pitch for carbon or a polycarbosilane for SiC, and the green composite is then pyrolyzed. Such processes are relatively flexible since the composition of the precursor can be tailored. Conversely, a shrinking of the matrix occurs during the pyrolysis step owing to the evolution of gaseous species. As a result, several PIP-sequences have to be applied in order to achieve a low enough residual porosity, which is time and labour consuming. Shrinkage can be limited by loading the liquid precursor with suitable fine powder, i. e. by using a slurry. Finally, the residual porosity can also significantly be reduced through a hot pressing step, an alternative that supposes that the matrix displays enough plasticity not to damage the fibres. This liquid impregnation/hot pressing technique is well suited to the fabrication of glass-ceramic matrix composites.

Expected Breakthroughs and Future Visions

The future of CMCs is directly depending on progress that would be achieved in the availability of higher performance constituents (fibres, interphases and tailored matrices) as well as in processing cost reduction.

As far as the reinforcements are concerned, two main breakthroughs are expected : (i) the availability of a low cost non-oxide fibre that could be used up to about 1500℃ and (ii) the development of a refractory oxide fibre resistant to grain growth and creep. Oxygen-free quasi-stoichiometric SiC fibres display much better high temperature properties than their Si-C-O counterparts fabricated from poly-carbosilane according to the Yajima's route. However, they are too costly (with respect to carbon fibres and CMC volume production) and their failure strain is too low. Amorphous Si-B-C-N fibres, presented as creep resistant at high

temperature, are still at a development stage. Although alumina-based binary oxide fibres, e. g. mullite/alumina or alumina/YAG fibres, represent a significant progress in terms of creep resistance with respect to pure α-alumina fibres, further improvement is still necessary to match the high temperature properties of non-oxide fibres. Finally, nanotubes, with their outstanding mechanical properties, may raise problems similar to those previously encountered with whiskers. The spectrum of suitable interphase materials that could be used in a realistic manner in CMCs remains extremely narrow. In non-oxide CMCs, there is presently no alternative to the carbon-based interphases. Boron nitride is obviously the only potential candidate. However, its sensitivity to moisture when poorly crystallized and its low bonding to SiC-based fibres are subjects of concern. Solving these two problems will be an interesting breakthrough. The search for new interphase materials, displaying a better oxidation resistance than carbon and boron nitride and which could be easily deposited in situ in multidirectional fibre preforms, should be strongly encouraged.

The recent discovery of the self-healing multilayered matrices has been an important breakthrough since it permits the use of non-oxide CMCs in oxidizing atmospheres. The concept should obviously be further developed in terms of material selection.

Finally, the processing cost of CMCs should be reduced (although the main contribution to the total cost of a given part is presently, e. g. in a SiC/SiC composite, that of the reinforcement, as previously mentioned). Gas phase route processes with a significant reduction of the overall densification time, liquid phase route processes with a limited number of PIP-sequences (through the use of appropriate precursors), both being compatible with CMC volume production, would obviously be significant breakthroughs.

Future Directions of Research

The interest of CMCs as thermostructural ceramics is now well established but their volume production at the plant level is still a challenge, which requires an important effort of research at the level of the European Union. Possible directions of research are.

(1) Development of low cost ceramic fibres (both non-oxide and oxide fibers) that could be used up to about 1500°C (the EU has presently no long term action that could be compared to what is done in Japan and U. S.).

(2) Development of one or two CMC(s), e. g. a SiC-based and an alumina-based composites, including that of an interphase material and a low cost processing technique, guided by one or two potential application (s).

(3) Development of sound data bases on CMCs and their constituents (including that of suitable standard tests and modelling).

(4) Development of the durability of CMCs, including that of suitable internal and external oxidation protection (for non-oxide CMCs), lifetime prediction, residual mechanical and thermal properties characterization and modelling.

(Selected from *Materials Synthesis and Processing*, by R. Naslain, 2002)

New Words and Expressions

intrinsic [in'trinsik] a. （性质）固有的，内在的，本质的

brittleness ['britlnis] n. 脆性

monolithic [ˌmɔnəu'liθik] n. 单片电路，单块集成电路

turbine ['təːbin, 'təːbain] n. 涡轮

fusion ['fjuːʒən] n. 熔化，熔解，熔合，熔接

fluid ['flu(ː)id] n. 流动性，流度；a. 流动的

whisker ['hwiskə] n. 晶须，针状单晶

failure strength 破坏强度

cutting ['kʌtiŋ] n. 切断，开凿，切下

cutting tool 刀具，切削工具

yarn [jɑːn] n. 纱，纱线，纤维纱

stiffness ['stifnis] n. 坚硬，硬度

refractoriness [ri'fræktərinis] n. 耐火度

preferably ['prefərəbli] a. 更适宜的，更可取的

embed [im'bed] vt. 使插入，使嵌入，深留，嵌入；包埋

creep resistance 抗蠕变性

notch [nɔtʃ] n. 槽口，凹口，切口

isobaric [ˌaisəu'bærik] a. 等压的，等压面的

isothermal [ˌaisəu'θəːməl] a. 等温的，等温线的；n. 等温线

residual [ri'zidjuə] a. 剩余的，残留的

porosity [pɔː'rɔsiti] n. 多孔性，有孔性，孔隙度

fabrication [ˌfæbri'keiʃən] n. 制作，构成，制造

preform ['priː'fɔːm] vt. 预先形成；n. 粗加工的成品，初制品，预制型品

capillary [kæ'piləri] n. 毛细管；a. 毛状的，毛细作用的

thermosetting resin 热固性树脂

pitch [pitʃ] n. 沥青，树脂，松脂

slurry ['sləːri] n. 泥浆，浆

amorphous [ə'mɔːfəs] a. 无定形的，无组织的，非晶形的

binary ['bainəri] a. 二进位的，二元的

crystallize ['kristəlaiz] v. 结晶

Notes

① Further, carbon fibres are extensively used in volume production of polymer-matrix composites. further，主要指在"程度"上"更进一步地"、"更远地"、"此外"、"而且"，具有递进的含义，注意 further 与 farther 的区别，farther 是表示"更远地"、"再往前地"；volume production，大量生产。

② Oxide-CMCs would obviously be the best choice, from a thermodynamic standpoint, for long term applications in oxidizing atmospheres. from a thermodynamic standpoint，从热

力学的观点来看。参考译文：很明显，要使材料在具有氧化作用的空气中长期使用，从热力学的观点来看，氧化物-陶瓷基复合材料可能是最好的选择。

③ It is a relatively slow process since mass transfer in the preform is mainly by diffusion and it yields some residual porosity and density gradient. 句中的两个 it 均代表上句中的 CVI process；mass transfer，物质转换（由一种物质转换成另一种物质）；residual porosity，剩余孔隙度；density gradient，密度梯度。参考译文：该过程相当慢，因为在加工过程中物质的转换主要是通过扩散作用来实现的，而且该过程会产生剩余空隙度和密度梯度。

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Unit 18　Composites Turn Green （Part Ⅰ）

Ecological concern has recently resulted in a renewed interest in natural materials, and issues such as recyclability and environmental safety have become increasingly important for the introduction of new materials and products. Environmental legislation as well as consumer pressure are all increasing the pressure on manufacturers of materials and end-products to consider the environmental impact of their products at all stages of their life cycle, including ultimate disposal, viz. a from 'cradle-to-grave' approach. As such 'eco-design' has become a philosophy that is applied to more and more materials and products. These environmental issues in combination with their low cost have recently generated considerable interest in wood fibres and plant fibres like flax, hemp and kenaf as fillers for polymer composites. Besides the use of renewable resources for the development of 'green composites', also completely recyclable all-polymer composites are being developed for the automotive and construction industry. This and the following unit aim to provide a short review on developments in the area of eco-composites and their applications.

Wood Fibre Plastics

While the high-performance composite industry is still hoping to cash in on promising opportunities that are out on the horizon but never seem to be within reach, the natural fibre composite business continues to show strong growth. In the year 2000 it saw a staggering growth of some 50%, which is fairly close to predictions made in Kline's study 'The Outlook for Natural-Fiber Composites', which predicts an annual growth rate for natural fibre composites of some 60% over the years 2000~2005. The major part of this growth comes however from wood fibre composites for building applications such as outdoor decking, fences, window and door frames (Fig. 5.1), whereas only a minor part comes from natural fibre composites based on ligno-cellulose fibres such as flax and hemp. Decking products dominate the market and at this moment some 8% of all decking materials, worth 300 million dollars, are made from wood fibre composites and the figure is still increasing rapidly. The World production of wood fibre plastic decking has doubled annually since 1996 and despite higher initial cost prices, it has been very successful because of its low life-cycle and maintenance costs and environmental concern with pressure treated lumber.

The majority of these wood fibre plastics are currently produced by North American companies like Trex, US Plastic Lumber and AERT. Their success has triggered a number of companies outside the US to start developments in this area. One of them, EIN Engineering in Japan, has developed composites from waste wood and recycled plastics and demonstrated the potential for use of these composites in out-door applications. EIN Engineering is investigating in co-operation with the Japan Public Highway Corporation the potential of

the materials for sound-absorbing panels and crash barriers. Also the European Industry is showing increasing interest in wood fibre composites. Tech-Wood International of the Neth erlands are developing construction elements for the building industry such as window and door frames, siding, decking and other sheet materials. Tech-Wood® contains 70% pine-wood fibres and 30% compatibilized polypropylene (PP). Their products will be used to build 50 000 hurricane-proof houses over the next five years in the Caribbean. The houses consist of six different wood plastic profiles including windows and complete roof profiles. Manufacturing of the profiles will be carried out by the Puerto Rican firm Industrias Vassallo under license from Tech-Wood, which will supply profiles for the first 1000 buildings while the Vassallo plant is being installed. Another example of a European innovation in this area is Fasal®, being a development from the Inter-University Research Institute for Agricultural Biotechnology (IFA), Austria. Fasal® contains around 60% of wood fibres and is aimed to replace wood in interior or short life products while having the advantage of polymer shaping methods.
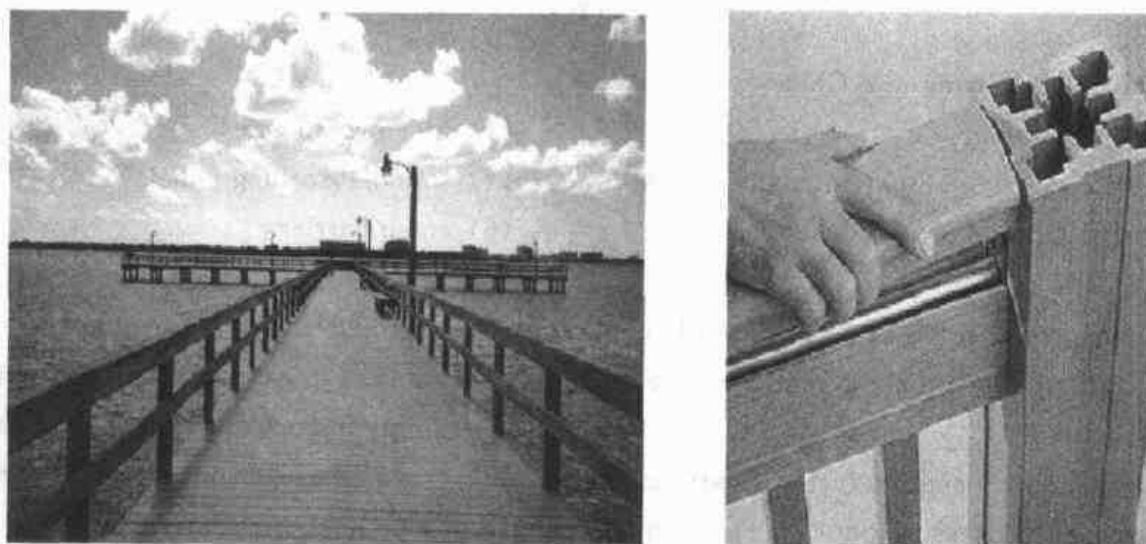
Fig. 5. 1 Composite lumber made from recovered wood and recycled plastic combines
a wood tone appearance with the processability and durability of plastics

(Selected from *Composites turn green*, by Queen Mary, 2002)

New Words and Expressions

flax ['flæks] *n.* 亚麻
hemp [hemp] *n.* 麻，大麻，纤维
kenaf [kə'næf] *n.* 洋麻，洋麻（或槿麻）纤维
panel ['pænl] *n.* 嵌板，仪表板
polypropylene [pɔli'prəupiliːn] *n.* 聚丙烯
hurricane ['hʌrikən] *n.* 飓风，暴风，暴风雨
recyclability 再循环能力
ligno-cellulose 木质纤维素
compatibilized 兼容的

Notes

① Environmental legislation as well as consumer pressure are all increasing the pressure on manufacturers of materials and end-products to consider the environmental impact of their products at all stages of their life cycle，including ultimate disposal，viz. a from 'cradle-to-grave' approach. viz. 是拉丁语"即，就是"的意思，读作 namely。cradle-to-grave，从摇篮到墓地，这里是指产品的生命周期。

② While the high-performance composite industry is still hoping to cash in on promising opportunities that are out on the horizon but never seem to be within reach，the natural fibre composite business continues to show strong growth. 这里 while 引导的是一个弱语气的让步状语从句。cash in，兑现现金。参考译文：尽管高性能复合材料工业仍然希望从一些有前景的机会中赚到钱（而这些机会似乎是可望而不可及的），而天然纤维复合材料业务则继续呈现强势增长。

Exercises

1. Put the following into Chinese:
   (1) eco-design   (2) green composites
   (3) recyclable all-polymer composites   (4) sound-absorbing panels
   (5) hurricane-proof houses   (6) crash barriers
   (7) life cycle

2. Compete the notes blow with words taken from the text above.

   _____ concern has recently resulted in a renewed interest in natural materials，and issues such as _____ and _____ have become increasingly important for the introduction of new materials and products. Environmental _____ as well as consumer pressure are all increasing the pressure on _____ of materials and end-products to consider the _____ impact of their products at all stages of their _____，including ultimate disposal，viz. a from 'cradle-to-grave' approach.

Reading Material

Natural Fibre Composites

Where wood flour or waste wood is mainly used as a cost-cutting alternative to mineral fillers in commodity plastics like polyethylene (PE) and PP resin or for the upgrading of post-consumer recycled plastics, plant fibres like flax, hemp and kenaf are currently being evaluated as environmentally friendly and low-cost alternatives for glass fibres in engineering composites.

Plant fibres have a number of advantages over glass fibres. They are：

- renewable
- abundant
- cheap
- lightweight
- biodegradable
- non-abrasive to processing equipment
- CO_2 neutral (when burned)
- can be incinerated with energy recovery
- show less concern with safety and health (no skin irritations)
- exhibit good mechanical properties
- as well as good acoustic and thermal insulating properties.

The combination of interesting mechanical and physical properties (see Tab. 5.1) together with their environmentally friendly character has triggered various activities in the area of 'green composites', and many European universities and institutes have started activities in this area through various 'eco-driven' R&D programmes. Especially the European automotive industry is trying to make every component recyclable and is looking seriously into the possibility of using natural fibres reinforced thermoplastics as a way to serve the environment and at the same time save weight and cost. In 2005 the EU Directive on end-of-life vehicles (ELVs) states that vehicles need to be homologated to 95% recovery of which 85% by reuse or recycling and 10% by energy recovery or thermal recycling. In a large research programme Daimler-Chrysler has evaluated flax and hemp fibres as potential candidates to replace glass fibres in engineering composites and has developed a number of automotive products based on NMT, being a natural fibre counterpart of glass-mat-reinforced thermoplastics (GMT).

Tab. 5.1 Mechanical properties of glass and flax fibres

	Density in g/m^3	Tensile strength in GPa	Modulus in GPa	Specific strength in $GPa/(g \cdot m^{-3})$	Specific modulus in $GPa/(g \cdot m^{-3})$
Glass	2.5	2.4	70	0.9	28
Flax	1.5	0.6~1.5	50	0.4~1.0	30

Natural fibres have a strong potential in the automotive industry as flax and hemp is 40% lighter than glass fibres. Up to now most of the use of natural fibres in automotive applications has been limited to interior components. Recently, researcher at the Daimler-Chrysler research centre in Ulm have developed however a number of natural fibre reinforced exterior parts. Products include not only prototype parts such as underbody panels for the A-Class, but also a flax-fibre-reinforced polyester engine and transmission cover with improved sound insulation for the new Travego travel coach. This part, which is manufactured by resin transfer moulding (RTM), is an important innovation since it is the first exterior component made from natural fibre composites on a commercial vehicle and must be able to withstand extreme environmental conditions such as wetness and chipping.

Also other car manufacturers are actively looking into natural fibre composites and cur-

rently some 25 000 tons of natural fibres are used in the European automotive industry. Audi for example have developed interior door trim panels made from polyurethane (PUR) reinforced with mixed flax/sisal non-woven mats for their new A2. Ford's materials engineering department in Cologne has done considerable development work in the area of injection mouldable flax/PP grades for radiator grilles, front ends and engine shields for the new Ford Focus. Parts can be up to 30% lighter than current glass fibre reinforced parts. Also Fiat is active in the area and has developed gaskets, seat parts, dashboards and handles produced by gas-assisted injection moulding.

Despite the ecological advantages of natural fibres over glass fibres, natural fibres also possess a number of disadvantages. Natural fibres can easily compete with glass fibres in terms of stiffness. However, the tensile strength, compressive strength and especially impact strength of natural fibre composites are relatively low compared to glass fibre composites. Up to now most research has focused on the interfacial bond strength with the polymer matrix to improve the properties of natural fibre composites. These interface modifications often follow schemes similar to the ones used in the past for glass fibre. However, unlike isotropic glass fibres, natural fibres like most biological materials exhibit a highly anisotropic hierarchical composite-like structure (Fig. 5.2). Tailoring of interfaces within this hierarchical structure may turn out to be more important for bridging the (toughness) gap with glass fibre systems than tailoring of the interface with the polymer matrix.
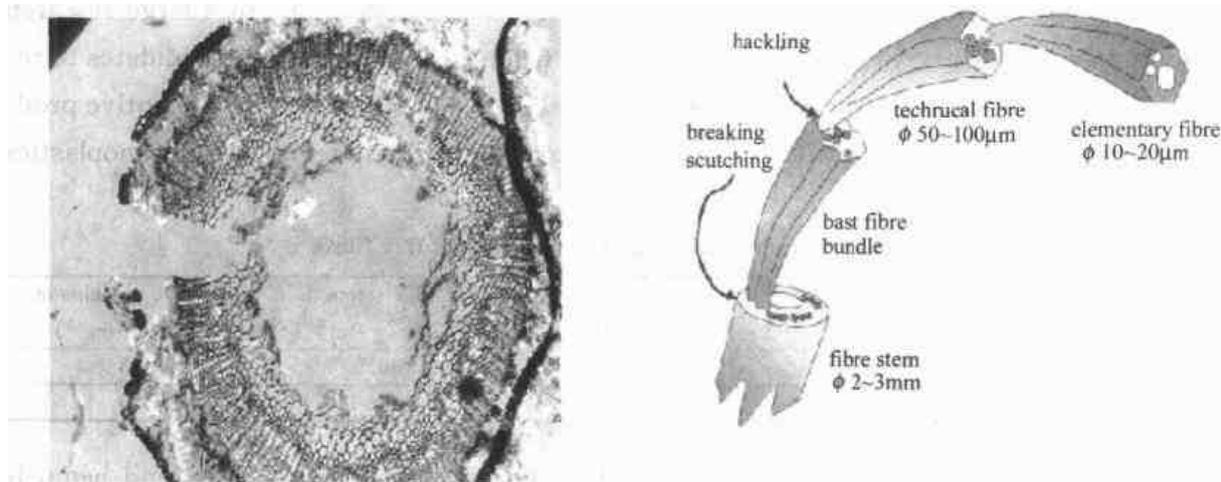
Fig. 5. 2 Micrograph of the cross-section of a flax stem, clearly showing the bast fibres bundles.
On the right a schematic representation the hierarchical microstructure of flax plant
(after ATO-DLO, Wageningen, Netherlands)

Natural fibres like flax consist of cellulose microfibrils with diameters in the order of a couple of nanometers, which form together the actual fibre cells of 10~20 microns in diameter. These cells are bonded together by an organic matrix, forming fibre bundles with a diameter of around 50 ~ 100 microns. Depending on the effectiveness of the fibre opening process one can go further down in microstructure, hence removing weak spots in the composite-like structure and obtaining reinforcing elements of higher strength. Unfortunately, despite various attempts to separate the fibre cells from the fibre bundles, most of today's

fibres used in composite application are fibre bundles. These fibre bundles have a relatively low strength of around 600~700 MPa. The actual fibre cell is however much stronger (up to 1500 MPa) and could on a weight basis compete with glass fibres. Even higher strengths are foreseen when microfibrils could be used as reinforcing elements in nanocomposites. To fully exploit the intrinsic potential of natural fibres, future developments in materials optimisation should therefore focus on new or improved fibre opening processes, which at the same time can raise it from a level of craftsmanship to an industrial scale.

An interesting development in the area of cellulose based nanocomposites was reported by researchers from Daicel Chemical Industries (Japan) and Virginia Tech. By reacting wood pulp fibres in a solvent medium that does not fully penetrate the fibres and subsequent hot-pressing the partially modified wood pulp at elevated temperature, a semi-transparent polymer sheet is formed. By hot-pressing these partially modified pulp fibres the cellulose ester surfaces of the modified microfibrils fuse to form a continuous material, which consists of a mixture of cellulose and cellulose ester in which each component has a dimension of several nanometers.

Another area of concern relates to the poor moisture resistance (rotting) and dimensional stability (swelling) of natural fibres, which can lead to debonding and microcracking in the composite. The moisture resistance of natural fibres can, however, be improved through fibre treatments like acetylation and a novel upgrading process recently developed by Ceres Fibres in the Netherlands. The availability of fibre processes for improved moisture resistance like the Duralin® developed by Ceres Fibres may remove one of the restrictions for the successful application of plant fibres in some high-quality engineering applications. On the other hand, in the case of a well-wetted fibre in combination with a hydrophobic polymer like PP, the matrix has the perfect ability to protect the hydrophilic natural fibre because of its strong hydrophobic and apolar character. Hence, moisture uptake will be relatively low and may turn out not to be such a problem.

A potentially more serious threat for natural fibre composites is related to processing. Natural fibres tend to degrade near the processing temperature of most thermoplastics. Even in the case of PP processing can be tricky, not to mention the problems in case of other engineering polymers. Natural fibres tend to give off an unpleasant odour when processed at high temperatures, which can give problems in processing facilities or in some case even during use of the final part. Thermal degradation during processing not only limits the number of polymers that can serve as a matrix system but gives especially concern with respect to reprocessing. Although one may get away with the narrow processing window for natural fibre composites in a single step process, it may give problems in the case of reprocessing and mechanical recycling.

At this moment natural fibres are pushed because of their 'green' image, mainly because they are renewable and can be incinerated at the end of the materials lifetime. However, the recycling issue may be key in answering the question: How green are natural fibres actually? In most cases, from an eco-performance point-of-view, mechanical recycling is fa-

voured over thermal recycling and landfill. Hence, problems related to thermal degradation during recycling and reprocessing may significantly lower the eco-performance of natural fibre composites. This is especially the case with a well recyclable polymer like PP, where the addition of natural fibres will strongly affect the recyclability and hence the eco-performance of the resulting composite material. On the other hand, the upgrading of recycled plastics——which are close to the end of their lifetime——with natural fibres or waste wood is clearly an environmentally sound option because of the clear advantages with respect to end-of-lifetime disposal by incineration. Therefore, whenever mechanical recycling should be favoured it remains to be seen if natural fibres in combination with virgin plastics are the best alternative.

In fact, to date the few life cycle assessment (LCA) studies that have been performed on natural fibre composites show that the advantage of natural fibres over glass fibres, at least for automotive applications, are mainly related to their low weight rather than their 'natural' origin. However at this moment the 'green' image of natural fibres comes mainly from the fact that they are 'natural' rather than from clear benefits shown in LCA studies. LCA is therefore going to be essential in the eco-performance evaluation of natural fibre composite materials and products and identifying the truly 'green' character of these materials. Although natural fibres may not have clear advantages in case of mechanical recycling they do have clear advantages over glass fibres in case of thermal recycling.

(Selected from *Composites turn green*, by Queen Mary, 2002)

New Words and Expressions

renewable [ri'njuəbl] *a.* 可更新的，可再生的

biodegradable [ˌbaiəudi'greidəbl] *a.* 生物所能分解的，可生物降解的

incinerate [in'sinəreit] *v.* 烧弃，焚化

acoustic [ə'ku:stik] *a.* 听觉的，声学的

homologate [hə'mɔləgeit] *v.* 承认，同意

reinforced [ri:in'fɔ:sd] *a.* 强化的，增强的

prototype ['prəutətaip] *n.* 原型

wetness ['wetnis] *n.* 湿润

chipping ['tʃipiŋ] *n.* 清理，修整

polyurethane [pɔli'jurəθein] *n.* 聚氨酯

sisal ['saisl] *n.* 剑麻，西沙尔麻

isotropic [aisəu'trɔpik] *n.* 各向同性的

anisotropic [ænˌaisəu'trɔpik] *n.* 各向异性的

abrasive [ə'breisiv] *n.* 磨料，磨蚀剂，研磨材料

hierarchical [ˌhaiə'ra:kikl] *n.* 分级的，分层的

intrinsic [in'trinsik] *a.* 本质的，原有的

cellulose ['seljuləus] *n.* 纤维素

microcrack ['maikrəukræk] *n.* 微裂纹，微区破裂；*v.* （使）产生微裂纹

acetylation ［əˌsetiˈleiʃən］ 乙酰化；乙酰化作用

apolar ［eiˈpoulə］ *a.* 非极性的；无极的

thermoplastic ［θəːmouˈplæstik］ *n.* 热塑性塑料，热塑性材料

matrix ［ˈmeitriks］ *n.* 基体，基质

landfill ［ˈlændfil］ *n.* （掩埋式）垃圾处理场

microfibrils ［ˌmaikrəuˈfaibril］ *n.* 微纤维，微纤丝

debond *v.* 解离，解黏合

specific strength 比强度，强度系数

specific modulus 比模量

glass mat 玻璃纤维板，玻璃垫

resin transfer moulding （RTM） 树脂转移模塑

interfacial bond strength 界面结合力

Thermal degradation 热降解

life cycle assessment （LCA） 生命周期评价

Unit 19　Composites Turn Green（Part Ⅱ）

Single Polymer Composites

As an alternative to natural fibre composites the development of single polymer composites based on high-strength polymer fibres in a similar polymer matrix might be a more promising approach towards future eco-composites. Because of recyclability, nowadays there is a major trend to focus on simple, monocomponent systems rather than on complex polymer blends and alloys. Polypropylene is apparently the major polymeric construction material of the future in view of its impressive growth figures of the past years. However, PP as such has to be reinforced to meet the high demands on stiffness and strength in engineering applications. Unfortunately, in view of recyclability, the addition of any filler, including natural fibres, will cause environmental problems as it is in conflict with the basic idea behind mono-material products. Following such 'eco-design' concepts, an obvious reinforcing element for PP would therefore be the use of high strength PP fibres.

Research teams at Leeds University and Eindhoven University of Technology and Queen Mary, University of London are independently working on preparation routes for these so-called 'all-PP' composites, being single polymer composites based on a PP matrix reinforced with oriented PP fibres. Such self-reinforced composites have specific economic and ecological advantages since, upon recycling, a PP resin is obtained which can be re-used to make again all-PP composites, or alternatively, be used for other PP-based applications. Essential for this concept is that the PP fibre and matrix is optimised in terms of structure. processability and performance. An important challenge of the research project is to find viable routes to 'impregnate' PP fibres with a PP matrix, both having the same chemical structure and hence melting temperature.

An interesting processing method for single polymer composites was developed at the University of Leeds (UK). They introduced a so-called hot-compaction process for manufacturing of composites based on polymer fibres. Here, the skin of the fibres is partially melted in a hot-press and compacted to a sheet. This leads to an architecture of remained fibre cores surrounded by a matrix of molten and recrystallised polymer skin parts of the original fibre. A clear advantage of this processing method is that there is no actual impregnation step. Instead the fibres are 'welded' together. This processing route, which yields composites with very high fibre volume fractions——up to 90%——has been applied to polypropylene fibres and is now being commercialised by BP under the trade name Curv®. It exhibits interesting properties such as lightweight and high impact resistance. Current applications being considered range from interior trim to underbody shields in the automotive industry, sporting goods such as ice hockey gear and loudspeaker cones.

A disadvantage of the Curv® process is however the rather narrow temperature window

and the relatively unsatisfactory mechanical properties. Recently a research program seeking for routes for the preparation of high-modulus all-PP composites with an enlarged processing window called 'PURE' was initiated by Eindhoven University of Technology. Together with Queen Mary, University of London and four Dutch industrial partners (Lankhorst Indutech, BW Industrial, Polynorm Plastics and DSM) they are developing all-PP composites, which on a weight basis can out-perform glass-fibre-reinforced PP. The technology developed is based on co-extrusion technology for high-performance PP tapes. The co-extruded tapes consist of a highly oriented——high strength & high modulus——core and a copolymer skin to weld the tapes together in a subsequent compaction process using hot-press or continuous belt-press technology. Because of the ductile character of the oriented PP fibres the composites developed so far have outstanding properties in terms of stiffness, strength and toughness. Advantages of 'PURE' over Curv® technology are mainly in manufacturing and the result of a larger processing window. A wide variety of manufacturing technologies are possible, including thermoforming techniques like matched-die forming, rubber and vacuum forming of pre-consolidated sheets and filament winding. Pre-consolidated sheets in combination with PP foam or PP honeycomb can also be used as skins to form single polymer sandwich panels (Fig. 5. 3). If necessary they could even come in green...
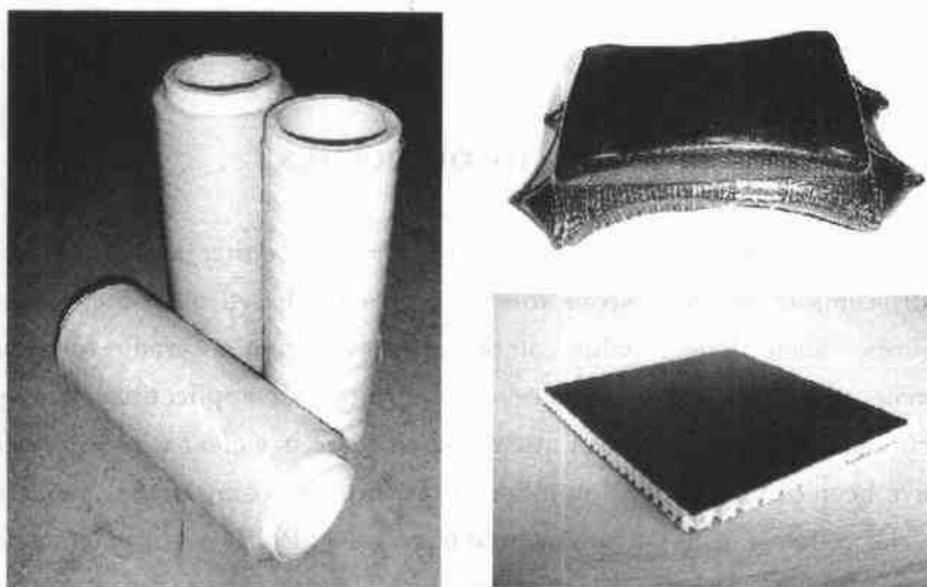
Fig. 5. 3 The PURE project involves the development of high strength co-extruded PP tape which can be woven into fabrics and hot-pressed into sheets. These sheets can be shaped into products using thermoforming technology. Combined with PP honeycomb core they can be used to make all-PP sandwich panels

(Selected from *Composites turn green*, by Queen Mary, 2002)

New Words and Expressions

oriented　['ɔːrientid]　*a.* 取向的，定向拉伸的
thermoforme　['θəːməuˌfɔːm]　热压成形
pultrude　拉挤

Fibreboard　*n.*　纤维板
hot-compaction process　热压塑工艺
hot-press　热压
processing window　加工范围

Exercises

Complete the notes below with words taken from the text above

(1) Because of recyclability, nowadays there is a major trend to focus on simple, _____ systems rather than on complex polymer _____ and _____.

(2) In view of recyclability, the addition of any _____, including natural fibres, will cause environmental problems as it is in conflict with the basic idea behind _____ products.

(3) These so-called 'all-PP' composites, being single polymer composites, are based on a PP _____ reinforced with oriented PP _____.

(4) A disadvantage of the 'all-PP' composites is the rather narrow _____ and the relatively unsatisfactory _____ properties.

Reading Material

True Biocomposites

Since car manufacturers are aiming to make every part either recyclable or biodegradable, there still seems to be some scope for biocomposites based on biodegradable polymers and natural fibres. Such biodegradable composites may, from a 'cradle-to-grave' point-of-view, have some advantages over traditional composites for applications where biodegradability is functional, recycling problem-atic or when there is a clear consumer demand. Biocomposites have been developed by a number of laboratories using a wide range of biodegradable plastics like cellulose esters, polyhydroxybutyrates (PHB), polyesteramides (BAK), poly (lactic acid) (PLA) and starch derivatives and blends. The German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e. V., DLR) in Braunschweig has evaluated over the years many of these bioplastics for the manufacturing of biodegradable composites. DLR started as early as 1989 with an extensive research programme on composites from renewable resources. Prototype products have been developed in co-operation with industrial partners and include office chairs, panelling elements, pultruded support beams and safety helmets. However, because of economic reasons, until now only few of these prototype products have been commercialised.

An interesting development in the area of biocomposites comes from the ACRES (affordable composites from renewable resources) group at the University of Delaware. They developed in co-operation with John Deere Company a fibre-reinforced plastic hay baler door

based on soybean oil resin using RTM techniques. The idea of using soybean oil resin is far from new, since Henry Ford made already in 1938 his first fibre reinforced car body panel using a plastic matrix derived from soybean products. The Delaware material involves chemically modifying soybean oil, a commodity that's 50% cheaper than polyester and vinyl ester resins. The chemistry of the product can be 'tailored' to provide the properties needed for processing and performance. Although the resins are generally not biodegradable, special formulations could easily be made to biodegrade under certain conditions. Currently the use of natural fibres for the development of 'true' biocomposites is evaluated.

Using similar technology Ashland Specialty Chemicals (Ohio, US), a division of Ashland Inc. , have recently introduced a new resin system, called ENVIREZ® 5000 soybean and corn resin. In contrast to the Delaware resin, the ENVIREZ® 5000 resin contains only 25% renewable-source content for the making of polyester resin. The new resin system is to be used in sheet-molding-compound (SMC) for the trans-portation, agricultural and construction market. For the transportation market, it can be formulated into Class A body-panel applications. Ashland has granted John Deere exclusive rights to use ENVIREZ® 5000 for their products until mid-March 2002. Beginning with the 2002 model year, all John Deere combines will have exterior body panels made from a soy-based plastic composite called Harvest Form®.

Other examples of biocomposites can be found in the panel board industry, which shows a growing interest in non-wood resources like cheap natural fibre residues as well as the use of new formaldehyde free adhesives and binders such as natural resins. Phenix Biocomposites in the US, for example, is using a soy-based resin in their Environ® biocomposite, whereas the Biocomposites Centre at the University of Wales have developed a novel resin based on cashew nutshell resin as a formaldehyde free binder for use in fibreboard panels.

<div align="right">(Selected from Composites turn green, by Queen Mary, 2002)</div>

New Words and Expressions

biocomposite　　*n.*　生物复合材料

derivative　[di'rivətiv]　*a.* 衍生的; *n.* 衍生物

formaldehyde　[fɔ:'mældəhaid]　*n.* 甲醛

adhesives　[əd'hi:siv]　*n.* 黏合剂; 黏接材料

binder　['baində]　*n.* 黏结剂, 黏合剂

cashew　['kæʃu:]　*n.* 腰果树, 腰果

nutshell　['nʌtʃel]　*n.* 坚果壳

polyhydroxybutyrate (PHB)　聚羟基丁酸酯

polyesteramide (BAK)　聚酰胺酯

poly (lactic acid) (PLA)　聚乳酸

cellulose ester　纤维素酯

soybean oil resin　大豆油树脂

PART VI NANOMATERIALS

Unit 20 Nanostructured Materials —— Categories of Nanostructured Materials

One of the very basic results of the physics and chemistry of solids is the insight that most properties of solids depend on the microstructure, i. e. the chemical composition, the arrangement of the atoms (the atomic structure) and the size of a solid in one, two or three dimensions. In other words, if one changes one or several of these parameters, the properties of a solid vary. The most well known example of the correlation between the atomic structure and the properties of a bulk material is probably the spectacular variation in the hardness of carbon when it transforms from diamond to graphite. Comparable variations have been noted if the atomic structure of a solid deviates far from equilibrium or if its size is reduced to a few interatomic spacings in one, two or three dimensions. An example of the latter case is the change in color of CdS crystals if their size is reduced to a few nanometers.

The synthesis of materials and/or devices with new properties by means of the controlled manipulation of their microstructure on the atomic level has become an emerging interdisciplinary field based on solid state physics, chemistry, biology and materials science. The materials and/or devices involved may be divided into the following three categories.

The first category comprises materials and/or devices with reduced dimensions and/or dimensionality in the form of (isolated, substrate-supported or embedded) nanometer-sized particles, thin wires or thin films. CVD, PVD, inert gas condensation, various aerosol techniques, precipitation from the vapor, from supersaturated liquids or solids (both crystalline and amorphous) appear to be the techniques most frequently used to generate this type of microstructure. Well-known examples of technological applications of materials the properties of which depend on this type of microstructure are catalysts and semiconductor devices utilizing single or multilayer quantum well structures.

The second category comprises materials and/or devices in which the nanometer-sized microstructure is limited to a thin (nanometer-sized) surface region of a bulk material. PVD, CVD, ion implantation and laser beam treatments are the most widely applied procedures to modify the chemical composition and/or atomic structure of solid surfaces on a nanometer scale. Surfaces with enhanced corrosion resistance, hardness, wear resistance or protective coatings (e. g. by diamond) are examples taken from today's technology in which the properties of a thin surface layer are improved by means of creating a nanometer-sized microstructure in a thin surface region. An important subgroup of this category is materials

with structured surface region on a nanometer scale by "Writing" a nanometer-sized structural pattern on the free surface. For example, patterns in the form of an array of nanometer-sized islands connected by thin (nanometer scale) wires. Patterns of this type may be synthesized by lithography, by means of local probes (e. g. the tip of a tunneling microscope, near-field methods, focused electron or ion beams) and/or surface precipitation processes. Processes and devices of this sort are expected to play a key role in the production of the next generation of electronic devices such as highly integrated circuits, single electron transistors, quantum computers, etc.

We shall focus attention on the third category of bulk solids with a nanometer-scale microstructure. In fact, we shall focus on bulk solids in which the chemical composition, the atomic arrangement and/or the size of the building blocks (e. g. crystallites or atomic/molecular groups) forming the solid vary on a length scale of a few nanometers throughout the bulk.

Two classes of such solids may be distinguished. In the first class, the atomic structure and/or the chemical composition vary in space continuously throughout the solid on an atomic scale. Glasses, gels, supersaturated solid solutions or implanted materials are examples of this type. In many cases these types of solids are produced by quenching a high-temperature (equilibrium) structure, e. g. a melt or a solid solution to low temperatures at which the structure is far away from equilibrium.

In the last two decades a second class of materials with a nanometer-sized microstructure has been synthesized and studied. These materials are assembled of nanometer-sized building blocks mostly crystallites. These building blocks may differ in their atomic structure, their crystallographic orientation and/or their chemical composition. If the building blocks are crystallites, incoherent or coherent interfaces may be formed between them, depending on the atomic structure, the crystallographic orientation and/or the chemical composition of adjacent crystallites. In other words, materials assembled of nanometer-sized building blocks are microstructurally heterogeneous consisting of the building blocks (e. g. crystallites) and the regions between adjacent building blocks (e. g. grain boundaries). It is this inherently heterogeneous structure on a nanometer-scale that is crucial for many of their properties and distinguishes them from glasses, gels, etc. that are microstructurally homogeneous. Materials with a nanometer-sized microstructure are called "Nanostructured Materials" (NsM) or synonymously, nanophase materials, nanocrystalline materials or supramolecular solids. In this paper we shall focus on these "Nanostructured Materials" and use this term exclusively.

The synthesis, characterization and processing of such NsM are part of an emerging and rapidly growing field referred to as nanotechnology. R&D in this field emphasizes scientific discoveries in generation of materials with controlled microstructural characteristics, research on their processing into bulk materials with engineered properties and technological functions, and introduction of new device concepts and manufacturing methods.

(Selected from *Acta Materials*, by H. Gleiter, 2000)

New Words and Expressions

insight ['insait] *n.* 洞察力，见识

spectacular [spek'tækjulə] *a.* 引人入胜的，壮观的

bulk [bʌlk] *n.* 大小，体积，大批，大多数，散装

graphite ['græfait] *n.* 石墨

embed [im'bed] *vt.* 使插入，使嵌入，深留，嵌入

aerosol ['eərəsɔl] *n.* 浮质（气体中的悬浮微粒，如烟，雾等）；气溶胶，气雾剂，烟雾剂

precipitation [prisipi'teiʃən] *n.* 沉淀，沉积

interdisciplinary [intə'disiplinəri] *a.* 各学科间的

implantation [ˌimplɑːn'teiʃən] *n.* 移植，安放，注入

lithography [li'θɔgrəfi] *n.* 平版印刷术

supersaturate [sjuːpə'sætʃəreit] *vt.* 使过度饱和

inherently [in'hiərəntli] *ad.* 天性地，固有地

quench [kwentʃ] *v.* （使）熄灭，急冷

synonymous [si'nɔniməs] *a.* 同义的

atomic structure 原子结构

interdisciplinary field 多学科

ion implantation 离子浸射

Notes

① interatomic spacings，原子间距。

② CVD，chemical vapor deposition，化学气相沉积。

③ PVD，physical vapor deposition，物理气相沉积。

④ quantum well structures，量子井结构。

⑤ tunneling microscope，隧道扫描显微镜。

⑥ building blocks，构成单元。

⑦ supersaturated solid solutions，过饱和固溶体。

⑧ incoherent or coherent interfaces，不连续或连续的界面。

Exercises

1. Reading comprehension

    (1) What factors can affect the materials microstructures?

    (2) Please give your own definition about nanostructured materials.

    (3) How are the nanostructured materials classified?

2. Translate the following into Chinese

    laser beam treatment   bulk material

    corrosion resistance   protective coating

    supersaturated solid solution   crystallographic orientation

    heterogeneous structure

- Two classes of such solids may be distinguished. In the first class, the atomic structure and/or the chemical composition vary in space continuously throughout the solid on an atomic scale. Glasses, gels, supersaturated solid solutions or implanted materials are examples of this type. In many cases these types of solids are produced by quenching a high-temperature (equilibrium) structure, e. g. a melt or a solid solution to low temperatures at which the structure is far away from equilibrium.

- R&D in this field emphasizes scientific discoveries in generation of materials with controlled microstructural characteristics, research on their processing into bulk materials with engineered properties and technological functions, and introduction of new device concepts and manufacturing methods.

3. Translate the following into English

硬度 　　　　　　　　　　　纳米尺寸粉体

化学成分 　　　　　　　　　沉淀过程

集成电路

Reading Material

Nanostructured Materials —— Factors Controlling the Properties of Nanostructured Materials

As the properties of solids depend on size, atomic structure and chemical composition, NsM exhibit new properties due to one or several of the following effects.

1. Size effects. Size effects result if the characteristic size of the building blocks of the microstructure (e. g. the crystallite size) is reduced to the point where critical length scales of physical phenomena become comparable with the characteristic size of the building blocks of the microstructure. If the thickness of the layers of a superlattice is comparable with the wavelength of the electrons at the Fermi edge, discrete energy levels for electrons and holes are formed in the quantum wells.

2. Change of the dimensionality of the system. If a NsM consists of thin needle-shaped or flat, two-dimensional crystallites, only two or one dimension of the building blocks becomes comparable with the length scale of a physical phenomenon. In other words, in these cases the NsM becomes a two- or one-dimensional system with respect to this phenomenon.

3. Changes of the atomic structure. Changes in the atomic structure result if a high density of incoherent interfaces or other lattice defects such as dislocations, vacancies, etc. is incorporated. The cores of lattice defects represent a constrained state of solid matter differing structurally from (unconstrained) crystals and/or glasses. As a consequence, a solid containing a high density of defect cores differs structurally from a defect-free solid with the

same (average) chemical composition. The misfit between adjacent crystallites changes the atomic structure (e. g. the average atomic density, the nearest-neighbor coordination, etc.) in the boundary regions relative to the perfect crystal. At high defect densities the volume fraction of defect cores becomes comparable with the volume fraction of the crystal-line regions. In fact, this is the case if the crystal diameter becomes comparable with the thickness of the interfaces, i. e. for crystal sizes on the order of one or a few nanometers as is the case in NsM.

4. Alloying of components (e. g. elements) that are immiscible in the solid and/or the molten state. The following cases of this type of immiscible components in NsM may be distinguished: solute atoms with little solubility in the lattice of the crystallites frequently segregate to the boundary cores (e. g. the free energy of the system in several alloys is reduced if large solute atoms segregate to the boundary core). The second case of nanostructured alloys results if the crystallites of a NsM have different chemical compositions. Even if the constituents are immiscible in the crystalline and/or molten state (e. g. Fe and Ag), the formation of solid solutions in the boundary regions of the NsM has been noticed. Finally, it may be pointed out that NsM are by no means limited to polycrystalline materials consisting of this type. In semicrystalline polymers, nanometer-sized microstructures are formed that consist of crystalline and non-crystalline regions differing in molecular structure and/ or chemical composition. NsM synthesized by supramolecular chemistry result if different types of molecular building blocks are self-assembled into a large variety of one-, two-or three-dimensional arrays.

The remarkable potential the field of NsM offers in the form of bulk materials, composites or coating materials to optoelectronic engineering, magnetic recording technologies, micro-manufacturing, bioengineering, etc. is recognized by industry. Large-scale programs, institutes and research networks have been initiated recently on these and other topics in the United States, Japan, EC, China and other countries. In order to keep this article within the length required, it will be limited to considering the microstructure of equilibrium and non-equilibrium NsM. In other words, nanostructured devices, carbon-based nanostructures (e. g. nanotubes), high surface area (nanometer-sized) materials, suspensions of nanometer-sized crystals, thin films and materials with nanostructured surface regions will not be discussed.

(Selected from *Acta Materials*, by H. Gleiter, 2000)

New Words and Expressions

superlattice [sjuːpə'lætis] *n.* 超点阵，超晶格
constrained [kən'streind] *a.* 不舒服的，被强迫的，拘泥的
coordination [kəuɔːdi'neifən] *n.* 同等，调和，配位
immiscible [i'misibl] *a.* 不能混合的，不融和的
alloy ['ælɔi] *n.* 合金; *vt.* 使成合金
polycrystalline [pɔli'kristəlain] *a.* 多晶的

semicrystalline ［ˌsemiˈkristəlain］ *a.* 半晶质的

supramolecular ［ˈsjuːprəməˈlekjulə］ *a.* 超分子的，由许多分子组成的

optoelectronic ［ˌɔptəuilekˈtrɔnik］ *a.* 光电子的

segregate ［ˈsegrigeit］ *v.* 隔离

size effects 尺寸效应

needle-shaped 针状

Notes

① building blocks，构成单元。

② Fermi edge，费米能级边缘［固体物理术语］。

③ discrete energy levels，能级。

④ quantum wells，量子势井［固体物理术语］。

⑤ incoherent interfaces，不连续界面。

⑥ the nearest-neighbor coordination，配位数。

⑦ micro-manufacturing，超微制造。

Unit 21 Nanostructured Materials ——— Recent Scientific Advances

Synthesis and processing of nanostructures will employ a diverse array of material types———organic, inorganic, and biological———well beyond examples already realized. The driving forces will be creativity, applications, opportunities, and economics in broad areas of science, medicine, and technology. Increasing emphasis will be placed on synthesis and assembly at a very high degree of precision, achieved through innovative processing. The result will be control of the size, shape, structure, morphology, and connectivity of molecules, nano-objects, nanostructured materials and devices. Integration of top-down physical assembly concepts with bottom-up chemical and biological assembly concepts may be required to create fully functional nanostructures that are operational at mesoscopic scales. The combination of new nanoscale building blocks and new paradigms in assembly strategies will provide nanostructured materials and devices with new, unprecedented capabilities limited only by our imagination.

Synthesis of Individual Building Blocks

Polymeric materials, dendrimers, and block copolymers. The last decade has seen tremendous advances in the preparation of organic building blocks of considerable complexity. The discovery of a new topology for polymers, dendrimers, has led to an exciting new class of nanoscale component, with interesting optical and mechanical properties. Precise nanoscale architectures ranging between 10 nm and 100 nm have been successfully synthesized. These constructions involve the reaction of an excess of dendrimer shell reagent with a reactive dendrimer core reagent. The new compositions are referred to as tecto (dendrimer) core-shell molecules. These molecules have demonstrated potential as unique nanoscale reactors, intermediates for new coatings/controlled delivery, compatibilizers, and building blocks for higher order nanoscale constructions. There have also been steady advances in engineering new phases using block copolymers; the recent development of tri-component block copolymer is noteworthy in this regard.

Nanocrystals. There has been significant progress made in the preparation of nanocrystals in recent years. Many common materials, such as metals, semiconductors, and magnets, can be prepared as nanocrystals, using colloidal chemistry techniques. The concepts of ligand exchange and surface derivatization have been well developed, and these methods permit nanocrystals with narrow size distribution (typically $5\% \sim 15\%$ variation in diameter) to be isolated and then used further as chemical reagents. This field has been aided greatly by improved understanding of size-dependent scaling laws, which have emerged from funda-

mental studies in chemical physics and condensed matter physics. The fact that a simple property like light emission depends so strongly upon size in semiconductors has greatly facilitated the development of reliable preparations. The same size dependence has also led to a wide range of applications in unexpected areas, such as in biological tagging.

Nanotubes and rods. The exciting discovery of the fullerenes was followed closely by the discovery of nanotubes of carbon. Nanotubes show tremendous promise as building blocks for new materials. Because of their topology, nanotubes have no dangling bonds, and so despite being very small, they do not exhibit "surface effects." As a consequence, individual nanotubes exhibit nearly ideal electrical, optical, and mechanical properties. Nanorods are also under extensive development and investigation.

Nanoparticle structures. Controlled particle formation is an important synthetic route to nanoscale building blocks relevant to many technologies from ceramics to pharmaceuticals. Some interesting new nanoparticle structures are composed of chain-like arrays of nanoparticles of relatively low coordination number. There are two main types: agglomerates (or aggregates) and aerogels. In particular, these structures can be characterized by their morphology (for example, coordination number) and the energies of the bonds that hold the primary (individual) particles together.

Processing of Nanostructures

Assembly. The development of self-assembly methodology, which is the archetypal bio-inspired synthesis route, has greatly expanded the methods of construction of nanostructures. In the design of complex materials such as electrical devices, we currently rely on our ability to create designed patterns lithographically. New ways of bonding, assembly, and linking macromolecules and nano-objects have been developed that are based on interactions that are both more complex and individually weaker (e. g. , steric, electrostatic, hydrophobic, and hydrogen bonding) than the classical electronic bond. Multiple bonding interactions are often needed to stabilize complex nanostructures. In the last decade, nanoscale objects such as nanoparticles or nanocrystals have been assembled into periodic arrays, or supercrystals. Such arrays exhibit novel optical and electrical characteristics. Several proposals have been put forward for how to pattern nanocrystals and nanotubes using biological molecules.

Templated growth of mesoporous materials. In the last decade, tremendous advances have occurred in the preparation of mesoporous inorganic solids. The initial work showed that it is possible to use organic surfactant molecules to prepare a complex pattern. That pattern can serve as the template for the formation of an inorganic phase. This has led to many exciting discoveries in chemical synthesis and to immediate practical advances in catalysis. Nanoporous media science (the control of void space) has advanced in some very important ways. For example, new scaffolds and matrices for tissue repair and engineering have been realized, and a large range of tailored porous catalysts and membranes, such as Mobil's MCM-41, have achieved commercial success. In another example, Nylon-6 nano-

composite with only two volume percent clay nanoparticles has a heat deformation temperature of 150°C, as opposed to 60°C for traditional Nylon-6.

Direct structuring. The ability to direct the assembly and organization of materials with nanomanipulation and nanolithography, based, for example, on scanning microprobe techniques, has achieved directed assembly and structuring of materials at the molecular level. New methodologies in this area include 3-D printing and various forms of soft lithography.

(Selected from *Nanotechnology Research Directions*: *IWGN Workshop Report*, edited by M. C. Roco, S. Williams, P. Alivisatos, Kluwer Academic Publishers, February 2000)

New Words and Expressions

morphology [mɔː'fɔlədʒi] *n.* 组织，结构，形态

paradigm ['pærədaim] *n.* 范例

unprecedented ['ʌn'presidəntid] *a.* 没有前例的

topology [tə'pɔlədʒi] *n.* 构造，结构，配置，外形

ligand ['ligənd] *n.* 配合基 [体]，向心配合（价）体

derivatization [di'rivətaizeiʃən] *n.* 派生

tagging ['tægiŋ] *n.* 标记

fullerene ['fulərən] *n.* 空心碳球化合物（由芳香碳环构成的空心球）

dangle ['dæŋgl] *v.* 摇摆

pharmaceuticals [faːmə'sjuːtikəls] *n.* 医药品

aerogel ['ɛərədʒəl] *n.* 气凝胶

methodology [meθə'dɔlədʒi] *n.* 方法学，方法论

lithography [li'θɔgrəfi] *n.* 平板印刷

mesoporous ['mesəpɔrəus] *a.* 中孔

scaffold ['skæfəld] *n.* 支架

dendrimer [den'drimə] 树枝状单体

block copolymers 嵌段共聚物

Notes

① synthesis and assembly，合成和组装。

② building blocks，构成单元。

③ precise nanoscale architectures，精确的纳米结构。

④ dendrimer shell reagent，做外层反应物的 dendrimer。

⑤ tecto (dendrimer) core-shell molecules，具有核心和外壳结构的 dendrimer 分子。

⑥ ligand exchange and surface derivatization，配位体交换和表面派生。

⑦ to pattern nanocrystals and nanotubes using biological molecule，使用生物分子作为模板来得到纳米晶体和纳米碳管。

⑧ tissue repair and engineering，生物组织修复工程。

⑨ nanomanipulation，纳米尺寸操作。

Exercises

1. Reading comprehension

   (1) What kinds of materials could be fabricated through nano-technology?

   (2) Please describe the synthesis method for nanostructured materials using template.

2. Translate the following into Chinese

   mesoscopic scales

   compatibilizer

   agglomerates (or aggregates) and aerogels

   porous catalysts and membranes

   considerable complexity

   chemical reagent

   the archetypal bio-inspired synthesis route

   scanning microprobe techniques

   - Increasing emphasis will be placed on synthesis and assembly at a very high degree of precision, achieved through innovative processing. The result will be control of the size, shape, structure, morphology, and connectivity of molecules, nano-objects, nanostructured materials and devices. Integration of top-down physical assembly concepts with bottom-up chemical and biological assembly concepts may be required to create fully functional nanostructures that are operational at mesoscopic scales.

   - The ability to direct the assembly and organization of materials with nanomanipulation and nanolithography, based, for example, on scanning microprobe techniques, has achieved directed assembly and structuring of materials at the molecular level.

3. Translate the following into English

   窄的粒度分布

   生物标记

   配位数

   凝聚态物理

   表面效应

Reading Material

Nanostructured Materials——Recent Technological Advances

One key to advanced technology emerging over the past decade has been nanomaterials. The aggressive advance of smart materials, solid state devices, and biomimetic technologies and the concurrent push towards miniaturization are making the understanding and development of materials on the nanometer level critical and are encouraging the design of nanoscale structure and functionality into materials systems. The focus on nanostructuring of materials systems has been further sharpened by the need to develop materials having novel and/or enhanced properties without resorting to new synthetic chemistries with the associated environmental and cost issues. Enhancements in mechanical performance, wear resistance, integrity under thermal stress, flammability, and transport properties have all been linked to nanostructure in materials systems within the past five years, demonstrating that the technology has reached a level of maturity where it is ripe for exploitation in systems demanding both high performance and reliability.

A very important technological advance in recent years has been in the area of large-scale, reliable production of uniform, nano-sized particles. This has been particularly important in the high-performance ceramic materials and the pharmaceutical areas, where materials properties, through defect control, drug delivery, and control of uptake, have been favorably influenced by nanoparticle production. Aerogels are normally fabricated by condensed phase (sol-gel) methods, even though the final product is a gas/solid system. Recently, aerogel-like structures have been fabricated directly by gas-phase processes without passing through the sol-gel state. This could lead to less expensive fabrication processes, use of a wider range of materials in aerogel fabrication, and excellent control of multilayer deposition processes, with applications in magnetic and optical devices. Soft lithography and nanoimprinting have been developed and identified as low-cost patterning approaches, with several new applications on the horizon. Nanostructured zeolite catalysts can be tailored to perform oxidation reactions more efficiently than enzymes. While not strictly speaking a nanotechnology, the tremendous advances in organic electronics, such as organic light-emitting diodes, must be noted, since that field is highly likely to benefit from advances in organic nanoscale synthesis in the future.

New nanostructured materials have the potential to significantly reduce production costs and the time of parts assembly, for example, in the automotive, consumer appliance, tooling, and container industries. The potential of significant reductions in weight due to these new materials as they are applied in the transportation industries will have great impact on energy consumption and the environment. Understanding nanoparticle formation is paying dividends in dealing with environmental issues such as atmospheric particulate formation as well.

Many fundamental phenomena in energy science, such as electron transfer and exciton diffusion, occur on the nanometer length scale. Thus, the ability to arrange matter, i. e., to inexpensively pattern and to develop effective nanostructuring processes, will be a vital asset in designing next-generation electronic devices, photovoltaics, and batteries.

Size and cost reduction due to advances in the design and manufacture of healthcare-related diagnostic systems has the potential to empower individuals to diagnose and treat diseases in their own homes, decentralizing the healthcare system.

Sensors based on nanotechnology will revolutionize healthcare (e. g., via remote patient monitoring), climate control, detection of toxic substances (for environment, defense, and healthcare applications), and energy consumption in homes, consumer appliances, and power tools.

The ability to assemble and interconnect nanoparticles and molecules at nanometer dimensions will enable the development of new types of nanoelectronic circuitry and nanomechanical machinery.

(Selected from *Nanotechnology Research Directions: IWGN Workshop Report*, edited by M. C. Roco, S. Williams, P. Alivisatos, Kluwer Academic Publishers, February 2000)

New Words and Expressions

aggressive [ə'gresiv] *a.* 好斗的，敢作敢为的，有闯劲的，侵略性的

biomimetic [baimi'metik] *a.* 仿生的

concurrent [kən'kʌrənt] *n.* 同时发生的事件；*a.* 并发的，协作的，一致的

ripe [raip] *a.* 熟的，成熟的，时机成熟的

zeolite ['zi:əlait] *n.* 沸石，与沸石类似的天然的或人工的硅酸盐

enzyme ['enzaim] *n.* 酶

dividend ['dividend] *n.* 被除数，股息，红利，额外津贴，奖金，年息

atmospheric [ætməs'ferik] *a.* 大气的

photovoltaics [fəutəuvɔl'teiiks] *a.* 光电的

diagnostic [daiəg'nɔstik] *a.* 诊断的；*n.* 诊断

empower [im'pauə] *v.* 授权与，使能够

decentralize [di:'sentrəlaiz] *vt.* 分散

thermal stress 热应力 "

Notes

① condensed phase (sol-gel) methods，凝相方法，sol-gel，溶胶-凝胶。

② patterning approach，仿形方法。

③ exciton diffusion，电子空穴扩散。

④ healthcare-related，有关健康保护的。

Unit 22　Nanostructured Materials ——Applications

Nanostructure science and technology (nanotechnology) is fundamentally changing the way that materials and the structures made from them will be manufactured in the future. Our increasing ability to synthesize and assemble nanoscale building blocks with precisely controlled sizes and chemistries into consolidated nanostructures and nanocomposites with unique properties and functionalities likely will lead to revolutionary changes in industry.

A number of major scientific and technological advances in the area of consolidated nanostructures have occurred in the past decade, and many more are expected. Such advances, some of which are listed below, have already led to commercial scale-up of some nanostructured materials and also to products incorporating them.

- Production of layered nanostructures with control of thickness at the atomic level and the subsequently developed ability to engineer the resisto-magnetic-field response by varying nanoscale architecture to make useful devices for magnetic recording.

- Development of processes to net-shape-form nanophase ceramics and ceramic-based composites into finished parts while maintaining ultrafine grain size and nanoscale properties when desired.

- Discovery and development of unique nanostructured hard and soft magnetic materials for a variety of applications, including information technology hardware.

- Development of nanoscale hard materials for improved cutting-tool performance with superior wear resistance and fracture toughness.

- Development of direct methods for fabricating nanostructured coatings yielding exceptional electrical, chemical, thermal, mechanical, and environmental protection of the coated parts.

- Creation of a wide range of nanocomposites, such as nanoparticle- or nanotube-filled polymers, with enhanced or fundamentally new and controllable engineering performance, including significantly increased strength and reduced flammability.

- Development of biological templating for the directed growth and patterning of nanostructures for biomedical and electronic applications.

- Engineering of scaled-up and economical industrial processes for production of nanopowders and nanostructured bulk materials in the multi-tonnage range.

In order to move nanostructure science and technology forward effectively during the next five to ten years, there are a number of significant issues that must be considered.

- Nanostructured systems will be manufactured primarily from the bottom up using nanoscale building blocks and not from the top down as in conventional manufacturing methods.

- Up-front costs may be higher, but net commercial savings will result from more efficient design and processing, use of only necessary material, and decreased and less deleterious effluent.

- New scale-up methods will be required, along with novel scenarios for processing and handling of materials and parts.

- Statistically driven process controls with real time diagnostics and precise reliability standards will also be needed.

- Realistic multiscale theoretical modeling of nanostructuring and the properties and functionalities of the resulting nanostructures and systems will be important to their ultimate success.

- Understanding of the structure and properties of surfaces and interfaces and how to control these in a variety of nanostructure assembly strategies will need to be significantly increased.

Many new applications in the area of consolidated nanostructures will become available when these issues are faced and the appropriate barriers surmounted. Some examples follow:

- Ultrahigh-strength, tough structural materials;
- Novel soft and hard ferromagnets;
- Ductile and strong cements;
- High-brightness displays based on nanotubes;
- Bio-inspired medical prostheses;
- Self-assembled arrays of biomolecular single-electron devices;
- Drugs from consolidated nanoparticles.

Several additional opportunities can be suggested that will lead to a wide range of useful developments.

- High-pressure sintering of nanophase oxide ceramics should be extended to difficult-to-sinter non-oxide ceramics for a variety of industrial applications, including high-efficiency automotive parts.

- Magnetic nanocomposites with 5-10-fold increases in magnetocaloric effects should be used to develop magnetic refrigerators that operate at room temperature.

- A unique new class of nanostructured permanent magnets with higher saturation magnetization values than are presently available should be developed for many in formation technology applications.

- Textiles and plastics filled with dispersed nanoparticles should be created that will enhance the materials' mechanical performances while reducing their flammability.

- Lithium-ion batteries composed of nanodispersed ceramics in polymer matrices should be developed for the next generation of lightweight rechargeable batteries for cellular telephones, laptop computers, and transportable CD players and radios.

(Selected from *Nanotechnology Research Directions: IWGN Workshop Report*, edited by M. C. Roco, S. Williams, P. Alivisatos, Kluwer Academic Publishers, February 2000)

New Words and Expressions

consolidate [kən'sɔlideit] *a.* 固态的

ultrafine [ˌʌltrə'fain] *a.* 超细的

toughness ['tʌfnis] *a.* 坚韧的，具有韧性的

flammability [ˌflæmə'biliti] *n.* 易燃，可燃性

biomedical [ˌbaiəu'medikəl] *a.* 生物医学的

deleterious [deli'tiəriəs] *a.* 有害的，有毒的

effluent ['efluənt] *a.* 发出的，流出的；*n.* 流出物，排水道，污水

scenario [si'nɑːriou] *n.* 设想

surmount [səː'maunt] *vt.* 战胜，超越，克服，在……顶上

prostheses ['prɔsθiːsis] *n.* 人造器官

magnetocaloric [mæg'niːtəukə'lɔrik] *a.* 磁（致）热的

Notes

① consolidated nanostructures，形成固体的纳米结构。

② the resisto-magnetic-field response，磁阻反应。

③ cutting-tool performance，切割工具的性能。

④ biological templating，生物模板。

⑤ from the bottom up，由小到大。

⑥ less deleterious effluent，少的有害物排放。

⑦ tough structural materials，具有韧性的结构材料。

⑧ 5-10-fold，五到十倍的。

Exercises

1. Reading comprehension

    (1) Please list some commercialized nanostructured materials or their applications.

    (2) What are the science and technological issues that should be addressed for the advancement of nanostructured materials?

2. Translate the following into Chinese

    net-shape-form nanophase ceramic   superior wear resistanc

    scaled-up   up-front costs

    bio-inspired medical prostheses   difficult-to-sinter

    biomolecular single-electron devices

    • Nanostructure science and technology (nanotechnology) is fundamentally changing the way that materials and the structures made from them will be manufactured in the future. Our increasing ability to synthesize and assemble nanoscale building blocks with precisely controlled sizes and chemistries into consolidated nanostructures and nanocomposites with unique properties and functionalities likely will lead to revolutionary changes in industry.

- Lithium-ion batteries composed of nanodispersed ceramics in polymer matrices should be developed for the next generation of lightweight rechargeable batteries for cellular telephones, laptop computers, and transportable CD players and radios.

3. Translate the following into Englsih

层状纳米结构　　　　　　　　陶瓷基复合材料

断裂韧性　　　　　　　　　　理论模拟

生物医学应用

Reading Material

Nanostructured Materials——Carbon Materials

The carbon-based materials of interest from a molecular self-assembly point of view include fullerenes and their relatives, including metal-coated fullerenes, carbon nanotubes, carbon nanoparticles, and porous carbons. Since 1990 with the discovery of techniques to produce soluble carbon in a bottle, research on and with carbon materials has skyrocketed. Not only can the molecular forms of carbon (the fullerenes and their derivatives) be synthesized, characterized, and studied for applications, but many other new carbon materials such as multi- and single-walled carbon nanotubes can now be produced in macroscopic quantities.

A broad variety of carbon nanotube structures whose properties are now being examined both theoretically and experimentally. A rich literature on these new carbon materials now exists. This report will only attempt to highlight a few important recent examples in the area of high surface area materials. Of particular interest for future catalytic applications is the recent report that not only can C_{60} be coated with metal atoms, but that the metal coating can consist of a precise number of metal atoms. For example, $C_{60}Li_{12}$ and $C_{60}Ca_{32}$ have been identified mass spectroscopically. C_{60} has been coated with a variety of different metals, including Li, Ca, Sr, Ba, V, Ta and other transition metals. Interestingly, addition of more than 3 Ta atoms to C_{60} breaks the C_{60} cage. Replacement of one carbon atom in C_{60} by a transition metal atom such as Co or Ir is being studied for possible catalytic applications. The future technological challenge will be to discover techniques to fabricate large quantities of such materials, so that such catalyst materials can be put in a bottle and not just in molecular beams.

Carbon nanotubes have the interesting property that they are predicted to be either semiconducting or conducting (metallic), depending on the chirality and diameter of the nanotube. Such materials are being studied as conductive additives to plastics and for use in electrochemical applications where the uniformity of the nanotube diameter and length is not overly critical. Another approach is to use the carbon nanotube as a template for a nanotube of an inorganic oxide. Hollow nanotubes of zirconia and yttria-stablilized zirconia have been

prepared by coating treated carbon nanotubes with a zirconium compound and then burning out the carbon template. Finally, large scale production of single-walled nanotubes has recently been demonstrated, so one may anticipate a strong upsurge in the characterization and potential usage of single-walled carbon nanotubes in the future.

Porous carbons are of interest as molecular sieve materials, both as sorbants and as membranes for filtration. One of the major research objectives is to develop materials or structures with exceedingly high storage capacity per unit volume and weight for gases such as H_2 or CH_4. H_2 or CH_4 could become an economic source of combustion fuel or a means to power fuel cells for ultralow-emission vehicles or for electric power generation. Microporous hollow carbon fibers have exhibited high permeance and high selectivity as hydrogen selective membranes, and development is now underway to scale up these membranes to commercial levels. Carbon fiber materials produced via catalytic decomposition of hydrocarbon vapors have also recently been reported to exhibit exceptionally high hydrogen adsorption capacity. More mundane uses of nanotubes are as nanometer reinforcing rods in polymers or even in concrete. Incorporation of conducting carbon nanotubes in construction materials such as concrete or structural plastics opens opportunities for real time monitoring of material integrity and quality.

Several research groups around the world have succeeded in fabricating electrical switches such as the field-effect transistor from single-walled carbon nanotubes. A single-walled carbon nanotube 1. 6 nm in diameter could be manipulated into place using an atomic force microscope. Once placed on the metal contacts, the semiconducting tube behaved like the channel in a field-effect transistor, turning on or off depending on the applied gate voltage. Nanotubes hold great promise as electronic elements for a variety of different nanostructures. Researchers are just beginning to understand how they conduct electricity and how to place them into appropriate device structures. It is interesting to note that both the atomic force microscope used to fabricate this structure and the carbon nanotubes that form the critical element were developed only in the past decade.

(Selected from *Nanotechnology Research Directions: IWGN Workshop Report*, edited by M. C. Roco, S. Williams, P. Alivisatos, Kluwer Academic Publishers, February 2000)

New Words and Expressions

derivative [di'rivətiv] *a.* 引出的，系出的；*n.* 派生的事物，派生词

spectroscopically [spektrəs'kɔpikəli] *ad.* 利用光谱方法，利用分光设备

cage [keidʒ] *n.* 笼，槛，（矿井）罐笼

chirality ['tʃiːrəliti] *n.* 手征，手性

upsurge ['ʌpˌsəːdʒ] *n.* 高潮

sorbent [sɔːbənt] *n.* 吸附剂

permeance ['pəːmiəns] *n.* 浸透，透过

mundane ['mʌndein] *a.* 世界的，世俗的，平凡的

Notes

① macroscopic quantities，大批量。

② mass spectroscopically，质谱分析。

③ electrochemical applications，电化学应用。

④ molecular sieve materials，分子筛材料。

⑤ catalytic decomposition，催化分解，

⑥ field-effect transistor，场效应晶体管。

⑦ atomic force microscope，原子力显微镜。

Unit 23 The Future of Nanostructure Science and Technology

Nanostructure science and technology is clearly a very broad and interdisciplinary area of research and development activity worldwide. It has been growing explosively in the past few years, since the realization that creating new materials and devices from nanoscale building blocks could access new and improved properties and functionalities. While many aspects of the field existed well before nanostructure science and technology became a definable entity during the past decade, it has really only become a coherent field of endeavor through the confluence of three crucial technological streams:

(1) new and improved control of the size and manipulation of nanoscale building blocks;

(2) new and improved characterization (e. g. , spatial resolution, chemical sensitivity) of materials at the nanoscale;

(3) new and improved understanding of the relationships between nanostructure and properties and how these can be engineered.

These developments have allowed for an accelerating rate of information transfer across disciplinary boundaries, with the realization that nanostructure scientists can and should borrow insights and techniques across disciplines, and for an increased access to common enabling tools and technologies. We are now at the threshold of a revolution in the ways in which materials and products are created. How this revolution will develop, and how great will be the opportunities that nanostructuring can yield in the future, will depend upon the ways in which a number of challenges are met.

Among the challenges facing nanostructure scientists and engineers in order for rapid progress to continue in this field are the necessary advances that must be made in several enabling technologies. We need to increase the capabilities in material characterization, be it in visualization or analytical chemistry, at ever finer size scales. We also need to be able to manipulate matter at finer and finer size scales, and we must eventually use computational approaches in directing this. Experiment simply cannot do it alone; theory and modeling are essential. Fortunately, this is an area in which the sizes of the building blocks and their assemblies are small enough that it is possible, with the ever increasing capabilities of computational sciences, to start doing very serious controlled modeling experiments to guide researchers in the nanostructuring of matter. Hence, multiscale modeling, across atomic, mesoscopic, and macroscopic length scales, of nanostructuring and the resulting hierarchical structures and material properties is an absolute necessity as we attempt in the coming decades to utilize the tremendous potential of nanostructure science and technology.

Another challenge is to fully understand the critical roles that surfaces and interfaces

play in nanomaterials, owing to the very high specific surface areas of nanoparticles and the large areas of interfaces in the assembled nanophase forms. We need to know in detail not only the structures of these interfaces, but also their local chemistries and the effects of segregation and interaction between the nanoscale building blocks and their surroundings. We also need to learn more about the control parameters of nanostructure size and size distribution, composition, and assembly. For some applications of these building blocks, there are very stringent conditions on these parameters; in other applications considerably less so. We must therefore understand the relationships between the limits of this stringency and the desired material or device properties if efficient utilization of nanostructuring is to be achieved.

Since nanostructures are often inherently unstable owing to their small constituent sizes and high chemical activity, a further challenge is to increase the thermal, chemical, and structural stability of these materials and the devices made therefrom, in the various temperatures and chemistries of the environments in which the nanostructures are asked to function. A nanostructure that is only a nanostructure at the beginning of a process is not of much use unless the process is over in a very short time or unless the process itself is the actual nanostructure advantage. So, stability is a real concern in many applications. Researchers must determine whether natural stability or metastability is sufficient or if we must additionally stabilize against the changes that we cannot afford. Fortunately, it appears that many nanostructures possess either a deeply metastable structure or they can be readily stabilized or passivated using rather traditional strategies.

Reproducibility and scalability of nanoparticle synthesis and consolidation processes in nanostructuring are paramount for successful utilization of nanostructure research and development. What is accomplished in the laboratory must eventually benefit the society that pays the bills for the research, or the field will simply die. Also, significant enhancements in statistically driven process controls are required if we are to be able to effectively commercialize and utilize the nanostructuring of matter. New thinking is needed, not only about the materials, not only about the processing and assembly of these materials, but also about the manufacture of products from these materials and the economic impact of dealing with effluents. Given the commercial promise of net-shape forming of nanoscale ceramics, for example, the viability of such nanostructure production and utilization depends upon the total integrated costs of precursors or raw materials, synthesis of the building blocks, manufacturing of parts from those building blocks, and finally, disposition of the effluents. Higher than normal up-front costs for the nanoparticles or building blocks may be affordable if the processing steps save more than that. It is the total integrated costs, along with societal needs, that will determine commercial viability

Education is also of tremendous importance to the future of the field of nanostructure science and technology. The creation of a new breed of researchers working across traditional disciplines and thinking "outside the box" is an absolute necessity for the field of nanostructure science and technology to truly reach fruition and to impact society with full force.

The education of this new breed of researchers, who will either themselves work across disciplines or know how to work with others across disciplinary lines in the interfaces between disciplines, is necessary to make this happen in the future. People will need to start thinking in truly unconventional ways, if we are to take full advantage of this excitingly new and revolutionary field.

It appears that nanostructure science and technology at present resembles only the tip of a pyramid that has recently been uncovered from the sands of ignorance. As the new and expanding research community of nanostructure scholars worldwide digs away at these sands and uncovers more and more of the exciting field of nanostructure science and technology, we will eventually learn how truly important the field will have become and how great its impact will be on society. From our present vantage point, this future looks very exciting.

(Selected from *Nanostructure Science and Technology*, by Richard W. Siegel, 1999)

New Words and Expressions

Nanostructure ['nænəu'strʌktʃə] *n.* 纳米结构

definable [di'fainəbl] *a.* 可定义的

coherent [kəu'hiərənt] *a.* 粘在一起的，一致的，连贯的

confluence ['kɔnfluəns] *n.* 汇合

visualization [ˌvizjuəlai'zeiʃən] *n.* 使看得见的，清楚地呈现

metastability [ˌmetəstə'biliti] *n.* 亚稳性，亚稳度

scalability [ˌskeilə'biliti] *n.* 可量测性

effluent ['efluənt] *a.* 发出的，流出的；*n.* 流出物，排水道，污水

vantage ['vɑːntidʒ] *n.* 优势，有利情况

Notes

It appears that nanostructure science and technology at present resembles only the tip of a pyramid that has recently been uncovered from the sands of ignorance. 作者在全文中采用通俗易懂的语言，描述了纳米结构科学和技术的最近研究进展及科学家在未来研究中面临的挑战。该自然段是对全文的总结，并将 nanostructure science and technology 比喻成被埋在沙漠中的金字塔的塔尖，随着新研究团体的加入和研究的扩展，人们将真正了解该学科的重要性和对社会的重大影响，并指出未来令人振奋。

Exercises

1. Question for discussion
   (1) What is nanostructure science and technology?
   (2) Please describe the recent development of nanostructure science and technology.
   (3) Which challenges do nanostructure scientists and engineers face in the future?
2. Translate the following into Chinese
   nanostructure science and technology   building block
   material characterization   integrated cost

hierarchical structure   nanoparticle synthesis

- Nanostructure science and technology is clearly a very broad and interdisciplinary area of research and development activity worldwide. It has been growing explosively in the past few years, since the realization that creating new materials and devices from nanoscale building blocks could access new and improved properties and functionalities.

- Hence, multiscale modeling, across atomic, mesoscopic, and macroscopic length scales, of nanostructuring and the resulting hierarchical structures and material properties is an absolute necessity as we attempt in the coming decades to utilize the tremendous potential of nanostructure science and technology.

- Reproducibility and scalability of nanoparticle synthesis and consolidation processes in nanostructuring are paramount for successful utilization of nanostructure research and development.

- It appears that nanostructure science and technology at present resembles only the tip of a pyramid that has recently been uncovered from the sands of ignorance.

3. Translate the following into English

纳米结构   分析化学
分辨率   纳米级陶瓷材料
计算科学   污水

Reading Material

Synthesis of Nanocrystalline Materials

Nanocrystalline materials have high potential for use in structural and device applications in which enhanced mechanical and physical characteristics are required. At present, a number of "far from equilibrium processes" including mechanical alloying, severe plastic deformation, mechanochemical processing and supercritical fluid processing have been utilized to synthesize nanocrystalline materials.

Production of Nanocrystalline and Submicrocrystalline Structures

Two approaches have been used to produce nanocrystalline and submicrocrystalline structures (grain size $\leqslant 100$nm) or submicrocrystalline (grain size $\leqslant 1\mu$m) structures. One approach is production of amorphous or nanocrystalline powders by mechanical alloying (MA), a high-energy-input process in which heavy working of powder particles results in intimate alloying by repeated deformation, fracturing and welding. Once amorphous or nanocrystalline phases are synthesized, reliable methods are needed to consolidate these materials. The interest lies in producing a nanocrystalline structure in the compacted material from the amorphous or nanocrystalline powders by compaction under controlled conditions.

Hot isostatic pressing (HIP'ing) has effectively been used for compaction of a number of fully dense nanocrystalline titanium aluminide based alloys and composites. A decrease in the HIP'ing temperature led to a decrease in the final grain size.

Another approach for grain refinement is multi-directional isothermal forging with a forging temperature decreasing from higher to lower. High formability at higher temperature has been shown to be due to extensive dynamic recrystallization (DRX). The grain refinement in a whole part results in further improvement in the formability of an alloy. This makes possible subsequent working at lower temperatures which, in turn, leads to further microstructure refinement. This approach allows production of submicron-sized grains in large-scale billets. The initial microstructure and chemical composition affect much the easiness of production and homogeneity of the fine-grained structure.

Grain Growth

The main problem of a nanocrystalline structure is its instability at high temperatures. Because of the large excess free energy. significant grain growth has been observed in several nanocrystalline materials. On the other hand, stabilization of the nanocrystalline grain structure was observed in many materials after continuous annealing. For example, the Ti_5Si_3 phase has the closest coefficient of thermal expansion to that of TiAl, which, together with its high stiffness and strength, makes Ti_5Si_3 an attractive potential reinforcing phase in TiAl. Considerable grain growth occurred during the initial stages of annealing of the HIP's samples, with a tendency to reach a saturation stage where grains grew very slowly. After annealing for 500 hours at 850°C and 975°C, for example, the average grain size in Ti-47Al-3Cr was 170nm and 415 nm, respectively. The same tendency for grain growth was observed in the nanocrystalline Ti-48Al-2Nb-2Cr alloy, and Ti-47Al-3Cr/Ti_5Si_3 composite.

Superplasticity (SP)

Materials such as Titanium aluminides with submicrocrystalline and nanocrystalline structures showed a high elongation to rupture (above 200%) and high strain rate sensitivity ($m > 0.3$), features characteristics of superplastic SP behavior, at temperatures 700 ~ 900°C, that is 200~400°C lower than that for the alloys with micron-sized grains. The activation energy for SP flow of titanium aluminides with grain size $< 1\mu$m was determined to be 180~195 kJ/mol, suggesting that grain boundary diffusion was the rate controlling mechanism.

Nanocrystalline Aluminum-Iron Alloys

Aluminum-iron alloys are attractive for applications at temperatures beyond those normally associated with aluminum alloy use. Alloying aluminum with iron increases the high temperature strength due to a dispersion of second-phase particles. Unfortunately, the equilibrium solubility of iron in the aluminum lattice is very low and even at high temperatures it does not exceed 0.03 %, and these alloys cannot be dispersion-strengthened with the use of

conventional solid state heat treatments. The strengthening effect can be enhanced by increasing the solid solubility of iron in the aluminum matrix by "far-from-equilibrium" techniques such as rapid solidification, mechanical alloying or severe plastic deformation. Severe plastic deformation can refine the microstructure of metals and alloys into the nanometer-sized range and lead to formation of metastable phases, including supersaturated solid solutions. These novel constitutional and microstructural effects can enhance physical and mechanical properties. Severe plastic deformation was used to extend the iron solubility in aluminum and to produce a nanocrystalline dispersion-strengthened structure after aging.

Synthesis by Mechanochemical Process

The mechanochemical process (MCP) is broadly the use of mechanical energy to cause reactions, which normally require elevated temperatures, to occur at ambient temperatures by MCP including titanium aluminides, and titanium carbides.

Titanium aluminide The basis for the synthesis of titanium-aluminum alloys is the co-reduction reaction:

$$6TiCl_4 + 2AlCl_3 + 7CaH_2 + 8Mg \longrightarrow 2Ti_3Al\ (H) + 7CaCl_2 + 8MgCl_2 \qquad (1)$$
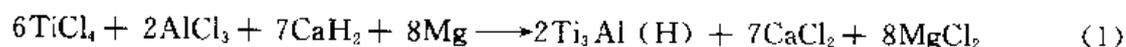
induced by mechanical milling. The reaction product after leaching is $Ti_3Al(H)$ with the hydrogen appearing to occupy interstitial sites in the Ti_3Al structure. The reaction shown above differs from conventional reduction processes in which metallic elements are used for reduction reactions. The use of CaH_2 as a reducing agent in the present case results in the formation of $Ti_3Al(H)$ which is more passive to oxidation than Ti_3Al.

Titanium Carbide Nanocrystalline TiC has been synthesized by the displacement reaction

$$TiCl_4 + 2CaC_2 \longrightarrow TiC + 2CaCl_2 + 3C \qquad (2)$$
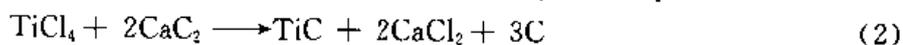
The reaction has also been modified to avoid the liberation of free carbon, by the addition of Mg,

$$2TiCl_4 + CaC_2 + 3Mg \longrightarrow 2TiC + CaCl_2 + 3MgCl_2 \qquad (3)$$
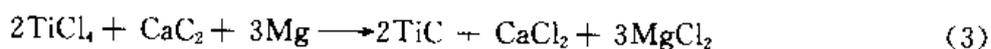
The Ti produced by reduction of $TiCl_4$ with Mg, and the C generated by the reaction between $TiCl_4$ and CaC_2 combine to form TiC. Experiments involving stoichiometric amounts of reactants produced nanocrystalline TiC. This was very encouraging, as an incomplete reaction would have resulted in unreacted $TiCl_4$ or sub-chlorides. For example, reduction reactions which are normally carried out at temperatures close to 1000℃ can be achieved at ambient temperatures through MCP. Normally, the reaction products formed by mechanochemical processing are ultrafine powders with a wide distribution of particle size ranging from few nanometers to one micron. A number of metals, alloys and inorganic compounds have been prepared in ultrafine (nanometer sized particles) form of transmission electron microscopy (TEM) examination showed a wide distribution of TiC particles in the size range of 10~200 nm.

Synthesis by Supercritical Fluid Processing

Supercritical fluid processing for the synthesis of metals and metal oxides is a recent ad-

dition to the list of modern processing techniques. Recent work has demonstrated the feasibility of coating metal and oxide films on silicon substrates. This process involves the dissolution of organic compounds containing the metal ions in supercritical fluid and reducing or oxidizing the compound to generate an ultrafine metal or oxide. Any substance at a temperature above its critical temperature, T_c, and pressure above its critical pressure, P_c, is defined as a supercritical fluid (SF). The critical temperature is the highest temperature at which a gas can be converted to a liquid by increasing the pressure. The critical pressure is the highest pressure at which a liquid can be converted to a gas by an increase in temperature. In the supercritical region, the dense fluid has many useful characteristics. Diffusivities are typically an order of magnitude higher than the corresponding liquid; viscosities are usually many times lower than those of ordinary liquids, providing appreciable penetrating powder into a solid matrix resulting in an efficient extraction. These factors along with low surface tension allow supercritical fluids to have mass transport characteristics of a gas while retaining liquid-like solvating strengths. To carry out reduction or oxidation reactions, CO_2 has been found to be an ideal supercritical fluid, because it is nontoxic, non-reactive, and inexpensive. In addition, CO_2 can be kept in the supercritical fluid state at a temperature as low as 31.1℃. Ease of dissolution of organometallic compounds in the supercritical fluid facilitate chemical reactions in reducing or oxidizing environment at low temperatures, resulting in the nucleation and growth of ultrafine solids.

An example of metal particles produced by hydrogen reduction of copper hexafluoroacetylacetone, $Cu(HFA)_2$ in supercritical carbon dioxide are the copper particles. This fluorinated copper compound has high solubility in the supercritical carbon dioxide and can be reduced to copper metal according to the following reaction:

$$Cu(CF_3—C—CH=C—CF_3)_2 + H_2 \longrightarrow Cu + 2 CF_3-C-CH_2—C—CF_3$$
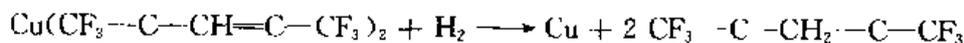
In the presence of hydrogen gas at elevated temperatures, $Cu(HFA)_2$ can be reduced to copper metal in supercritical fluid carbon dioxide. Because of the high solubility of HFA in supercritical carbon dioxide, it will remain in the fluid phase while copper atoms displaced by hydrogen condense on the substrate at 250℃.

(Selected from *Synthesis of Nanocrystalline Materials——An Overview*, by F. H. (Sam) Froes, O. N. Senkov and E. G. Baburaj, 2001)

New Words and Expressions

supercritical　[ˌsjuːpəˈkritikəl]　*a.* 超临界的

billet　[ˈbilit]　*n.* （金属的）坯段，钢坯

homogeneity　[ˌhɔməudʒeˈniːiti]　*n.* 同种，同质，均匀性，均一性

anneal　[əˈniːl]　*n.* 退火，焖火，锻炼

elongation　[ˌiːlɔŋˈgeiʃən]　*n.* 延长

rupture　[ˈrʌptʃə]　*v.* 破裂，裂开，割裂；*n.* 破裂，割裂

ambient　[ˈæmbiənt]　*a.* 周围的；*n.* 周围环境

interstitial　[ˌintə(ː)ˈstiʃəl]　*a.* 空隙的；在裂缝间的

stoichiometric constant　论量常数

ultrafine　['ʌltrə'fain]　*a.* 极其细小的，非常细微的，超微细的，精细的

micron　['maikrɔn]　*n.* 微米

substrate　['sʌbstreit]　*n.* (=substratum) 基体，基础

viscosity　[vis'kɔsiti]　*n.* 黏度，黏性

diffusivity　[ˌdifju:'siviti]　*n.* 扩散能力，扩散率

fluorinate　['flu(:)ərineit]　*v.* 使与氟素化合，在（饮水）加少量之氟

Notes

① At present, a number of "far from equilibrium processes" including mechanical alloying, severe plastic deformation, mechanochemical processing and supercritical fluid processing have been utilized to synthesize nanocrystalline materials. "far from equilibrium processes"，远离平衡过程；supercritical fluid，超临界流体；mechanochemical processing，机械化学处理；nanocrystalline materials，纳米结晶材料。

② The initial microstructure and chemical composition affect much the easiness of production and homogeneity of the fine-grained structure. fine-grained，细粒的，与之相反的是 course-grained（粗粒的）。参考译文：初始微结构和化学成分严重影响细粒结构物质的生产的难易程度及其均一性。

③ Unfortunately, the equilibrium solubility of iron in the aluminum lattice is very low and even at high temperatures it does not exceed 0.03 %, and these alloys cannot be dispersion-strengthened with the use of conventional solid state heat treatments. 参考译文：不幸的是，铁在铝晶格中的平衡溶解度很低，即使在高温下也不超过 0.03%；若用通常的固态热处理技术，这些合金不能得到分散强化。

④ Normally, the reaction products formed by mechanochemical processing are ultrafine powders with a wide distribution of particle size ranging from few nanometers to one micron. ultrafine，极其细小的，非常细微的。参考译文：一般地，由机械化学作用形成的反应产物为极其细微的粉末，其颗粒大小具有很宽的分布范围，可从几纳米到 1 微米。

⑤ Supercritical fluid processing for the synthesis of metals and metal oxides is a recent addition to the list of modern processing techniques. A recent addition to the list of modern processing techniques，其原意是 supercritical fluid processing 这一方法"最近添加到现代加工技术列表中"。参考译文：金属和金属氧化物合成的超临界流体加工技术是一种新的现代材料加工技术。

PART VII BIOMATERIALS

Unit 24 Biomaterials Introduction

As we enter the 21st century, the field of biomaterials is becoming one of the most intellectually exciting areas of materials science and engineering. Even though activity in this field is not new, there is currently fresh energy in this subject brought about by the remarkable advances in molecular and cell biology of the past two decades. Early activities in this field (40 or 50 years ago) dealt with the selection and characterization of well-established synthetic materials to fabricate implants for use in medicine and as restorative materials in dentistry. Materials well established in technology and not originally developed as biomaterials were being used for human repair. For example, bone implants used by orthopedic surgeons were being fabricated from low-corrosion steels and other alloys or from ultrahigh-density polyethylene. Methacrylate polymers were being tested and used as bone cements and dental restoratives, and polyethylene terephthalate fibers were being woven into fabrics that could function as artificial blood vessels. During the early period of this field, cellulose-based membranes were being introduced in kidney dialysis machines. Therefore, biomaterials research was mostly centered on in vitro testing of these materials under conditions that simulated the biological environment (e. g. , corrosion, fatigue, creep, wear). Extensive histological work ensued following the implantation of these materials into experimental animals in order to understand the biological response elicited by materials in various tissues, with scant research done to explore the use of alternative materials for similar applications. Therefore, the field focused on the application of materials science principles to materials in biomedical use. With only very few exceptions, biomaterials were synthetic and intended to be permanent implants that substituted for structure and/or function in diseased or traumatized tissues. Biomaterials research was mostly in the hands of engineers, physical scientists, pathologists, and clinicians who brought their skills to these new applications of technological materials.

The main objective in biomaterials research has become the design of materials that can interact specifically with the biological environment for a given purpose. This includes the so-called tissue regeneration approach: Biomaterials are considered as temporary "anchoring scaffolds" to which specific types of cells can colonize and use to elaborate three-dimensional tissues. The objective is to help biology regenerate the missing or dysfunctional body parts by providing a biodegradable substrate. Another more recent objective is to use materials as vehicles to deliver large and small molecules to specific tissues in order to restore normal physiological function. A good example in this genomic era is the use of biomaterials to de

liver genes to cells to reverse disease, at least temporarily, or to alleviate the symptoms of disease. This is accomplished by transfecting cells with the missing normal genes encapsulated or dispersed in various structures. These structures play a key role in the success of such procedures, and therefore the correct biomaterials design of this purpose is of critical importance. In increasingly sophisticated ways, specially designed biomaterials are also being explored as delivery agents of therapeutic drugs or as encapsulants of non-autologous cells. In this last example, cells are exploited for the delivery of the biomacromolecules they produce but are hidden from the immune system by the biomaterials used to encapsulate them. The strategy of using materials as delivery agents provides many opportunities related to the design of micromaterials and, eventually, nanomaterials, which are miniaturized constructs designed to encapsulate, target, and deliver cargo to a specific tissue site. This strategy could contribute immensely to the eradication of cancer morbidity or the cure of other diseases. The general field of very smart micro- and nano-biomaterials will continue to expand with contributions to molecular design from materials scientists, chemists, and bioengineers.

The field of biomaterials has also grown and evolved in its capacity to study the molecular biology and cell biology of the implant-tissue interface. This work aims at understanding the biological response elicited by synthetic materials used in human repair, and great advances have occurred over the past few years that are useful in implant design. The surgical introduction of synthetic materials in living tissues elicits the expected inflammatory response, but depending on material composition, chemical degradation, surface texture, and other factors, a continuum of other responses can be observed. These include immune and foreign body responses often culminating in the fibrous encapsulation of implants with avascular tissue, which in turn contributes to a high risk of infection and limited implant durability. Over the past decade, biological response to materials has taken advantage of advances in molecular biology in an attempt to decipher the complex proteomics operating at these interfaces.

Experts in the field of biomaterials have been working in the new areas and directions discussed above. One area covered is the biological response to synthetic materials, including specific mechanisms involved in osteoblast response to implant surfaces. This topic is of great interest in bone repair and is one of the most useful applications of biomaterials in medicine. Another area covers the new field of biomaterials designed for specific biological or delivery functions. This area will certainly continue to grow with increasingly sophisticated molecular biomaterials designed to achieve targeted functions. Specific systems such as phospholipid strategies for biominerlization, photopolymerizable biomaterials, materials for gene delivery, and self-asssembling polymer membranes and colloids have also been studying by other scientists. From the field of biominerlization other strategies are being explored that could lead to the development of biomimetic biomaterials for tissue repair. All these efforts, combined with emerging capabilities in nanoscale materials science, are defining an exciting new field of biomaterials science and engineering that not only targets human body repair but also science and technology in general.

(Seclected from *Annual Review of Materials Science*, by Samuel I. Stupp, 2001)

New Words and Expressions

synthetic [sin'θetik] *a.* 合成的，人造的，综合的

implant [im'plɑ:nt] *vt.* 植入

orthopedic [ˌɔːθəu'piːdik] (=orthopaedic) *a.* 整形外科的

ultrahigh ['ʌltrə'hai] *a.* 超高的，特高的

terephthalate ['teˌræf'θæleit] *n.* 对苯二酸盐（或酯）

fabric ['fæbrik] *n.* 织品，织物，布，结构，建筑物，构造

cellulose ['seljuləus] *n.* 纤维，纤维素

dialysis [dai'ælisis] *n.* 透析，分离

elicit [i'lisit] *vt.* 得出，引出，抽出，引起

traumatize ['trɔːmətaiz] *vt.* 使受损伤，使受精神上创伤

pathologist [pə'θɔlədʒist] *n.* 病理学者

anchor ['æŋkə] *vt.、vi.* 抛锚；停泊；使稳固；使稳定

elaborate [i'læbərit] *a.* 精细的，精巧的，复杂的；*v.* 详细描述

genomic [dʒi'nɔmik] *a.* 基因组的，染色体组的

transfect [træns'fekt] *vt.* 使转染，使（细胞）感染病毒核酸

encapsulate [in'kæpsjuleit] *vt.* 装入胶囊，压缩；*vi.* 形成胶囊

therapeutic [ˌθerə'pjuːtik] *a.* 治疗的，治疗学的；*n.* 治疗剂，治疗药物

autologous [ɔː'tɔləgəs] *a.* 自体同源的，自体固有的

macromolecule [ˌmækrəu'mɔlikjuːl] *n.* 巨大分子，高分子

miniaturize ['miniətʃəraiz] *vt.* 使小型化

eradication [iˌrædi'keiʃən] *n.* 连根拔除，根除

morbidity [mɔː'biditi] *n.* 病态，不健全，发病率

inflammatory [in'flæmətəri] *a.* 发炎的，引起炎症的

texture ['tekstʃə] *n.* （织品的）质地，（木材，岩石等的）纹理，（皮肤）肌理，（文艺作品）结构

continuum [kən'tinjuəm] *n.* 连续统一体，连续统，闭联集

culminate ['kʌlmineit] *v.* 达到顶点（高潮）

fibrous ['faibrəs] *a.* 含纤维的，纤维性的

avascular [ə'væskjulə] *a.* （组织等）无血管的

osteoblast ['ɔstiəblæst] *n.* 造骨细胞

biomineralization ['baiəuˌminərəlai'zeiʃən] *n.* 生物成矿，生物矿化

photopolymerization ['fəutəuˌpɔlimərai'zeiʃən] *n.* 光聚作用，光压聚合作用

phospholipid [ˌfɔsfə'lipid] *n.* 磷脂

assemble [ə'sembl] *vt.* 集合，聚集，装配；*vi.* 集合

membrane ['membrein] *n.* 膜，隔膜

colloid ['kɔlɔid] *n.* 胶体；*a.* 胶体的

Notes

① Therefore, biomaterials research was mostly centered on in vitro testing of these materi-

als under conditions that simulated the biological environment. in vitro，在生物体外的。

参考译文：因此，生物材料研究大多集中在模拟生物环境条件下材料的体外检测。

② One area covered is the biological response to synthetic materials, including specific mechanisms involved in osteoblast response to implant surfaces. the biological response to synthetic materials，对合成材料的生物学反应。参考译文：其中一个研究领域是对合成材料的生物学反应，包括涉及造骨细胞对植入体表面反应的特殊机理。

Exercises

1. Question for discussion

   (1) Briefly state the development of biomaterials research.

   (2) What are the main purposes of biomaterials research?

   (3) Which new areas are covered in the field of biomaterials?

2. Translate the following into Chinese

biomaterials	cell biology
biodegradable substrate	pathologist
molecular biomaterials	implant-tissue interface

   • With only very few exceptions, biomaterials were synthetic and intended to be permanent implants that substituted for structure and/or function in diseased or traumatized tissues.

   • The field of biomaterials has also grown and evolved in its capacity to study the molecular biology and cell biology of the implant-tissue interface.

   • The surgical introduction of synthetic materials in living tissues elicits the expected inflammatory response, but depending on material composition, chemical degradation, surface texture, and other factors, a continuum of other responses can be observed.

   • Specific systems such as phospholipid strategies for biominerlization, photopolymerizable biomaterials, materials for gene delivery, and self-asssembling polymer membranes and colloids have also been studying by scientists

3. Translate the following into English

分子生物学	整形外科医生
人造血管	光压聚合生物材料
免疫系统	纳米生物材料
基因传递	生物巨分子

Reading Material

Bioactive Alternative Materials

During the last decade considerable attention has been directed towards the use of im-

plants with bioactive fixation, where bioactive fixation is defined as interfacial bonding of an implant to tissue by means of formation of a biologically active hydroxyapatite layer on the implant surface. An important advantage of bioactive fixation is that a bioactive bond forms at the implant-bone interface with a strength equal to or greater than bone after $3 \sim 6$ months.

Materials for clinical use can be classified into 3 categories; resorbable, bioactive and nearly inert materials. A bioactive material is defined as a material that elicits a specific biological response at the interface of the material, which results in a formation of a bond between the tissue and that material. The level of bioactivity of a specific material can be related to the time taken for more than 50% of the interface to bond to bone ($t_{0.5bb}$);

Bioactivity index $\qquad I_B = 100/t_{0.5bb}$ $\hfill$ (1)

Materials exhibiting an I_B value greater than 8 (class A), e. g. 45S5 Bioglass, will bond to both soft and hard tissue. Materials with an I_B value less than 8 (class B), but greater than 0, e. g. synthetic hydroxyapatite, will bond only to hard tissue. A bioactive glass is one that undergoes surface dissolution in a physiological environment in order to form a hydroxycarbonate apatite (HCA) layer. The larger the solubility of a bioactive glass, the more pronounced is the effect of bone tissue growth.

Features of Class A Bioactive Materials

An important feature of Class A bioactive particulates is that they are osteoproductive as well as osteoconductive. In contrast, Class B bioactive materials exhibit only osteoconductivity, defined as the characteristic of bone growth and bonding along a surface. As indicated in dense synthetic hydroxyapatite (HA) ceramic implants exhibit Class B bioactivity. Osteoproduction occurs when bone proliferates on the particulate surfaces of a mass due to enhanced osteoblast activity. Enhanced proliferation and differentiation of osteoprogenitor cells, stimulated by slow resorption of the Class A bioactive particles, are responsible for osteoproduction.

Is Bioactive Fixation the Solution?

During the last decade, it has been assumed that improved interfacial stability achieved with bioactive fixation would improve implant survivability. Clinical trials have shown this to often not be the case. Replacement of the roots of extracted teeth with dense HA ceramic cones to preserve the edentulous alveolar ridge of denture wearers resulted in generally less than 50% survivability at only five years. Early use of HA-coated orthopaedic implants seldom showed ten-year survivability greater than the 85% figure for cemented total hip prostheses. However, long-term success rates of bioactive HA coatings have improved during the last decade due to greater control of the coating process. The survivability of HA-coated femoral stems is now equivalent at ten years to cemented prostheses. It will take another five years to know if survivability is superior when HA coatings are used.

Why is bioactive fixation not a panacea to implant survivability? There are three primary

reasons: (1) *metallic prostheses with a bioactive coating still have a mismatch in mechanical properties with host bone*, and therefore less than optimal biomechanical and bioelectric stimuli, at the bonded interface, (2) the bioactive bonded interface is unable to remodel in response to applied load, and (3) use of bioactive materials does not solve the problem of osteolysis due to wear debris generated from the polyethylene cups. Use of alumina-alumina bearing surfaces eliminates most wear debris from total hip prostheses but increases the cost of the prosthesis by 200% ~ 300%. For younger patients the cost is well invested, but for the general population it often is considered to be too expensive.

Most biomaterials in use today and the prostheses made from the materials have evolved from trial and error experiments. Optimal biochemical and biomechanical features that match living tissues have not been achieved, so it also is not surprising that long-term implant survivability has not been improved very much during the last 15 years.

Bioactive Gel-Glasses: A Regenerative Material?

The biological response to bioactive gel-glasses made from the CaO-P_2O_5-SiO_2 system provides recent evidence that bone regeneration is feasible. Low-temperature hydrolysis and condensation reactions of tetraethoxysilane (TEOS) and calcium and phosphorous alkoxide precursors create a highly interconnected 3-D gel network composed of $(SiO_4)^{4-}$ tetrahedra bonded either to neighbouring silica tetrahedra via bridging oxygen (BO) bonds or by Si—O—Ca or Si—O—P non-bridging (NBO) bonds. The 1 ~ 10 nm scale solid network that comprises the gel is completely interpenetrated by pore liquid. The pore liquid consists of a highly structured hydrated layer that has substantially different physical chemical properties than free water and is more like the bound water contained within highly hydrated connective tissues such as cartilage. Biological molecules can exchange with these hydrated layers inside the pores of gel-glasses and maintain their conformation and biological activity. Many enzymes remain active within a hydrated gel matrix, and in some cases exhibit enhanced activity. Such hierarchical structures and behaviour go far beyond historically important bioinert orthopaedic materials such as PMMA, ultrahigh molecular weight polyethylene, stainless steel, Co-Cr and Ti-alloys towards matching the ultrastructure and molecular chemistry of bone. An important factor for future research is that the structure and chemistry of bioactive gel-glasses can be tailored at a molecular level by varying either composition (such as SiO_2 content) or thermal or environmental processing history. The compositional range for Class A bioactive behaviour is considerably extended for the bioactive gel-glasses over Class A bioactive glasses and glass-ceramics made by standard high-temperature melting or hot pressing. Thus, gel-glasses offer several new degrees of freedom over the influence of cellular differentiation and tissue proliferation. This enhanced biomolecular control will be vital in developing the matrices and scaffolds for engineering of tissues and for the *in vivo* regenerative allograft stimulation of tissue repair.

Evidence of the regenerative capacity of bioactive gel-glasses is based on comparison of the rates of proliferation of trabecular bone in a rabbit femoral defect model. Melt-derived

Class A 45S5 bioactive glass particles exhibit substantially greater rates of trabecular bone growth and a greater final quantity of bone than Class B synthetic HA ceramic or bioactive glass-ceramic particles. The restored trabecular bone has a morphological structure equivalent to the normal host bone after 6 weeks; however, the regenerated bone still contains some of the larger (>90 micrometers) bioactive glass particles. Recent studies show that use of bioactive gel-glass particles in the same animal model produces an even faster rate of trabecular bone regeneration with no residual gel-glass particles. The gel-glass particles resorb more rapidly during proliferation of trabecular bone. The mechanical quality of the regenerated bone appears to be equivalent to that of the control sites. Thus, the criteria of a regenerative allograft cited above appear to have been met. Our challenge for the future is to extend these findings to studies in compromised bones, with osteopenia and osteoporosis, to apply the concept to humans with ageing bones and degenerative joint disease and to use the results to design the 3 D architectures required for engineering of tissues.

Genetic Control by Bioactive Materials

We have now discovered the genes involved in phenotype expression and bone and joint morphogenesis, and thus are on the way towards learning the correct combination of extracellular and intracellular chemical concentration gradients, cellular attachment complexes and other stimuli required to activate tissue regeneration *in situ*. Professor Julia Polak's group at the Imperial College Tissue Engineering Centre has recently shown that seven families of genes are up-regulated and down-regulated by bioactive glass extracts during proliferation and differentiation of primary human osteoblasts *in vitro*. These findings should make it possible to design a new generation of bioactive materials for regeneration of bone. The significant new finding is that low levels of dissolution of the bioactive glass particles in the physiological environment exert a genetic control over osteoblast cell cycle and rapid expression of genes that regulate osteogenesis and the production of growth factors.

Inverstigation have also shown that within 48 hours a group of genes was activated including genes encoding nuclear transcription factors and potent growth factors. These results were obtained using cultures of human osteoblasts, obtained from excised femoral heads of patients (50~70 years) undergoing total hip arthroplasy.

In particular, insulin-like growth factor (IGF) II, IGF-binding proteins and proteases that cleave IGF-II from their binding proteins were identified. The activation of numerous early response genes and synthesis of growth factors was shown to modulate the cell cycle response of osteoblasts to the bioactive glasses and their ionic dissolution products. These results indicate that bioactive glasses enchance osteogenesis through a direct control over genes that regulate cell cycle induction and progression. However, these molecular biology results also confirm that the osteoprogenitor cells must be in a chemical environment suitable for passing checkpoints in the cell cycle towards the synthesis and mitosis phases. Only a select number of cells from a population are capable of dividing and becoming mature osteoblasts. The others are switched into apoptosis. The number of progenitor cells capable of being

stimulated by a bioactive medium decreases as a patient ages. These findings may account for the time delay in formation of new bone in augmented sites.

Orthopaedic Clinical Use of Regenerative Bioactive Materials

Clinical application of the use of a regenerative biomaterial in orthopaedics is beginning. In 1993, particulate bioactive glass, 45S5 Bioglass was cleared in the USA for clinical use as a bone graft material for the repair of periodontal osseous defects. Since that time, numerous oral and maxillofacial clinical studies have been conducted to expand the material indication. More than 2 000 000 reconstructive surgeries in the jaw have been performed with the material. The same material has been used by several orthopaedic surgeons to fill a variety of osseous defects and for clinical use in orthopaedics, such as Nova Bone, which is now approved for clinical use in Europe.

(Selected from *Material Science and Technology*, by J. R. Jones and L. L. Hench, 2001)

New Words and Expressions

hydroxyapatite ［hai'drɔksil'æpətait］ *n.* 羟磷灰石

proliferate ［prəu'lifəreit］ *v.* 增生扩散

edentulous ［iː'dentjuləs］ *a.* 缺齿的

alveolar ［æl'vialə］ *a.* 齿槽的

denture ［'dentʃə］ *n.* 一副假牙，一副牙齿

hip ［hip］ *n.* 臀

panacea ［ˌpænə'siə］ *n.* 万能药

host ［həust］ *n.* 晶核，基质

optimal ［'ɔptiməl］ *a.* 最佳的，最理想的

tetraethoxy ［ˌtetrəi'θɔksi］ *a.* 四羟基的

tetraethoxysilane ［ˌtetrəi'θɔksi'silein］ *n.* 四乙氧基硅烷

alkoxide ［æl'kɔksaid］ *n.* 醇盐；*a.* 烷氧基的

hydrate ［'haidreit］ *n.* 氢氧化物；*v.* 与水化合

cartilage ［'kɑːtilidʒ］ *n.* 软骨

enzyme ［'enzaim］ *n.* 酶

hierarchical ［ˌhaiə'rɑːkikəl］ *a.* 分等级的

inert ［i'nəːt］ *a.* 无活动的，惰性的，迟钝的

polyethylene ［ˌpɔli'eθiliːn］ 聚乙烯

ultrastructure ［'ʌltrə'strʌktʃə］ *n.* 超微结构，亚显微结构

proliferation ［prəuˌlifə'reiʃən］ *n.* 增殖，扩散

regenerative ［ri'dʒenəreitiv］ *a.* 再生的

allograft ［'æləgrɑːft］ *n.* 同种异体移植，异源移植

morphological ［ˌmɔːfə'lɔdʒikəl］ *a.* 形态学的

resorb ［ri'sɔːb］ *v.* 再吸收，消融

degenerative ［di'dʒenərətiv］ *a.* 退步的，退化的，变质的

phenotype ［'fi:nətaip］ *n.* 表型，具有共同表型的一类有机物

intracellular ［ˌintrə'selju:lə］ *a.* 细胞内的

excise ［ek'saiz］ *n. & v.* 切除

femoral ［'femərəl］ *a.* 股骨的，大腿骨的，大腿的，股动脉的

arthroplasy ［'ɑ:θrəuˌplæsi］ *a.* 亲关节的，向关节的，致关节疾病的

progenitor ［prəu'dʒenitə］ *n.* 祖先，起源，前身

orthopaedics ［ˌɔ:θəu'pi:diks］ *n.* 整形外科，整形术

periodontal ［ˌperiəu'dəntəl］ *a.* 牙齿周围的，牙齿膜的

osseous ［'ɔsiəs］ *a.* 骨的，骨质的

maxillofacial ［mækˌsiləu'feiʃəl］ *a.* 上颌面的

Notes

① A bioactive material is defined as a material that elicits a specific biological response at the interface of the material, which results in a formation of a bond between the tissue and that material. bioactive material，生物活性材料。参考译文：生物活性材料是 一种能在材料界面引起特殊的生物学反应的材料，可使生物组织与材料之间形成一种结合键。

② Most biomaterials in use today and the prostheses made from the materials have evolved from trial and error experiments. trial and error，反复实验，不断摸索；evolve from，由……进化。参考译文：当今使用的大多数生物材料以及由这些材料制成的各种修补物假体，都是通过反复实验获得的。

③ Optimal biochemical and biomechanical features that match living tissues have not been achieved,... Biochemical feature，生物化学性质；living tissue，生物组织。

④ The pore liquid consists of a highly structured hydrated layer that has substantially different physical chemical properties than free water and is more like the bound water contained within highly hydrated connective tissues such as cartilage. pore liquid，孔隙流体；physical chemical properties，物理化学特性，物理化学是 physical chemistry；free water，自由水，与 bound water 相对应。

⑤ Inverstigation have also shown that within 48 hours a group of genes was activated including genes encoding nuclear transcription factors and potent growth factors. a group of genes，一组基因；be activated 在此处是"被激活"、"活化"的意思；transcription，转录，例如：nuclear transcription factors，核转录因子；genetic transcription，基因转录；potent growth factor，有效生长因子。

⑥ Only a select number of cells from a population are capable of dividing and becoming mature osteoblasts. 本句以"Only"开头，强调主语。a select number of cells，被严格挑选出来的若干（一些）细胞。

Unit 25   Design of Novel Functional Biomaterials

Important advances have recently been made in the development of biomimetic materials that are capable of interacting specifically with their biological environment. This interaction has been accomplished by harnessing the principles involved in biological recognition between protein and proteoglycan receptors on cell surfaces with other biological molecules normally present in the extracellular matrix (ECM), on another cell, or in solution. These biologically active materials can play a pivotal role in tissue engineering by allowing initially cell-free materials to elicit cellular infiltration within an implanted material and to direct the formation of new tissues within the material at the local implant site. In this approach, the implanted materials function both as a mechanical scaffold for tissue regeneration and as a pharmacological agent that alters the course of regeneration via the transmission of biological signals to cells in the surrounding tissue.

Fox example, biomimetic materials can be used to enhance peripheral nerve regeneration. Synthetic nerve guidance tubes have been used for decades as a mechanical means to reconnect the ends of a severed nerve. However, simply providing a physical connection between the ends of a severed nerve is not sufficient to induce nerve regeneration across a critical size defect. In order for successful nerve regeneration to occur, a tissue-engineered scaffold must be provided that supplies not only the mechanical support for regenerating axons and protection against the ingrowth of scar tissue, but it must also supply direction cues to guide the regenerating nerve back to the appropriate targets of innervation and survival factors to prevent neuronal death during regeneration. Guidance signals in the form of adhesion factors can be incorporated into biomimetic materials to enhance migration on or through the material toward the proper target. In addition, survival and differentiation factors can be covalently or non-covalently incorporated into biomaterials to create delivery systems to mod ify cellular response during tissue regeneration.

Biological recognition of materials can take several forms. Incorporation of biomimetic adhesion sites for the case of nerve regeneration can be used to promote cell adhesion and migration on or within bioactive materials. The incorporation and controlled release of growth factors is a second approach for controlling biological recognition within materials. Incorporation of DNA into bioactive materials provides an additional method for controlling cellular response. Furthermore, material transformation can be designed to occur in response to an external stimulus, such as light, temperature, or chemical composition. And at last, microfabricated biomaterials is a new class of biomimetic materials.

Incorporation of Biomimetic Adhesion Signals

Biomaterials can be endowed with biological activity through the incorporation of adhe-

sion-promoting oligopeptides. In vivo, cell recognition of traditional biomaterials, such as polytetrafluoroethylene, silicone rubber, or polyethylene, occurs indirectly. Proteins from body fluids adsorb nonspecifically onto the surfaces of these materials, and some of the proteins adsorbed, including fibronectin, vitronectin, and fibrinogen, promote the adhesion of cells via cell-surface adhesion receptors for these proteins. Preventing the nonspecific adhesion of proteins on the material surface and incorporating cell-type-specific adhesion-promoting peptides allows more direct control of cell adhesion on biomaterials.

The incorporation of adhesion-promoting peptides into biomaterial surfaces has been studied extensively. These peptides are short primary sequences taken from the receptor-binding domains of adhesion proteins such as laminine and fibronectin. The most commonly studied adhesion peptide is the tri-peptide sequence, RGD. Now, RGD has been used extensively to render surfaces and materials biologically active. The advantages of using small peptides rather than whole proteins are that they are relatively inexpensive to make and easy to purify; whereas whole adhesion proteins, such as fibronectin or laminin, are expensive and often not available in a clinically acceptable form.

Biomaterials for Drug Delivery

Polypeptide growth factors are powerful regulators of biological function. They modulate many cellular functions including migration, proliferation, differentiation, and survival. Incorporation of growth factors is an additional approach for rendering biomaterials biologically active. However, the biological activity of growth factors is dependent not only on their presence in solution, but also on their interactions with the ECM. For example, some growth factors are most effective when release occurs over a prolonged period of time, whereas others are more effective when delivered in a bolus; some factors are active while tethered to a material, whereas others are only active when they have been released from the material and are internalized into a cell. These differences may result from the different pathways that are used to transduce signals from a particular growth factor and how its receptors traffic and are recycled within the cell. All these differences between growth factors must be taken into account when designing a delivery system to be incorporated into a biomaterial, and they often play an important role in selecting what kind of delivery system should be used.

Biomaterials for Gene Delivery

The immobilization of DNA is another method for incorporating biological signals into biomimetic materials. Typically, plasmid DNA is presented on or within a biomaterial to enhance the efficiency of its uptake and limit expression of the protein encoded for by the plasmid to the target tissue of interest. DNA incorporation provides an additional degree of control in manipulating the cellular response during tissue repair and regeneration. For example, DNA delivery can be used to express proteins that typically act primarily as an extra-

cellular component in a signaling cascade, such as growth factors. By incorporating the DNA into the biomaterial, its release from the material and uptake by cell can be regulated through modifications to the material.

In Situ Transformation of Materials

An important feature for functional biomaterials is that active material transformation from one state to another, i. e. , from liquid precursor to solid material, can occur in the presence of biological systems. Material transformation can be designed to occur in response to an external stimulus, such as light, temperature, or chemical composition. Materials capable of such in situ transformation are attractive because they enable new minimally invasive surgical procedures, such as the closure of internal incisions by the injection of a bioactive surgical sealant.

One type of material transformation that can be used to modulate the biological activity of materials is the swelling or collapse of materials in response to environmental stimuli. By designing materials that exhibit lower or upper critical solution behavior, gels can be formed at temperature greater than critical temperature of the material. These types of transitions can be exploited to develop materials that are liquid at room temperature, but upon injection undergo a transition and form nonflowing solids at physiological temperature. In addition, drug-containing biomaterials can be developed that do not release drug until they reach the target tissue for delivery, at which time a shift in the biological environment triggers release.

Microfabricated Devices

Another approach for creating biologically active materials is the use of microfabrication techniques to design materials. These materials can have features whose size is the same order of magnitude as a cell diameter, and by using techniques that can be controlled on the micron scale, the cell-sized features created on or within materials can be much more complex in nature because of the enhanced degree of control in the fabrication. For example, microchip devices can be fabricated to contain biologically active feature, or features that can become biologically active in response to an external stimulus, such as pulsatile electric fields. Micofabrication techniques can also be applied to develop complex tissue-engineered scaffolds with elaborate features the size of a cell.

In summary, the development of modern biomaterials requires that the materials designed are not only bio-inert but also that they interact with and even respond to their biological environment. Bioactive materials must be able to provide biologically active signals that can indicate cell adhesion, migration, proliferation, differentiation, or even apoptosis. Through this type of communication, the materials can share their messages with the surrounding biological environment; for example by providing a morphogenetic signal to promote tissue regeneration. Bioactive materials that are designed to respond to stimuli can also respond to biological activity around them: for example by releasing a drug or degrading in response to a cellular stimulus. The ability of biomaterials to sense biological demand or

changes in their environment is critical in the development of "intelligent biomaterials" for the future.

<div align="right">

(Selected from *Functional Biomaterials*: *Design of Novel biomaterials*,

by SE Sakiyama-Elbert and JA Hubbell, 2001)

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New Words and Expressions

proteoglycan [ˌprəutiə'glaikæn] *n.* 蛋白聚糖，蛋白多糖

pivotal ['pivətl] *a.* 枢轴的，中枢的，关键的

pharmacological [ˌfɑːməkə'lɔdʒik] *a.* 药理学的，药物学的

peripheral [pə'rifərəl] *a.* 周界的，外围的，（神经）末梢区域的

axon ['ækson] *n.* （神经的）轴突，轴突（输出端）

innervation [ˌinəː'veifən] *n.* 神经分布，神经支配，神经兴奋作用（或过程）

neuronal ['njuərənəl] *a.* 神经原的，神经细胞的

neuronal ensemble 神经元集合

fibrinogen [fai'brinədʒən] *n.* 纤维蛋白原

peptide ['peptaid] *n.* 缩氨酸，肽

laminine ['læminin] *n.* 昆布氨酸，*N*-三甲基赖氨酸内盐

tether ['teðə] *n.* 范围，限度；*v.* 限定，束缚

transduce [træns'djuːs] *v.* 转换（能、信号等）

plasmid ['plæzmid] *n.* 质粒，质体

cascade [kæs'keid] *n.* 层叠

situs ['saitəs] *n.* [*sing.*，*pl.*] 部位（尤指动植物器官生来的原位置），地点

incision [in'siʒən] *n.* 切割，切开，切口

sealant ['siːlənt] *n.* 密封剂，密封胶，密封腻子

Notes

① In this approach, the implanted materials function both as a mechanical scaffold for tissue regeneration and as a pharmacological agent.... function as, 起……作用，相当于 serve as 或 act as, as 为介词，其后跟着两个由 both... and... 连接的宾语，分别为 a mechanical scaffold 和 a pharmacological agent。

② An important feature for functional biomaterials is that active material transformation from one state to another, i. e., from liquid precursor to solid material, can occur in the presence of biological systems. from liquid precursor to solid material, 从原来的流体转变成固体材料，注意 precursor 的意思是产物母体、先质、前体。参考译文：功能生物材料的一个重要性质是，在生物体系中，可发生生物活性材料由一种状态向另一种状态的转变的现象，例如从原来的流体状态转变成固体材料。

Exercises

1. Question for discussion

(1) How many and which approaches can we use to control biological recognition within

materials?

(2) What preconditions does the development of modern biomaterials depend on?

2. Translate the following into Chinese

functional biomaterials	material transformation
drug delivery	biomimetic materials
bioactive surgical sealant	microfabrication technique

- Biological recognition of materials can take several forms. Incorporation of biomimetic adhesion sites for the case of nerve regeneration can be used to promote cell adhesion and migration on or within bioactive materials. The incorporation and controlled release of growth factors is a second approach for controlling biological recognition within materials. Incorporation of DNA into bioactive materials provides an additional method for controlling cellular response. Furthermore, material transformation can be designed to occur in response to an external stimulus, such as light, temperature, or chemical composition. And at last, microfabricated biomaterials is a new class of biomimetic materials.

- The ability of biomaterials to sense biological demand or changes in their environment is critical in the development of "intelligent biomaterials" for the future.

3. Translate the following into English

蛋白质	细胞渗透
智能生物材料	组织修复
生长因子	临界温度

Reading Material

Functional Biomaterials: Active Material Transformation

Functional biomaterials must be capable of undergoing an active material transformation from one state to another in the presence of biological systems. This ability to transform from an injectable state to a solid state is highly beneficial for use in minimally invasive surgical procedures. The material transformation can be designed to occur in response to an external stimulus, such as light, temperature, or chemical composition.

Artificial-Protein Materials

One approach to developing materials that can undergo transformation while in contact with a biological system is to borrow from nature itself. Many biological protein assemble in multimeric structures bases on a class of proteins, which are found in many proteins, control the assembly of intracellular regulatory proteins such as Jun, a transcription factor that is only active in the dimeric state. Coiled-coil structures, such as the leucine zipper, have

been studied extensively. Several researchers have utilized the knowledge derived from these studies to develop materials that assemble based on coiled-coil protein interactions. These materials often undergo a transition in response to either temperature or pH changes.

Coiled-Coil Self-Assembling Materials: Artificial protein polymers are developed that undergo reversible gelation in response to changes in pH or temperature. These protein contained a central water-soluble polyelectrolyte segment, consisting of the tri-peptide sequence $(PFG)_x$, and terminal leucine zipper domains flank this central domain on either end. These terminal leucine zipper domains undergo a transformation near neutral pH that results in the formation of a three-dimensional network owing to coil aggregation. This transition is reversible, and at higher pHs the coiled-coil aggregates dissociate, resulting in dissolution of the network. These materials may be useful for cell encapsulation or drug delivery applications.

Scientists have developed a stimulus-sensitive hybrid hydrogel that is assembled from water-soluble synthetic polymers and proteins containing coiled-coil protein-folding motifs, which swell or shrink in response to environmental stimuli. These hydrogels undergo a reversible, temperature-induced collapse owing to the cooperative conformational transition of the coiled-coil protein domain. The synthetic polymer component is made up of a liner hydrophilic copolymer of N-(2-hydroxylpropy) -methacrylamide (HPMA) and a metal chelating monomer N-(N'-N''-dicarboxymethylaminopropyl) methacrylamide (DAMA) with pendant iminodiacetate (IDA) groups that serve as metal chelating ligands. The IDA groups formed a complex with Ni^{2+}, and these complexes can bind to terminal histidine residues (His tag) of the protein component of the hydrogels Hydrogels were formed by mixing the chelating copolymers of HPMA charged with Ni^{2+} and the coiled-coil proteins. Homogeneous films of these materials were formed by drying the mixture on Teflon sheets. The dried films were rehydrated and under physiological conditions were stable for at least 24 h. whereas control films lacking polymer, Ni^{2+}, or coiled-coil protein dissolved upon hydration. When heated to 70℃ the gels underwent a sudden collapse to 10% of the equilibrium volume at 25℃. Because of the mild conditions under which these hydrogels are formed, they may be excellent candidates for the delivery of protein drugs. In addition, the properties of the materials can be varied by tailoring the transition temperature of the coiled-coil domains.

Elastin-Based Materials: Another approach to materials design that can be derived from nature is to mimic the structure of naturally occurring proteins to obtain artificial protein polymers with similar mechanical properties. The most commonly mimicked protein is elastin, which has a short-repeating sequence, GVGVP, that can endow artificial protein with secondary structure and mechanical properties similar to those of elastin.

At present, materials scientists have developed protein-based polymers that mimic the GVGVP repeats found in elastin. These elastin-like proteins can also be cross-linked through the use of gamma irradiation or. If lysine residues are included in the polymer backbone, lysyl oxidase can be used to cross-link the fibers. Such materials may be useful for

soft tissue augmentation.

Scientists have also developed protein polymers that mimic silk and elastin consisting of GAGAGS and GVGVP repeats, which undergo liquid-to-solid phase transitions in aqueous solution. These protein polymer gels can be used for the delivery of proteins or other high-molecular-weight drugs, without significant reduction of protein activity. The phase transition by which the gels are formed can be controlled by varying the number of silk versus elastin domains, as well as by varying the polymer concentration in solution to alter the gelation temperature and gel time. In addition, this transformation from liquid to solid requires no additional cross-linking agents, which are often toxic and cannot be used for in situ cross-linking.

Self-Assembling Peptide-Based Systems: Biomaterials researchers have developed materials that form self-assembling matrices based in ionic self-complementary oligopeptides. These oligopeptides self-assemble under physiological conditions to form three-dimensional tissue-engineered matrices capable of supporting cell adhesion. The study on the mechanical properties of matrices found that the elastic modulus increased with increasing peptide concentration in the matrices.

Synthetic Materials

Much research in biomaterials has focused on the design and development of synthetic materials that can undergo transitions in the presence of biological systems. These phase transitions must occur under conditions that do not cause significant damage to the surrounding tissue, but the transitions must also be controllable, for example, so that the precursor material does not become a solid prior to injection. However, because synthetic material design is not constrained by the building blocks supplied by nature, there are more possibilities for material chemistries that will allow activation of material transformation in the presence of biological systems. For example, light can be used in combination with a photo-initiator to trigger material transformation, or material transformation can be triggered by the mixing of two reactive liquids. In addition, transformation stimuli used for artificial protein materials, such as temperature or pH changes, can also be used for the development of biologically active synthetic materials.

Photopolymerized Materials: Synthetic materials that can undergo phase transitions in contact with biological systems have a great potential for use in surgery, for example, as adhesives, sealants, and barriers to cell-tissue adhesion. Polyethylene glycol (PEG) -based materials have been developed that contain a central PEG block with oligo (lactic acid) flanking blocks and terminal acrylates. The PEG block provides water solubility and enhances the biocompatibility for use in polymerization. These polymers can be rapidly transformed into hydrogels by exposure to light in the presence of suitable photo-initiators, such as eosin yellowish. These materials can also be used to block platelet adhesion following balloon angioplasty to prevent restenosis or to prevent scar tissue adhesions formation after gynecological surgery.

Temperature-Induced Gelation: Temperature-induced material transformation is one of the most widely used methods for the development of biologically active materials. Scientists have extensively studied polymers that exhibit phase transitions in response to stimuli such as a change in pH or temperature; and developed pH-sensitive hydrogels based on the incorporation of poly (acrylic acid) (PAAc) into temperature-sensitive polymers. These polys undergo phase separation in response to changes in temperature and pH in a manner similar to individual polymers. These materials can be used as reversible cell culture substrates upon which cell monolayer or multiplayer can be cultured, and then after material transformation, these cell layers can be released in the form of intact sheets for subsequent transplantation. These materials can also be used to block a ligand-binding site on proteins in thermally controlled manner, by utilizing the transformation of an extended chain to a collapsed chain to block binding above a given temperature.

Multifunctional Reactive Polymers: Another approach to developing materials that can undergo transformation in the presence of biological molecules is mixing two solutions when reacted will form elastic gels. This approach can be applied in a manner similar to the clinical use of fibrin glue kits, in which two species react rapidly upon mixing to form three-dimensional networks in vivo. For example, an ester-containing, amine-reactive PEG derivative is synthesized and reacted with a branched PEG multiamine to form a hydrogel. Proteins can be incorporated into the gel during polymerization, either by physical entrapment of the protein within the network or by covalently coupling the protein to the hydrogel via a free amine group on the protein. These hydrogels degrade via hydrolysis of the ester linkages to release protein and low-molecular-weight Peg derivatives that can be cleared from the body.

Additionally, developing implantable biomimetic materials that incorporate growth factors, developing materials for the oral delivery of proteins such as insulin is another possibility. By taking advantage of the changes in the chemical environment in the gastrointestinal tract, materials can be developed that undergo a transition as they pass from the low pH environment of the stomach to the higher pH environment of the intestine.

In conclusion, the field of biomaterials has recently been focused on the design of intelligent materials. Toward this goal, materials have been developed that can provide specific bioactive function to control the biological environment around them during the process of materials integration and wound healing. In addition, materials have been developed that can respond to changes in their environment, such as a change in pH or cell-associated enzymatic activity. In designing such novel biomaterials, scientists have sought not merely to create bio-inert materials, but rather materials that can respond to the cellular environment around them to improve device integration and tissue regeneration.

(Selected from *Functional Biomaterials: Design of Novel biomaterials*,
by SE Sakiyama-Elbert and JA Hubbell, 2001)

New Words and Expressions

injectable [in'dʒekteibl]　*n.* 血管注射剂；*a.* 可注射的

dimeric [dai'merik] *a.* 二聚的，二分子的，二聚物的

intracellular [ˌintrə'selju:lə] *a.* 细胞内的

leucine ['lu:si:n] *n.* 亮氨酸，白氨酸

zip [zip] *n.* 拉链，拉锁

coiled-coil *n.* 线圈，感应器，环绕

gelation [dʒi'leiʃən] *n.* 冻结，凝胶化

terminal ['tə:minl] *n.* 终点站，终端，接线端；*a.* 末梢的，端的

dissociate [di'səuʃieit] *v.* 分离，游离，分裂

hydrophilic [ˌhaidrəu'filik] *a.* 亲水的，吸水的

chelate ['ki:leit] *n.* 螯化的；*a.* 有螯的，螯合的

pendant ['pendənt] *n.* 垂环，垂饰，下垂物

histidine ['histidi:n] *n.* 组氨酸，组织氨基酸

rehydrate [ri'haiˌdreit] *v.* 再水化，再水合

hydration [hai'dreiʃən] *n.* 水合，水合作用

elastin [i'læstin] *n.* 弹性蛋白

mimic ['mimik] *a.* 模仿的；拟态的

adhsion [əd'hi:ʒən] *n.* 黏着，附着，黏连

eosin ['i:əsin] *n.* 曙红（四溴萤光素，鲜红色的染料）

platelet ['pleitlit] *n.* 血小板，小盘，小板

restenosis [ˌri:sti'nəusis] *n.* （尤指心瓣手术后的）再狭窄

gynecological [ˌgainikə'lɔdʒikəl] *a.* 妇产科医学的

monolayer [ˌmɔnəu'leiə] *n.* 单层

vivo ['vi:vəu] *n.* 体内

amine ['æmi:n] *n.* 胺

ester-containing *a.* 含酯的

mimetic [mi'metik] *a.* 模仿的，好模仿的；拟态的；类似的

gastrointestinal [ˌgæstrɔuin'testinl] *a.* 胃与肠的

Notes

① These materials often undergo a transition in response to either temperature or pH changes. in response to, 对……作出回答、响应、反应。参考译文：这些材料经常对环境温度或 pH 值的改变作出响应，发生相的转变。

② The study on the mechanical properties of matrices found that the elastic modulus increased with increasing peptide concentration in the matrices. 参考译文：基质的力学特性研究发现，其弹性模数随着基体中缩氨酸浓度的增加而增加。

③ Synthetic materials that can undergo phase transitions in contact with biological systems have a great potential for use in surgery. ... undergo phase transitions，经历相转变；in contact with，与……接触，保持联系；have a great potential for (use)，具有很大的（应用）前景。

Unit 26   Typical Applications of Biocomposites:
Soft Tissue Applications

Many different types of implants are used in the surgery to correct soft tissue deformities or defects which can be congenital, developmental, or acquired defects, the last category usually being secondary to trauma or tumor excision. Depending on the intended application, the soft tissue implants perform various functions: fill the space from some defect; enclose, store, isolate, or transport something in the body; and mechanical support or serving as a scaffold for tissue growth.

Bulk Space Fillers

Bulk space fillers are used to restore cosmetic defects, atrophy, or hypoplasty to an aesthetically satisfactory condition. They are mostly used in the head and neck. The materials used in these applications include SR (silicone rubber), PE (polyethylene), and PTFE (polytetrafluoroethylene). The space-fillers are also investigated for the replacement of articular cartilage in the case of its deterioration by osteoarthritis. Articular cartilage, $1 \sim 2$ mm thick, covers the opposing bony surfaces of typical synovial joints. The cartilage provides a means of absrobing force and provides low-friction bearing surfaces for joints. The cartilage replacement material must be hydrophilic with controlled water content, must have sufficient strength, and should be very smooth. Polymers such as SR and PTFE are proposed to fill the defects in the articular surfaces or to replace meniscus or fibrous tissues following the condylar shave or high condylectomy in the treatment of painful arthritis and to restore normal joint function. Composites comprising PET (polyethylenetereph-thalate) or PTFE fabrics and PU are more suitable for this purpose, as they are found to reduce the cartilage degeneration following the meniscectomy. At the same time, woven carbon fiber fabrics and their composites can be clinically used for the treatment of cartilage defects. No inflammatory change or deterioration in joint damage was reported, indicating the usefulness of the prostheses. Further improvements in the composite materials in terms of retaining the shape of the implant could further improve the joint biomechanics.

Encapsulants and Carriers

Wound Dressing: Burn victims are often treated with skin dressings. In order to conform to irregular surfaces, the skin dressing must be elastic and flexible. There are two opposite requirements for skin dressing to meet: it should prevent loss of fluids, electrolytes and other biomolecules from the wound and obstruct bacterial entry, but it should also be permeable enough to allow the passage of discharge through pores or cuts. In addition it

should be able to adhere to the wound surface, and easy to peel from the skin without disturbing new tissue growth. Woven fabrics or porous layers of resorbable polymers such as collagen, chitin, and PLLA [poly (L-lactic acid)] are used in many skin dressings. In hybrid skin dressings, synthetic polymers and cultured cells are combined to form vital/avital composites. They are designed to initiate, accelerate and control the natural skin repair process. Until now there is no synthetic material that can meet all the requirements of a skin substitute exactly.

Ureter Prosthesis: Ureter prostheses made of PVC (pilyvinylchloride), PE, nylon, PTFE, and SR were used without much long-term success. They were not very successful because of the difficulty of joining a fluid-tight prosthesis to the living system. In addition, constant danger of microbial infection and blockage of passage by calcification deposits from urine have proven to be difficult to overcome. Polyester fiber reinforced glycol methacrylate gel prostheses with a fabric backing was reported to be successful. The fabric backing facilitated easy attachment of prosthesis firmly on to the mucous membrane without irritation, and the hydrophilic nature of the gel helped to maintain a clear inner space. Similar solution was proposed for the replacement of portions of intestinal wall. There is a need to develop new materials with improved surface properties of minimal microbial adhesion, low friction, and control of cell and protein adsorption.

Catheters: Catheters (tubes) are increasingly used to access remote regions of the human body to administer fluids (e. g. nutrients, isotonic saline, glucose, medications, blood and blood products) as well as to obtain data (e. g. artery pressure, gases, collecting blood samples for analysis). PU (polyurethane) and SR are widely used materials for making catheters because of their flexibility and ease of fabrication in to variety of sizes and lengths in order to accommodate the wide range of vessels to be cannulated. Since catheter interfaces with blood, it is important that its design and material properties ensure blood compatibility, nonthrombogenicity, and inhibit infection. An ideal vascular catheter also must be flexible enough to allow vein and patient movement without becoming extravascular and damaging both the vessel and the surrounding structures. Catheters that are initially supple may become brittle over time, resulting in vascular wall damage. Newer designs consists of polymers (PU, and PVC) reinforced with braided Nitinol (Ni-Ti alloy) ribbons with the purpose of making a catheter having an exceptionally thin wall, controlled stiffness, high resistance to kinking, and complete recovery in vivo from kinking situations.

Functional Load-carrying and Supporting Implants

Tendons and Ligaments: The use of biomaterials in tendon/ligament repair is one of the most demanding applications of prostheses in soft tissues. A ligament or tendon prosthesis should: a) possess the same flexibility as the natural tissue in order to bend around articulations and assure the transmission of the force to the muscle always in the mode of a traction, b) reproduce similar mechanical properties including J-shaped stress-strain behavior, large extensibility without permanent deformation, and damping properties, and c) assure time

invariance of the mechanical properties. Biomaterials are used in a number of ways in tendon healing. They may be used to replace the tendon, to hold a damaged tendon in proper alignment, or to form a new sheath. In the last approach, a two-stage surgical procedure is followed. In the first operation, the tendon is replaced by a gliding implant that facilitates the formation of a new tendon sheath. In the second operation, a tendon graft replaces the gliding implant inside the newly formed sheath.

Vascular Grafts: Vascular Grafts are used to replace segments of the natural cardiovascular system (mainly successful in the case of blood vessels with lumen diameter of over 5 mm) that are diseased or blocked (atherosclerosis, deposits on the inner surface of the vessels restricting the flow of blood and increasing blood pressure). A typical example is to replace a section of aorta where aneurysm has occurred. Another example is the arteries in the legs of diabetic patients that have a tendency to be blocked. The composite graft is anisotropic, and isocompliant with the natural artery. The matrix material is designed to resorb in in vivo condition. At the time of implantation the impervious graft prevents any loss of blood. The resorption of matrix material during healing process will result in pores. The ingrowth of granulation tissue into pores provides a stable anchorage for the development of a viable cellular lining. The optimum pore size of the outer and inner layers of the graft can be designed to meet the exact needs of ingrowth and anchorage. The composite grafts are in the clinical research phase and yet to be used clinically.

Others: Hernia is an irregular protrusion of tissue, organ, or a portion of an organ through an abnormal break in the surrounding cavity's muscular or connective tissue wall. A number of materials such as nylon, PTFE, carbon, stainless steel, and tantalum in the form of fabrics or meshes are used to repair hernias. The fabrics or meshes facilitate tissue ingrowth thus providing stability to the prosthesis. Other suitable applications being currently investigated include tracheal prostheses (combined with stainless steel mesh or SR), prosthetic sphincters for gastrointestinal tracts, and urethral prostheses.

Additionally, prostheses are also used for restoring the conductive hearing loss from otosclerosis (a hereditary defect which involves a change in the bones of the middle ear). Otology prostheses made of polymers namely PMMA (polymethylmethacrylate), PTFE, PE, and SR, and CF (glass fiber) /PTFE composites have been tried to replace defective ossicles (three tiny bones of middle ear, malleus, incus, and stapes) Researchers are also developing PE/PU flexible composite materials as tympanic membrane replacements. Tympanic membrane transmits sound vibrations to the inner ear through three auditory ossicles.

(Selected from *Biocomposite Materials*, by S Remakrishna and Z H Huang, 2003)

New Words and Expressions

congenital [kən'dʒenitl] *a.* 天生的，先天的，天赋的
excision [ek'siʒən] *n.* 切除，删除；切除（术）
osteoarthritis [ˌɔstiəuɑː'θraitis] *n.* 骨关节炎
condylar ['kɔndilə] *a.* 髁的

chitin ['kaitin] *n.* 壳质，角素

ureter [juə'riːtə] *n.* 尿管，输尿管

intestinal [in'testinl] *a.* 肠的，肠内的，（疾病）侵袭肠的

glucose ['gluːkəus] *n.* 葡萄糖

isotonic [ˌaisəu'tɔnik] *a.* 等压的，等张的，等分的

artery ['ɑːtəri] *n.* 动脉，要道

catheter ['kæθitə] *n.* 导尿管，尿液管，导管

thrombophlebitis [ˌθrɔmbəufli'baitis] *n.* 血栓（性）静脉炎

vascular ['væskjulə] *a.* 脉管的，有脉管的，血管的

extravascular ['ekstrə'væskjulə] 额外动脉管

sheath [ʃiːθ] *n.* 鞘，护套，外壳

lumen ['luːmin] *n.* 流明（光通量单位）；内腔

aorta [ei'ɔːtə] *n.* 大动脉

aneurysm ['ænjuərizəm] *n.* 动脉瘤

diabetic [ˌdaiə'betik] *a.* 糖尿病的；*n.* 糖尿病患者

compliant [kəm'plaiənt] *a.* 顺从的，适应的

granulation [ˌgrænju'leiʃən] *n.* 使成粒状，有粒的表面，粗糙

anchorage ['æŋkəridʒ] *n.* 停泊地点，抛锚地点

hernia ['həːniə] *n.* 疝气，脱肠

protrusion [prə'truːʒən] *n.* 伸出，突出

cavity ['kæviti] *n.* 洞，空穴；腔

tantalum ['tæntələm] *n.* 钽（金属元素），符号 Ta，原子量序号 73

tracheal [trə'kiːəl] *a.* 气管的，导管的，呼吸管的

urethral [juə'riːθrəl] *a.* 尿道的

otology [əu'tɔlədʒi] *n.* 耳科学

ossicle ['ɔsikl] *n.* 小骨，小骨片

malleus ['mæliəs] *n.* 锤骨

incus ['iŋkəs] *n.* 砧骨（位于中耳）

stapes ['steipiːz] *n.* 镫骨

Notes

① Many different types of implants are used in the surgery to correct soft tissue deformities or defects which can be congenital, developmental, or acquired defects, the last category usually being secondary to trauma or tumor excision. soft tissue deformities or defects，软组织缺陷或病变；congenital，先天性的；acquired defects，后天获得的缺陷；tumor，瘤。

② The materials used in these applications include SR (silicone rubber), PE (polyethylene), and PTFE (polytetrafluoroethylene). silicone rubber，硅（氧）橡胶，硅酮橡胶；polytetrafluoroethylene，聚四氟乙烯。参考译文：用于这些方面的材料包括硅酮橡胶、聚乙烯和聚四氟乙烯。

③ They may be used to replace the tendon, to hold a damaged tendon in proper alignment，

or to form a new sheath. be used to，可用于，可用来，to 引导三个并列的不定式短语，即 to replace、to hold 和 to form。

④ A number of materials such as nylon，PTFE，carbon，stainless steel，and tantalum in the form of fabrics or meshes are used to repair hernias. 参考译文：很多材料诸如尼龙、聚四氟乙烯（PTFE）、炭、不锈钢和以织网状形式存在的钽，都可用于修复脱肠。

Exercises

1. Question for discussion
   (1) Which biocomposites can be used to replace skin? Why?
   (2) Which composites can be functioned As load-carrying or supporting materials?
2. Translate the following into Chinese

soft tissue	silicone rubber
skin dressing	Nitinol ribbon
calcification deposit	stress-strain behavior
blood compatibility	articular cartilage
vascular graft	cardiovascular system
blood pressure	tendon healing

- Depending on the intended application，the soft tissue implants perform various functions: fill the space from some defect; enclose，store，isolate，or transport something in the body; and mechanical support or serving as a scaffold for tissue growth.
- Burn victims are often treated with skin dressings. In order to conform to irregular surfaces，the skin dressing must be elastic and flexible.
- There is a need to develop new materials with improved surface properties of minimal microbial adhesion，low friction，and control of cell and protein adsorption.
- Vascular grafts are used to replace segments of the natural cardiovascular system (mainly successful in the case of blood vessels with lumen diameter of over 5 mm) that are diseased or blocked (atherosclerosis，deposits on the inner surface of the vessels restricting the flow of blood and increasing blood pressure).

Reading Material

Typical Applications of Biocomposites: Hard Tissue Applications

Many different biocomposites can be used in the surgery to correct hard tissue. Depending on the intended use，the hard tissue applications perform various functions: repair bone fracture，replace joint or bone，and serve as a spine or dental instrumentation.

Bone Fracture Repair

Bone is an anisotropic material because its properties are directionally dependent. it is

generally weak in tension and shear, particularly along the longitudinal plane. Under excessive loading or impact bone fractures, and there are many types of bone fractures depending on the crack size, orientation, morphology, and location. Bone fractures are treated (anatomic reduction) in different ways and they may be grouped into two types namely external fixation and internal fixation.

In the external fixation approach the bone fragments are held in alignment through various means such as splints, casts, braces, and external fixator systems. Casting materials or platser bandages are used to form splints, casts or braces. The casting material essentially is a composite made of woven cotton fabrics (woven gauze) and Plaster of Paris matrix (calcium sulphate). Other reinforcements include fabrics of glass and polyester fibers. Although the plaster bandages have many advantages, they also have many disadvantages such as messy application, heavy, bulky, low specific strength and modulus, low water resistance, low fatigue strength, radiopaque, and long setting time to become load bearing. Recently, casts made of glass or polyester fiber fabrics, and water activated polyurethanes are gaining popularity. An ideal cast material should be easy to handle, light weight, conformable to anatomical shape, strong, stiff, water proof, radiolucent, and easy to remove. More over it should be permeable to ventilation without which the patient's skin may be scorched or weakened.

In the internal fixation approach the bone fragments are held together by different ways using implants such as wires, pins, screws, plates, and intramedullary nails. The conventional implants are made of stainless steel, Co-Cr, or Ti alloys. The surgeon based on his experience and the type of fracture judges the bone fracture treatment method. Surgical wires and pins are the simplest implants used to hold the small fragments of bones together. For example wires are used to reattach the greater trochanter, which is often detached during total hip joint replacement. They are also used to provide additional stability in long oblique or spiral fractures of long bones (femur, humerus, radius, ulna, tibia, and fibula). Most widely used bone screws are two types, cortical bone screws (with smaller threads), and cancellous screws (with larger threads). They are used either to directly fasten bone fragments together or to attach a plate to the fractured bone. However proper implant design and surgical technique must be utilized to ensure the desired biomechanical outcome of the fixation and to avoid additional tissue trauma and devascularization at the fracture site. Fracture healing also would depend on the patient activities, as they determine the stable or unstable mechanical conditions at the fracture site. It may be noted that all these implants are temporarily placed inside the body. After satisfactory healing of bone fracture, the implants may be removed based on the discretion of the surgeon.

Bone Replacement (Synthetic Bone Graft) Materials

Synthetic bone grafts are necessary to fill bone defects or to replace fractured bones. The bone graft material must be sufficiently strong and stiff, and also capable of bonding to

the residual bones. PE is considered biocompatible from its satisfactory usage in hip and knee joint replacements for many years. Stiffness and strength of PE are much lower than those of the bone. For load bearing applications, properties of PE need to be enhanced. In order to improve the mechanical properties some researchers reinforced PE (polyethylene) using HA (hysroxyapatite) particles, which are bioactive. The resulting composite has an elastic modulus of $1 \sim 8$ GPa and strain to failure value of over 90% to 3% as the volume fraction of HA increases to 50%. It was reported that for HA particulate volume fractions above 40% the composite is brittle. Moreover the bioactivity of the composite is less than optimal because the surface area of HA available is low and the rate of bone bonding of HA is slow. Further work requires consideration of using more bioactive materials such as Bioglass as reinforcements in PE. A typical composition of Bioglass is 45% SiO_2, 6% P_2O_5, 24.5% CaO, 24.5% Na_2O by weight. The Bioglass reacts with physiological fluids and forms tenacious bond to hard or soft tissues through cellular activity. To increase the interface between HA particles and the bone tissues, some researchers developed partially resorbable composites. They reinforced resorbable polymers such as PEG (polyethyleneglycol), PBT (polybutylene terephthalate), PLLA [poly (L-lactic acid)], PHB (polyhydroxybutyrate), alginate and gelatin with bioactive particles. Upon implantation, as the matrix polymer resorbs, more and more bioactive particles come in contact with the growing tissues, thus achieving good integration of the biomaterial into the bone. The wide range of material combinations offers the possibility of making composites with various desired properties such as stiffness, strength, biodegradation, and bioactivity.

Joint Replacements

Joints enable the movement of body and its parts. Many joints in the body are synovial types, which permit free movement. Hence, we are able to do various physical activities such as walk, jog, run, jump, turn, bend, bow, stand, and sit in our daily life. Hip, knee, shoulder, and elbow are few common examples of synovial joints. They all posses two opposing articular surfaces, which are protected by a thin layer of articular cartilage and lubricated by elastic-viscous synovial fluid. The fluid is made of water, hyaluronic acid, and high molecular weight mucopolysaccharides. The synovial fluid adheres to the cartilage and upon loading can be permeated out onto the surface to reduce friction. The coefficient of friction in a synovial joint is less than 0.01, better than that of a skate blade on ice. Coordinating the ligaments, tendons, and muscles performs the actual articulation of the joint. Osteoarthritis is one of the common causes for joint degeneration and some times hypertrophic changes in the bone and cartilage of joints in middle aged people. This is associated with progressive wearing down of opposing joint surfaces with consequent distortion of joint position. Joints also damage upon exposure to severe mechanical or metabolic injury. Over the years a number of artificial joints are designed to replace or augment many joints in the body. Unlike those used to treat bone fractures, the artificial joints are generally placed permanently in the body. The extensive bone and cartilage removed during implantation makes

this procedure irreversible. Considering the extent of loading, complexity of joint function, and severity of the physiological environment, joint replacement is one of the most demanding of all the implant applications in the body. The most commonly used artificial joints are total hip replacement (THR) and total knee replacement (TKR).

Spine Instrumentation

The spine serves two distinct and apparently conflicting roles. First, it must provide a strong, yet mobile, central axis onto which the appendicular skeleton is applied. Second, it must protect the spinal cord and the roots of delicate nerves connecting the brain to the periphery. The proper blending of mobility, stability, and structural integrity is essential to fulfill these goals simultaneously. The dual function is realized by a linked structure consisting of 33 vertebrae superimposed on one another. The vertebrae are separated by fibrocartilaginous intervertebral discs (IVD) and are united by articular capsules and ligaments. The IVD is a composite structure made up of a core, nucleus pulposus, surrounded by multilayered fibers (90 concentric layers) of the annulus fibrosis. The orientation of annulus fibers vary from 62 degree at the periphery to 45 degree in the vicinity of the nucleus, thus imparting structurally graded architecture to the disc. The disc is covered on upper and lower surfaces by a thin layer of cartilaginous endplates, which contain perforations that allow the exchange of water, nutrients and products of metabolism. The main role of the disc is to act as a shock absorber for the spine, to cushion adjacent vertebral segments. A number of spine related disorders is identified over the years. Often reported spine disorders include metastasis of vertebral body and disc, disc herniation, facet degeneration, stenosis, and structural abnormalities such as kyphosis, scoliosis, and spondylolistheses. Often one disorder has cascading effect on the other, and primary causes of many spinal disorders remain largely speculative. A variety of reasons including birth deformities, aging, tumorous lesions (metastasis), and mechanical loads caused by sports and work, lead to spine disorders.

In the case the defect is limited to few vertebrae alternative approaches, such as a) spinal fusion and b) disc replacement, are used. These methods are used alone or in combination depending on the patient condition and prognosis. In broader sense, spinal fusion means surgical immobilization of joint between two vertebrae. Various methods are employed in spinal fusion. One such approach is the surgical removal of the affected (portions of) vertebrae and restore the defect using synthetic bone graft, as the autologous or homologous bone grafts are limited by risk of infection, shortage of donor bone sites (with risk of AIDS and hepatitis in the case of autologous donors), and postoperative resorption and collapse of the graft. Synthetic bone graft material must have adequate strength and stiffness, also capable of bonding to the residual vertebrae. Another approach is to use special vertebral prostheses such as baskets, cages, and threaded inserts, which are made of metals or bioceramics. They are designed such that tissues grow into the prostheses there by ensuring rigid anchoring of protheses to the bone.

The internal fixations require surgery and there are many types of instrumentation (screws, plates, rods, and expanding jacks) available. Some cases, adjustable stainless steel rod also known as Harrington spinal distraction rod is used to stabilize or straighten the curvature. The rod is attached to the spinous process at two points and by adjusting the rod length between the attachment points, the spine is straightened.

It may be noted that efficient fixation of spinal deformities is difficult. This is attributed to the irregular shape of the vertebrae, and complex and large forces the prostheses need to withstand. Most of the designs used in various spine instrumentations, and the criteria that have evolved are primarily based on general biologic and engineering principles. Unfortunately, the specific mechanical and physical properties required for ideal spine instrumentation have not yet been defined. Until controlled clinical investigations provide these guidelines, many materials and designs must be evaluated in the laboratory.

Dental Applications

Dental treatment is one of the most frequent medical treatments performed upon human beings. Dental treatment ranges from filling cavities (also called 'dental caries') to replacing fractured or decayed teeth. A large variety of materials are used in the dental treatments such as cavity lining, cavity filling, luting, endodontic, crown and bridge, prosthetic, preventive, orthodontic, and periodontal treatment of teeth. These materials are also generally described as biomaterials. The choice of material is dependent on its ability to resemble the physical, mechanical and esthetic properties of natural tooth structure. For example, dental composite resins, which are translucent with refractive index matching that of the enamel, are very commonly used to restore posterior teeth as well as anterior teeth. When the severely damaged tooth lacks the structure to adequately retain a filling or restoration, often composite materials of dental post or cast dowel are used. And composites (SiC/carbon and CF/carbon) can be as dental implants for the damaged or condemned teeth. Additionally, orthodontic arch composite wires (approximately 0.5mm in diameter) are used to correct the alignment of teeth.

(Selected from *Biocomposite Materials*, by S Remakrishna and Z H Huang, 2003)

New Words and Expressions

spine [spain] *n.* 脊骨，脊椎，脊椎骨

shear [ʃiə] *v.* 剪，修剪，剪切

longitudinal [ˌlɔndʒiˈtjuːdinl] *a.* 经度的，纵向的

crack [kræk] *n.* 裂缝；*v.* （使）破裂，裂纹

morphology [mɔːˈfɔlədʒi] *n.* 形态学、形态论

alignment [əˈlainmənt] *n.* 队列，结盟

splint [splint] *n.* （外科用的）夹板；*v.* 用夹板夹

gauze [gɔːz] *n.* 纱布

messy [ˈmesi] *a.* 肮脏的，凌乱的，杂乱

radiopaque ['reidiəupeik] *a.* 辐射透不过的

anatomical [ˌænə'təmikəl] *a.* 解剖的，解剖学的

radiolucent ['reidiəu'lju:sənt] *a.* 射线可透的，射线透明的

permeable ['pə:mjəbl] *a.* 有浸透性的，能透过的

ventilation [ˌventi'leiʃən] *n.* 通风，流通空气

scorch [skɔ:tʃ] *v.* 烧焦，枯萎；*n.* 烧焦，焦痕，枯黄

rigidity [ri'dʒiditi] *n.* 坚硬，刚性，硬度

intramedullary [ˌintrə'medələri] *a.* 骨髓的，脊髓的

oblique [ə'bli:k] *a.* 倾斜的，间接的

femur ['fi:mə] *n.* 大腿骨，腿节

humerus ['hju:mərəs] *n.* 肱上膊，肱部

spiral ['spaiərəl] *a.* 螺旋形的；*n.* 螺旋

radius ['reidjəs] *n.* 半径，范围，辐射光线，范围，界限

ulna ['ʌlnə] *n.* 尺骨

tibia ['tibiə] *n.* 胫骨

fibula ['fibjulə] *n.* 腓骨

cortical ['kɔ:tikəl] *a.* 皮层的，皮质的，有关脑皮层的

trauma ['trɔ:mə] *n.* 外伤，损伤

discretion [dis'kreʃən] *n.* 判断力

tenacious [ti'neiʃəs] *a.* 顽强的

alginate ['ældʒineit] *n.* 藻酸盐；*v.* 褐藻胶化

synovial [si'nəuviəl] *a.* 滑液的，含有滑液的，分泌滑液的

lubricate ['lju:brikeit] *v.* 润滑，加润滑油

resorb [ri'sɔ:b] *v.* 再吸收

resorbable [ri'sɔ:bəbl] *a.* 可再吸收的

hyaluronic acid 透明质酸

ligament ['ligəmənt] *n.* 系带，韧带

tendon ['tendən] *n.* 腱

osteoarthritis [ˌɔstiəuɑ:'θraitis] *n.* 骨关节炎

metabolic [ˌmetə'bɔlik] *a.* 代谢作用的，新陈代谢的

irreversible [ˌiri'və:səbl] *a.* 不能撤回的，不能取消的

periphery [pə'rifəri] *n.* 外围

cord [kɔ:d] *n.* 绳索，束缚

vertebra ['və:tibrə] *n.* 脊椎骨，椎骨

pulpous ['pʌlpəs] *a.* 果肉状的，纸浆状的

annulus ['ænjuləs] *n.* 环面

endplate ['endpleit] *n.* 终板

herniation [ˌhə:ni'eiʃən] *n.* 形成疝

kyphosis [kai'fəusis] *n.* 驼背

scoliosis [ˌskɔli'əusis] *n.* 脊柱侧凸

spondylolisthesis ［ˌspɔndiləulis'θiːsis］ *n.* 脊椎前移

cascade ［kæs'keid］ *n.* 层叠，成下垂状的东西

lesion ［'liːʒən］ *n.* 损害，身体上的伤害

tumour ［'tjuːmə］ *a.* 肿瘤的，肿胀的

autologous ［ɔː'tɔləgəs］ *a.* 自体同源的，自体同存的

donor ［'dəunə］ *n.* 捐赠人

rod ［rɔd］ *n.* 杆，棒

hepatitis ［ˌhepə'taitis］ *n.* 肝炎

lining ［'lainiŋ］ *n.* 加衬里，内层，衬套

luting ［ljuːtiŋ］ *n.* 火泥密封，涂胶泥，用油灰接合

endodontic ［ˌendə'dɔntik］ *a.* 牙髓学的

preventive ［pri'ventiv］ *a.* 预防性的

orthodontics ［ˌɔːθə'dɔntiks］ *n.* 畸齿矫正（术），正牙学

esthetic ［iːs'θetik］ *a.* 感觉的

enamel ［i'næməl］ *n.* 珐琅、瓷釉，指甲油；*vt.* 涂以瓷釉，彩饰

dowel ［'dauəl］ *n.* 木钉，销子；*vt.* 用暗销接合

Notes

① Bone is an anisotropic material because its properties are directionally dependent. aniso-tropic，各向异性的。参考译文：骨是一种各向异性物质，因为其特性取决于方向。

② Under excessive loading or impact bone fractures，and there are many types of bone frac-tures depending on the crack size，orientation，morphology，and location. 本句 Under excessive loading or impact 是条件状语，bone fractures 是第一句的主语和谓语。参考译文：在超负荷或撞击情况下，会发生骨折；根据其大小、方向、形态及位置，骨折可分为许多种。

③ It may be noted that all these implants are temporarily placed inside the body. After sat-isfactory healing of bone fracture，the implants may be removed …. 参考译文：值得注意的是，所有这些植入材料都只是暂时放置在体内，当骨折完全痊愈后，植入物可以从体内取出 ……。

④ The bone graft material must be sufficiently strong and stiff，and also capable of bonding to the residual bones. the residual bones 是指原来的骨头（坏死的骨或碎裂的骨被取出后剩下的骨头）。参考译文：骨移植材料必须具有足够的强度和硬度，并能与原来的骨头牢固地结合在一起。

⑤ Unlike those used to treat bone fractures，the artificial joints are generally placed perma-nently in the body. those，指代前面提到的 bone graft material；treat，治疗。参考译文：与治疗骨折的材料不同，人造关节一般被永久地植入体内。

⑥ These methods are used alone or in combination depending on the patient condition and prognosis. the patient condition and prognosis 是指病人的具体情况及诊断结果。参考译文：根据病人的具体情形及诊断结果，这些方法可单独使用，也可联合采用。

Unit 27 Biomedical Materials for the New Millennium: A Perspective on the Future

Devices and prostheses made from orthopaedic biomaterials ideally should survive without failure for the lifetime of the patient. The challenge is that the lifetime of patients has progressively increased during the last century and will continue to do so for many years to come. Average life expectancy is currently at more than 80 years, an increase of more than 10 years since the 1960s, when Professor Sir John Charnley pioneered the use of low friction total hip replacement. There is a compound effect of increased patient lifetime on the survivability of orthopaedic prostheses; many more patients need prostheses and the quality of bone of the patients progressively deteriorates with age, especially for women after the menopause. The two effects are multiplicative and contribute to the continuing decline in implant survivability with patient age.

There are two options to satisfy increasing needs for orthopaedic repair in the new millennium: (1) improve implant survivability by 10 to 20 years; or (2) develop alternative means of orthopaedic treatment that do not require implants, or at least delays the need for prostheses by 10~20 years.

Alternatives for 2000~2020

Two alternative pathways of treatment of patients with chronic bone and joint defects are now possible: (1) transplantation or (2) implantation. Harvesting the patient's tissue from a donor site and transplanting it to a host site, at times even maintaining blood supply, has become a 'gold standard' for many orthopaedic procedures such as vertebral fusion and revision surgery.

This type of tissue graft, called an *autograft*, has important limitations, especially limited availability, second site morbidity, tendency towards resorption, and sometimes a compromise in biomechanical properties. A partial solution to some of these limitations is use of transplant tissue from a human donor, a *homograft*, either as a living transplant (heart, heart-lung, kidney, liver, retina) or from cadavers (freeze-dried bone). Availability lost, requirement for lifetime use of immunosuppressant drugs, concern for viral or prion contamination, ethical and religious concerns all limit the use of homografts.

Either living or non-living transplants, from other species, called *heterografts* or *xenografts*, provide a third option for tissue replacement. Non-living, chemically treated xenografts are routinely used as heart valve replacements (porcine) with about 50% survivability at 10 years. Bovine bone grafts are still in use but concern of transmission of prions is growing. Use of genetically modified living heterografts, especially from pigs, has been advocated but is controversial and not used at present. Concern about transmission of viruses from

animals to humans may prevent this approach from ever being approved by government agencies.

The second line of attack in the revolution to replace tissues was the development, or in many cases modification, in the 1960s and 1970s, of man-made materials to interface with living, host tissues, e. g. implants or prostheses made from biomaterials. There are important advantages of implants over transplants, including: availability, reproducibility and reliability. Good manufacturing practice, international standards, government regulations and quality assurance testing minimise the probability of mechanical failure of implants. Failure rate of the materials used in most prostheses are very low at less than 0.01%. As a result, survivability of orthopaedic implants such as the Charnley low friction metal-polyethylene total hip replacement is very high for 15 years.

However, many implants in use today continue to suffer from problems of interfacial stability with host tissues, biomechanical mismatch of elastic moduli, production of wear debris and maintenance of a stable blood supply. These problems lead to accelerated wear rates, loosening and fracture of the bone, interface or device. These problems become worse as the patient becomes older. Repair of failed devices, called revision surgery, also becomes more difficult as the patient ages due to decreased quality of bone, reduced mobility and poorer circulation of blood. In addition, all present day orthopaedic implants lack two of the most critical characteristics of living tissues: (1) ability to self-repair; and (2) ability to modify their structure and properties in response to environmental factors such as mechanical load.

The consequences of the limitations listed above are profound. All implants have limited lifetimes. Many years of research and development have led to only marginal improvements in the survivability of orthopaedic implants at more than 15 years. For example, efforts to improve lifetimes of orthopaedic prostheses through morphological fixation (large surface areas or fenestrations) or by biological fixation (porous ingrowth) have not improved survivability over cement fixation of prostheses.

The Biocomposites Alternative

Biocomposites are being developed to eliminate the problem of elastic modulus mismatch and stress shielding of bone. Two approaches have been tried. Bioinert composites, such as carbon-carbon fibre composite materials, are routinely used in aerospace and automotive applications. These lightweight, strong and low modulus materials would seem to offer great potential for load-bearing orthopaedic devices. However, delamination can occur under cyclic loading which releases carbon fibres into the interfacial tissues. The carbon fibres give rise to a chronic inflammatory response. Thus, bioinert composites are not widely used and are unlikely to be a fruitful direction for development in the next decade.

The second approach is to make a bioactive composite that does not degrade, such as pioneered by Professor W. Bonfield in the IRC in Biomedical Materials, University of London. The composite processing stiffens a compliant biocompatible synthetic polymer, such

as polyethylene, with a higher modulus bioactive ceramic second phase, such as synthetic HA. The result is a material that has an elastic modulus that is much closer to that of bone and will produce a bioactive bond to bone when implanted. An important advantage of this concept is that the mechanical properties of strength and elastic modulus can be controlled, within limits, by varying the volume fraction, size and distribution of the second phase. Ideally, it is possible to match the properties of both cancellous and cortical bone, although, as shown in, this is seldom achieved by the biocomposites available today. A challenge for the next decade is to use advanced materials processing technology to improve the interfacial bonding between the phases and reduce the size of the second phase particles, thereby increasing the strength and fracture toughness of these new materials.

Another option is to use a resorbable polymer matrix for a biocomposite that will be replaced with mineralizing bone as the load on the device is increased. Work in this area is in progress but it is difficult to maintain structural integrity as resorption occurs. The tissue engineering alternative is based upon this concept.

A New Revolution in Orthopedics?

The orthopaedics revolution of the last 30 years, the revolution of replacement of tissues by transplants and implants, has run its course. It has led to a remarkable increase in the quality of life for millions of patients; total joint prostheses provide excellent performance and survivability for 15～20 years. Prostheses will still be the treatment of choice for many years to come for patients of 70 years or older. However, continuing the same approach of the last century; i. e. modification of implant materials and designs is not likely to reach a goal of 25～30 years implant survivability, an increasing need of our ageing population. We need a change in emphasis in orthopaedic materials research; in fact, we need a new revolution.

The Future: Regeneration of Tissues

The challenge for the next millennium in biomedical materials is to shift the emphasis of biomaterials research towards assisting or enhancing the body's own reparative capacity. Scientists must recognize that within our cells lies the genetic information needed to replicate or repair any tissue. It is necessary to learn how to activate the genes to initiate repair at the right site.

The working hypothesis should be: 'long-term survivability of prostheses will be increased by the use of biomaterials that enhance the regeneration of natural tissues'. The goal of regeneration of tissues should encompass the restoration of metabolic and biochemical behavior at the defect site, which leads to restoration of biomechanical performance by means of structure restoration. This leads to our objective: restoration of physiological function.

The concept requires that we develop biomaterials that behave in a manner equivalent to an autograft, i. e. what we seek is a regenerative allograft. This is a great challenge.

However, the time is ripe for such a revolution in thinking and priorities. Enormous advances have been made in developmental biology, genetic engineering, cellular and tissue engineering, imaging and diagnosis, and in micro-optical and micro-mechanical surgery and repair. Few of these advances have, as yet, been incorporated with the molecular design of new biomaterials. This must be a high priority for the next two decades of research.

Molecular control of the texture of hierarchical bioactive materials over six orders of magnitude, from scales of nanometers to millimeters, is now possible using a new generation of low-temperature chemical sol-gel processing of materials. Self-assembled biomolecular structures are feasible. Microporous and mesoporous inorganic and hybrid inorganic-organic matrices and scaffolds can be produced with controlled rates of resorption and controlled surface chemistries with isoelectric points ranging from pH values of $5 \sim 8$, thereby matching the electro-chemical changes that occur during the repair of bone by natural means. Not only can the rates of resorption be controlled in such materials but the type and concentration of inorganic or organic species and their sequence of release can be varied, a vital requirement in stimulating cell proliferation or enhancing cell differentiation following proliferation.

(Selected from *Material Science and Technology*,
by J. R. Jones and L. L. Hench, 2001)

New Words and Expressions

prosthesis　['prɔsθisis]　*n.*　弥补术，人造器官
friction　['frikʃən]　*n.*　摩擦，摩擦力
menopause　['menəpɔːz]　*n.*　绝经期，更年期
multiplicative　[ˌmʌti'plikətiv]　*n.*　增殖；*a.* 增殖的
millennium　[mi'leniəm]　*n.*　太平盛世，一千年
vertebral　['vəːtibrəl]　*a.*　椎骨的，脊椎的，由椎骨组成的，有脊椎的
fusion　['fjuːʒən]　*n.*　熔化，熔解，熔合，熔接
revision　[ri'viʒən]　*n.*　修订，修改，修正，修订本
autograft　['ɔːtəgrɑːft]　*n.*　自体移植物（如皮肤，组织等）
morbidity　[mɔː'biditi]　*n.*　病态，不健全，发病率
resorption　[ri'sɔːpʃən]　*n.*　再吸收，再吞
homograft　['hɔməugrɑːft]　*n.*　自体移植物，同种移植物
retina　['retinə]　*n.*　视网膜
cadaver　[kə'deivə]　*n.*　死尸，尸体
immunosuppressant　[ˌimjunəusə'presənt]　*n.*　免疫抑制剂
viral　['vaiərəl]　*a.*　滤过性毒菌的，滤过性毒菌引起的
heterograft　[ˌhetərəu'grɑːft]　*n.*　异种移植；异种移植物
xenograft　['zenəgrɑːft]　*n.*　异种移植物
valve　[vælv]　*n.*　阀；电子管，真空管
bovine　['bəuvain]　*a.*　迟钝的，牛的，似牛的，耐心的

minimize ['minimaiz] *vt.* 将……减到最少；*v.* 最小化

modulo ['mɔdjuləu] *prep.* 以……为模

marginal ['mɑːdʒinəl] *a.* 记在页边的，边缘的，边际的

morphological [ˌmɔːfə'lɔdʒikəl] *a.* 形态学（上），结构学的

delamination [diːˌlæmi'neiʃən] *n.* 分层，分叶

cortical ['kɔːtikəl] *a.* 皮层的，皮质的，有关皮层的

cellular ['seljulə] *a.* 细胞的

sol-gel [sɔl-dʒel] *n.* 溶胶，凝胶

microporous ['maikrəu'pɔːrəs] *a.* 微孔的

Notes

① In addition, all present day orthopaedic implants lack two of the most critical characteristics of living tissues: (1) ability to self-repair; and (2) ability to modify their structure and properties in response to environmental factors such as mechanical load. critical 在此处是"重大的"、"重要的"意思；self-repair，自修复，自我治疗。参考译文：除此以外，目前所有的整形外科植入材料都缺乏生物组织的两个最重要的特征：（1）自修复能力；（2）自动改变其结构和特性来适应环境变化（如机械负荷）的能力。

② Not only can the rates of resorption be controlled in such materials but the type and concentration of inorganic or organic species and their sequence of release can be varied,... 本句句型为 Not only... but (also)... 。以 Not 开头的句型需用倒装句，其助动词 (can) 应提至主语之前。

Exercises

1. Question for discussion
   (1) Why the lifetime of patients has increased in 20th century?
   (2) What are the differences between *autograft*, *homegraph* and *heterografts*?
   (3) Which limitations do implants have?
2. Translate the following into Chinese

orthopaedic biomaterials	transplants and implants
bioinert composites	genetic engineering
blood circulation	biochemical behavior
low-temperature chemical sol-gel processing	self-assembled biomolecular structures
physiological function	electro-chemical
cell proliferation	cell differentiation

   - However, many implants in use today continue to suffer from problems of interfacial stability with host tissues, biomechanical mismatch of elastic moduli, production of wear debris and maintenance of a stable blood supply.
   - A challenge for the next decade is to use advanced materials processing technology to improve the interfacial bonding between the phases and reduce the size of the second phase particles, thereby increasing the strength and fracture toughness of these new

materials.

- Long-term survivability of prostheses will be increased by the use of biomaterials that enhance the regeneration of natural tissues.
- Microporous and mesoporous inorganic and hybrid inorganic-organic matrices and scaffolds can be produced with controlled rates of resorption and controlled surface chemistries with isoelectric points ranging from pH values of $5\sim8$, thereby matching the electro-chemical changes that occur during the repair of bone by natural means.

Reading Material

Composite Biomaterials: Biocompatibility and Future Advance

Composites are those materials that contain two or more distinct constituent phases, on a scale larger than the atomic. In composites properties such as the elastic modulus are significantly different from those of the constituents alone but are significantly altered by the constituent structures and contents. From a structural point of view, composites are anisotropic in nature. Their mechanical properties are different in different directions. Most of the living tissues such as bone, dentin, collagen, cartilage, and skin are essentially composites. By definition, a biocomposite is a non viable composite material which can be used in a biomedical device intended to interact with biological host systems. Such composites are essentially a combination of two constituent phases, i. e. a reinforcing phase such as fiber or particle and a continuous phase called matrix. There are typically three kinds of reinforcement biocomposites, i. e. short fibers, continuous fibers, and particulates (powders). All of them have been used in making composites for bio-medical applications, such as screws and total hip replacement stems made from short fiber reinforcements, orthopaedic bone plates fabricated using unidirectional (UD) laminae or multidirectional tape laminates, powder reinforced dental composites.

The primary motive in the development of biocomposites is that by varying the type and distribution of the reinforcing phases in the composites it is possible to obtain a wide range of mechanical and biological properties, and hence to optimize the structure and performance of the biomedical devices and their interaction with the surrounding tissues. Until presently, the majority of biomedical devices in clinical use is made of biocompatible homogeneous materials such as metals, ceramics, or polymers. However, limitations of these single-phase material devices have been recognized. For example, most of the implants in orthopaedic surgery are made of metals. Their drawbacks include: (1) they are too stiff so that a stress protection of the fractured bone while healing can be developed; (2) they produce considerable artefacts under X-ray, which make the interpretation of radiographs difficult; and (3) metal sensitisation can occur and the implants may cause mutagenicity. In the contrast, these drawbacks can be overcome using implants made of polymer matrix composites. Fur-

thermore, biodegradable implants can be developed based on composite technology. which require no additional operation for the removal of them once fixed into host tissues. This is an advantage that cannot be shared by any metal implant.

As composite medical devices can offer a variety of advantages over those of homogeneous materials, a great number of research groups are engaged in the development of such devices all over the world. The research of composites focus on the following topics; mechanics of composites. classifications of biocomposites, typical application examples of composites in biomedical engineering. biocompatibility, fabrication and characterization, structure property relationship, effect of processing and environment, design example, and future advance.

Biocompatibility of Composites

Biocompatibility is the term used to describe the state of affairs when a biomaterial exists within a physiological environment, without adversely and significantly affecting each other of the body of the environment and the material. All materials used in invasive medical device must be biocompatible, and so are biocomposites.

Material properties that are relevant to the biocompatibility include chemical inertness, toxicity, thrombogenicity and resistance to adhesions. The biocompatibility is primarily concerned with the interactions between foreign materials and the host tissues. It is those situations in which biomaterials are placed in direct contact with the tissues that are usually examined in the search for the interaction mechanisms. Foreign substances also gain access to the tissues in a number of other ways and, although these materials may be of a different physical form, their fate in the tissues may be of relevance to biocompatibility in the biomaterials context.

The most obvious indication of the extent of interaction between an implanted material and the tissues of the body is the cellular response in the immediate vicinity. There are two important aspects of the inflammatory response. One is the role of macrophage and giant cells in the host response to implanted foreign bodies, covering macrophage origin, phagocytic recognition, chemotaxis, activation and epithelioid, and giant cells. Another is the cellular biochemistry in relation to the biomaterials-induced inflammatory response, including the biochemical feature of the polymorphonuclear leucocytes, macrophages, lymphocytes, plasma cells, mast cells, fibroblasts, and foreign body giant cells.

The surface chemistry of biomaterials plays a major role in determining host response and biocompatibility. As polymer matrix is the continuous phase in which the reinforcement phase in contained, the surface chemistry of the polymer matrix predominates that of the biocomposite. Furthermore, the biocompatibility characterization for the composite can be performed using the same techniques as for the polymers, for which protein conditioning and cellular adhesion phenomena on exposure to body fluids have been linked directly to the surface energetics and morphology of the materials. Some of the key problems in the biocomposite performance can be related directly to surface interactions, e. g. the encrustation of

urinary stents is mediated through inorganic deposits forming on an adsorbed protein layer derived from urine. The level of bacterial adsorption and colonization in implant-associated infection is also dependent in part on the surface structure.

In order to gain a greater understanding of the structure-activity relationships that exist between biomaterial surfaces (and their possible modification) and observed biointeractions, a range of advanced surface analytical techniques have been exploited to define the interfacial properties. We now understand that the surface chemistry of a biomedical device is not necessarily similar to that of the bulk phase. Phase separation of preferential surface orientation of one or more components, or the presence of contaminants derived from the fabrication process, are just some of the factors which will manipulate the surface chemistry of biomaterials. The interfacial region is also a dynamic structure where the influence of hydration and adsorption of biomolecules on exposure to body fluids may induce significant surface structural reorganization. Two most suitable techniques for the chemical analysis of the solid polymeric biomaterials, and hence biocomposites, are the X-ray photoelectron spectroscopy (XPS) and the secondary ion mass spectrometry (SIMS).

Of the experimental methods of biocompatibility evaluation, tissue culture tests are unique in that they do not involve implantation into tissue as such. These methods, in effect, assess the toxicity of the material in relation to specific cells and although they theoretically suffer the disadvantage of being divorced from the real, practical situation, they can produce sound quantitative and qualitative data on precise effects. An alternative method for assessing the extent of the inflammatory response in tissue is to monitor the release of lysosomal and other enzymes from cells. This technique could be used for any tissue sections that are prepared in the appropriate manner and are therefore applicable to animal experiments or human biopsy material.

In reality, if any of its constituent materials is not biocompatible, the resulting composite generally cannot be biocompatible. Thus, only biocompatible matrices and reinforcement materials such as fibers are used to fabricate biocomposites. However, even if both the constituents are well biocompatible, the resulting composite is not always biocompatible. This is because the fabrication process may violate the biocompatibility of the constituents. Furthermore, additional agents or fillers such as coating or release agent introduced in the composite fabrication can also affect the biocompatibility. It is necessary to conduct biocompatibility tests before any biocomposite product can be used clinically.

Recently, the emphasis of biocompatibility has been focused on two directions. One is biosafety, which involves the avoidance of harmful effects, and another is concerned with the functional performance of the biomaterial product in vivo.

Future Advance

Composite materials are a relatively recent addition to the class of materials used in structural applications. In the biomaterials field, the ingress of composites has been even more recent. A major flaw in the current literature dealing with implants made of polymer biocomposites is the lack of proper understanding of composite behavior and theories, and

far more work especially on understanding the behaviour of composite implants is necessary. As the composite materials are distinctly different from the homogenous materials in terms of anisotropy, fracture behavior, and environmental sensitivity, the polymer composite implants must be designed using criteria separate from those intended for isotropic material-based implants. This may even lead to the design of superior performance implants in the future. Innovations such as spatially varying fiber volume fraction and/or fiber orientation are adding new types of functionally graded composite materials to implant applications. New design criteria need to be developed to harness the potential of this new class of materials and to design implants with improved performance.

The success of polymer composites as biomaterials also relies greatly on the quality of the implant, which is determined by the reproducibility of the fabrication process. Many of the polymer composite biomaterials investigated so far were produced in biomedical research laboratories with limited success in clinical applications. This is because of the trial-and-error approach followed in making the composites without proper understanding and implementation of finer aspects of polymer composite fabrication processes. The composite fabrication methods used for engineering applications have been used directly for producing implants. It is important to realize that the requirements for the two applications are different, and the composite fabrication methods need to be tailored to suit the biomedical applications. For example, for a hip joint replacement application, the composite material surface should be completely covered with a continuous matrix layer in order to prevent a potential release of fiber particle debris during implantation. More over the fabrication method needs to be optimized such that it enables desired local and global arrangement of reinforcement phase so as to make the composite implant structurally compatible with the host tissues. The various flexibilities of composites in terms of material combinations, fiber/matrix interface control, fiber volume fractions, and fiber and matrix distributions are yet to be fully exploited in fabricating functionally superior implants. Thus far, polymer composite biomaterials are mainly reinforced with particulates, short fibers and unidirectional fiber prepregs, and very few works reported on woven fabric composites. The many advantages offered by textile composite materials have not been well exploited in the biomedical field. Efforts should be made to harness the potential of textile composite materials in designing implants with improved performance. It is also important to consider the cost of composite implant. Efforts must be made to develop suitable manufacturing methods for composite implants so as to compete with the current commercial implants.

Nevertheless, with increased understanding of function and interaction of implants with the human body, it is clear now that for greater success, the implants should be surface compatible as well as structurally compatible with host tissues. In this regard, the polymer composite biomaterials are particularly attractive because of their tailorable manufacturing processes, and properties comparable to those of the host tissues. Innovations in the composite material design and fabrication processes are raising the possibility of realizing implants with improved performance. However, for successful application, surgeons must be

convinced with the long-term durability and reliability of polymer composite biomaterials. Monolithic materials have long been used and there is considerable experimental and clinical data supporting their continued usage. Such data with respect to polymer composite biomaterials are relatively small. This requires further research efforts to elucidate the long-term durability of composite biomaterials in the human body conditions. In view of their potential for high performance, composite materials are likely to find increasing use as biomaterials.

(Selected from *Biocomposite Materials*, by S Remakrishna and Z H Huang, 2003)

New Words and Expressions

collagen ['kɔlədʒən] *n.* 骨胶原，成胶质

laminate ['læmineit] *n.* 薄片制品，层压板

artefact ['ɑːtifækt] *n.* 人工品，赝象

mutagenicity [ˌmjuːtədʒə'nisiti] *n.* 诱变（性）

thrombogenicity [ˌθrɔmbəudʒe'nisiti] *n.* 血小板

toxicity [tɔk'sisiti] *n.* 毒性

epithelioid [ˌepi'θiːliɔid] *a.* 上皮状的，上皮样的

phagocytic [ˌfægəu'sitik] *a.* 噬菌细胞的

chemotaxis [ˌkemə'tæksis] *n.* 化学向性，趋化现象，趋药性

leucocyte ['ljuːkəsait] *n.* 白细胞，白血球

macrophage ['mækəufeidʒ] *n.* 巨噬细胞

lymphocyte ['limfəsait] *n.* 淋巴球、淋巴细胞

plasma ['plæzmə] *n.* 血浆，乳浆；等离子体，等离子区

fibroblast ['faibrəblɑːst] *n.* 纤维质细胞

encrustation [in'krʌsteiʃən] *n.* 结壳，用覆盖物，镶嵌，硬壳

urinary ['juərinəri] *a.* 尿的，泌尿器的

stent [stent] *a.* 展幅的，扩张的；*n.* 印模，支架（保持管道通畅）

spectra ['spektrə] *n.* 范围，光谱

spectroscopy [spek'trɔskəpi] *n.* 光谱学，波谱学

lysosome ['laisəsəum] *n.* （细胞中的）溶酶体

enzyme ['enzaim] *n.* 酶

biopsy [bai'ɔpsi] *n.* 活组织检查，活组织切片检查

ingress ['ingres] *n.* 进人，人口处

prepreg ['priːpreg] *n.* （塑料或其他合成材料在模塑之前用树脂浸饱的）预浸料坯

monolithic [ˌmɔnəu'liθik] *n.* 单片电路，单块集成电路

elucidate [i'ljuːsideit] *vt.* 阐明，说明

Notes

① From a structural point of view, composites are anisotropic in nature. 参考译文：从结构的观点来看，复合材料具有各向异性特征。

② The biocompatibility is primarily concerned with the interactions between foreign materi-

als and the host tissues. biocompatibility，生物兼容性，生物相容性；foreign materials，（植入体内的）外来材料；host tissues，主组织，寄主组织。参考译文：生物相容性主要与外来材料和寄主组织之间的相互作用有关。

③ The level of bacterial adsorption and colonization in implant-associated infection is also dependent in part on the surface structure. colonization，移生，移地发育；in part，部分地；the surface structure，是指植入物的表面结构。参考译文：在与植入物相关的感染中，细菌吸附及移地发育水平也部分取决于其表面结构。

④ Thus，only biocompatible matrices and reinforcement materials such as fibers are used to fabricate biocomposites. However，even if both the constituents are well biocompatible，the resulting composite is not always biocompatible. 句中 both the constituents 代指 biocompatible matrices 和 reinforcement materials。参考译文：因此，仅仅只有生物相容性基体和加强型材料（如纤维）才用来制作生物复合材料；然而，即使这两种材料都具有很好的生物相容性，但其合成的复合材料并不总是具有生物相容性。

APPENDIXES

Append. 1   Elements Listed by Atomic Number

atomic number	name	symbol	Chinese name	atomic number	name	symbol	Chinese name
1	Hydrogen	H	氢	37	Rubidium	Rb	铷
2	Helium	He	氦	38	Strontium	Sr	锶
3	Lithium	Li	锂	39	Yttrium	Y	钇
4	Beryllium	Be	铍	40	Zirconium	Zr	锆
5	Boron	B	硼	41	Niobium	Nb	铌
6	Carbon	C	碳	42	Molybdenum	Mo	钼
7	Nitrogen	N	氮	43	Technetium	Tc	锝
8	Oxygen	O	氧	44	Ruthenium	Ru	钌
9	Fluorine	F	氟	45	Rhodium	Rh	铑
10	Neon	Ne	氖	46	Palladium	Pd	钯
11	Sodium	Na	钠	47	Silver	Ag	银
12	Magnesium	Mg	镁	48	Cadmium	Cd	镉
13	Aluminum	Al	铝	49	Indium	In	铟
14	Silicon	Si	硅	50	Tin	Sn	锡
15	Phosphorus	P	磷	51	Antimony	Sb	锑
16	Sulfur	S	硫	52	Tellurium	Te	碲
17	Chlorine	Cl	氯	53	Iodine	I	碘
18	Argon	Ar	氩	54	Xenon	Xe	氙
19	Potassium	K	钾	55	Cesium	Cs	铯
20	Calcium	Ca	钙	56	Barium	Ba	钡
21	Scandium	Sc	钪	57	Lanthanum	La	镧
22	Titanium	Ti	钛	58	Cerium	Ce	铈
23	Vanadium	V	钒	59	Praseodymium	Pr	镨
24	Chromium	Cr	铬	60	Neodymium	Nd	钕
25	Manganese	Mn	锰	61	Promethium	Pm	钷
26	Iron	Fe	铁	62	Samarium	Sm	钐
27	Cobalt	Co	钴	63	Europium	Eu	铕
28	Nickel	Ni	镍	64	Gadolinium	Gd	钆
29	Copper	Cu	铜	65	Terbium	Tb	铽
30	Zinc	Zn	锌	66	Dysprosium	Dy	镝
31	Gallium	Ga	镓	67	Holmium	Ho	钬
32	Germanium	Ge	锗	68	Erbium	Er	铒
33	Arsenic	As	砷	69	Thulium	Tm	铥
34	Selenium	Se	硒	70	Ytterbium	Yb	镱
35	Bromine	Br	溴	71	Lutetium	Lu	镥
36	Krypton	Kr	氪	72	Hafnium	Hf	铪

续表

atomic number	name	symbol	Chinese name	atomic number	name	symbol	Chinese name
73	Tantalum	Ta	钽	90	Thorium	Th	钍
74	Wolfram	W	钨	91	Protactinium	Pa	镤
75	Rhenium	Re	铼	92	Uranium	U	铀
76	Osmium	Os	锇	93	Neptunium	Np	镎
77	Iridium	Ir	铱	94	Plutonium	Pu	钚
78	Platinum	Pt	铂	95	Americium	Am	镅
79	Gold	Au	金	96	Curium	Cm	锔
80	Mercury	Hg	汞	97	Berkelium	Bk	锫
81	Thallium	Tl	铊	98	Californium	Cf	锎
82	Lead	Pb	铅	99	Einsteinium	Es	锿
83	Bismuth	Bi	铋	100	Fermium	Fm	镄
84	Polonium	Po	钋	101	Mendelevium	Md	钔
85	Astatine	At	砹	102	Nobelium	No	锘
86	Radon	Rn	氡	103	Lawrencium	Lr	铹
87	Francium	Fr	钫	104	Rutherfordium	Rf	𬬻
88	Radium	Ra	镭	105	Hahnium	Ha	𬭊
89	Actinium	Ac	锕				

Append. 2   Main Journals of Materials Science and Technology

1. Acta Materialia
2. Additives for Polymers
3. Advanced Cement Based Materials
4. Advanced Engineering Materials
5. Advanced Materials
6. Advanced Materials & Processes
7. AIChE Journal
8. Annales de Chimie Science des Matériaux
9. Annual Review of Materials Science
10. Applied Clay Science
11. Applied Physics A: Materials Science & Processing
12. Applied Superconductivity
13. Applied Surface Science
14. Biomaterials
15. Biomedical Materials
16. Calphad
17. Canadian Metallurgical Quarterly
18. Carbon
19. Cement and Concrete Composites
20. Cement and Concrete Research

61. Journal of Alloys and Compounds
62. Journal of Colloid and Interface Science
63. Journal of Crystal Growth
64. Journal of Electronic Materials
65. Journal of Light Metals
66. Journal of Magnetism and Magnetic Materials
67. Journal of Material Science Letters
68. Journal of Materials Chemistry
69. Journal of Materials Engineering and Performance
70. Journal of Materials Processing Technology
71. Journal of Materials Research
72. Journal of Materials Science
73. Journal of Materials Science Letters, Electronic Version
74. Journal of Materials Science, Electronic Version
75. Journal of Non-Crystalline Solids
76. Journal of Nuclear Materials
77. Journal of Phase Equilibria
78. Journal of Physics and Chemistry of Solids
79. Journal of Solid State Chemistry
80. Journal of Sound and Vibration
81. Journal of the European Ceramic Society
82. Journal of the Mechanics and Physics of Solids
83. Journal of Thermal Spray Technology
84. Journal of Wind Engineering and Industrial Aerodynamics
85. Materials & Design
86. Materials Characterization
87. Materials Chemistry and Physics
88. Materials Letters
89. Materials Research Bulletin
90. Materials Science and Engineering A
91. Materials Science and Engineering B
92. Materials Science and Engineering C
93. Materials Science and Engineering R: Reports
94. Materials Science and Technology
95. Materials Science in Semiconductor Processing
96. Materials Today
97. Materials World
98. Mécanique & Industries
99. Mechanics of Materials
100. Mechanics Research Communications

101. Metal Finishing
102. Metal Powder Report
103. Metallurgical and Materials Transactions A
104. Metallurgical and Materials Transactions B
105. Microelectronic Engineering
106. Microelectronics Journal
107. Microelectronics Reliability
108. Minerals Engineering
109. Modelling and Simulation in Materials Science and Engineering
110. MRS Bulletin
111. Nanostructured Materials
112. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms
113. Optical Fiber Technology
114. Optical Materials
115. Organic Electronics
116. Physica B: Condensed Matter
117. Physica C: Superconductivity
118. Physica E: Low-dimensional Systems and Nanostructures
119. Plastics, Additives and Compounding
120. Polymer
121. Polymer Contents
122. Polymer Degradation and Stability
123. Polymer Gels and Networks
124. Polymer Testing
125. Progress in Crystal Growth and Characterization of Materials
126. Progress in Materials Science
127. Progress in Organic Coatings
128. Progress in Polymer Science
129. Progress in Quantum Electronics
130. Progress in Solid State Chemistry
131. Progress in Surface Science
132. Reactive and Functional Polymers
133. Reinforced Plastics
134. Reviews in Molecular Biotechnology
135. Science and Technology of Advanced Materials
136. Scripta Materialia
137. Scripta Metallurgica et Materialia
138. Smart Materials and Structures
139. Solar Energy Materials and Solar Cells

140. Solid State Communications
141. Solid State Ionics
142. Solid State Nuclear Magnetic Resonance
143. Solid State Sciences
144. Solid-State Electronics
145. Superlattices and Microstructures
146. Supramolecular Science
147. Surface and Coatings Technology
148. Surface Review and Letters
149. Surface Science
150. Surface Science Reports
151. Synthetic Metals
152. The Journal of Computer-Aided Materials Design
153. Theoretical and Applied Fracture Mechanics
154. Tribology International
155. Vacuum
156. Vibrational Spectroscopy
157. Wave Motion
158. Wear Acta Materialia

Append. 3   Research Group and Society of Materials Science and Technology

1. Advanced Materials and Casting Technology Group, Delft University of Technology
2. Applied Chemistry Materials Research Group, Royal Melbourne Institute of Technology
3. Biomaterials Research, University of Technology, Sydney
4. Brockhouse Institute for Materials Research, McMaster University
5. The Cambridge Materials Science Group, The UK Car-Parrinello Consortium
6. Centre for Advanced Materials Technology, University of Sydney
7. Centre for Materials Technology, University of Technology, Sydney
8. Functional Materials Group, Interdisciplinary Research in Materials for High Performance Applications, University of Birmingham
9. Inorganic Material Science, Universiteit Twente
10. Interdisciplinary Research Centre in Materials for High Performance Applications, University of Birmingham
11. Materials Chemistry, Chemical Science and Technology Division, Los Almos National Laboratory
12. Materials Design and Engineering, University of Newcastle Upon Tyne
13. Materials Engineering Research, Monash University
14. Materials Processing Division, School of Chemical Engineering, University of Birmingham
15. Materials Science & Engineering Group, Delft University of Technology

16. Materials Science and Engineering Laboratory, National Institute of Standards and Technology, A HREF= "http: //www. mst. csiro. au/" > Materials Science and Technology Division, The Commonwealth Scientific and Industrial Research Organisation

17. Mechanical Behavior of Materials Group , Delft University of Technology

18. Molecular Magnetism and New Materials, University of Wroclaw

19. National Institute of Materials and Chemistry Research, Agency of Industrial Science and Technology, Ministry of International Trade and Industry

20. Oxford Material UKCP Group, The UK Car-Parrinello Consortium

21. School of Metallurgy and Materials Research, The University of Birmingham

22. Technology of Structured Materials, Universiteit Twente

23. ASM International: The Materials Information Society

24. High Temperature Materials Division, The Electrochemical Society, Inc.

25. International Union of Materials Research Societies

26. Liverpool and North Wales Materials Society

27. The London Materials Society

28. Luminescence and Display Materials Division, The Electrochemical Society

29. Sensor Division, the Electrochemical Society, Inc.

Append. 4   The List of Polymers in Common Use

类　别	中文名称	英文名称	缩写
乙烯类	聚乙烯	Polyethylene	PE
	聚丙烯	Polypropylene	PP
	聚氯乙烯	Poly(vinyl chloride)	PVC
	聚醋酸乙烯酯	Poly(vinyl acetate)	PVAc
	聚乙烯醇	Poly(vinyl alcohol)	PVA
	聚苯乙烯	Polystyrene	PS
	聚丙烯酸酯	Polyacrylate	
	聚甲基丙烯酸酯	Polymethacrylate	PMA
	聚甲基丙烯酸甲酯	Poly(methyl methacrylate)	PMMA
	聚丙烯腈	Polyacrylonitrile	PAN
	聚异丁烯	Polyisobutylene	PIB
	聚四氟乙烯	Polytetrafluoroethylene	PTFE
双烯类	聚丁二烯	Polybutadiene	PB
	聚异戊二烯	Polyisoprene	PIP
	聚氯丁二烯	Polychlorobutadiene	PCB
		Polychloroprene	PCP
烯烃共聚物	乙烯-丙烯-二烯烃 三元聚合物（三元乙丙胶）	Ethylene-propylene-diene monomer	EPDM
聚酯	聚对苯二甲酸乙二醇酯	Poly(ethylene terephthalate)	PET
聚碳酸酯	聚碳酸酯	Polycarbonate	PC
聚砜	聚砜	Polysulfone	PSF
		Polysulphone	
	聚芳砜	Polyarylsulfone	PASF
		Polyarylsulphone	

类　别	中文名称	英文名称	缩　写
聚酰胺	聚酰胺	Polyamide	PA
聚酰亚胺	聚酰亚胺	Polyimide	PI
聚脲	聚脲	Polyurea	PU
聚氨酯	聚氨基甲酸酯	Polyurethane	PUR PU
聚醚	聚甲醛	Poly(oxymethylene)	POM
	环氧树脂	Epoxy resin	EP
其他	酚醛树脂	Phenol/formaldehyde resin	PF
	脲醛树脂	Urea/formaldehyde resin	UF
	三聚氰胺树脂	Melamine resin	
	不饱和树脂	Unsaurated polyester	UP

Glossary

A

abrasion　*n.* 擦伤，磨损

abrasive　*n.* 磨料，磨蚀剂，研磨剂；*a.* 研磨的

absence　*n.* 缺少（席，少），没有，不存在

acetylation　乙酰化；乙酰化作用

acoustic　*a.* 听觉的，声学的

acquisition　*n.* 获得，收获，探测，发现

active center　活性中心

actuate　*vt.* 开动，促使

addition polymerization　加成聚合

adhesive　*a.* 带黏性的，胶黏；*n.* 黏合剂

adhesion　*n.* 黏着，附着，黏连

advanced ceramics　高级陶瓷，先进技术陶瓷

aerogel　*n.* 气凝胶

aerosol　*n.* 浮质（气体中的悬浮微粒，如烟，雾等）；气溶胶，气雾剂，烟雾剂

agglomerate　*v.* （使）聚集，成团，团聚；*n.* 大块，大堆，聚集；*a.* 成块的，凝聚的

aggregate　*n.* 集合体

aggressive　*a.* 好斗的，敢作敢为的，有闯劲的，侵略性的

alginate　*n.* 藻酸盐；*v.* 褐藻胶化

alignment　*n.* 队列，结盟

alkoxide　*n.* 醇盐；*a.* 烷氧基的

allograft　*n.* 同种异体移植，异源移植

alloy　*n.* 合金；*vt.* 使成合金

alumina　*n.* 氧化铝

alveolar　*a.* 齿槽的

ambient　*a.* 周围的；*n.* 周围环境

amine　*n.* 胺

amorphous　*a.* 无定向的，无晶形的，隐晶质的

amplifier　*n.* 放大器

anatomical　*a.* 解剖的，解剖学的

anatomy　*n.* 剖析，解剖学

anchor　*vt, vi* 抛锚；停泊；使稳固；使稳定

anchorage　*n.* 停泊地点，抛锚地点

aneurysm　*n.* 动脉瘤

anion　*n.* 阴离子

anisotropic　*a.* 各向异性的

anneal　*n.* 退火，焖火，锻炼

annealing　*n.* 退火

annulus　*n.* 环面

aorta　*n.* 大动脉

apolar　*a.* 非极性的；无极的

arbitrary　*a.* 任（随）意的，任选的、随机的

archaeologist　*n.* 考古学家

armor　*n.* 装甲

aromatic　*a.* 芳香族的

arrangement　*n.* 排列

artefact　*n.* 人工品，赝象

artery　*n.* 动脉，要道

arthroplasy　*a.* 亲关节的，向关节的，致关节疾病的

assemble　*vt.* 集合，聚集，装配；*vi.* 集合

assembly　*n.* 组合，装配，集合，会议

atactic　*a.* 无规立构的

atmospheric　*a.* 大气的

atomic structure　原子结构

atomize　*vt.* 使雾化，喷雾，散布

austenite　*n.* 体，奥氏体，碳丙铁

autograft　*n.* 自体移植物（如皮肤，组织等）

autologous　*a.* 自体同源的，自体同存的

avascular　*a.* [解]（组织等）无血管的

awesome　*a.* 令人敬畏的

axial ratios　轴向比率（长径比）

axon　*n.* （神经的）轴突，轴突（输出端）

B

band　*n.* 键；*v.* 键合，成键

batches　*n.* 一次生产量，批量

benchmark　*n.* 基准

benign　*a.* 有益健康的，温和的，良好的

benzoyl peroxide　过氧化苯甲酰

bevel　*a.* 斜角，倾斜，倾斜的

billet　*n.* （金属的）坯段，钢坯

binary　*a.* 二进位的，二元的

binder　*n.*　粘结剂，粘合剂
bioceramics　*n.*　生物陶瓷
biocomposite　*n.*　生物复合材料
biodegradable　*a.*　生物所能分解的，可生物降解的
biohybrid　*n.*　生物杂交种，混合物
biologist　*n.*　生物学家
biomaterial　*n.*　生物材料
biomedical　*a.*　生物医学的
biomimetic　*a.*　仿生的
biomineralization　*n.*　生物成矿，生物矿化
biopsy　*n.*　活组织检查，活组织切片检查
biotechnology　*n.*　生物技术，生物工艺学
blade　*n.*　刀刃，刀片
block copolymer　嵌段共聚物
blockbuster　*n.*　（破坏力极大的）巨型炸弹
body-centered　*a.*　体心的
boride　*n.*　硼化物
bovine　*a.*　迟钝的，牛的，似牛的，耐心的
braces　*n.*　支柱，带子；*vt.*　振作精神
bracket　*n.*　括弧，支架
branched polymer　支化聚合物
braze　*vt.*　铜焊；用黄铜镶或制造
brittle　*a.*　易脆的，易碎的
brittleness　*n.*　脆性
Bromo-　溴代
bulk　*n.*　大小，体积，大批，大多数，散装
bullet-proof vest　防弹背心
buoyancy　*n.*　浮性，浮力，轻快
burgeon　*n.*　嫩芽；*v.*　萌芽
butadiene　*n.*　丁二烯
by virtue of　依靠（…力量），凭借，由于，因为

C

cadaver　*n.*　死尸，尸体
cage　*n.*　笼，槛，（矿井）罐笼
calibrate　*v.*　校准
cannibalize　*vt.*　吞噬
capacitor　*n.*　电容器
capillary　*n.*　毛细管；*a.*　毛状的，毛细作用的
carbide　*n.*　碳化物，碳化钙
cartilage　*n.*　软骨
cascade　*n.*　层叠，成下垂状的东西
cashew　*n.*　腰果树，腰果
catalyst　*n.*　催化剂

catheter　*n.*　导尿管，尿液管，导管
cathode　*n.*　阴极
cation　*n.*　阳离子
cavity　*n.*　洞，空穴，［解剖］腔
cellular　*a.*　细胞的
celluloid　*n.*　赛璐珞
cellulose　*n.*　纤维，纤维素
cellulose ester　纤维素酯
cement　*n.*　水泥，接合剂；*vt.*　接合，用水泥涂，巩固；*vi.*　粘牢
centrifugal casting　离心成型
ceramic　*n.*　陶瓷，陶瓷制品
cermet　*n.*　金属陶瓷，含陶合金
chelate　*n.*　螯化的；*a.*　有螯的，螯合的
chemotaxis　*n.*　（动物）化学向性；（生物）趋化现象，趋药性
chipping　*n.*　清理，修整
chirality　*n.*　手征对称性，手征性
chitin　*n.*　壳质，角素
Chloro-　氯代
chromium　*n.*　铬
circuitry　*n.*　电路，线路
cis-　顺式
cleavage　*n.*　劈开，分裂
close-packed　*a.*　紧密堆积的
coalesce　*v.*　接合
coaster　*n.*　垫子，银盘
coexist　*vi.*　共存
coherent　*a.*　粘在一起的，一致的，连贯的
coiled-coil　*n.*　线圈，感应器，环绕
collagen　*n.*　骨胶原，成胶质
collective　*a.*　集体的；*n.*　集体
colloid　*n.*　胶体；*a.*　胶体的
combination　*n.*　偶合（终止）
combustor　*n.*　喷射引擎之燃烧室
compatibilized　*a.*　兼容的
complement　*vt.*　补充，配套
compliant　*a.*　顺从的，适应的
composite　*a.*　合成的，复合的；*n.*　合成物，复合材料
compressibility　*n.*　可压缩性
concurrent　*n.*　同时发生的事件；*a.*　并发的，协作的，一致的
condylar　*a.*　髁的

confer　*vt.* 赠与，使……具有性能

configuration　*n.* 构型

confluence　*n.* 汇合

conformation　*n.* 构象

congenital　*a.* 天生的，先天的，天赋的

consolidated　*a.* 固态的

consolidation　*n.* 巩固，合并

constrained　*a.* 不舒服的，被强迫的，拘泥的

continuum　*n.* 连续统一体，连续统，闭联集

coordination　*n.* 配位，配位体

cord　*n.* 绳索，束缚

corrosive　*a.* 腐蚀的，蚀坏的，腐蚀性的；*n.* 腐蚀物，腐蚀剂

cortical　*a.* 皮层的，皮质的，有关皮层的

counterpart　*n.* 对应物，配对物

covalent　*a.* 共价的，共价键的

crack　*n.* 裂缝；*v.* （使）破裂，裂纹

creep resistance　抗蠕变性

criterion　*n.* （*pl.* criteria）标准，准则，尺度

cross-disciplinary　*n.* 交叉学科

crosslink　*n.* 交联

crumple　*v.* 弄皱，压皱，变皱，崩溃，垮台

crystalline　*a.* 结晶的，结晶性的

crystallization　*n.* 晶化，结晶

crystallize　*v.* 结晶

crystallogphy　*n.* 结晶学，晶体学

cuboid　*a.* 立方体的，立方形的，三次方的，立方的

culminate　*v.* 达到顶点（高潮）

cure　*v.* 固化；*n.* 固化，加工处理

cutting　*n.* 切断，开凿，切下

cutting tool　刀具，切削工具

cylinder　*n.* 圆筒，圆柱体，汽缸，柱面

cylinder liner　汽缸衬垫，垫圈

D

damper　*n.* 起抑制作用的因素，节气闸，断音装置

dangle　*v.* 摇摆

datum　*n.* 数据，资料

debond　*v.* 解离，解黏合

debris　*n.* 碎片，残骸

decentralize　*n.* 分散

definable　*a.* 可定义的

deflector　*n.* 偏转器

degenerative　*a.* 退步的，退化的，变质的

degradation　*n.* 降低，下降，降解

degree of polymerization（DP）　聚合

delamination　*n.* 分层，分叶

deleterious　*a.* 有害的，有毒的

dendrimer　*n.* 树枝状单体

dendritic　*a.* 树枝状的

denture　*n.* 一副假牙，一副牙齿

derivation　*n.* 衍生物

derivative　*a.* 衍生的；*n.* 衍生物

derivatization　*n.* 派生

despoil　*vt.* 夺取，掠夺

diabetes　*n.* 糖尿病，多尿症

diabetic　*a.* 糖尿病的；*n.* 糖尿病患者

diacid　*n.* 二酸

diagnostic　*a.* 诊断的

dialysis　*n.* 透析，分离

diamine　*n.* 二胺

diastereomer　*n.* 非对映异构体

dielectric　*a.* 不导电的，介质，介电材料

dielectric constant　介电常数

diesel　*n.* 柴油机，内燃机

differential scanning calorimeter　差示扫描量热仪

diffusion　*n.* 扩散

diffusivity　*n.* 扩散能力，扩散率

dilation　*n.* 膨胀，扩张，扩大

dilatometer　*n.* 膨胀计

dimeric　*a.* 二聚的，二分子的，二聚物的

diode　*n.* 二极管

direct-casting　直接成型法

disconcert　*vt.* 使惊惶，使仓皇失措，破坏

discretion　*n.* 判断力

dispersant　*n.* 分散剂

disproportionation　*n.* 歧化（终止）

dissociate　*v.* 分离，游离，分裂

dividend　*n.* 被除数，额外津贴，奖金，年息

dominate　*v.* 支配，占优势

donate　*v.* 捐赠，赠予，给予，贡献

donor　*n.* 捐赠人

dowel　*n.* 木钉，销子；*vt.* 用暗销接合

down scaling　减小尺度

ductile　*a.* 易延展的，易教导的，柔软的

ductility　*n.* 延展性，韧性，柔软性

E

ecological　*a.* 生态学的，社会生态学的

edentulous   *a.* 缺齿的

effluent   *a.* 发出的，流出的；*n.* 流出物，排水道，污水

elaborate   *a.* 精细的，精巧的，复杂的；*v.* 详细描述

elaboration   *n.* 详尽的细节，解释，阐述

elastic modulus   弹性模数，弹性组件、弹性计量单位

elastin   *n.* 弹性蛋白

elasto-dynamics   弹性动力学

elastomer   *n.* 弹性体；合成橡胶

elastomeric   *a.* 弹性的

electrical conductivity   电导性，电导率

electrolyte   *n.* 电解，电解液

electronic ceramics   电子陶瓷

electro-optic modulator   电-光调制器

electrostatic   *a.* 静电的，静电学的

elicit   *vt.* 得出，引出，抽出，引起

elongation   *n.* 延长

elucidate   *vt.* 阐明，说明

embed   *vt.* 使溶入，使嵌入，深留，嵌入

emission   *n.* 发（放，辐）射，散发，传播

empower   *vt.* 授权，准许；使能够

empower sb. to do sth.   授权某人做某事

enamel   *n.* 珐琅，瓷釉；*vt.* 涂以瓷釉，彩饰

enantiomer   *n.* 对映（结构）体

encapsulate   *vt.* 装入胶囊，压缩；*vi.* 形成胶囊

encompass   *v.* 包围，拥有，围（环）绕

encrustation   *n.* 结壳，用覆盖物，镶嵌，硬壳

endodontic   *a.* 牙髓学的

endplate   *n.* 终板

energetically   *ad.* 精力充沛地，积极地

ensemble   *n.* 全体，整体，系统，组，束

enthalpy   *n.* 焓，热函

entrepreneurial   *a.* 企业家的

enzyme   *n.* 酶

eosin   *n.* 曙红（四溴荧光素，鲜红色的染料）

epithelioid   *a.* 上皮状的，上皮样的

equiaxed   *a.* 各方等大的，由等轴晶粒组成的

eradication   *n.* 连根拔除，根除

erosion   *n.* 磨损，风化

ester   *n.* 酯

ester-containing   *a.* 含酯的

esthetic   *a.* 感觉的

ethylene   *n.* 乙烯

eutectic   *a.* 最容易溶解的，在最低温度可熔化的，共熔的；*n.* 共晶

exacerbate   *vt.* 恶化，增剧，激怒，使加剧，使烦恼

excise   *n. & v.* 切除

excision   *n.* 切除，删除；切除（术）

extrapolate   *v.* 推断，外推

extravascular   *n.* 额外动脉管

extrinsic   *a.* 外在的，外表的，外来的

extrusion   *n.* 挤出

F

fabric   *n.* 织品，织物，布，结构，建筑物，构造

fabricate   *vt.* 制造，建造，装配，伪造

fabrication   *n.* 制作，构成，制造

face-centered (cubic)   *a.* 面心（立方）的

facilitate   *vt.* 使容易，使便利，推动，促进

failure strength   破坏强度

fatigue resistance   耐疲劳性，抗疲劳强度

feedstock   *n.* 原料

femoral   *a.* 股骨的，大腿骨的，大腿的，股动脉的

femur   *n.* 大腿骨，腿节

ferrite   *n.* （正）铁酸盐，（冶）铁素体，铁氧体

ferroconcrete   *n.* 钢筋混凝土，钢骨水泥

ferroelasticity   *n.* 铁弹性

ferroelectric   *n.* 铁电物质；*a.* 铁电的

ferroelectricity   *n.* 铁电性

fibreboard   *n.* 纤维板

fibrinogen   *n.* 纤维蛋白原

fibroblast   *n.* 纤维质细胞

fibrous   *a.* 含纤维的，纤维性的

fibula   *n.* 腓骨

figurine   *n.* 小雕像

filament   *n.* 细丝，细线

filler   *n.* 装填者，补白，装填物，填料，掺入物

flammability   *n.* 易燃，可燃性

flax   *n.* 亚麻

flexibility   *n.* 弹性，适应性，机动性，挠性

flocculate   *v.* 絮凝，沉淀

fluid   *n.* 流动性，流度；*a.* 流动的

fluorescent   *a.* 荧光的

fluoride   *n.* 氟化物

fluorinate   *v.* 使与氟素化合

Fluoro-   氟代

forerunner   *n.* 先驱（者），传令官，预兆

forging   *n.* 锻造

formaldehyde *n.* 甲醛

fragment *n.* 碎片，（使）成碎片，分裂

free radical 自由基

friction *n.* 摩擦，摩擦力

fullerene *n.* 空心碳球化合物（由芳香碳环构成的空心球），富勒烯

functional material 功能材料

fusion *n.* 熔化，熔解，熔合，熔接

G

garnet *n.* 石榴石

gastrointestinal *a.* 胃与肠的

gauche *a.* 非对称的

gauge *n.* 标准尺，规格，量规，量表；*v.* 测量

gauze *n.* 纱布

gel *n.* 凝胶，冻胶

gelation *n.* 冻结，凝胶化

gemstone *n.* 宝石

genomic *a.* 基因组的，染色体组的，染色体的

geometry *n.* 几何学

glass mat 玻璃纤维板，玻璃垫

glass transition 玻璃化转变

glass transition temperature（T_g）玻璃化转变温度

glaze *n.* 釉料，釉面

glucose *n.* 葡萄糖

gooey *a.* 胶黏的；*n.* 胶黏物

graft *n. v.* 接枝，嫁接，（使）接合，移植

graft copolymer 接枝共聚

granulation *n.* 使成粒状，有粒的表面，粗糙

granule *n.* 小（颗，细）粒

graphite *n.* 石墨

green compact 生坯，未经高温烧结的坯体

grit *n.* 粗砂；*v.* 研磨，在……上铺砂砾

groove *n.* 切口，（凹，空心）槽

gynecological *a.* 妇产科医学的

H

hardness *n.* 硬度，刚度，坚固

heat capacity 热容

helical *a.* 螺线，螺旋状的

hemp *n.* 麻，大麻，纤维

hepatitis *n.* 肝炎

hermetically *ad.* 密封地，气密地

hernia *n.* 疝气，脱肠

herniation *n.* 形成疝

heterogeneity *n.* 非均一性；异种，异质

heterogeneous *a.* 不同种类的，异类的

heterograft *n.* 异种移植；异种移植物

hierarchical *a.* 分等级的，分层的

high density polyethylene 高密度聚乙烯

hip *n.* 臀

histidine *n.* 组氨酸，组织氨基酸

hobbing *n.* 滚刀（切，铣）

homogeneity *n.* 同种，同质，均匀性，均一性

homogeneous *a.* 同（族，质，种）的，一致性的

homograft *n.* 自体移植物，同种移植物

homologate *v.* 承认，同意

honeycomb *n.* 蜂房，蜂巢

host *n.* 晶核，基质

hostile environments 敌对环境

hot-compaction process 热压塑工艺

hot-press 热压

hub *n.* 毂，木片，中心；*n.* 网络集线器，网络中心

hull *n.* 外壳，船体

humerus *n.* 肱上髀，肱部

hurricane *n.* 飓风，暴风，暴风雨

hyaluronic acid 透明质酸

hybrid atomic orbital 杂化原子轨道

hybridize *v.*（使）杂化

hydrate *n.* 氢氧化物；*v.* 与水化合

hydration *n.* 水合，水合作用

hydraulic *a.* 水力学的，液力的

hydrophilic *a.* 亲水的，吸水的

hydroxyapatite *n.* 羟磷灰石

hygienic *a.* 卫生的

hyperbranched *a.* 超支化的

I

immiscible *a.* 不能混合的，不融和的

immunosuppressant *n.* 免疫抑制剂

implant *vt. & n.* 移植，植入

implantation *n.* 移植，安放，注入

implement *n.* 工具，器具；*vt.* 贯彻，实现；*v.* 执行

impregnate *v.* 注入，充满，灌注

impurity *n.* 杂质，混杂物，不洁，不纯

incandescent　*a.* 过热发光的，白炽的

incinerate　*v.* 烧弃，焚化

incision　*n.* 切割，切开，切口

incus　*n.* 砧骨（位于中耳）

indentor　*n.* 压锥，压头，挤入体

inert　*a.* 无活动的，惰性的，迟钝的

inertness　*n.* 不活泼，没有生气

infiltration　*n.* 渗透，渗入，渗透物

inflammatory　*a.* 发炎的，引起炎症的

infrared　*a.* 红外线的

infrastructure　*n.* 基础结构

ingot　*n.* （铸）块，浇锭

ingress　*n.* 进入，入口处

inherently　*ad.* 天性地，固有地

initiation　*n.* 引发

initiator　*n.* 引发剂

injectable　*n.* 血管注射剂；*a.* 可注射的

injection molding　注射成型，注塑

innervation　*n.* 神经分布，神经支配，神经兴奋作用（或过程）

insight　*n.* 洞察力，见识

integration　*n.* 综合

interdisciplinary　*a.* 交叉学科的

interdisciplinary field　交叉学科

interfacial　*a.* 界面的，分界面的，面间的

interfacial bond strength　界面结合力

interionic　*a.* 离子间的

interleave　*vt.* 插入纸，使隔行，使交织

intermediate　*a.* 中间的；*n.* 媒介，中间品

interparticle repulsion　颗粒间相互斥力

intersection　*n.* 交叉点

interstitial　*a.* 空隙的；在裂缝间的

intertwine　*v.* （使）纠缠，（使）缠绕

intestinal　*a.* 肠的，肠内的，（疾病）侵袭肠的

intracellular　*a.* 细胞内的

intramedullary　*a.* 骨髓的，脊髓的

intrinsic　*a.* （性质）固有的，内在的，本质的

investment　*n.* 投资，投入，包围，熔模（蜡模）制造

Iodo-　碘代

ion implantation　离子浸射

ionic　*a.* 离子的，离子键的

ironing　*n.* 熨平

irreversible　*a.* 不能撤回的，不能取消的

isobaric　*a.* 等压的，等压面的

isoelectric point　等静电点

isomer　*n.* 异构体

isoprene　*n.* 橡胶基质

isotactic　全同立构

isothermal　*a.* 等温的，等温线的；*n.* 等温线

isotonic　*a.* 等压的，等张的，等分的

isotropic　*a.* 等方性的，各向同性的

J

judicious　*a.* 明智的

K

kenaf　*n.* 洋麻，洋麻（或槿麻）纤维

kinetic　*a.* （运）动的，动力（学）的

kink　*n.* 纽结，蜷缩

kyphosis　*n.* 驼背

L

ladle　*n.* 钢水包

laminate　*n.* 薄片制品，层压板

laminine　昆布氨酸，N-三甲基赖氨酸内盐

landfill　*n.* （掩埋式）垃圾处理场

laser beam　激光束

lattice　*n.* 格子

leaching　*n.* 浸出，浸析

lesion　*n.* 损害，身体上的伤害

leucine　*n.* 亮氨酸，白氨酸

leucocyte　*n.* 白细胞，白血球

levitation　*n.* 轻轻浮起，升在空中

life cycle assessment（LCA）　生命周期评价

life cycle　寿命周期，使用寿命

ligament　*n.* 系带，韧带

ligand　*n.* 配合基［体］，向心配合（价）体

ligno-cellulose　*n.* 木质纤维素

linear　*a.* 线性的，直线的

liner　*n.* 衬垫，底垫

lining　*n.* 加衬里，内层，衬套

lithographic　*a.* 平版印刷的，平版的

lithography　*n.* 平板印刷

living polymerization　活性聚合

longitudinal　*a.* 经度的，纵向的

loom　*n.* 织布机，织机；*v.* 隐现，迫近

low density polyethylene　低密度聚乙烯

lubricate　v. 润滑，加润滑油

lubrication　n. 润滑

lumen　n. 流明（光通量单位）；内腔

lustrous　a. 有光泽的，光辉的

luting　火泥密封，涂胶泥，用油灰接合

lymphocyte　n. 淋巴球，淋巴细胞

lysosome　n. （细胞中的）溶酶体

M

macromolecule　n. 巨大分子，高分子

macrophage　n. 巨噬细胞

macroscopic　a. 宏观的，肉眼可见的

maglev　n., a. 磁力悬浮火车（的）

magnetic　a. 磁性的，磁铁的

magnetic ferrites　磁性铁氧体

magnetism　n. 磁，磁力，吸引力，磁学

magnetocaloric　a. 磁（致）热的

magneto-elastic　a. 磁致弹性的

magnetoresistive　n. &a. 磁（致电）阻的

magnetostriction　n. 磁缩性

malleable　a. 有延展性的，可锻的

malleus　n. 锤骨

manganite　n. 水锰矿；亚锰酸盐

marginal　a. 记在页边的、边缘的，边际的

matrix　n. 基质，基体

maxillofacial　a. 上颌面的

membrane　n. 膜，隔膜

menopause　n. 绝经期，更年期

merger　n. 合并，联合

mesogen　致晶链节

mesomorphic　a. 介晶的

mesophase　中间相，介晶相

mesoporous　a. 中孔

messy　a. 肮脏的，凌乱的，杂乱

metabolic　a. 代谢作用的，新陈代谢的

metallic　a. 金属的，金属键的

metallurgy　n. 冶金学

metastability　n. 亚稳性，亚稳度

metastable　a. 亚稳的

methane　n. 甲烷，沼气

methodology　n. 方法学，方法论

methyl　n. 甲基

methylene　n. 亚甲基

microcracking　n. 微裂纹，微区破裂

microfibrils　n. 微纤维，微纤丝

micron　n. 微米

microporous　a. 微孔的

millennium　n. 太平盛世，一千年

mimetic　a. 模仿的，好模仿的；拟态的；类似的

mimetic　a. 模仿的，好模仿的

mimic　a. 模仿的；拟态的

mindset　n. 固定的习惯

miniaturization　n. 小型化

miniaturize　vt. 使小型化

minimize　vt. 将……减到最少；v. 最小化

modulator　n. 调制器

modulo　prep. 以……为模

molecular weight　分子量

molecular weight distribution　分子量分布

monofilament　n. 单（根长）丝，单纤（维）丝

monolayer　n. 单层

monolith　n. 独石

monolithic　n. 单片电路，单块集成电路

monomer　n. 单体

morbidity　n. 病态，不健全，发病率

morphological　a. 形态学（上），结构学的

morphology　n. 组织，形态；形态学，形态论

multiplicative　n. 增殖；a. 增殖的

mundane　a. 世界的，世俗的，平凡的

mutagenicity　n. 诱变（性）

N

nanochemistry　n. 纳米化学

nanostructure　n. 纳米结构

nanotechnology　n. 纳米技术

nanotube　n. 纳米管

naphthalene　n. 萘（球），卫生球

nautical　a. 船员的，船舶的，海上的，航海的

nebulous　a. 星云的，云雾状的，模糊的，朦胧的

needle-shaped　针状

nematic phases　向列相

neon　n. 氖

neoprene　n. 氯丁胶

neuronal　a. 神经原的，神经细胞的

neuronal ensemble　神经元集合

niche　n. 小生境，墙壁的凹入处，壁龛

nitride　n. 氮化物

nitrocellulose　*n.* 硝化纤维素

nomenclature　*n.* 命名法，专门语，术语

non-covalent　*a.* 非共价键的

non-equilibrium state　非平衡态

non-linear　*a.* 非线性的

notch　*n.* 槽口，凹口，切口

notch filter　陷波滤波器

noxious　*a.* 有害的

nucleation　*n.* 成核现象，晶核形成

nutshell　*n.* 坚果壳

O

oblique　*a.* 倾斜的，间接的

optical amplifier　光学放大器

optical waveguide　光学波导（波导管，波导器）

optically-addressed spatial light modulator　光寻址
　空间光调制器

optimal　*a.* 最佳的，最理想的

optimization　*n.* 最佳化，最优化

optoelectronic　*a.* 光电子的

orbital　*a.* 轨道的

organometallic　*a.* 有机金属的

orientation　*n.* 定向，取向

oriented　*a.* 取向的，定向拉伸的

orthodontics　*n.* 畸齿矫正（术），正牙学

orthogonal　*a.* 直角的，直交的

orthopaedics　*n.* 整形外科，整形术

orthopedic　（＝orthopaedic）*a.* 整形外科的

orthorhombic　*a.* 正交晶的，斜方晶的

osseous　*a.* 骨的，骨质的

ossicle　*n.* 小骨，小骨片

osteoarthritis　*n.* 骨关节炎

osteoblast　*n.* 造骨细胞

otology　*n.* 耳科学

overriding　*a.* 最重要的；高于一切的

oxide　*n.* 氧化物

Oxy-　氧代，含氧的

P

packaging　*n.* 包装，包装术，包装业

panacea　*n.* 万能药

panel　*n.* 嵌板，仪表板

paradigm　*n.* 范例

paramount　*a.* 极为重要的

pathologist　*n.* 病理学者

patriot　*n.* 爱国者

pendant　*n.* 垂环，垂饰，下垂物

peptide　*n.* 缩氨酸，肽

percolate　*n.* 滤过之液体、滤液；*v.* 过滤

perform　*vt.* 预先形成；*n.* 粗加工的成品，初制
　品，预制型品

periodontal　*a.* 牙齿周围的，牙齿膜的

peripheral　*a.* 周界的，外围的，（神经）末梢区域的

periphery　*n.* 外围

peritectic　*a.* 包晶的，转熔的

permeable　*a.* 有渗透性的，能透过的

permeance　*n.* 浸透，透过

permittivity　*n.* 介电常数，电容率

permute　*v.* 序列改变

perovskite　*n.* 钙钛矿

perpendicular　*a.* 垂直的，正交的；*n.* 垂线

phagocytic　*a.* 噬菌细胞的

pharmaceutical　*a.* 制药的；药学的

pharmaceuticals　*n.* 医药品

pharmacological　*a.* 药理学的，药物学的

phase　*n.* 相

phenotype　*n.* 表型，具有共同表型的一类有机物

phonon　*n.* 声子

phosphate　*n.* 磷酸盐

phospholipid　*n.* 磷脂

photochromism　*n.* 光致变色现象

photomagnetic　*a.* 光磁的

photomagnetic effect　光磁效应

photopolymerization　*n.* 光聚作用，光压聚合作用

photovoltaics　*a.* 光电的

piezoelectric　*a.* 压电的

piezotransformers　*n.* 压电能量转换器

piston　*n.* 活塞

pit　*n.* 坑，槽

pitch　*n.* 沥青，树脂，松脂

pivotal　*a.* 枢轴的，中枢的，关键的

planar　*a.* 平面的，二维的

plasma　*n.* 血浆，乳浆；等离子体，等离子区

plasmid　*n.* 质粒，质体

plasticizer　*n.* 增塑剂

plastics　*n.* 塑料

platelet　*n.* 血小板，小盘，小板

plug　*n.*　塞，栓，插头

polarizability　*n.*　极化

polarizer　*n.*　偏光器，起偏镜

poly（lactic acid）（PLA）　聚乳酸

polycrystalline　*a.*　多晶的

polydispersity　*n.*　多分散性；聚合度多分散性

polyesteramide（BAK）　聚酰胺酯

polyethylene　聚乙烯

polygonal　*a.*　多角形的，多边形的

polyhydroxybutyrate（PHB）　聚羟基丁酸酯

polymer　*n.*　聚合物，聚合体，聚合材料

polypropylene　*n.*　聚丙烯

polystyrene　*n.*　聚苯乙烯

polyurethane　*n.*　聚氨酯

porosity　*n.*　多孔性，有孔性，孔隙度

potential　*a.*　潜在的，可能的，电位的；*n.*　电位

potential energies　势能

pottery　*n.*　陶器

powder synthesis　粉体合成

precipitate　*n.*　沉淀物；*vt.*　使沉淀，析出，凝结

precipitation　*n.*　沉淀，沉积

preferably　*ad.*　更适宜的，更可取的

prejudice　*n.*　偏见，歧视

prepreg　*n.*（塑料或其他合成材料在模塑之前用树脂浸饱的）预浸料坯

pressure casting　压力注浆成型

preventive　*a.*　预防性的

processing window　加工范围

progenitor　*n.*　祖先，起源，前身

prohibitive　*a.*　禁止的，抑制的

projectile　*n.*　抛射体，枪弹

proliferate　*v.*　增生扩散

proliferation　*n.*　增殖，扩散

propagation　*n.*　增长

propylene　*n.*　丙烯

prosthesis　*n.*　（*pl.* -ses）修复术，弥补术；修补物，假体，人造器官

proteoglycan　*n.*　蛋白聚糖，蛋白多糖

protocol　*n.*　科学实验报告

prototype　*n.*　原型

protrusion　*n.*　伸出，突出

proviso　*n.*　限制性条款，附文，附带条件

pulpous　*a.*　果肉状的，纸浆状的

pultrude　*v.*　拉挤

Q

quantum mechanical calculations　量子力学计算

quench　*v. & n.*　淬火，熄灭，急冷

quest　*n. & v.*　追求，寻求，调查

R

racket　*n.*　球拍

radiolucent　*a.*　射线可透的，射线透明的

radiopaque　*a.*　辐射透不过的

radius　*n.*　半径，范围，辐射光线，范围，界限

radome　*n.*　雷达天线罩

ram　*n.*　撞锤，水压机活塞

random copolymer　无规共聚

recesses　*n.*　深孔，凹口

reciprocating screw　往复式螺杆

recyclability　*n.*　再循环能力

recycle　*n. & vt.*（使）再循环，再利用，回收

reflectivity　*n.*　反射

refraction　*n.*　衍射

refractoriness　*n.*　耐火度

refractory　*a. & n.*　难熔的，耐火材料

regenerative　*a.*　再生的

rehydrate　*v.*　再水化，再水合

reinforced　*a.*　强化的，增强的

relative densities　相对密度

renewable　*a.*　可更新的，可再生的

repulsion　*n.*　推斥，排斥

reshuffle　*vt. & n.*　重新洗牌，重组，改组

residual　*a.*　剩余的，残留的

resin transfer moulding（RTM）　树脂转移模塑

resonance　*n.*　共振，谐振

resorb　*v.*　再吸收，消融

resorbable　*a.*　可再吸收的

resorption　*n.*　再吸收，再吞

restenosis　*n.*　（尤指心瓣手术后的）再狭窄

retina　*n.*　视网膜

revision　*n.*　修订，修改，修正，修订本

rigidity　*n.*　坚硬，刚性，硬度

ripe　*a.*　熟的，成熟的，时机成熟的；*v.*　成熟

rivet　*n.*　铆钉；*v.*　固定

roam　*v. & n.*　漫游，闲逛，徘徊

rod　*n.*　杆，棒

rubble　n. 碎石

rupture　v. 破裂，裂开，割裂；n. 破裂，割裂

S

sag　v. 松弛，下陷，下垂，漂流；n. 下垂，下陷，物价下跌，随风漂流，垂度

sanitary　a. （环境）卫生的，清洁的，保健的

sanskrit　a. 梵语的

sapphire　n. 蓝宝石

scaffold　n. 脚手架，支架

scalability　n. 可量测性

scenarios　n. 设想

scoliosis　n. 脊柱侧凸

scorch　v. 烧焦，枯萎；n. 烧焦，焦痕，枯黄

scrap　n. 碎片，断片，废品

sealant　n. 密封剂，密封胶，密封腻子

segregate　v. 隔离

self-assembly　n. 自组装

semiconductor　n. 半导体，半导体材料

semicrystalline　a. 半晶质的

sequence　n. （分子的）序列结构

shaft　n. 轴，杆状物

shear　v. 剪，修剪，剪切

sheath　n. 鞘，护套，外壳

shell　n. 壳，外壳

silicate　n. 硅酸盐

silicon nitride　氮化硅

simulation　n. 仿真，模拟，模拟实验

sinter　n. 泉华，烧结物，熔渣；vt. 使烧结

sintering　n. 烧结

sisal　n. 剑麻，西沙尔麻

situs　n. [sing., pl.] 部位（尤指动植物器官生来的原位置），地点

size effects　尺寸效应

skeleton　n. （动物之）骨架，骨骼，格架

slip casting　注浆成型

slot　n. 缝，槽

slump　n. & vi. 衰退，滑动，坍塌，落下

slurry　n. 稀（泥，沙）浆，悬浮体

smart material　智能材料

smectic phases　近晶相

sodium　n. 钠

sol-gel　n. 溶胶，凝胶

soluble　a. 可溶的，可溶解的

sorbant　n. 吸附剂

soybean oil resin　大豆油树脂

spacer　（柔性的）间隔链节

spatial　a. 空间的

specific modulus　比模量

specific strength　比强度，强度系数

specific volume　比容

spectacular　a. 引人入胜的，壮观的

spectra　n. 范围，光谱

spectroscopically　ad. 利用光谱方法，利用分光设备

spectroscopy　n. 光谱学，波谱学

spherical　a. 球的，球形的

spine　n. 脊骨，脊椎，脊椎骨

spinning　n. 纺丝，纺织

spiral　a. 螺旋形的；n. 螺旋

splint　n. （外科用的）夹板；v. 用夹板夹

spondylolisthesis　n. 脊椎前移

spray　vt. & n. 浪花，喷雾，喷涂

spray forming　喷溅成型

squeeze　v. 压，压缩，挤

stapes　n. 镫骨

star-branching　星形支化

stent　a. 展幅的，扩张的

stepwise　a. 逐步地，分阶段地

stereoisomer　n. 立体异构体

stereoregularity　立构规整性

steric hindrance　空间位阻

sterically　ad. 空间（上）地

stiffness　n. 刚度，刚性，坚硬，硬度

stoichiometric constant　论量常数

strain　n. 应变

strength　n. 强度

stress　n. 应力

striation　n. 条痕，条纹状

structural ceramics　结构陶瓷

structural diagram　结构图

styrene　n. 苯乙烯

styrene-butadiene rubber　丁苯橡胶

sublimation　n. 升华，提纯，纯化

substantial　a. 坚固的，实质的，真实的，充实的

substituent group　取代基团

substrate　n. 基片，衬基

sulfur　n. 硫磺

superconductivity　n. 超导性，超导率

superconductor *n.* 超导（电）体

supercritical *a.* 超临界的

superimposible *a.* 可叠合的

superlattice *n.* 超点阵、超晶格

supersaturate *vt.* 使过度饱和

supplement *n.* 补遗，补充，附录，增刊；*v.* 补充

supramolecular *a.* 超分子的

supramolecular chemistry 超分子化学

surmount *vt.* 战胜，超越，克服，在……顶上

susceptibility *n.* 磁化系数

suspension *n.* 悬浊液

sway *v.* 摇摆，摇动

swing *v.* 摇摆，摆动，回转，旋转

syndiotactic 间同立构

synergy *n.* 合力，协力，协同作用

synonymous *a.* 同义的

synovial *a.* 滑液的，含有滑液的，分泌滑液的

synthetic *a.* 合成的，人造的，综合的

synthetic fiber 合成纤维

T

tacticity *n.* 立构规整度

tagging *n.* 标记

tailored *a.* 剪裁讲究的，特制的，特定的

tantalum *n.* 钽（金属元素），符号 Ta

template *n.* （=templet）模板

tenacious *a.* 顽强的

tendon *n.* 腱

tensile *a.* 可拉长的，可伸长的；张力的，拉力的

tensile strength 抗张强度

terephthalate *n.* 对苯二酸盐（或酯）

terminal *n.* 终端，接线端；*a.* 末梢的，端的

termination *n.* 终止

termite *n.* 白蚁

tether *n.* 范围，限度；*v.* 限定，束缚

tetraethoxy *a.* 四羟基的

tetraethoxysilane *n.* 四乙氧基硅烷

tetragonal *a.* 正方晶的，四方晶的

tetrahedral *a.* 四面体的

tetrahedron *n.* 四面体

textile *n.* 纺织品；*a.* 纺织的

texture *n.* 质地，纹理，（皮肤）肌理，结构

therapeutic *a.* 治疗的，治疗学的；*n.* 治疗剂，治疗药物

thermal conductivity 热导性，热导率

thermal degradation 热降解

thermal stress 热应力

thermochromism *n.* 热致变色现象

thermodynamic *a.* 热力学的，热动力学的

thermoforming 热压成形

thermolysis *n.* 热（分）解（作用），散热（作用）

thermoplastic *a.* 热塑性的；*n.* 热塑性塑料

thermoset *a.* 热固性；*n.* 热固性材料

thermosetting *a.* 热塑性的

thermosetting resin 热固性树脂

thrombogenicity *n.* 血小板

thrombophlebitis *n.* 血栓（性）静脉炎

tibia *n.* 胫骨

tile *n.* 瓦片，瓷砖

titanium *n.* 钛

topology *n.* 构造，结构，配置，外形

torsional angle 扭转角

toughness *n.* 韧度，韧性

toxicity *n.* 毒性

tracheal *a.* 气管的，导管的，呼吸管的

track *n.* 轨迹，途径；*vt.* 循路而行，追踪，通过

trans- 反式

transduce *v.* 转换（能、信号等）

transfect *vt.* 使转染，使（细胞）感染病毒核酸

transistor *n.* 晶体管

transition *n.* 转换，跃迁，过渡

transparent *a.* 透明的，显然的，明晰的

transverse strength 抗挠强度，横向强度

trauma *n.* 外伤，损伤

traumatize *vt.* 使受损伤，使受精神上创伤

trigonal *a.* 三角的，三角形的

trough *n.* 出钢水口

tumour *a.* 肿瘤的，肿胀的

tungsten *n.* 钨

turbine *n.* 涡轮

U

ulna *n.* 尺骨

ultrafine *a.* 超细的，超微细的，精细的

ultrahigh *a.* 超高的，特高的

ultra-high molecular weight polyethylene 超高分子量聚乙烯

ultrastructure *n.* 超微结构，亚显微结构

underlie *vt.* 位于……之下，成为……的基础

unpaired electron　未成对电子

unprecedented　*a.* 没有前例的

upsurge　*n.* 高潮

urea　*n.* 尿素

ureter　*n.* 尿管，输尿管

urethral　*a.* 尿道的

urinary　*a.* 尿的，泌尿器的

V

valence　*n.* （化合）价，（原子）价

valve　*n.* 阀；电子管，真空管

vantage　*n.* 优势，有利情况

vascular　*a.* 脉管的，有脉管的，血管的

vector　*n.* 向量，矢量

ventilation　*n.* 通风，流通空气

venture capital　*n.* 风险投资

versus　*prep.* 反对，与……比较

vertebra　*n.* 脊椎骨，椎骨

vertebral　*a.* 椎骨的，脊椎的，由椎骨组成的，有脊椎的

vertice　*n.* 顶点，至高点

vinyl　*n.* 乙烯基，乙烯树脂

viral　*a.* 滤过性毒菌的，滤过性毒菌引起的

virtuosity　*n.* 艺术鉴别力

viscoelastic　*a.* 黏弹性的

viscosity　*n.* 黏度，黏性

viscous　*a.* 黏性的，黏滞的，胶黏的

visualization　*n.* 使看得见的，清楚地呈现

vivo　*n.* 体内

vulcanization　*n.* 橡胶的硬化，硫化

W

waveguide　*n.* 波导

welding　*n.* 焊接法，定位焊接

wetness　*n.* 湿润

whisker　*n.* 晶须，针状单晶

wrought　*a.* 锻（制）的，可锻造的，精致的

X

xenograft　*n.* 异种移植物

Y

yarn　*n.* 纱，纱线，纤维纱

yield　*v.*，*n.* 产生，发生，输出，流动性，塑流

yttrium oxide　氧化钇

Z

zeolite　*n.* 沸石，与沸石类似的天然的或人工的硅酸盐

zip　*n.* 拉链，拉锁

zirconium dioxide　氧化锆