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Advanced composite materials manufacturing technology

Zhijin Tang, Hongliang Zhang, Mingqi Sun, Xiaoting Zhao

School of Materials Science and Engineering, Shenzhen Engineering University, Guangdong, China

ABSTRACT

In recent years, a variety of composite materials preparation technology has been updated, from ceramic matrix composites, metal matrix composites to polymer matrix composites, a variety of preparation techniques have been greatly improved, making the composite properties and applications significantly improved. This paper reviews several important preparation methods and applications of ceramic matrix composites, metal matrix composites and polymer matrix composites.

KEYWORDS: advanced, composite materials, manufacturing technology.

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***Correspondence to:** Xiaoting Zhao, School of Materials Science and Engineering, Shenzhen Engineering University, Guangdong, China. zxtxt@sina.com.cn

1. Introduction

Composite material is combined by two or more different nature of the material, through physical or chemical methods, in the macro to form a new material with the material. A variety of materials in the performance of each other learn from each other, resulting in synergistic effect, so that the composite performance is better than the original composition of materials to meet a variety of different requirements [1]. The matrix material of the composite material is divided into two categories: metal and nonmetal. Metal matrix commonly used aluminum, magnesium, copper, titanium and its alloys. The non-metallic matrix mainly is synthetic resin, rubber, ceramics, graphite, carbon and so on. Reinforcing materials are glass fiber, carbon fiber, boron fiber, aramid fiber, silicon carbide fiber, asbestos fiber, whisker, wire and hard particles.

The Nano-composite material is a continuous phase with resin, rubber, ceramic and metal as the continuous phase, and is modified into a dispersed phase by Nano-sized metal, semiconductors, rigid particles and other inorganic particles, fibers, carbon nanotubes and the like. The modifier is uniformly dispersed in the matrix material with a dispersed phase having at least one dimension (diameter, length, width or thickness) of less than 100 nm. The design of nanocomposites and the design of nanocomposites are all hotspots.

2. Ceramic matrix composites

2.1. Introduction of Fiber Reinforced Ceramic Matrix Composites

The development of engineering ceramics is very important at home and abroad of new materials research. Pure ceramic materials because of its brittle, cannot meet the harsh conditions of the use of requirements. Therefore, the current extensive toughening technology is to improve the use of ceramic performance. Fiber and whisker toughening ceramics is an effective method. The technology to enhance the ceramic with fiber is the beginning of the decade, initially with carbon fiber reinforced ceramics, since the eighties has developed a ceramic fiber and whisker toughened ceramics, toughening effect of continuous progress, toughening technology Constantly innovate. Continuous fiber reinforced ceramic matrix composite material is one of the most promising high temperature structural materials, with its excellent high toughness, high strength of the world's attention.

Continuous fiber reinforced ceramic matrix composites (CFCC) is a high performance composite material formed by implanting high temperature resistant fibers into ceramic matrix. Because of its high strength and high toughness, especially with ordinary ceramic different non-failure fracture, it has been the world's great concern. Continuous fiber reinforced ceramic matrix composites have been widely used in aerospace, defense and other fields [2-4]. 20th century, the early 70s, J Aveston [3] in the continuous fiber reinforced polymer matrix composites and fiber reinforced metal

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Based on the research of composite materials, the concept of fiber reinforced ceramic matrix composites is put forward for the first time, which opens up a direction for the research and development of high performance ceramic materials. With the progress of fiber preparation technology and other related technologies, people have gradually developed an effective method for the preparation of such materials, making the fiber reinforced ceramic matrix composite material preparation technology matures.

Because fiber reinforced ceramic matrix composites have excellent high temperature performance, high toughness, high specific strength, high specific modulus and good thermal stability can effectively overcome the sensitivity of cracks and thermal shock [5-6], so, in the field of repeated use of thermal protection has an important application and a wide range of markets.

2.1.1 Continuous fiber reinforced ceramic matrix composite material selection principle [7]

Ceramic matrix and fiber should meet the structural requirements of structural parts. The use of the environment include: the minimum working temperature, the maximum temperature, humidity, corrosion of the working medium and so on.

Matching of elastic modulus between ceramic matrix and fiber. When the composite material is subjected to a load, its stress and elastic modulus are subject to the summing principle.

$$\Sigma c = \sigma_f V_f + \sigma_m V_m \quad (1)$$

$$E_c = E_f V_f + E_m V_m$$

$$V_f + V_m = 1$$

In the above equation, σ denotes the stress to be borne, V is the volume fraction, and E is the elastic modulus. Subscript c, f, m, respectively, represents the composite material, fiber, matrix.

Match the thermal expansion coefficient of the ceramic matrix and the fiber. Composite elements must meet the physical and chemical compatibility, the most important of which is the thermal expansion coefficient of the match.

The material should meet the specific requirements of the structure, but the components cannot occur between the obvious chemical reaction, dissolution and serious diffusion. In contrast, it also needs to meet the performance requirements of the premise, the cost as low as possible.

2.1.2 Toughening mechanism of continuous fiber reinforced ceramic matrix composites

Any solid material under the load, the energy absorption of only two ways: the material deformation and the formation of new surfaces [8]. For brittle ceramic materials, the material can only be very small deformation, can only increase the fracture surface, and increase the crack propagation path to consume energy. For the CFCC, the toughening mechanism mainly includes the load transfer due to the difference of modulus, micro cracking toughening, crack deflection, fiber debonding and fiber extraction, etc. [9]. Under the action of axial force, the CFCC fault consists of three stages: OA section, the stress level is low and the material is in the linear elastic phase. A linear deviation occurs at point A, point A is the ultimate strength of the matrix, and the matrix begins to crack. AB segment, with the increase in stress cracks more and more, more and more [10]. At point B, the internal fibers of the composite material begin to break, i.e. point B is the ultimate strength of CFCC. Compared with the single-phase ceramic material, although the ultimate strength of single-phase ceramics may be greater than the ultimate strength of CFCC, but its strain value is much smaller than the CFCC strain value, so CFCC fracture Work far greater than the single-phase ceramic fracture work. BC section, with the stress continues to increase, fiber and matrix debonding, along with the fiber fracture and pull out. Under the action of axial force, CFCC fracture includes: matrix cracking, fiber breakage, fiber debonding, fiber extraction and fiber fracture and other complex processes. Therefore, for CFCC, fiber extraction and fiber bridging are the main toughening ceramic mechanisms [11-12].

2.1.3 Summary

(1) Continuous fiber toughened ceramic matrix composite material has a similar metal fracture behavior, is not sensitive to the crack, no catastrophic damage. Its high temperature and low density characteristics make it a key material for the development of advanced aero engines, rocket engines and airborne aircraft heat-resistant structures.

(2) CVI method is the main method of making large, thin-walled and complex continuous fiber toughened ceramic matrix composites. It is also the only commercial method. It can design and fabricate the matrix, interface layer and Surface protective coating. Implementation of variable process parameters control can be obtained short preparation cycle, high density, high densification rate and density gradient of the composite material.

3. Metal matrix composites

3.1. Introduction of metal matrix composites

The metal matrix composites have the advantages of high strength, high specific rigidity, heat resistance, wear resistance, heat conduction, conductivity and dimensional stability. It is a promising new material. Metal matrix composites are widely used in the manufacture of aerospace Parts, but also for the manufacture of various civilian products.

According to the matrix, the metal matrix composite material is divided into: metal matrix composite material such as aluminum base, magnesium base, titanium base, zinc base, iron base and copper base. According to the reinforcing material, it can be divided into: fiber reinforced metal matrix composite material; The fibers are: C, SiC, Si₃N₄, B₄C, Al₂O₃ and other fibers; particle reinforced metal matrix composites, reinforced particles are: Al₂O₃, TiC, SiC, Si₃N₄, BN, SiC, MgO and so forth.

3.2. Method for manufacturing fiber reinforced metal matrix composites

3.2.1 A method for producing a laminated metal matrix composite material

(1) Laminated pressure method: the process is: the metal (alloy) foil or fiber reinforced metal sheet cut as required, and a layer of layers, and then heated and pressed to form and connection, generally in a vacuum or in a gas. Materials suitable for these methods are aluminum, titanium, copper, super alloys, and their reinforcing fibers are subject to suitability. In order to improve the connection performance, something between the two pieces by adding intermediate metal or to be connected to the surface coating or deposition of a layer of intermediate metal.

(2) Roll forming connection method: its main substrate is aluminum, titanium foil, reinforced fiber is mainly B, C, SiC, Si₃N₄, etc., sometimes in the substrate surface to be coated with a layer of low melting point of the intermediate metal, The reinforcing fiber surface is pre-impregnated with aluminum or treated by physical vapor deposition (PVD), chemical vapor deposition (CVD).

(3) Brazing method: between the reinforcing fiber and the substrate by adding foil, powder or paste solder, by vacuum brazing or protection brazing made. Brazing method can be made pipe, profiles, leaves and so on.

(4) Hot isostatic pressing method: the fiber and the substrate were laminated and into a mold, so that at high temperatures by the uniform pressure in all directions to shape and connect. A typical example is the manufacture of a B / Al composite tube for a space shuttle. The process is as follows: B / Al fiber reinforced on the core, the outer seal with iron, and 520 °C, 68.6MPa under the hot isostatic pressing and diffusion connection, after treatment to remove iron, iron, and then Electron beam welding on titanium joints.

3.2.2 Method for manufacturing short fiber reinforced metal matrix composites

Casting method: the current use of casting method to create fiber reinforced metal matrix composite material is the most simple and inexpensive way, so not only in the aerospace industry applications, automobiles, ships and other civilian industries have also applied. The casting methods are: metal casting method, sand casting, investment casting, high pressure casting, can cast a standard ingot, by extrusion or rolling into a variety of profiles, tubular, sheet can also directly cast a variety of parts. The

Liquid Casting Method: As shown in the figure, the SiC fiber is arranged on the steel frame and preheated then placed in the mold, into the molten metal alloy, the mold plus 49-98MPa pressure and under pressure solidification.

3.3. Preparation of Particulate Reinforced Metal Matrix Composites

Because of the different reinforcement of metal matrix composites, the preparation method is different. Granular reinforced metal matrix composite materials are: powder metallurgy, spray deposition method, in situ reaction method, mixing casting method and extrusion casting method.

3.3.1 Powder metallurgy method

Powder metallurgy method is the first development of the preparation of metal-based composite materials for the preparation of the preparation of metal-based composite materials excellent performance [13]. General powder metallurgy includes powder preparation, powder forming and powder sintering processes. The preparation method of the powder is mainly divided into mechanical milling, physical milling and chemical milling. The mechanical pulverization

can be divided into mechanical grinding and air grinding. The physical powder is divided into liquid atomization and evaporation. Vapor deposition reduction and electrochemical method.

3.3.2 Multilayer spray deposition method

The multi-layer spray deposition method is a method in which a metal liquid is injected into a crucible, flows into a gun through a conduit, is atomized by a high-pressure gas into a liquid ejection liquid, and the atomizer is moved in a computer-controlled manner, depending on the shape of the deposit and the speed Requirements, according to a certain law for uniform or variable speed movement, liquid particles deposited on the substrate scan. The lifting device of the base is also controlled by a computer to keep the descending rate of the matrix consistent with the growth rate of the slab, which is subjected to multiple reciprocating scanning of the atomized liquid stream and finally formed into blank [14]. However, the density of the spray-deposited ore is generally 85% -90% of the theoretical density, and there is no complete metallurgical bonding between the particles and the layer interface between the microporous particles in the blank.

3.3.3 Stirring casting method

Agitation Casting originated from 1968 Ray S in the molten aluminum solution by adding alumina particles to prepare the composite material. According to the casting temperature can be divided into full liquid mixing casting, semi-solid mixing casting and melting casting. Stirring casting process is simple, easy to operate, can produce large volumes of composite materials, but the increase in the volume fraction of the general increase of not more than 20%, and easily lead to enhanced particle distribution uneven.

Casting or liquid impregnation is impregnated with liquid metal fiber bundles, or fiber bundles through the liquid metal bath, so that each fiber is molten metal melt to get composite wire, and then squeeze the composite wire to make it into one to make composite Material, because the fiber is difficult to be molten metal wetting, so only less metal-based composite material can be directly made by liquid impregnation method. Moisturizing properties can be improved by coating the fibers with improved wettability prior to impregnation. Squeeze casting or pressure impregnation is to force the liquid metal into the fiber preform, the pressure continues until the end of solidification. Since the extrusion casting forces the molten metal into the fiber preform, it is not required that the molten metal has good wettability to the reinforcing material. The preparation of steel-based composites by extrusion casting was carried out by using the extrusion casting pressure infiltration process to prepare the alumina short fibers and the aluminum carbonate staple fibers to increase the strong aluminum matrix composites.

3.3.4 In situ synthesis

In situ synthesis means that the reinforcing material is generated and grown in the matrix during the manufacture of the composite material, in situ generation of small size and uniform distribution of the enhanced phase. Compared with other processes, in situ synthesis method has the advantages of simple process, low sintering temperature and small grain size of sintered body. The synthesized reinforcing phase includes oxides, carbides, nitrides, borides, silicide and the like, such as Al₂O₃, TiC, SiC, Si₃N₄ and the like. In situ generation of enhanced particles and the interface between the matrixes without pollution, between the two ideal for in situ matching, the interface is good, and enhance the thermal stability of particles. At present, the in situ synthesis methods are: exothermic dispersion, gas-liquid reaction synthesis, self-propagating combustion reaction and reactive jet deposition.

3.4. Summary

After more than 20 years of development, metal-based composites have been successfully from the laboratory to the market, and in many applications to gain a firm foothold, which benefit from extensive and in-depth basic research work for low-cost, high-efficiency production of metal Based composite materials to provide strong technical support. The future research and development work should focus on two aspects, that is, to further improve the existing metal-based composite materials and technology at the same time, to seek a new generation of metal-based composite materials design and preparation of the breakthrough, so as to metal-based composite materials sustainable lay the foundation for development. At present, the research and development of metal matrix composites presents three trends: 1, the composite design will be more attention, focusing on the spatial distribution of the enhanced reinforcement to achieve reinforcement; 2, structural and functional integration, multi-functional will become The future of metal-based composite materials, the inevitable way of high-performance; 3, despite the controversial, carbon nanotubes as the representative of the metal-based nanocomposites will eventually board the stage of history.

4. Polymer-based composites

4.1. Introduction of polymer / nanocomposites

Polymeric / nanocomposites are the hotspots studied this year. Polymer nanocomposites are new composite materials with Nano-sized materials and polymer materials in a variety of ways. Polymer nanocomposites can not only give full play to the specific properties of nanomaterials by maintaining the excellent properties of the polymer itself. When the Nano-scale (dispersed phase) size of the nanocomposite in the polymer-based nanocomposites reaches the nanometer scale, the material will produce Nano-size effect, and the physical properties of the nanocomposites with macro-sized dispersion are not available.

4.2. Research Methods for Polymers / Nanocomposites

Polymer / nanocomposite research methods are mainly intercalation method, sol-gel method, blending method, in situ polymerization method [15]. The following will focus on the polymer / layered silicate nanocomposites.

The intercalation method is the main method for the preparation of polymer nanocomposites. Ai Chunling et al. [16] modified the waterborne coatings with montmorillonite intercalated nanocomposites and showed performance tests. The results showed that the properties of the modified coatings were improved in different degrees. Gao Liangbin et al. [17] prepared HDPE / LLDPE / OMMT nanocomposites by direct injection. The results show that the addition of montmorillonite greatly improves the mechanical properties and thermal deformation temperature of nanocomposites.

According to the compound process, intercalation method can be divided into three categories [18-20], 1) Intercalation polymerization method: the principle is to disperse the polymer monomer, intercalation into the layered silicate sheet, and then the original Polymerization, the use of polymerization to release a large amount of heat to overcome the siliceous layer between the silicate layer, so that the peeling of the silicate sheet and the polymer matrix in nanoscale composite; 2) Melt intercalation method: The principle is to insert the inorganic and polymer into the layered inorganic layer, the method has no advantage of other media, do not pollute the environment, simple operation, wide application. 3) Solution intercalation method: the principle is the polymer chain in the solution by means of solvent and inserted into the inorganic layer, and then volatile to remove the solvent.

4.3. Excellent performance of polymer / nanocomposites

The polymer / layered silicate nanocomposites, the polymer / layered silicate nanocomposites, the polymer / layered silicate nanocomposites, the polymer / layered silicate nanocomposites, the polymer / layered silicate nanocomposites. The material has the following excellent performance:

- (1) The enhancement of the polymer, toughening effect;
- (2) Improved the heat resistance of the material (high heat distortion temperature and decomposition temperature);
- (3) To improve the material's flame retardant and ablative performance;
- (4) Improved the barrier properties of the material;
- (5) To improve the dimensional stability of the material, reducing the residual material within the material.

4.4. Application of polymer / nanocomposites

Because polymer nanocomposites can not only reflect the characteristics of small size, specific surface area, surface effect and quantum effect, but also to maintain the excellent properties of the polymer itself, the polymer nanocomposites exhibit the effect of conventional materials. With the characteristics, has a broad application prospects.

The application of polymer / nanocomposites is mainly used in coatings, medical materials, electronic functional materials, packaging materials, catalysts, etc., has a wide range of applications. The development of polymer nanocomposites with excellent performance is the focus of our future work. Although the research on polymer nanocomposites has made great progress, but because of its complex structure, small size, surface effect, Quantum effect and other factors, the relationship between the structural morphology of the material and the material properties remains to be further studied. In the synthesis method, it is necessary to break through the existing synthetic methods, especially in broadening the scope of its application is an urgent need to solve the problem.

5. Conclusion

After decades of development, composite materials preparation technology is maturing, from the success of the laboratory to the market, and in many areas of a firm foothold, which are benefited from scientific research personnel extensive and in-depth basic research work. In the optimization of existing technology, reduce manufacturing costs, to solve the adaptability to the environment, to achieve its recycling and recycling, to achieve sustainable development of society and so on, will gradually be people's attention.

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