Polymesters composites and technology

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Introduction to polymer matrix composites

1.1 Introduction

Materials are the basis for improving human production and living standards. They provide milestones in human progress. Humans have been accessing and using materials for several thousand years. Looking over the history of human civilization, we will find that its development is about human access and use of materials using social productive forces, science and technology. It reflects human ability to understand and transform nature. Whenever there is a new epoch-making material, productivity will also receive a huge development and human society will leap forward. Therefore, materials have become a symbol of the progress of human civilization, and have become milestones for dividing eras of human history. From the material point of view, human society has experienced the Stone Age, Bronze Age, and Iron Age. High-performance plastics and composites, which appeared in the 20th century, have infiltrated to the national economy and people’s lives in various fields with a rare rate of development in the history. They have become the substitutes for traditional materials, showing improved performance. Now, with the rapid development of science and technology, materials play an important role in the national economy and defense. New materials are the basis of new technologies, and materials science, energy technology and information science have become the three pillars of modern science and technology.

Materials science is the integrated discipline. It is closely related to a wide range of other disciplines. It explains the laws of materials’ macroscopic properties from the chemical composition and the principle of internal structure, and then develops a set of principles in designing, manufacturing and using new materials with specific properties. It mainly includes three parts contents: ① from the chemical point of view, the relationship of the chemical composition of materials and each component is researched, and the relationship between the composition and performance is researched, and the preparation methods of materials are researched; ② from the physical point of view, the performance of material is studied, and the relationship between the internal structure of materials (the combination of atoms and molecules, the arrangement distribution in space and the state of aggregation)
and performance is studied; ③ under the guidance of chemical and physical theory, the technical problems which related to the preparation and application of materials are researched.

There are many different types of materials. Basically, they can be divided into three types of materials with vastly different performance by the way the atoms or molecules are bonded together (the main combination bonds): ① metallic materials, metal elements are combined by metal bonds; ② organic polymer materials, non-metallic elements are bonded covalently to macromolecular compounds; ③ ceramic materials, non-metallic elements and metal elements are combined by covalent bonds, ionic bonds, or a mixture of the two bonds. From the service performance point, there are two main types of materials: ① structural materials; ② functional materials. For structural material, its mechanical properties, such as strength, stiffness, deformation and so on, are majorly considered, while for functional material, its sound, light, electricity, heat and magnetic properties are mainly used. In this case, we should know the behavior of materials in sound, light, electricity, heat and magnetic field.

As the rapid development of modern science and technology, there are more harsh special requirements for materials. The research of material is gradually breaking away from the track of researching by experiences and fumbling methods. It develops in the direction of material designing according to the designed properties. The composite material which is made of metallic, non-metallic and polymeric material by certain processes, can retain the advantages of the original components, overcomes some shortcomings and show some new properties. The emergence and development of such composite materials is a classic example of material designing.

Composite material is a multi-phase system consisted of matrix material and reinforcing material. Matrix material is a continuous phase, and it includes metal matrix composite materials, inorganic non-metallic matrix composite materials and polymer matrix composites by the different matrix materials. Reinforcing material is a dispersed phase, usually fibrous materials such as glass fiber, organic fiber and so on. We only discuss polymer matrix composites in this book.

Polymer matrix composite material is the one that uses organic polymer as matrix and fiber as reinforcement. Strength and modulus of fiber are much higher than the matrix material normally. This makes fibers the main load-bearing component. However, there must be a matrix material with good adhesion properties to firmly bond fibers together. At the same time, the matrix material can serve to uniformly distribute the applied load, and transfer the loads to fiber. In addition, some properties of composite materials mainly depend on the characteristics of the matrix material. As a result, in composite materials, the performance of fiber, matrix and the interface between them directly impact on the performance of composite materials.
1.2 The definition of composite materials

The term of composite materials was firstly used in abroad in the 1950s, and it has been used domestically from about the 1960s. Composite material is a kind of complex multi-component multi-phase system, and it is difficult to be defined accurately. A concise definition is shown: composite material is a multi-phase combination material of two or more component materials with different properties and different forms through compounding processes, it not only maintains the main characteristics of the original component, but also shows new character which are not possessed by any of the original components. Composite materials should have the following characteristics: ① microscopically it is non-homogeneous material and has a distinct interface; ② there are big differences in the performance of component materials; ③ the formed composite materials should have a great improvement in performance; ④ the volume fraction of component materials are larger than 10%. According to this definition, composite materials in a wide range of areas, straw mud wall, steel bar reinforced concrete, and tire cord, etc. all belong to the scope of composite materials.

From analysis of the composition and the internal structure of composite materials we found that it includes three basic physical phases. One is called matrix phase which is continuous, another is called reinforcement which is scattered and surrounded by the matrix. The other is called composites’ interface which is an interface between reinforcement phase and matrix phase. For further study on micro-structure level, we found that, owing to the complex physical and chemical reasons in compounding process, the reinforcement phase and the matrix phase near the interface become a complex structure which is different from both of the matrix phase and the reinforcement phase of their own. And at the same time, we found that the structure and morphology have an impact on macroscopic performance of composites, so the microscopic area near the interface changes in structure and properties. Thus it becomes the third phase of composites, which is called interphase. Therefore, composite material is composed of matrix phase, reinforcement phase and interphase. The structure and the nature of these three phases, their configuration and interaction, as well as the relative content determine the performance of composite materials.

“Material Dictionary” edited by Changxu Shi gave a more comprehensive and integrity definition on composite material: “Composite materials are new materials that are combinations of different types of materials, such as organic polymers, inorganic non-metal or metal and so on, through compound technology. It not only retains the key feature of the original component materials, but also gets the performances that are not depicted by the original components through the combined effects. Materials designing can make the performance of each component to mutual supplement and interrelate to each other, thus produce a new superiority of
performance, which has essential differences from general materials mixed simply.” The definition stresses the important feature of composite materials that they are designable. In industry, composite materials are usually referred to the materials with excellent integrated performance which is made of reinforcement with high-strength, high modulus and brittleness, and matrix material with low modulus and toughness by a certain processing process. Composite materials discussed in modern materials science are generally referred to as fiber, sheet, and particle reinforced, or self-reinforced polymer matrix, ceramic matrix or metal matrix composites. This definition grasps the essence of the composite materials, namely the enhancing concept by enhancer. The fiber is the most widely used and the most effective reinforcement, so the composite material that people often talk about is a narrow meaning of composite materials, i.e. fiber-reinforced composite materials, which are discussed in this book.

1.3 Naming and classification of composite materials

1.3.1 Naming of composite materials

The development of many new materials is before their scientific name, so traditionally we often firstly use a number of popular names. For example, domestic composite material with glass fiber and resin began to appear in the 1950s, which is called the “glass steel”, and its other names are: glass fiber reinforced plastics (GFRP), glass plastics, glass cloth laminates, and glass fiber composite materials. For the same kind of materials, if they have many names and some names are even inaccurate or misleading, it is easy to cause confusion. This is certainly not desirable to the application and development of materials.

Composite materials can be named by reinforcement and the matrix material. According to the type of matrix materials, there are metal matrix composite material, aluminum matrix composites, polymer matrix composite material, and epoxy resin matrix composite material. Polymer matrix composites are often named by the type of their reinforced fiber, such as glass fiber composite material (commonly known as glass fiber reinforced plastics), carbon fiber composites, and hybrid fiber composites. More specifically, the name of the reinforcement is put the front of the name of the matrix material, along with “composite material” on the back. For example, composite material with E-GF and epoxy resin can be named “E-glass fiber epoxy composite material”. For convenient writing, it can also be written as abbreviation of the reinforcement and matrix materials, with a “/” separating them, along with “composite material” on the back, and so the former “E-glass fiber epoxy composite material” is briefly called “E-GF/epoxy composite material” (traditionally called epoxy GFRP). Composite material of carbon fiber and metal matrix is called “metal matrix composites”, and can also be written as “carbon/metal composite material”. Carbon fiber reinforced carbon
matrix composite material is called “carbon/carbon composite” or “C/C composite material”. The above-mentioned nomenclature can also be addressed using commodities trademark directly, for example, T300/648, M40/5208, S-GF/5245C, Kevlar49/QY8911, HT3/5405 and so on.

1.3.2 Classification of composite materials

There are many ways to classify composite materials. For example, in accordance with the reinforcing principle, there are diffusion-enhanced composite materials, particle-enhanced composite materials and fiber-reinforced composite materials. Based on different application requirement, there are structural and functional composite materials. Functional composite materials, in accordance with its function, can also be divided into electrical functional composite materials, thermal functional composite materials, optical functional composite materials, and so on. According to different preparation processes, it is classified as laminated composite materials, winding structural composites, pultrusion composite materials, textile structural composite materials and so on.

According to the meaning of composite materials and its naming principles in this book, the classification of composite materials is shown in follows.

(1) Classification in accordance with the type of matrix material. ① Metal matrix composites (MMC’s); ② inorganic non-metallic matrix composite materials; ③ polymer matrix composites (PMC’s). The most important inorganic non-metallic matrix composite materials are ceramic matrix composites (CMC’s) and carbon-based composite materials such as C/C composite materials. In the polymer matrix composite materials, there are thermosetting resin-based composite materials and thermoplastic resin-based composite materials, as well as one-component polymer matrix composite materials and polymer blends matrix composite materials.

(2) Classification in accordance with the form of dispersed phase. ① Continuous fiber-reinforced composite materials; ② fibrous fabric, braid reinforced composite materials; ③ sheet reinforced composite materials; ④ short fiber or whisker reinforced composite materials; ⑤ particle reinforced composite materials; ⑥ nanometer particle reinforced composite materials.

(3) Classification in accordance with the type of reinforcing fibers. ① Carbon fiber composite material; ② glass fiber composite materials; ③ organic fiber composite materials; ④ boron fiber or silicon carbide fiber composite materials; ⑤ hybrid fiber composite materials.

1.4 Molding methods of composite materials

There are many processing methods of composite materials, and big differences in different types of molding processes of composite materials. The molding process
about hand lay-up fiber reinforced plastics (FRP) (Fig. 1.1) is a typical process of preparing thermosetting polymer matrix composites. We see that there are many manual labours in process. Compounding of fibers and resins and curing reaction process of resin system are the forming processes of composite materials and at the same time, the formation processes of composite material products. Preparation of materials and products completes in the same process, which is another character that the composite materials are different from metallic materials.

![Technique flow chart of FRP by hand lay-up.](image)

**Fig. 1.1** Technique flow chart of FRP by hand lay-up.

### 1.5 Characteristics of composite materials

From the classification of composite materials, we already know that there’s a wide range of composite materials. It is a truism that different types of composite materials have different performance characteristics. However, composite materials also have some common characteristics. Polymer matrix composites, because of their inherent characteristics, have become the fastest growing and most widely used composite materials. Compared with traditional materials such as metals, polymer matrix composites have the following characteristics.

#### 1.5.1 High specific strength, high specific modulus

The prominent advantages of polymer matrix composite materials are their high specific strength and high specific modulus. The specific strength is the ratio of strength and density and the specific modulus is the ratio of modulus and density, and the dimensions or units are both length. Under the premise of equal weight, they are indices of measuring bearing capacity and stiffness properties of the material. Such properties are very important for aerospace structural materials to work in the air or the space. Table 1.1 lists the specific strength and specific modulus of several common structural materials, in which carbon fiber resin matrix composites shows higher specific modulus and specific strength. The high specific strength and high specific modulus of composite materials result from high-performance and low-density of reinforcing fibers. As a result of relatively low modulus, high density of glass fiber, the specific modulus of the glass fiber resin matrix composites is slightly lower than metallic materials.
1.5 Characteristics of composite materials

Table 1.1  Specific strength and specific modulus of some common used materials and fiber composites

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (g/cm³)</th>
<th>Tensile strength (GPa)</th>
<th>Elastic modulus (10²GPa)</th>
<th>Specific strength (10⁶cm)</th>
<th>Specific modulus (10⁸cm)</th>
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</thead>
<tbody>
<tr>
<td>Steel</td>
<td>7.8</td>
<td>1.03</td>
<td>2.1</td>
<td>1.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td>2.8</td>
<td>0.47</td>
<td>0.75</td>
<td>1.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Titanium alloy</td>
<td>4.5</td>
<td>0.96</td>
<td>1.14</td>
<td>2.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Glass fiber composite materials</td>
<td>2.0</td>
<td>1.06</td>
<td>0.4</td>
<td>5.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Carbon fiber II/epoxy composite materials</td>
<td>1.45</td>
<td>1.50</td>
<td>1.4</td>
<td>10.3</td>
<td>9.7</td>
</tr>
<tr>
<td>Carbon fiber I/epoxy composite materials</td>
<td>1.6</td>
<td>1.07</td>
<td>2.4</td>
<td>6.7</td>
<td>15</td>
</tr>
<tr>
<td>Organic fiber/epoxy composites</td>
<td>1.4</td>
<td>1.40</td>
<td>0.8</td>
<td>1.0</td>
<td>5.7</td>
</tr>
<tr>
<td>Boron fiber/epoxy composites</td>
<td>2.1</td>
<td>1.38</td>
<td>2.1</td>
<td>6.6</td>
<td>10</td>
</tr>
<tr>
<td>Boron fiber/aluminum matrix composites</td>
<td>2.65</td>
<td>1.0</td>
<td>2.0</td>
<td>3.8</td>
<td>7.5</td>
</tr>
</tbody>
</table>

1.5.2 Good fatigue resistance and high damage tolerance

The fatigue failure of metallic materials is often of no obvious omen to the salience of damage. The interface between fiber and matrix in composite materials can prevent the propagation of crack. The fatigue failure always initiates from the weak links of fiber. Crack growth or damage continues gradually for a long time, so there is a significant harbinger before the final destruction. As we see from the $S$-$N$ curve of fatigue properties, the fatigue strength of the majority of metallic materials is 30% to 50% of tensile strength, while the fatigue strength of carbon fiber/polyester composite material is 70% to 80% of its tensile strength, the proportion of glass fiber composite materials is between them.

Unlike traditional materials, damage of composite material is not due to the unstable propagation of the main crack and then suddenly happening, but it experiences the development of a series of damages such as matrix cracking, interfacial debonding, fiber pull-out and fiber split or break. A large number of independent fibers in matrix are typical mechanical statically indeterminate system. When a small number of fibers fracture, the part of the load they bore will be transferred via the matrix and quickly diffuse to other fibers. Composite materials will not lose the bearing capacity in short term. Composite material will not fracture with some defects and cracks in it for a sudden development.

1.5.3 Good damping characteristics

The natural frequency of vibration of forced structure relates to the shape of the structure itself, as well it is proportional to the square root of the specific modulus of structural materials. Therefore, composite materials have a high natural frequency, and it’s not easy to have a resonance in general. At the same time, the interface between the fiber and matrix in composite materials has a great ability
to absorb vibrational energy, resulting in a high vibration damping of materials. Once the vibration occurs, it can be stopped in a short time.

1.5.4 Multi-functional performance

(1) High instantaneous temperature resistance and good ablation resistance. Thermal conductivity of FRP (fiberglass reinforced plastics) is only 1% of metal materials. It can also be made into the materials with high specific heat, high melting heat and high vaporization heat. Thus, FRP can be used as the ablation-resistant protective material for missile nose cone.

(2) Superior electric insulation performance and high frequency dielectric properties. FRP is a superior insulating material in power frequency. Besides insulation property, FRP has good high-frequency dielectric properties as well. It can thus be used as the high-frequency wave-transparent materials for radome.

(3) Good friction property. Carbon fiber has low friction coefficient and self-lubricating property. Its composite materials have good friction-resistance and antifriction properties.

(4) Excellent chemical corrosion resistance.

(5) Special optical, electrical and magnetic properties.

1.5.5 Good processing technics

(1) Fiber, matrix and other raw materials can be chosen in accordance with the use condition and performance requirement of the product, that is, material can be designed.

(2) Molding processing methods can be chosen in accordance with the shape, size, and number of the product.

(3) The integrated molding can reduce the number of assembly parts and thus save time, save material, reduce weight.

1.5.6 Anisotropic and properties designability

Fiber composite materials are characterized prominently by anisotropy, which is related to the designing of performance. The mechanical and physical properties of fiber composite materials are determined not only by the type of fiber and resin type and relative volume fraction, but also closely related with by the direction of fiber arrangement, ply stacking sequence and layer number. Therefore, based on the load distribution and the different application requirement of the engineering structure, we select the corresponding material and ply designing to meet the established requirements. Taking advantage of this feature, we can get the optimal design of parts, to be safe, reliable, economical and reasonable.

There are some shortcomings and problems for polymer matrix composites. First, the degree of the automation and mechanization processes is low. Also, the
consistency of the material properties and the stability of product quality are both poor. The methods of quality testing are imperfect too. Moreover, the properties of long-term high temperature resistance and aging resistance are poor and so on. These issues need to be studied and dealt with in order to promote the development of composite materials and produce more mature technology and materials.

1.6 Application of composite materials

In composite materials, the glass fiber polymer matrix composites are the first developed and applied materials. In the 1940s, Americans compounded glass fiber and unsaturated polyester resin firstly, and then produced military radar and aircraft fuel tank by hand lay-up process, which opened the path for the glass fiber composite materials to be applied in military industry. Since then, with the development of glass fiber, resin matrix and composite materials processing, glass fiber composite materials are not only used in the aerospace industry, but also widely used in a variety of civilian industry, and become important engineering materials.

However, after entering the 1960s, people noted that the mass of the glass fiber reinforced plastics is big and the modulus is low. It could not meet the requirements of high-tech products for high specific modulus and high specific strength such as aircraft. Therefore, the lightweight carbon fiber and carbon fiber composite with high specific modulus and high specific strength were developed between the 1960s and the 1970s. Following the carbon fiber, the aromatic polyamide fibers (aramid fiber) and other high-performance fibers were developed. Such new composite materials starting from carbon fiber composite material was known as the advanced composite materials (ACM).

At present, the world’s total output of composite materials is in megatons. It is difficult to statistic the accurate output. It was reported that the world’s output was 3.9 million tons in 1990, of which 1.503 million tons in the United States, 1.485 million tons in Western Europe, 0.643 million tons in Japan, and 0.106 million tons in China. Nevertheless, the output of composite materials compared with other structural materials is still very small. Now, the world’s output of steel is up to thousand megatons, and the production of plastics also reaches hundred megatons. This shows that there is still much room for the composite materials to develop, and there is also need to speed up the development.

Although the first application of composite is in aerospace sector, and its development has been driven by aerospace demand, but the composite materials for aerospace applications are only a small fraction of total output (only 1%∼2%). Large amount of composite materials are used in transport sector (cars, boats, etc.), construction, chemical corrosion equipment and electric or electronic appliance.
1.6.1 Application in the aircraft and aerospace industry

Although the composite materials of application in the aerospace industry take only a very small share, most of the materials it adopted are advanced composite materials, representing the most advanced technology of composite materials industry. It is worthwhile to discuss this application first.

The root cause for aircraft to use composite materials is to reduce the weight, which can improve aircraft’s performance and reduce the costs. Advanced composite materials in the application of military aircraft passed a developmental way that was from small to large, weak to strong, few to many and from structural load to increasing function in the nearly past 40 years.

Most battleplanes in the world that start serving the force after 1980s have some parts made of ACM. Specifically, the components of its wings, tail and other parts are almost all made of ACM, whose weight accounts for 20% to 30% of the body structural weight. The French Rafale, maiden flight in 1980, 50% of its wings, tail, vertical and the fuselage structure were ACM, which took 40% of the body structural weight. The United States B-2 stealth bomber, maiden flight in 1989, the amount of composite materials took 40% of the body structure. Now, ACM has been widely used in the aircraft’s primary and secondary structure, such as the vertical tail, horizontal stabilizer, rudder, aileron, frontal fuselage and wing skin and so on. The usage of composite materials in modern helicopter is more than military aircraft, and is currently as high as 50% to 80%. There is the ACAP (Advanced Composites Application Program) in the United States, in which several developing helicopters H360, S-75, BK-117 and V-22 all use largely ACM. For example, the V-22 which cruises in high-speed after vertical take-off, landing and tilting rotor, uses nearly 3,000 kilograms’ composite material, accounting for 45% of total structural weight, including most of the structure of the fuselage and wing, joints of the engine and fastening device of blades. In the total weight of the U.S. light reconnaissance and attack helicopters of the latest development, the RAH-66, with stealth capabilities, composite material accounts for about 50%. The length of its keel beam of fuselage is 7.62m, and layer number is as high as 1000. For the Tiger-type helicopter gunship of Franco-German cooperation in the development, the amount of composite materials is as much as 80% of the total weight.

ACM in the application of commercial aircraft is also increasing. Take an example of Boeing, the usage area of composite materials on B707 at 18.5m², on B737 at 330m², on B747 at 930m². For 10 years from B707 to B747, the increase of the area of the fuselage is less than double, but the increase of the area of composite materials used has reached 50 times. The amount of composite materials in B757 is 1429 kg, the amount in B767 is 1524kg, and the amount of the latest development of the B777 has increased to 9900kg, accounting for 11% of structural weight. ACM in European A340 is more than 4 tons, accounting for 13% of the to-
tal structural weight. The branch aircraft ATR-72 was developed in cooperation by French and Italian, whose amount of composite materials is up to 20% because of the usage of the wing. Many small aircrafts using all-composite materials are also manufactured, the most famous in the world “Voyager”, setting the world record of non-fuel and non-stop flight for 9 days, which couldn’t be imagined before the composite materials appear.

Composite materials in space industry are mainly used on the adiabatic shell structures of combustion chamber of solid rocket motor, the inter-segment structure of missile and launch vehicle, structure of liquid hydrogen tanks, module structure of apparatus, missile and satellite fairing structure, heat insulation materials of missile and various satellite structures. Aerospace structural materials have also gone through the metal to fiberglass and then re-developed to the stage of ACM. A typical example is the solid rocket motor casings. The first generation of composite materials used by solid rocket motor is FRP. A successful example is missile engine fiberglass plastics shell of “Polaris A-3” in the early 1960s, which reduces the weight of the alloy steel by 60% and the cost by 66% than “Polaris A-1”. The usage of Kevlar-49 (aramid fiber), IM-7 (carbon fiber)/epoxy composite materials for advanced motor shell makes even more significant results of weight saving.

1.6.2 Application of composites in other industry

In addition to aerospace, the composite materials, especially glass fiber composite materials get a wider range of applications in the other economic areas as a result of advantages of their price and performance. They play an important role in the promotion of scientific and technological progress and the development of national economy. In United States, 1,171,000 tons of fiber composites were produced in 1991, of which 324,000 tons were used in transport, 205,000 tons in construction, 169,000 tons in shipbuilding, 163,000 tons in corrosion equipment, 110,000 tons in electronic appliances, 70,000 tons in business equipment, 75,000 tons in daily necessities, only 18,000 tons in aerospace military, and 37,000 tons in others.

(1) In the area of transport, composite materials have been applied in car, train, ship and other transport tools over half a century in history. Composite materials’ products have been increased year by year, and the amount within the realm of transportation has the greatest proportion. In the automotive manufacturing industry, composite materials are mainly used in a variety of body components, engine cover, dashboard, door, floor, seat, refrigerated truck, fire engine, box car and other transport tanker. In the railway transport, composite materials are used in passenger carriage, carriage door and window, water tank, toilet, refrigerator car body, storage tank of liquid transportation, container and various equipments of communication. Composite materials have become the champion of the new materials in
transportation.

(2) In the construction industry, CM is widely used in a variety of light house, large building structure, architectural feature and sculpture, sanitary, cooling tower, storage tank, waveform tile, door and window components, hydraulic construction and the ground and so on. Carbon fiber composite as strengthening and repair for infrastructure, has shown a large market in recent years.

(3) In the shipbuilding industry, composite materials are used in the production of a variety of work boat, fishing boat, transport boat, motor boat, lifeboat, cruise, military minesweeper and submarine.

(4) In anti-corrosion equipment, composite materials, especially glass fiber reinforced plastics are highly resistant to corrosive chemicals, and provide the new chemical anti-corrosion materials. Chemical anti-corrosion equipments made by glass fiber reinforced plastics, mainly include large tank, container, various pipes in mass transfer, elbow, three link, such as pipe fitting, ventilation duct, chimney, fan, pump, valve and so on.

(5) In electrical and electronic industry, composite materials are used in the production of laminate, copper clad laminate, insulative pipe, electrical retaining ring, wedge, insulator, street lights, telegraph pole, and tool of live operation.

(6) In ordnance, composite materials are mainly used in the production of fuses, bullets, cartridge cases (coach shells), retaining ring shells, butt, rocket launcher, shield of artillery, and so on.

(7) Composite materials are used in all kinds of sports equipments in sporting goods, such as the vaulting pole, bow and arrow, racing bicycle, skateboarding, rowing, kayak, oarage, and so on.

(8) In the agriculture and fisheries, composite materials are made into all kinds of greenhouse for vegetable, flower, aquaculture, chicken, pig, as well as the granaries, feed store, septic tank, drain, spray, flower pot, milk delivery vehicle, manure transport vehicle and so on.

(9) In the mechanical manufacturing, composite materials have a very wide range of usage, such as fan blades, paper-making machinery accessories (beater parts, the case of hanging roller and roller), diesel engine parts, textile machinery parts, synthetic fiber machinery parts (filters, centrifugal cans, chip sets, etc.), coal mining machinery parts, pumps, mold, food machinery parts, gears, flange, pulley and protective shield and so on.

1.7 The progress of composite materials

As we already pointed out that the composite materials obtain a wide range of applications in various economic fields, the amount of domestic usage is still small. There is a big gap between China and the developed countries in application of composites both in quantity and quality. To promote the development of com-
1.7 The progress of composite materials

Composite materials, the following main issues should be solved: reduce the price of composite materials in the basis of quality assurance; develop high-performance, in particular multi-functional composite materials; improve the effectiveness of their application; develop new types of more effective molding process; further promote the field of application of composite materials.

1.7.1 Reducing the price of fiber and developing new fibers

Reinforced fiber is the main raw material of composite materials. The current trend is to reduce the price of high-performance fibers and develop the reinforcing fibers with special function. Table 1.2 and Table 1.3 display respectively the estimated demand for advanced fibers and the average price of a variety of fibers between 1970 and 1995 and between 1995 and 2015. It can be seen that the demand for advanced fiber increases year by year, and the price falls. As an example of carbon fiber, the demand increases from 8,000 tons in 1995 to 40,000 tons in 2015, increased by 4 times, and the average price takes from 50US $/kg to 20US $/kg, decreased by 60%. Obviously the decline of advanced fiber prices expands its scope of application of composite materials, for example the application in the

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<tbody>
<tr>
<td>Carbon fiber (^2)</td>
<td>100</td>
<td>1,000</td>
<td>6,000</td>
<td>8,000</td>
<td>400</td>
</tr>
<tr>
<td>Organic fiber (^3)</td>
<td>50</td>
<td>5,000</td>
<td>15,000</td>
<td>18,000</td>
<td>500</td>
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<tr>
<td>High-performance glass fiber (^4)</td>
<td>10</td>
<td>500</td>
<td>2,000</td>
<td>3,000</td>
<td>50</td>
</tr>
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<td>Sum total</td>
<td>160</td>
<td>6,500</td>
<td>23,000</td>
<td>39,000</td>
<td>950</td>
</tr>
</tbody>
</table>

Note: 1) Including the total of fiber used in composite materials and other materials.
2) Including the average price of the pitch-based, PAN-based and PAN-based oxidation carbon fiber.
3) The average price of aramid.
4) The average price of high-strength borosilicate glass fiber.

<table>
<thead>
<tr>
<th>Fiber types</th>
<th>Demand(ton)</th>
<th>Sales value in 2015(million $)</th>
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<tr>
<td>Carbon fiber (^2)</td>
<td>8,000</td>
<td>800</td>
</tr>
<tr>
<td>Organic fiber (^3)</td>
<td>18,000</td>
<td>900</td>
</tr>
<tr>
<td>High-performance glass fiber (^4)</td>
<td>3,000</td>
<td>200</td>
</tr>
<tr>
<td>Sum total</td>
<td>39,000</td>
<td>1,900 0</td>
</tr>
</tbody>
</table>

Note: 1) Including the total of fiber used in composite materials and other materials.
2) Including the average price of the pitch-based, PAN-based and PAN-based oxidation carbon fiber.
3) The average price of aramid and ultrahigh molecular weight polyethylene fiber.
4) The average price of high-strength glass fiber.
cars. On the contrary, the expansion of the amount can promote the decline in prices of material.

The key measure to reduce the price of carbon fiber is to develop pitch-based carbon fiber and large-tow carbon fiber. The price of asphalt is much lower than polyacrylonitrile (PAN) fiber, the performance of current pitch-based carbon fiber has been close to or equivalent to that of the standard type PAN-based carbon fiber, and pitch-based carbon fiber is expected to become the staple products. In the past, the aerospace grade carbon fiber used in military defense technology mainly included 1K, 3K and 6K, but now develops progressively to 12K and 24K, as the small-tow carbon fiber. Commercial grade carbon fiber of more than 48K, which meets the needs of general industrial applications, is called large-tow carbon fiber, and it has been developed to 480K, 540K, and there is absolute advantage in price. As standard type T300 carbon fiber, the price level of the current international market for commercial large-tow has been lowered to $8∼10/1b\(^{\text{1}}\), while the price of aerospace-grade is $15∼20/1b$.

The organic fiber with high modulus was mainly aramid in the past. A number of new organic fibers have been developed since the 1980s. The ultra-high molecular weight polyethylene (UHMWPE), PBO (polybenzoxazole) and aromatic polyester fiber are representatives. UHMWPE fiber has high strength and modulus, a big potential in the price, and light weight, it is a promising reinforced material.

In order to adapt to the needs of high temperature resistant and multi-functional composite materials, a number of special fibers have also been developed in recent years, of which fibers silicon carbide and silicon nitride are more important, which are characterized by high temperature resistance and semiconductor. Their resin-based composite materials have absorption (stealth) performance.

### 1.7.2 Expanding the application of composite materials

At present, the application of composite materials is developing toward the industry of high-grade and staple products, such as the automobile industry, shipbuilding, construction and so on.

1) The automobile industry

Composite materials can significantly lower fuel consumption, and have anti-corrosion and anti-vibration performances, so a large number of composite materials will be used in the automobile industry. At present, the application ratio of automotive steel has dropped to 14%∼15%, and it has been reported that in 2000, there were one in five cars which was manufactured using composite materials in the United States. Moreover, in order to reduce environmental pollution, many countries are vigorously developing the usage of natural gas to replace gasoline

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\(^{1}\) 1b is illegal unit, 1b = 0.453592kg. The same is in the following.
as motor fuel, and the cylinders of natural gas use FRP structure. The working pressure can go 20~100MPa, life reaches 10~20 years, and this cylinder has been in series and into practical application.

Composite materials used in automotive components are mainly glass fiber unsaturated polyester. In the past they were made by hand lay-up and spray-up molding, but in recent years, sheet molding compound (SMC), glass fiber mat reinforced thermoplastics (GMT) compression molding and resin transfer molding (RTM) have been used. The method of making sheet molding compound (SMC) is that chopped glass fiber roving or glass fiber mat is impregnated using the mixture (paste resin) of unsaturated resin system, fillers and other additives, and then wrapped with polyethylene or polypropylene film on both sides of itself to form the sheet type compound. SMC is widely used as a result of continuous production, easy usage and lower price.

In addition to glass fiber composite materials, the application of advanced composite materials in the automotive industry can also be found. The factor of high cost restricts the usage of advanced composite materials, but the good news is that the current price of carbon fiber has dropped to somewhere close to the price that automobile industry can accept.

2) The shipping industry

It’s a long history for us to use composite materials in fishing boats, tugs, yachts, boats and minesweepers. The composite materials are light and can withstand the high external pressure, submersibles of composite materials are being developed, which will increase the application of composite materials in submarines.

3) The construction industry

In the construction industry, composite materials are used as a variety of light structural houses, decorative materials, sanitary ware and cooling towers, storage tanks and so on, besides, in recent years they have expanded the application of the reinforced tendons of concrete and the bridge. Composite materials are used as reinforced tendons of concrete instead of steel to create new type of concrete, which has attractive prospects, because it can improve the earthquake resistance and diamagnetism of building structure. The glass fiber, carbon fiber and aramid fiber or hybrid fibers for two-dimensional or three-dimensional woven or braiding are used as reinforcements in reinforced tendons. At present, this new type of concrete has been used in the foundation of bridges and buildings, such as magnetic observatories, high-frequency electrical room and so on, which can extend service life of buildings and play an important role in improving performance.

The application of composite materials in the construction of houses, bridges, tunnels, culverts, subways and their related structures of concrete and other infrastructure projects in recent years have become the fastest-growing civil and one of the most promising areas, and it has become world-wide hotspots of the research
Introduction to polymer matrix composites

Composite materials in various forms are used in the field, such as continuous cable, guard rails, handrails, grating; beams, columns, poles, stakes; laminates, wrapped material, short fibers (reinforced cement); ribs. Now, the most widely used are composite materials, especially carbon fiber composite materials for infrastructure repairing, renovating and strengthening, and the application forms are wrapped material (sheet) and laminate. The technology originated in the late 1980s and the early 1990s, was used for the restoration of Osaka earthquake, the Los Angeles earthquake. Thereafter, Japan, the United States and Europe vigorously promote the development of this technology, it has been rapidly developed into many application fields such as civil engineering, masonry, concrete work, and so on, and it has been formed new technology of industrialization and accepted by the world. The technology played a great role in rehabilitation and reconstruction of the “921” earthquake in Taiwan, and further stimulated the Taiwan carbon fiber industry.

1.7.3 Developing new design, preparation methods and new composite technologies

In addition to improving designing and preparation methods of composite materials, it is also necessary to open up the new avenues.

1. The new designing method. It is such as integrative design of composite materials integrating three aspects of materials-technology-design, the dummy technologies of composite materials and structure.

2. The new technology of materials compositing. It is such as composite technology including in-situ compositing, self-spread, and gradient compositing, molecular self-assembly, and super-molecular compositing.

3. Multi-purpose, low-cost technology. Composite molding process is the key to manufacture component. The choice of forming process depends on the shape, performance, uses of products and technology properties of composite materials. Now the number of developing consecutive and non-continuous molding process is large. In the 1990s, a distinctive feature of the development of molding process is from single to multi-purpose, automation and low-cost. Such as resin transfer molding (RTM) molding technique, resin film infusion (RFI) molding technique, reinforced reaction injection molding (RRIM) forming technique, electron beam curing technique, reinforced thermoplastic sheet (GMT) technique, of which the resin transfer molding (RTM) process is a success example.

RTM process is a closed-molding process. The course of basic process is shown: the liquid thermosetting resin system is immitted into the mold with reinforcing fibers (known as preformed flan), heated to solidify, demolded and post-processed into products.

RTM process has many advantages such as simple equipment, short molding...
cycle, easy managing in specialization and automation, excellent performance of products, and lower manufacturing costs than other forming processes, which is particularly evident for advanced composite material structures.

In fact, most prominent feature of RTM process is that preformed flan can be specialized in the design and manufacture. Therefore, fibers can be woven in multi-dimension, which solves the major problems about fiber reinforced in one-dimension by traditional ply-stacking process leads to low strength of interlaminar and in horizontal direction, and greatly improve the mechanical properties of composite materials, especially the damage tolerant properties.

The course of preformed flan manufacture mainly includes arrange manner and density of fiber yarns, interlaminar manner of fabric, overall status of fiber impregnation, in which fibers are braided or stitched. At present, three-dimensional braiding is more mature in multi-dimensional woven fiber technology. Three-dimensional weaving is to get the complete three-dimensional integral structure by intertwining the long fibers one another, characterized by creating a variety of inerratic shape and the solid body and hollow body of abnormity, and will make the structure of versatility.

Three-dimensional weaving technology which appeared abroad in the early 1980’s was a new textile technology emerged. The composite materials of the weaving structure which developed by the three-dimensional weaving get great development and application because of their excellent performances. The RTM process is in line with the manufacture of the woven structural composite materials. Thus, RTM process has broader development prospects.

The processing performance of the resin in RTM process has special requirement, which can be summarized in follows: it has low viscosity and a certain storage period at low temperature, and fast solidified at high temperature; and it has a good infiltration, match and adhesion for reinforced fibers. Now for the RTM use, special matrix materials of unsaturated polyester resin, epoxy resin and bis-maleimide resin have been developed. At present, RTM process has been widely used to manufacture the composite materials’ products in aerospace, automotive, machinery, construction industries.

1.7.4 Developing hybrid fiber composite materials

The characteristic of hybrid fiber composite materials is that different fibers can learn from each other and match in coordination, so that they have excellent performances and lower costs. If we use different mixing ratios and different structures, the adaptability can be broadened, and design freedom can be increased. Hybrid composites designed properly also have certain functionality, even as functional/structural composite materials.

Commonly used hybrid is a mixture of carbon fiber and aramid, in which carbon
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fiber provides compressive strength that aramid is lack of and aramid improves the toughness of the material. Another popular hybrid is a mixture of the carbon fiber and glass fiber. Carbon fiber provides high specific strength and specific modulus, and glass fiber provides better toughness and lower material cost.

Research and application about hybrid composites have got the great development since the 1970s. Firstly, hybrid composite materials were mainly used for structural materials. The application grows relatively fast, and has an increase of 10 times in 5 years between 1985 and 1990. Its applications popularize in all areas of the national economy. In recent years, the functional structural hybrid composites have been developed successfully, such as absorption/structural composite materials.

Hybrid fiber composite materials are higher-level composite materials than single fiber composites. First of all, the basic problem encountered is the hybrid effect, which involves the match of fiber type, hybrid ratio and hybrid mode. In addition, there are interface issues and manufacture problems. From a wide range of view, there are also the problems of the material strength theory, damage and component design. Further study on these issues is needed. However, one thing is clear, that is, we can manufacture composite materials of multiple applications with lower cost by mixing different types of fibers in different ways and different proportions. Therefore, the hybrid composites are an important development direction.

1.7.5 Developing functional, multi-functional, smart and intelligent composite materials

We have already pointed out that composite materials are the important structural materials. In fact, its design features with a large freedom is more suitable for the development of functional composite materials, especially in functional → multi-functional → smart → intelligent composite materials, that is, the process reflects from the lower forms to higher forms. That the design of composite materials has a large freedom is the result of regulating their multiplicity at random, choosing the connecting form, changing their symmetry and other factors, and the aim is to achieve the optimal value of functional materials.

1) Functional composite materials

Various functional materials can be produced by compounding different materials of function. Such as conductive functional composite materials, magnetic functional composite materials, electromagnetic absorption or permeation functional composite materials (all above are commonly called electromagnetic function composite materials), optical functional composite materials, acoustic damping functional materials, functional materials of friction wear, medical composite materials, etc.
At present, electromagnetic functional materials develop most rapidly and are used most commonly in the functional composite materials, and here we discuss it on focus.

Conductive composite materials and magnetic composite materials were developed earlier. The basic manufacture method is that conductive material (such as carbon black, carbon fiber, metal powder, or other fibers, metal-coated glass fiber) or magnetic powder is compounded with the resin matrix respectively, the above-mentioned fillers give material conductive and magnetic properties, and the resin matrix plays adhesive role to give material formability. Therefore, these composite materials can be processed into conductive products and magnetic products with the required shape and the certain mechanical properties by the general forming methods (such as compression molding, laminating, etc.) of polymeric materials.

In order to obtain a good overall performance, we must increase the amount of filler or enhanced material as much as possible, control the interface of composite materials and make composite materials have better processability.

Nowadays, the conductive and magnetic composite materials are used more widely. Conductive composite materials are mainly used for anti-static, electromagnetic shielding materials, integrated circuit materials, and magnetic composite materials as permanent magnets.

2) Multifunctional composite materials

Composite materials have the characteristics of multi-component, so they will certainly develop into the multi-functional composite materials. We could say that the development direction to multi-function is an inevitable trend to play the advantages of composite materials.

First of all, the reinforcing material is applied in functional composite materials, so it can form the composite materials of combination of function and structure, which is a major advantage of composite materials. For the functional and structural integration, the benefits of material are given fully. Therefore, the functional/structural materials are the ideal materials of practical applications. The following are currently in the development of the electromagnetic absorption or permeation the functional/structural composite materials which have very important use in electronic information and military technology.

When incident electromagnetic waves reach the material’s surface, electromagnetic waves will be reflected, permeated or absorbed depending on the material’s properties. The material that electromagnetic wave can permeate is called wave-transparent material; the material which reflects and absorbs electromagnetic waves is called electromagnetic shielding material; the material that can only absorb the electromagnetic waves is called absorbing material.

Wave-transparent materials are mainly used in the protection structure of radar systems (typically airborne or missile shield of radar antenna), while absorbing
materials are mainly used in the “stealth” of aircrafts and warships.

(1) Wave-transparent structural composite materials.

Wave-transparent performance of materials depends on their dielectric properties, in particular the dielectric loss angle tangent ($\tan\delta$). The lower the $\tan\delta$ is, the lower the loss of electromagnetic wave is, and thus leads to high wave penetration rate. Therefore, the fibers and resin matrix of excellent dielectric properties should be chosen to manufacture wave-transparent materials for structural components.

The reinforced fibers used for wave-transparent composite materials are glass, quartz and organic fibers, in which D glass fiber is the commonly used fiber. Quartz fiber with smaller $\tan\delta$, as a result of higher prices is applied generally in high-performance wave-transparent materials. Organic fibers are characterized by light, in which aramid is also commonly used. And ultra-high molecular weight polyethylene as a result of light and excellent dielectric properties is a promising type of wave-transparent materials.

Organic polymer generally has good dielectric properties. Previously, as the wave-transparent structural materials, the resin matrix materials are unsaturated polyester resins, phenolic resin and epoxy resin. In recent years, the resin with better dielectric and heat-resistant properties has been developed and applied, mainly bismaleimide resins, cyanate ester resin and a number of high-performance thermoplastic resin. These resin matrix composite materials reinforced by glass fiber have excellent dielectric properties. Among them, the quartz fiber / cyanate ester have best dielectric properties.

(2) Absorbing (stealth) composite materials.

Compared with the wave-transparent materials, electromagnetic wave-absorbing materials convert electromagnetic energy to other forms of energy (heat, electricity, etc.) by electromagnetic loss. Absorbing materials in general are compounded by the resin matrix and the loss media (absorbent). Therefore, the absorbent is the pivotal material. According to the different mechanism of absorption, absorption can be divided into two broad types of electric loss and magnetic loss. The former is such as various kind of conductive graphite, carborundum powder, carbon powder and carborundum fiber, special carbon fiber, aluminum fiber, barium titanate ceramics and conductive polymer, and its main feature is the high dielectric loss angle tangent ($\tan\delta$); the latter includes a variety of ferrite powder, carbonyl iron powder, ultra-fine metal powder, which have the high magnetic loss angle tangent ($\tan\delta_m$).

The absorbing material compounded by the absorbent powder and resin matrix, is in fact, coating, and it does not belong to the structural composite materials. This kind of absorbing coating can be considered to be the first generation absorbing composite materials, and has been applied on stealth aircraft B-2, F-117, F/A-18E/F and so on.
Ferrite is the most commonly used in absorbers, because it is the dual complex (combination of electric loss and magnetic loss) dielectric material, with high $\tan\delta_m$ and low price. The absorbing properties of ferrite are closely related to the chemical composition, molding process, particle shape and size, and using frequency, and it is generally believed that the sintering temperature is higher and absorbing properties of ferrite with disc-shaped and moderate size are better.

Another developing absorber is the ultra-fine metal powder with the particle size from nanometer to $10\mu$m. As the particle size reduces, the proportion of external atoms increases rapidly, which leads to a change in band structure, a series of quantum size effect, and the macro-quantum tunnel effect, so that the powder’s sound, light, electricity, magnetic, thermal and other properties are obviously different from the macro of the original material. Studies have shown that these powders are of good performance of attenuation for electromagnetic waves, especially electromagnetic waves at the high-frequency even in the scope of light, but its absorption mechanism is unclear. At present, this kind of material has been attached great importance to all countries. It has been reported that currently it is known as the “super black” absorbing material, and its absorption rate on the radar wave is up to 99%, so this absorbing material is most likely to be considered to be nano-scale material.

It must be pointed out that all currently used absorbents exist with the shortcomings of high density, and therefore it is of great practical significance to study a new generation of lightweight high electromagnetic loss absorber.

Although absorbing coating is simple in technics and convenient to use, it bring about the increase of aircraft mass and is easy to break off. Therefore it is better to develop absorbing structural composite materials.

Absorbing structural composite materials are often made of the reinforcing fibers and resin matrix, both of them have absorption feature (also by mixing absorbent powder in the resin). Carbon fiber is a conductor, and it can not only reflect but also absorb electromagnetic waves. If the carbon fiber is modified to semiconductor (resistivity is $10^{-6} \sim 10^{3}\Omega\cdot\text{cm}$), it can be a good absorber. In the end, we can get the semi-conductive carborundum fiber. In addition, studies have shown that its absorbing properties can be improved by changing the shape of the cross-section of carbon fiber (such as triangle, square or polygonal cross-section) or its surface properties (such as a layer of carbon particle with tiny holes or silicon carbide membrane deposited on the surface of carbon fiber).

Absorbing structural composite materials are generally used in the form of hybrid composites. Its surface layer is the wave-transparent layer, which is made of glass fiber, aramid and hybrid fiber composite materials; the middle layer is the absorbing layer, which is formed by the wave absorbing composite materials; and the bottom layer is the reflecting layer, which is made of the carbon fiber compos-
ite materials or metal film. The middle layer can also be made by honeycomb core or foam plastics core containing the absorbing agents.

Absorbing structural composite materials have been applied to advanced stealth fighter F-22 and bomber B-2, and they are the advanced materials currently for the large military powers to develop.

3) Smart composite materials

Human are expecting that material can have the ability of adapting to the response to apperceive the role of the outside world. We compound sensing functional material and implementing functional material through the matrix, connect the external information processing system, and give the sensor information to the implementing functional material and then it produces the corresponding action. This constitutes the smart composite material and its system. It can perceive the changes of external environment and give the active response, and its role may be manifested in the self-diagnosis, self-adaptive and self-repair capabilities. Smart composite materials is expected to have great applications in sophisticated national defense technology, construction, transportation, water conservancy, medical health, marine fisheries, at the same time also play a lot of role in economizing energy, reducing pollution and improving security.

4) Intelligent composite materials

The intelligent composite materials are the highest form of functional composite materials. It is developed to have the decision-making ability on the basis of smart composite materials, and rely on artificial intelligence systems added to external information processing system, analyze information, give the decision, and direct the implementing material to do the optimizing action. This gives higher demands for the sensitivity, accuracy and response speed of the sensing part and the implementing part of materials. Intelligent composite materials are the pursuit of the objectives in the 21st century.

1.7.6 Developing nano-composite materials and biomimetic composite materials

1) Nano-composite materials

When the size of material is in range of the nano-size, the main components of the material concentrate on the surface. For example, when the particle is 2nm in diameter, the surface atoms will occupy 80% overall. The enormous surface can produce surface energy, and then nanometer-sized objects generate the strong aggregation, which enlarges the particle size. If these nano-cell precursors can be dispersed in a matrix to form composite materials, so that single nanometer-sized individual can be maintained instead of being aggregated (particles or objects of other shapes), it will play the nano-effects. The emergence of this effect is derived from a state of disorder of the surface atoms. This gives rise to several special performances including the quantum size effect, the macro-quantum
tunnel effect and surface and interface effects. As a result of the existence of these effects, nano-composite materials have not only excellent mechanical properties, but also produce the function of optics, nonlinear optics, photochemistry and electricity.

Inorganic-inorganic nano-composites were studied earlier, but the speed of development is slow. The reason is that the inorganic nano-particles agglomerate rapidly or grain size grows easily in the molding process, thus the nano-effects lose. Ceramic-based nano-composites and metal-based nano-composites can be made by the method of nano-phase in-situ growth, their performances are improved significantly, but there are still difficulties to accurately control the content of reinforcements and the chemical composition of generated products by in-situ reaction.

At present, the nano-composite materials with organic-inorganic molecular interactions have developed rapidly, because the materials have very good application prospects in both structure and function, and also have the possibility of industrialization. Organic-inorganic molecular interactions have covalent bond type, coordination bond type and ionic bond type, each type of nano-composite material has its corresponding preparation methods. For example, the preparation of nano-composites with covalent bond type adopts the sol-gel method basically. The inorganic components of composite system are the silicon or metal oxide nanoparticles network, which is made from the silicon or metal alkoxy compounds by hydrolysis and condensation reactions, and the organic components are that the polymer monomers are introduced into the network and form nano-composites in situ polymerization. The material can achieve the level of the dispersion of molecular grade, so they get the superior performance. With regard to ligand-based nano-composite materials, the functional organic salts dissolve in soluble organic monomer with ligand and forms coordination bond. Then the material starts to polymerize, so that inorganic compound are dispersed in nano-phase in polymer to form nano-composites. This material has the strong nano-functional effect, and it is a functional composite materials of competitiveness. Recently, the rapidly developed ionic type of organic-inorganic nano-composites are obtained through intercalation to the inorganic lamella, therefore inorganic nano-phase is only one-dimensional nano-size. The negatively charged surface exists between the sheets of lameller silicate, therefore firstly the cation exchange resin is provided to intercalate by electrostatic attraction, while the resin can also have interaction with some polymer monomers or melts, and at last nano-composites are constituted. Research shows that the composite materials can be used not only as structural materials, but also as functional materials, and which have shown the prospect of industrialization.

2) Biomimetic composite materials

Natural biological materials are basically composite materials. From careful
analysis on these composite materials, we find that their structure and distribution are very reasonable. For example, the bamboo is made of tubular fiber, with dense outside and sparse inside, and arranges with the anti-spiral, and becomes an excellent long-term used natural material. Another example, the shell is composed of the alternately laminating layers based on inorganic and organic composition, and it is both high strength and good toughness. These are the optimized structure type formed in the long-term biological evolution. A large number of organisms adapt to the test of natural environment by various forms of combination, the survival of the fittest, and provide a way for human to learn. To this end, through the systematic analysis and comparison, we absorb the useful law and form the concept, and combine the knowledge learned from the biological material with the theory and means of materials science to carry out the design and manufacture of new materials. Therefore a new research area, biomimetic composites, is formed gradually. Precisely because of the rich biological information out there and the fact that its mechanism can’t be fully understood by the current level, the development has a strong vitality. Although there is a big gap for people to master the mysteries of biological materials of the natural world, it is the surest way for the development of composite materials, and it has a broad prospect.

1.8 The important role of composite materials in the 21st century

Before the discussion of composite materials’s role in the 21st century, we should first analyze and forecast the questions that human society will face and the characteristics and needs of the community. The development trend of the world is that people will enter into a highly information-based society. Simultaneously the level of the life quality and the pursuit of health will be higher. In addition, the problems existing in the earth are very serious: environmental pollution is to the intolerable point; extreme population boom tightens the clean fresh water provided by the earth; the arable land for providing food has reached unsustainable situation; the exploited land resources will face the depletion and shortage; community will be plunged into an energy crisis and the lack of raw materials. These will no doubt give composite materials a lot of development opportunities and challenges.

1) Providing services for information technology

Composite materials can be used in all aspects of information technology, such as transducer material for obtaining information, the chip packaging materials and circuit boards in information processing, the magnetic materials for information storage, the composite fiber, sheath tube, and antenna reflector panels for information transmission, and the mechanical structural materials in information implementation.
2) Making contributions to improve the quality of human life

Composite materials are of high-strength and light weight, noise insulation, vibration and noise reduction, and used in construction, transport, improving the houses and comfort of transport tools; composites have good impact toughness, and can be made into the smart composite materials of self-made diagnostics to improve the safety of people’s lives; composite materials can be used to repair or substitute human organs to enhance the level of human health.

3) Making contributions to solve the shortage of resources and the energy crisis

In the development of new energy and energy conservation, such as light battery of functional composite materials, wind turbine blade and columns manufactured by composite materials, composite materials can give fully its advantage that its production processes cost less energy. The integrated molding can be nearly no disposable and it can make the transport tools light, so as to save energy. In the development of the oceans and space, the composite material has the distinct advantages, light weight and high-strength, corrosion-resistant, resisting briny erosion and high-pressure in deep water, suitable for manufacturing a variety of spacecrafts and space stations. In taking full advantage of undeveloped resources, plant fiber or minerals whisker reinforced composite materials are developed. By using the composite materials to repair and reinforce, the lives of infrastructures are extended.

4) Composite materials in the role of environment management for example, composites cylinder with high-pressure for natural gas fuel, composite materials made of wastes, which can change harm to benefit, and developing the “green” composite materials of the natural degradation.

Exercises

1. What are the composite materials? What is the main difference compared to metallic materials?
2. How to name composites?
3. What are the advantages of composite materials? What are the main problems?
4. Talk about composite materials in brief, why the interface is also its important part?
5. What are advanced composite materials (ACM)? Talk about the application of ACM in military aircraft and civil aircraft. Why do all countries in the world develop ACM energetically?
6. Give the prospects of composite materials in civilian in brief.
7. Now there is a non-metallic material, the combination contains 100 parts of 618 # epoxy resin, 15 parts of 300 # and 400 # epoxy resin and 80 shares of endomethylene tetrahydrophthalic anhydride, whether the material can be called composite material or not? Adding 40% (weight percent) of chopped glass fiber in the preparation process of these materials, can the product be called composite materials? Why?
8. Talk about the development of composite materials.
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