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Review

Application of Carbon Fiber Reinforced Aluminum Matrix Composites in Automotive Industry

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Abstract: Although aluminum alloy has many excellent properties, it still has certain problems due to its strength and thermal deformation, which limits its application in the automotive industry. The carbon fiber reinforced aluminum alloy has the excellent characteristics of carbon fiber material and aluminum alloy material, with high strength, high modulus, high wear resistance and other characteristics, and has been extensively promoted in the automobile industry. This paper reviews the preparation process of carbon fiber reinforced aluminum alloy, including powder metallurgy, vacuum pressure immersion and squeeze casting. At the same time, carbon fiber reinforced aluminum alloy is introduced, mainly including automobile lightweight and the production of parts. This review paper will provide readers with a simple understanding of this field and offer some guidance regarding the application of carbon fiber reinforced aluminum alloy in the automotive industry.

Keywords: carbon fiber; aluminum alloys; automobile industry; engineering application

1. Introduction

With the continuous development of the automobile industry, lightweight alloys are gradually replacing steel to achieve lightweight body weight, and aluminum alloys are the first choice for lightweight materials due to their high specific strength and specific stiffness, low density, good mechanical properties, corrosion resistance, and easy processing properties [1–3]. At present, aluminum alloys commonly used in the automotive industry mainly include A1-Mg alloys and A1-Si alloys [4, 5]. Aluminum alloys can be divided into cast aluminum alloys and deformed aluminum alloys according to different processing methods [6]. Cast aluminum alloy is mainly through pressure casting, sand casting and other methods, while deformed aluminum alloy is mainly strengthened by plastic deformation, heat treatment, etc. Cast aluminum alloys are widely used in automobile engines, wheel hubs, transmissions, and other parts, and deformed aluminum alloys are used primarily in automobile bodies such as engine covers, fenders, roof covers, doors, trunk lids, and coverings [7].

Although aluminum alloys have many advantages in the automotive industry, there are still some problems in their manufacturing technology, such as high cost, the production process to be improved, and high transportation cost [8]. Despite the many advantages of aluminum, aluminum alloys are less strong and stiff than steel [9]. This makes it important to pay attention to the quality of the alloy components when using aluminum alloys. At present, there are many ways to treat aluminum alloy heat deformation, and there are many related researches, but there are still many problems. Ning [10] reviewed a number of literatures, and found that the results of the same series of studies are not the same, and the theoretical explanations are very different, which shows that the theory of aluminum alloy heating and deformation process is not perfect, and the aging mechanism after deformation is not very clear. Although there are numerous results, few practical applications of the thermal deformation process have been reported, which require continuous improvement of the relevant processes. The above shortcomings limit the application of aluminum alloys in the automotive industry, and it is necessary to improve the performance of aluminum alloys.

Carbon fiber is a kind of special fiber with high strength and high modulus with carbon content above 95%, and carbon fiber composite material comprises carbon fiber as reinforcement material and resin, metal and ceramics as matrix material [11]. Compared with traditional metals, carbon fiber is a new material with excellent mechanical properties, its specific gravity is less than a quarter of steel, lighter than aluminum, and its specific strength is 20 times that of iron [12]. In addition, carbon fiber composites have the characteristics of low density, high specific strength and specific modulus, advanced design, good fatigue resistance, good seismic performance, good high temperature performance, high damage safety, and easy of forming a large area as a whole [13]. These features are well-suited to automotive applications.

Carbon fiber reinforced aluminum matrix composites have light weight, high thermal and electrical conductivity, good high-temperature stability, high specific strength, high elastic modulus, and high wear resistance [14, 15], and can be widely used as materials and structural materials in the automotive industry. For example, Meng [16] used low-pressure permeation method to prepare carbon fiber reinforced pure aluminum, A336 alloy composites and carbon fiber-carbon nanofiber reinforced A336 alloy composites, and the results showed that the mechanical properties of carbon fiber-reinforced aluminum matrix composites were improved, and the high hardness provided theoretical support for the application of the composites in automobile body and other parts.

2. Preparation of Carbon Fiber Reinforced Aluminum Matrix Composites

Carbon fiber has low density, high strength, high modulus, high-temperature resistance, chemical corrosion resistance, high thermal conductivity, low thermal expansion, chemical radiation resistance and other characteristics, in addition to fiber flexibility and braiding, the specific strength and specific modulus is better than other inorganic fibers. When it is used as the reinforcement phase of aluminum alloy materials, the mechanical properties of aluminum alloy will be significantly improved, making it more widely used in various industrial production [17]. At present, there are many methods for preparing carbon fiber-reinforced aluminum matrix composites, including powder metallurgy method, vacuum pressure infiltration method, extrusion casting method [18], etc. The three preparation methods are introduced below.

2.1. Powder Metallurgy Method

Powder metallurgy method is to use a simple mechanical means to mix the reinforced body and aluminum powder evenly, and achieve consolidation under the action of cold pressure, then degassing or entering the protective gas, and then hot pressing sintering under vacuum or protective atmosphere at a set temperature, so that the powder raw material is combined into a block, and the composite material can be obtained [19]. When the carbon fiber reinforced aluminum matrix composites are prepared by powder metallurgy method, the ratio of aluminum powder to carbon fiber should be controlled to achieve better performance. Secondly, the aluminum-carbon interface has poor wettability and is prone to harmful reactions to form brittle phases, so it is necessary to coat the fiber surface with a coating to improve the wettability and isolate the carbon fiber from the aluminum melt in the preparation process of this composite, which is a key step in the preparation process.

The powder metallurgy method uses simple mechanical means, so it has the advantage of being relatively simple in operation. At the same time, because the preparation temperature does not have to exceed the melting point, the process is controllable and safe. The reason for the controllability is that the powder metallurgy method has the advantages of uniform phase distribution, controllable volume fraction, and low preparation temperature, while the safety is because the powder metallurgy process does not require high-temperature smelting, which eliminates the high-temperature energy consumption in traditional metallurgical processing [20]. At the same time, before sintering, the matrix and the reinforcement were evenly mixed, and due to the good combination of the two, the resulting product had better mixability, smaller grains, and less segregation. However, the disadvantage is that the preparation process of this method is also complicated, especially if the shielding gas is not pure, it will lead to many defects in the product, easy to oxidize, and so on.

2.2. Vacuum Pressure Infiltration Method

The vacuum pressure infiltration method fixes the carbon fiber-enhanced body as a prefabricated casting. Put it in a vacuum pressure furnace, seal it, and draw it to the vacuum. Insulation after the temperature, pass through a certain amount of nitrogen or argon for pressure, so that the melted substrate metal is pressed into the carbon fiber, and the composite material is obtained after solidification [19]. The vacuum pressure permeation method is entirely operated in a vacuum, which avoids the presence of excess gas in the system, so its advantage is that it can effectively prevent the oxidation of the matrix and carbon fiber in the production process. The vacuum pressure infiltration method uses a vacuum pump to pump out the air inside the casting, so that the metal liquid can be fully impregnated into the inside of the casting, which can improve the compactness and strength of the casting, and reduce the generation of porosity and defects. By vacuum pressure permeation, gas molecules can form a thin film on the material's surface, thus preventing oxidation. The parts produced are dense and have no casting defects such as porosity and shrinkage.

The disadvantage is that it is not suitable for preparing large-size components due to its long preparation cycle time and the need to improve production efficiency [21]. The main process of this process is to clean the parts, vacuum, pressure to make the impregnating agent into the micropores, through centrifugal spinning and other removal of residual glue, in the solid transformation. These steps are cumbersome and complex, and the time is long, which determines the long preparation cycle.

2.3. Extrusion Casting Method

Squeeze casting, also known as liquid die forging, is known as low-speed, high-pressure or liquid metal stamping. Squeeze casting is a production process that combines casting and forging, and is a method for rapid forming and solidification of metal melt under mechanical pressure [22]. The process is to make the carbon fiber into a precast and place it in the mold, and then the metal melt is poured in the mold and a mechanical pressure of hundreds of MPa is applied, and the metal melt is impregnated and fused with the carbon fiber preform under high pressure, and then it is quickly solidified [23]. The process requires strict control of vapor pressure. Hajjari [24] studied the effects of applied pressure and nickel plating on the microstructure development of extruded cast continuous carbon fiber reinforced aluminum composites. The results show that continuous carbon fiber reinforced aluminum composites with uncoated carbon fiber and nickel-plated carbon fiber can be produced by extrusion casting method under appropriate applied pressure. Carbon fiber-reinforced aluminium composites are manufactured by squeeze casting with optimal pressures of 50 and 30 MPa under uncoated and nickel-coated conditions, respectively. Both have a suitable pressure range, outside of which irregularities in the fiber distribution can occur, leading to unsatisfactory results.

In the process of solidification of the part, the pressurized part of the mold and the punch can be moved. Under pressure, the part will crystallize and become deformed, and the high mechanical properties and fineness of the structure of the part can be obtained. However, the disadvantage is that this method is suitable for simple shapes and high-performance composite castings due to the size of the part shape and the equipment conditions that limit the application of squeeze casting [18].

3. Application of Carbon Fiber Reinforced Aluminum Matrix Composites in the Automotive Industry

3.1. Automotive Lightweight

Since the advent of the automobile, we have been trying to improve the performance of the automobile by improving the existing situation, whether it is changing the type of materials or changing the layout of parts. The emergence of automotive lightweight technology is to reduce the mass of components on the premise of satisfying the performance of the original structure, such as strength, stiffness, impact resistance, impact energy absorption and dynamic fatigue [25]. Li et al.'s [26] research shows that vehicle lightweight can effectively reduce energy consumption. When the mass of new energy vehicles is reduced by 100 kg, the driving distance can be increased by 7.5%, which is significant for realizing energy conservation and emission reduction. Therefore, when the car is lightweight, it can effectively reduce fuel consumption and carbon emissions, reduce power loss, improve energy efficiency, and reduce the use of materials.

The application of carbon fiber-reinforced aluminum alloy composites can significantly reduce the quality of the original components while ensuring the performance. For example, Kang [27] designed car bumpers by replacing the steel material of bumper beams with carbon fiber-reinforced aluminum matrix composites. The results show that compared with the original bumper, the weight of carbon fiber-reinforced aluminum matrix composite bumper is reduced by 36.4%, which meets the requirements of collision safety. The results of this study are helpful to the realization of automobile lightweight. Carbon fiber reinforced aluminum alloy composite has the characteristics of low density and high specific strength/stiffness. When it is used as the raw material to prepare the load-bearing parts such as the automobile body, the total mass of the automobile can be effectively reduced under the premise of maintaining the original requirements to achieve the purpose of lightweight, energy-saving and emission reduction of the automobile [28].

3.2. Preparation of Automotive Components

Kong Xiaoli et al. [29] prepared a new type of carbon fiber felt-reinforced aluminum matrix composite by squeeze penetration process, and the test shows that its friction and wear characteristics are significantly better than the matrix alloy. At the same time, because of its high-temperature resistance, it can be used to produce automotive brake pads. In addition, many carbon fiber-reinforced aluminum matrix composites can also be used to produce automobile drive shaft, automobile wheel hub, among others. For example, Honda used a molding process to mix 12% Al_2O_3 fiber with 9% carbon fiber to make cylinder liner preforms, and then applied a new die-casting process to develop a partially strengthened cylinder liner block manufacturing technology, which significantly improved the sliding damage and sintering limit of the cylinder liner, which was conducive to the realization of small weight reduction and improved durability of the engine block [30]. There are also many parts such as automobile wheels, bumpers, automobile drive shafts and other parts that have begun to apply carbon fiber reinforced aluminum alloy. The new wheel made of carbon fiber reinforced aluminum alloy material, which combines carbon fiber and aluminum alloy material, not only increases the strength of the automobile wheel, reduces the weight of the wheel, but also lowers the cost compared with carbon fiber wheels.

4. Conclusions

Many properties of carbon fiber-reinforced aluminum matrix composites have made them widely used in the automotive field, especially for automotive lightweight applications. In addition, it can also be used to produce various auto parts. It is believed that with the continuous development of technology, the application of carbon fiber-reinforced aluminum matrix composite materials in the automotive industry is expected to become widespread.

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