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Application of Composite Materials in Engine

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ABSTRACT

This paper analyzes the technical and demand problems of the current automotive and aviation engines, and introduces the applications of carbon fiber reinforced metal matrix composites and resin matrix composites in the piston and connecting rods of automobile engines. Composite materials and ceramic matrix composites on civil aircraft engines, as well as composite materials and composites in military aerospace engines (solid rocket motors and transcendental ramjet) applications, and some of the composite materials The application raises key questions and suggestions.

KEYWORDS: Automobile engine ; Aero engine; Resin-based composite material; Metal matrix composite material; Ceramic matrix composite material

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1. Introduction

1.1. Background

Human society is facing a lot of needs and problems, such as the depletion of mineral energy and resources, environmental pollution problems, information technology and quality of life and other issues, which promote the development of composite materials and other emerging materials, but also to promote a variety of high-tech innovation constantly. Now scientific research has been fully entered into a material can be in accordance with the expected performance of the material design and comprehensive utilization of various materials for a new period.

Composite materials are considered to be the fourth largest class of materials other than metal materials, inorganic nonmetallic materials and polymer materials. It is the inevitable result of the development and application of single materials such as metals, inorganic nonmetallic and macromolecules. Automotive industry, aerospace and microelectronics and other high-tech areas of development, the material put forward more stringent requirements. It has been difficult to meet the advanced materials with high performance and high index requirements. Therefore, the material has become an inevitable trend in the process of material development, and it has also pushed forward the development process of composite materials. With a large number of new composite materials are constantly studied and found that the composite material because of its density is small, good thermal stability, high temperature, abrasion resistance, ablation resistance, thermal conductivity, high strength, small expansion coefficient, damping performance Excellent, fatigue resistance, good absorption characteristics, composite materials not only used in aircraft, missiles, rockets and artificial earth satellites and other high-tech cutting-edge areas, but also in the automotive construction, energy transportation, electronic machinery, medical sports and many other areas Is widely used [1]. This paper mainly introduces the application and progress of new advanced composites such as resin matrix composites, metal matrix composites and ceramic matrix composites in automobile engine, civil aviation engine and military aerospace engine.

1.2. Research progress of composite materials

The composite material is a new material obtained by two or more heterogeneous, heterogeneous, irregular materials through a certain composite process. It not only retains the main characteristics of the original component, but also obtains the original component by synergistic effect not the excellent performance. Composite materials since the sixties of the last century since the birth of its unique performance and advantages, has achieved a multi-level, wide areas, high efficiency applications, and also continue to develop and improve. In recent years, in the field of composite materials in the field of processing, made a large number of meaningful forward-looking progress, due to the advanced processing technology and application of computer design technology to help improve the competitiveness of composite materials in the market, its application Spatial dimension and depth are constantly expanding. Now we can see that the overall trend of composite materials presented as:

- Understand and control the interface characteristics of composite materials;
- Improve the physical and chemical properties of structural composites research;
- Establish a sound mechanical system of composite materials;
- Research on intelligent design for reinforce the structural composite materials.

2. Composite materials in the automotive engine applications

In today's world, the total amount of cars is growing, is increasingly influential people continue to change the people's work and lifestyle. But then exposed in the environmental pollution, energy shortages and other aspects of the problem is also significantly increased. Therefore, by reducing the fuel consumption ratio and engine pollutant emissions, reduce the quality of the car has become the modern automotive industry to pursue the pursuit of the goal. So to ensure that the overall performance of the car is not weakened under the conditions, by minimizing the quality of the parts, and strive to seek high power output, low vibration frequency, low friction and good handling, high reliability, so that the car Constantly close to low fuel consumption, lightweight, high-speed target requirements. And a very important and viable way is to develop and apply some new functional materials and structural materials to replace some of the traditional materials. In this new material competition, metal-based composite materials more and more manufacturers and designers attention, and in the application of high-performance engine has achieved fruitful results.

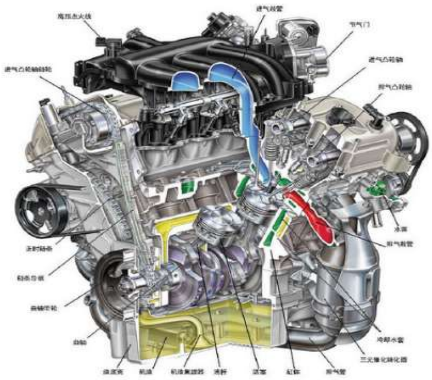

Figure 1 Automobile engine

2.1. Application of Metal Matrix Composites on Piston

The piston is one of the most important parts of the engine, its performance can directly determine the durability of the engine and the reliability of the work, because the combustion chamber in the engine working environment is very cruel, often leading to the first ring groove early serious Wear and the phenomenon of aluminum piston roofing. In order to solve this problem, in the mid-eighties of last century, Japanese auto industry giants took the lead in the development of the use of short fiber reinforced aluminum piston to replace the traditional ordinary automotive engine aluminum piston. After the short fiber reinforced, the piston ring groove area of the wear resistance has been significantly improved, which AC8A aluminum alloy = 5% -7% of the fiber reinforced to make its wear resistance than the high nickel austenitic cast iron increased 7 to make. The results show that the high temperature fatigue strength, anti-bite ability, thermal stability and thermal conductivity of the piston are obviously improved, and the thermal expansion coefficient is 8% -15% lower than that of the ordinary automobile engine. Stretch fiber reinforced aluminum piston can also reduce the crack direction of the edge of the combustion chamber at the top of the piston, thus improving the safety and reliability of the high-speed diesel engine aluminum piston.

Besides of Japan, some developed countries in Europe and the United States are also vigorously studying the use of metal-based composite materials to enhance the performance of the new piston technology. And the United States has some people to create a performance of short fiber reinforced aluminum alloy piston. In addition to the use of ceramic fibers in the first ring groove in the piston, the ceramic fiber reinforced composite material is used throughout the crown of the ring groove, thereby further improving the thermal resistance of the piston crown, and the automobile engine Combustion efficiency has also been significantly improved. France in the development of four-cylinder engine in the process, the piston and connecting rod on the application of metal-based composite materials, the engine fuel consumption level decreased by 15%, while increasing the engine life.

2.2. Application of Metal Matrix Composites on Connecting Rods

In the mid-80s of last century, FLOGGER and others with long fiber reinforced aluminum alloy trial out of the car engine connecting rod, the metal matrix composite material was also successfully applied to the car engine on the activities of the connecting rod. Later, Japan's MAZDA Company also developed the use of this composite engine piston rod. The weight of this kind of connecting rod itself is very light, anti-fatigue strength and tensile strength is very high, and the expansion coefficient is very small, so it can well meet the modern automotive engine operating link work requirements. Due to the use of this lightweight composite link to the crankshaft, bearings and other parts associated with the weight of the rods significantly reduced, and removed to reduce the noise and mechanical vibration imposed by the balanced weight, improve the engine reaction sensitivity [4].

At present, aluminum-based composite materials used alloy, the commonly used filler enhancer, including ceramic whiskers, ceramic particles and ceramic fibers. Compared with ordinary aluminum alloy, it is lighter in weight, higher in specific strength and modulus, and has better heat resistance and abrasion resistance, and can be used as a prospect material for the use of lightweight vehicles.

3. Composite materials in the application of civil aviation engine

With the continuous development of economic society, people's growing material demand is also rising, which is gradually reflected in the daily travel mode of diversification, and civil aviation because of its convenience, efficiency and comfort , By the public more and more love and pursuit. Therefore, the increase in the demand for air travel has become an inevitable trend of diversified development of transport, but because of its economic and security constraints also greatly limit the pace of rapid development of civil aviation. Therefore, the study of large weight ratio, low fuel consumption, green, safe and reliable high-performance engine to replace the traditional aero engine becomes the key to solve this problem. Because the composite material itself has a unique performance, material designers and materials manufacturers are increasingly paying attention to the development of some new composite materials, and put a huge amount of resources for research, and achieved good results.

3.1. GE90 engine composite applications

Resin-based composites (SMC) have a high specific strength and specific modulus, good fatigue resistance and corrosion resistance and strong noise resistance, and therefore has been in the aircraft engine casing, rotor blades, stator blades, Engine nacelle, casing and other cold end parts are widely used.

In the GE90 series engine, the United States General Electric Company in order to develop a titanium alloy can effectively replace the resin-based composite materials, invested heavily, and the use of carbon reinforced fiber and epoxy resin composite, to create a very high toughness of the composite material fan blades. The traditional titanium alloy fan blades compared with its anti-vibration ability, low noise level, anti-bird strike capacity and other aspects of the obvious lack of [5]. The results show that high toughness epoxy composites show excellent safety and reliability in the actual assembly of Boeing 777, and maintain maintainability greatly.

While enjoying the convenience of our resin-based composites for our lives, we should also be aware of the two problems we face: first, the waste left after use; and second, the process of the waste. In dealing with this problem, the traditional incineration and burial methods on the environmental pollution and land occupancy rate is too prominent. So in recent years the crushing method has been widely promoted.

3.2. Composite applications for LEAP-X engines

3.2.1 Fan blades for LEAP-X engines

LEAP-X engine found by the United States GE and France SNECMA joint company, CFM, for the development of modern large and medium-sized civil aircraft and the manufacture of large-channel than high-performance turbofan engine. In order to achieve substantial weight loss of the whole machine, the fan blades of the LEAP-X engine 2 use advanced carbon fiber composites made by three-dimensional braided resin mold transfer molding technology (3-DW RTM) and are used on the edge of the fan blades Titanium alloy. Through the use of this technology, CFM manufacturing LEAP-X engine with excellent durability, high fuel efficiency, maintenance-free features. Experiments show that the use of 3-DW RTM technology to create advanced carbon fiber composite fan blades, not only has a solid structure, lighter quality.

3.2.2 LEAP-X engine fan case

The metal-based composites used in the fan casing of the LEAP-X engine are superior to traditional metal materials in terms of strength, specific rigidity, high temperature resistance and stability. The fiber reinforced titanium matrix composites have high specific strength, specific stiffness and high temperature resistance, can maintain good strength and stiffness at 816 ℃, and its weight is only 50% of the traditional nickel-based alloy. The use of this composite material in the engine fan blades in terms of strength and hardness than the traditional titanium alloy material has obvious excellence, while the engine fan blades can be reduced by about 14%, improve the flight performance of the engine. Therefore, titanium-based, aluminum-based composite materials as the representative of the metal-based composite materials are widely used in the overall leaf ring, compressor blades, casing, connecting rod and other engine parts [6].

LEAP-X engine turbine guide structure, high pressure turbine nozzle, shock absorber blade in the application of new ceramic matrix composite materials, LEAP-X engine in the combustion efficiency, durability and stability, etc. have been greatly improved, and the weight can be significantly reduced.

Figure 2 Three-dimensional weaving resin mold transfer molding Composite fan blades

Figure 3 Ceramic-based composite low-pressure turbine guide blade

4. Composite materials in the military aerospace engine applications

Aircraft engine, as the core of the core components of the aircraft, its performance directly determines the aircraft's energy efficiency, reliability and economy, is a national science and technology process, the level of industrialization and national defense strength of an important manifestation. Because of the need to meet the requirements of high maneuverability, overload, heavy load and high flight speeds for modern aerospace vehicles, aircraft engines often have to endure the impact of extremely high temperature and high pressure working airflow environments, so traditional materials (nickel and titanium) Made of aero-engine in the higher cycle of the cycle, prone to thermal stress creep, fatigue and fracture of the phenomenon, resulting in engine failure, damage or even disintegration. Its high technical difficulty, the complexity of process design, resource investment is far more than the general industrial products can be compared, so known as the 'modern industry crown on the pearl.' In order to solve the technical threshold of the 'three high and three difficulties' faced by the aero engine, the development and application of new advanced composites has become the most effective entry point for breaking through the technical problems of aero engine so far. A few developed countries also have a variety of composite materials on aero engine the prospects of the application to do a lot of research and promotion, and have achieved fruitful results. At the same time in a variety of other aspects of the aircraft also extensive use of composite materials.

4.1. Application of C / C Composites in High Pressure Solid Rocket Motor Nozzle

C / C composites have the characteristics of thermal shock resistance, ablation resistance, low density, high modulus, high specific heat capacity and low thermal expansion coefficient, which are ideal for ablative materials, especially under high pressure and high heat flow conditions, to enhance it superiority. Especially the following characteristics:

● Thermal stability. The high specific heat capacity and low expansion coefficient of C / C composites make the workpiece made of this material have good dimensional stability in the engine work, and its specific heat capacity increases with the increasing working temperature. Highlight the superiority of this material.

● Ablation resistance. C / C composites exhibit good ablation resistance in ablative nonmetallic materials.

●Mechanical properties. The mechanical properties of C / C composites are also a leader in ablative materials, not only much higher than other products (such as graphite), but also their mechanical properties increase with increasing temperature.

● Low density. Another important addition to C / C composites is their low density. For a long time the engine nozzle, the proliferation of the ablation requirements of the high demand, and modern engines require high quality ratio, so the engine nozzle to ensure a certain safety margin on the basis of the requirements of the quality of light.

● Good thermal shock resistance [9].

4.1.1 Throat lining

As a nozzle laryngeal material, it must be able to withstand high pressure, high temperature airflow at 2000 ° C to 3500 ° C, and internal thermal stress due to high temperature gradients. Since C / C composites have the above-Mechanical properties, making it an important material for the current production of throat lining.

4.1.2 Throat inlet lining

High-pressure solid rocket engine nozzles are usually from the ablation performance of the difference between the non-metallic combination of large, so after the high temperature air erosion, the nozzle will be formed within the large ablated pits, resulting in bad vortex, severe Will make the nozzle leak caused by nozzle disassembly. In order to avoid this adverse effect, with a good thermal shock resistance of the C / C composite material as the nozzle into the lining material, can ensure that the workpiece in the working environment of the safety requirements [10, 11]. After the test, after about 40S of hot ablation erosion, the inlet lining ablation structure is still complete (as shown below).

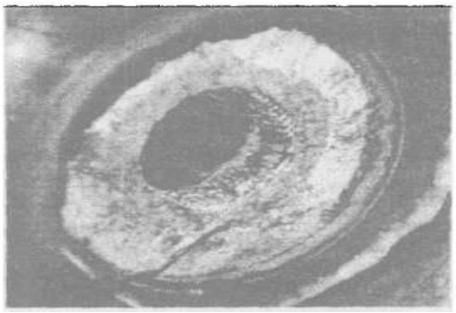

Figure 4 C / C composite material throat lining test

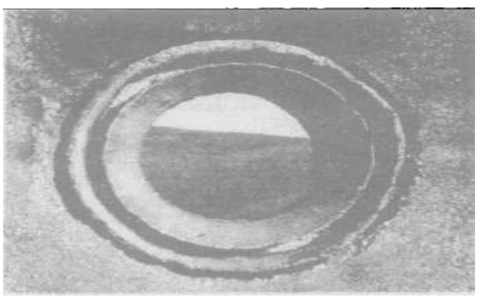

Figure 5 C / C composite nozzle lining test chart

At present, C / C composites have some limitations in the process of using C / C composites, so it is necessary to make them more suitable for large-scale application by improving the production process.

4.2. Application of C / SiC Composites in Scramjet

The scramjet is the core of the development of hypersonic technology, and its space combat aircraft, hypersonic aircraft, space shuttle and hypersonic cruise missiles are the most important significance for space transportation, space operations and national defense. The

4.2.1 Scramjet engine principle

Scramjet is a suction engine, mainly by the inlet, combustion chamber and tail nozzle composed of three parts. It has a simple structure, no compressor and turbine and other rotating parts, low cost, high-speed cruise flight performance, especially suitable for cross-atmospheric critical layer or the atmosphere for a long time continuous hypersonic flight, generally used in flight speed of 5 -25 Mach's aircraft, is to achieve a breakthrough in hypersonic technology, an important node. The process of 'stamping' in the engine is to slow down the air flow into the engine and improve the static pressure process. Theoretically had proven when the intake rate reach of 3 Mach, the engine pressure chamber air pressure can be increased by 37 times. High-speed air flow in the expansion after the slowdown, the temperature and pressure increased sharply, and then into the combustion chamber and fuel combustion. The temperature of the mixed gas after combustion is between 2000 and 2200, and finally the gas is accelerated by expansion and ejected from the nozzle at high speed to produce thrust [15].

4.2.2 Thermal protection of aloof ramjet engines

Because of the bad working environment of scramjet, make the material developers facing new technical challenges, severe embodied in: (1) High temperature resistant performance is good; (2) Anti-oxidation; (3) has a high thermal-mechanical (2) anti-oxidation; (2) anti-oxidation; (3) has a high thermal-mechanical Performance; (4) ablation resistance; (5) effective and reliable preparation technology; (6) light. It has been found that continuous carbon fiber reinforced matrix composites (C /) have more excellent thermal stability than other new materials.

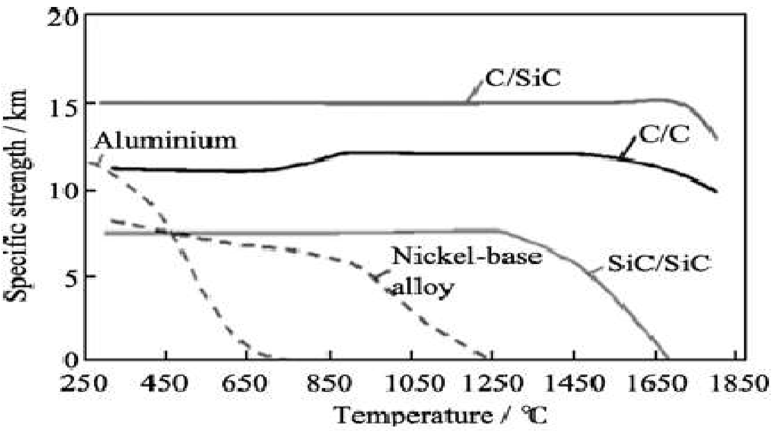

Figure 6 Ratio of strength to weight as a function of temperature

4.2.2.1 Passive thermal protection:

France and the United States joint JCS program in 1984 began to develop in the scramjet engine to achieve C / composite materials research, they use the C / composite materials made of suction nozzle, sharp lip and passive heat Panel as a test to examine the performance and durability of the above components under high temperature, high pressure and high speed conditions. The experimental results show that the C / composites meet the requirements of the work, instead of metal successfully in the stamping engine to achieve the application, reducing the quality of the engine to improve the work safety factor and combustion efficiency, but also verified in the Mach 7 to Mach 8 Of the working environment has a high repeatability.

In the mid-1990s, the US Air Force launched a program to test the use of CVD-coated C / composites for combustion chambers, sidewalls and inlet lips in high temperature, high pressure, and high speed experimental environments As a viable passive material. Planned studies have shown that, in the Mach8 / 600s state, C / composites are suitable for use on passive thermal protection structures.

4.2.2.2 Composite materials and metal combination of active cooling protection:

The study shows that C / composites are used as passive heat-resistant materials, and cannot meet the needs of repeated use and long-term use in the Mach state. In order to solve the above problems, it is necessary to actively develop an active cooling structure. It is easy to see that the C / composite material run through the entire planned material system [12] from the US National Aeronautics and Space Administration's roadmap for active cooling structures (Figure 14).

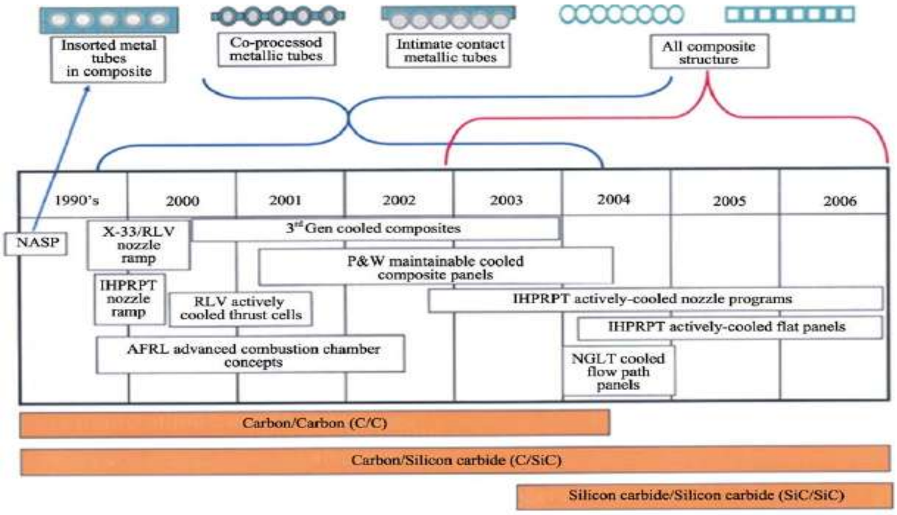

Figure 7 NASA's regenerative cooling ceramic matrix composites

In NASA at United States third-generation rocket combined cycle power aircraft program, had developed a picture shown as Figure 7 that alloy cooling pipe in contact with its back, is made of composite material on the back of the cold panel with the cooling pipe, while the surface facing the hot air is C / composite hot panel. Among them, the material of the cold panel is selected as the asphalt-based carbon fiber with high thermal conductivity, and the PAN-based carbon fiber with low thermal conductivity is used in the thickness direction.

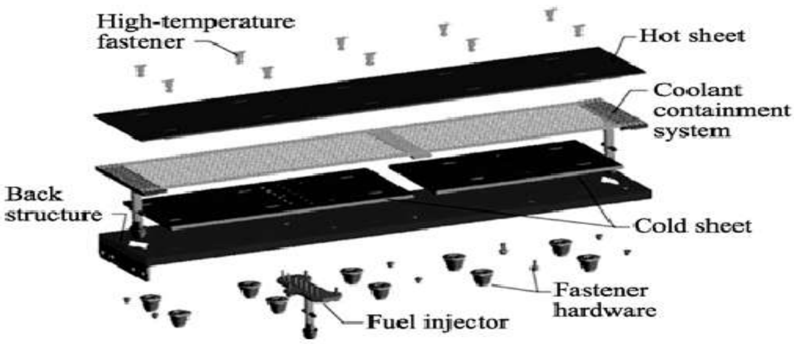

Figure 8 Exploded view of the cooling structure consisting of C / SiC composite panels and Ni alloy tubes

Although the C / SiC composites are widely studied and applied to the prospect of aero engine because of their high specific strength, high specific heat capacity, low coefficient of thermal expansion, low density, good thermal stability and strong thermal shock resistance. Some key technical issues that cannot be ignored need to be improved and resolved. Key technical issues include:

- Stabilization of interface and substrate;
- Matrix modification;
- Corrosion resistant coating technology;
- The stability of complex structures;
- High temperature of setting and heating seal technology.

5. The prospect of future development of composite materials

With the deepening of the research on composite materials and the continuous exploration of scientists, coupled with continuous improvement of the production and processing technology, so that the application of composite materials, universality, practicality and efficiency has been greatly improved, the application prospects are very broad. But cannot be ignored, and now there are many problems in the field of production and application of composite materials, and these problems also to a certain extent, limit the development of composite materials. Therefore, it is worthwhile to continue to explore the composite materials in depth.

5.1. Key issues of composite materials

The main key scientific issues include:

● The technical difficulty of composite materials is difficult to study and solve in many aspects such as interface stability, interface and matrix bonding problems, matrix modification problems, high performance reinforcing fiber preparation problems and composites oxidation problems The

● Composite materials, production and processing technology is complicated, resulting in composite technology, high cost, and expensive, long production cycle.

● The research field is not open to the composition, structure, material preparation and process technology of composite materials.

5.2. Solutions to Key Issues in Composites

The solution is to use the original from the simple, first after the local part of the overall research methods, the matrix interface to participate in the other or other means of modification, improve the stability of the matrix and antioxidant capacity, so that the matrix and enhancer of the increase in the degree of lubrication, The binding force is enhanced and the residual stress is reduced. (Such as solid-state method, liquid method, in-situ compound method, RTM, ICVI, Qinqi pyrolysis method) and processing technology (such as molding, hand laying, resin transfer molding, Injection molding and FRTP, etc.) to study the production technology of large-scale rapid production of materials to reduce the production price and cycle.

5.3. Feasibility analysis

Large-scale industrial mass production is the only way to reduce the cost of composite materials and shorten the production cycle of composite materials. This is based on reasonable production technology and processing technology and the preparation method of composite materials is determined by its own nature, Therefore, from the study of composite materials composition, structure, nature point of view to explore the improvement of composite materials and preparation room feasible.

Throughout history, the development of human civilization every time, every change in people's lifestyles and social development of each innovation can be seen as a material development of the amplification. Now emerging materials such as composite materials are constantly promoting the progress of science and technology. At the same time, along with the gradual development of social science and technology, especially in the automotive industry, aerospace and microelectronics and other high-tech field of rapid development, we have the performance of the material also made high demands and high standards, higher requirement. It is generally believed that advanced composites will continue to develop in the future in four directions: low cost, high performance, multi-function and intelligent.

6. Conclusion

China's composite materials industry compared with the developed countries, small-scale production, narrow application areas, and technology production technology thin. In view of the current problems, the relevant enterprises should be in the research, production and use of co-ordination, continuous improvement in research and development, in the application of continuous improvement, relying on personnel advantages, the theory and practice, so that China's composite materials industry continue to catch up Developed countries, and ultimately the world's leading.

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