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Application of Carbon Fiber Composite Materials for Automotive Lightweighting

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Abstract: The automobile industry is the first to form a typical representative of the global industry in modern industry, with the increase of the national emphasis on the environment, the automobile industry was regarded as an important energy consumption and one of the sources of environmental pollution, the policy of energy conservation and emission reduction requirements for the automobile industry are becoming stricter over the years, energy conservation and emission reduction has becomes the main direction of product optimization in the automobile industry in recent years. Due of a series of excellent properties such as light weight and high strength, composite materials have become the main material for the development of lightweight vehicles. With the development of material technology and the update and iteration of manufacturing technology, composite materials are currently popular being adopted in the automotive field.

Keywords: Automobile lightweight; Carbon fiber composite; Application research

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1. Introduction

1.1. Overview of carbon fiber composite materials

As a new type of high-performance material, carbon fiber composite has shown significant application value in many fields by virtue of its unique physical and chemical characteristics [1]. This type of material uses carbon fiber with more than 95% carbon content as reinforcement, combined with resin, metal or ceramic matrix, to form a composite system with high strength and high modulus characteristics. Carbon fiber composites have been widely adopted in aerospace, wind power generation, aircraft manufacturing and other fields [2]. At the same time, with the progress of technology and the change of market demand, this kind of material has gradually expanded to sports and leisure, automobile manufacturing, industrial machinery, rail transportation and medical equipment and other industries.

1.2. The advantages of carbon fiber materials applied to automobiles

In the automotive field, carbon fiber composite material stands out with its unique advantages. Compared to other

commonly used materials such as high-strength steel, aluminum alloy, magnesium alloy, titanium alloy and glass fiber composites, carbon fiber composites showed superior performance in several aspects [3]. From the perspective of material properties, carbon fiber composite materials can effectively achieve the goal of lightweight automotive. This feature not only reduces the mass of the vehicle, but also significantly improves the fuel economy and environmental performance. Research data show that when the weight of the vehicle is reduced by 10%, the fuel consumption can be reduced by 6–8%, the exhaust emission is reduced by 5–6%, and the acceleration performance (0100 km/h) is increased by 8–10%, and the braking distance is also shortened by 2 meters to 7 meters.

Safety is one of the most important considerations in the design of modern automobiles, and carbon fiber composites also perform well in this regard. By reducing body mass, the center of gravity of the vehicle can be moved down, which improves the vehicle handling stability and makes the driving process safer and more reliable. In addition, the energy absorption capacity of carbon fiber composites is far superior to that of traditional materials, and the energy absorption effect of carbon fiber composites can be six to seven times that of steel and three to four times that of aluminum, which provides a higher level of safety for passengers.

Comfort, as one of the important indicators to evaluate the performance of automobiles, has also been significantly improved by the application of carbon fiber composite materials. Due to the excellent vibration damping properties of the material, its performance in suppressing noise, vibration and acoustic vibration roughness (NVH) is particularly outstanding. Experimental data show that the traditional light alloy takes 9 seconds to completely stop vibration, while the carbon fiber composite takes only 2 seconds to complete the process [4]. Therefore, cars made up of carbon fiber composite materials has proven to provide a quieter and smoother driving experience during driving.

Reliability is a key parameter to measure the service life of automotive components. Carbon fiber composites have obvious advantages in fatigue strength, and their fatigue resistance can reach 70% to 80% of the tensile strength, which is much higher than the 30–50% of steel and aluminum. This means in practical applications, the carbon fiber composite materials of car parts can still maintain a high performance after long time use, to prolong the life of the vehicle and reduce maintenance costs.

Considering the above characteristics, the application prospect of carbon fiber composite materials in the automotive field is broad. Whether from the perspective of energy saving and emission reduction, or considering driving safety, ride comfort and component reliability, the material has shown unparalleled technical advantages. In the future, with the further reduction of production costs and continuous optimization of technical processes, CFRP is expected to play an even more important role in the automotive industry.

2. Applications of carbon fiber composites in automotive components

2.1. Drive shaft and high-pressure hydrogen storage bottle

Compared with the dry winding technology, the wet winding technology has a significant advantage in cost, which is about 40% lower. In addition, it provides better air tightness, better fiber alignment parallelism, and can effectively reduce fiber wear during production. These advantages have made the wet winding process widely used in many fields, especially in the automotive industry, such as the manufacture of drive shafts and hydrogen storage bottles [5]. The performance of automobile transmission shaft design including shaft bending rigidity, torsional rigidity and critical speed, this is because of its stress distribution is more complex, high demands on the performance of the material. The traditional drive shaft steel material will have poor stability and other ills.

Carbon fiber composite automobile transmission shaft can be a good solution to this problem and effectively improve the performance of the car. Carbon fiber composite materials have high tensile strength, low density, high specific strength, corrosion resistance, high modulus of elasticity and the modulus than the relatively low, the characteristics of the transmission shaft of alternative metal material can better meet the demand of use. In addition, the carbon fiber composite drive shaft not only can reduce weight by 40–50%, such as Toyota 86 carbon fiber transmission shaft and Lamborghini sixth element concept car drive shaft, and has better fatigue resistance and durability.

The wet winding process has also been used to prepare carbon fiber wrapped hydrogen bottles for new energy vehicles. High-pressure hydrogen storage bottles are divided into type I, type II, type III and type IV bottles according to the different liner materials and fiber winding, which are pure steel, steel liner fiber winding, metal (steel and aluminum) liner fiber winding and plastic liner fiber winding bottles [6]. In the technology of vehicle hydrogen storage bottle, the international has been able to produce a large number of 70MPa carbon fiber winding type IV bottle, and the mainstream domestic hydrogen storage bottle is still 35 MPa carbon fiber winding type III bottle, its inner material is aluminum alloy/plastic, the outer coating material is carbon fiber composite material. The research of the American Automotive Research Council shows that when the production scale of high-pressure hydrogen storage bottles increases from 10,000 sets to 500,000 sets, the cost will fall by one-fifth. Therefore, with the breakthrough of the domestic carbon fiber winding preparation technology and the expansion of the production scale, the vehicle high-pressure hydrogen storage bottle will certainly bloom in the future.

2.2. Wheel hub and brake disc

The autoclave process is used in the wheel hub forming process of the automobile. The autoclave process has several significant advantages: first, the pressure distribution is uniform; Secondly, the pressure and temperature are uniform and controllable; Then the mold design is simple, high efficiency, suitable for large area complex surface plate, shell, and simple shape plate, rod, tube, block; Finally, the molding process shows its stability and reliability. The use of carbon fiber composite hubs can significantly reduce weight, which helps reduce the wheel's rotational inertia, allowing the car to achieve faster speeds during starting, braking and steering [7]. Ford's new generation Mustang Shelby GT350R, for example, features such carbon fiber wheels. Similarly, Swedish supercar maker Koenisag uses carbon fiber for the rest of the entire hub in its Agera model, except for the tire valve nozzles. This design not only reduces weight, but also ensures structural sturdiness and safety.

In addition, the automobile brake disc also uses the autocompression tank process, the traditional brake liner mainly uses asbestos material, which will appear heat decay phenomenon under the high temperature generated by high-speed friction, thus producing asbestos dust, which is harmful to health. Carbon fiber composite material has high specific strength, excellent heat decay resistance and excellent wear resistance and heat resistance, which can completely replace asbestos in automobile brake system. The carbon fiber brake disc can withstand the high temperature of 2500 ℃, can reduce the speed from 300 km/h to 50 km/h within 50 m, and help to reduce the weight of the automobile chassis, improve the flexibility of the steering wheel, and reduce the jitter phenomenon above the body suspension, and ensure personal safety.

2.3. Roof structure and leaf spring

Carbon fiber composite materials have been widely used in automotive parts, such as battery box, support column, roof structure and leaf spring and other key parts are used in such materials. In the manufacturing process, the

high-pressure resin transfer molding process (HRRTM) is widely used. HRRTM is based on the traditional resin transfer molding process. The core of HRRTM is to inject a mixture of low viscosity resin and curing agent into the closed mold cavity under high pressure to achieve full impregnation of the fiber. At the same time, the curing process is completed by precise control of temperature and pressure, so as to form high-quality parts. Compared with autoclave molding process, HRRTM process has significant advantages of low cost, short cycle time and mass production [8].

In automobile suspension system, leaf spring, as an important part, is usually made of composite materials with high strength, large energy storage and corrosion resistance. This kind of material not only has good vibration attenuation performance, but also can achieve elastic bending, so it shows unique advantages in automobile design. There are various manufacturing processes for composite leaf springs, including winding model forming, high pressure resin transfer model forming, and SMC pultrusion forming methods. Among them, SMC pultrusion process takes the traction force as the driving force, and cures the fiber belt or fiber cloth through the mold to realize the continuous production of composite leaf springs with different section shapes. In the winding model forming process, the prepreg fiber is wound on the surface of the die, and the final product is formed through the die closing and curing steps.

With the development of lightweight automobile, mass production of composite leaf springs has become an inevitable demand. At this time, the high-pressure resin transfer model molding process has become an ideal choice to meet this demand because of its high degree of automation and fast production efficiency. Compared with the traditional leaf spring, the composite leaf spring shows obvious advantages in performance. Its high elasticity can effectively improve the comfort of vehicle driving; while having stronger fatigue resistance, fatigue life can reach 8 - 10 times of ordinary leaf spring. In addition, the composite plate spring has excellent performance in vibration damping, which can absorb vibration energy through its own damping characteristics, so as to ensure the smoothness of the vehicle [9]. The composite leaf spring consists of large number of independent fibers, which together form a statically uncertain system. When some fibers are broken, the load can be automatically transferred to other fibers to avoid the bearing capacity of the suspension structure being affected, so as to ensure the safety and stability of the car driving.

3. Application status of carbon fiber composite materials in automobile lightweight

3.1. The main challenges faced by the industrialization of carbon fiber composite materials

There were many constraints in the industrialization process of carbon fiber composite (CFRP). From the cost point of view, reducing the price of carbon fiber is the key to improve its market competitiveness. The Rock Mountain Research Institute has conducted an in-depth study on the application of carbon fiber in the automotive industry. The results indicated that when the price of carbon fiber unit drops below 16.5 US dollars /kg, it will show stronger competitiveness compared with steel. One of the effective ways to achieve this goal is to use low-cost large bundle carbon fiber, whose price is only 50% - 60% of small bundle carbon fiber [10]. At the manufacturing technology level, the existing production process of carbon fiber composites is generally inefficient, which is difficult to match the demand of the modern automobile industry for high production pace. Therefore, the development of new processing technology to shorten the molding cycle has become an important issue to be solved urgently. By improving the process flow, the production efficiency would be significantly improved. Hence, to better meet the requirements of large-scale quantitative production. In addition, it is also crucial to ensure the

stability of CFRP performance and the consistency of component quality.

The quality of composite products is affected by the characteristics of raw materials and various aspects of the process. In order to achieve high quality consistency, it is necessary to strictly control the curing process, optimize the process parameters, and introduce a highly automated production method to ensure a high degree of repeatability of the process. These measures can effectively reduce the variability, thus ensuring that the final product has a stable and reliable performance.

3.2. Progress in the application of carbon fiber composite materials in automobiles

Due to its excellent lightweight characteristics and mechanical properties, carbon fiber composites have shown a wide range of application prospects in the field of automotive parts. In recent years, CFRP has been gradually applied to the manufacturing of automotive core components, especially in the body and chassis. For example, GM's ultra-light concept car has achieved 68% weight reduction by using carbon fiber for body and chassis. The Subaru WRX STI TS uses a CFRP roof, which reduces weight by 80% compared to a high-strength steel roof. In the braking system, brands such as Porsche AG have put carbon fiber brake discs into use to successfully reduce the vehicle from 300 km/h to 50 km/h in only 50 m distance. Significant progress has also been made in the field of transmission shafts. The Toyota 86 is equipped with a carbon fiber shaft weighing only 5.53 kg, which is 50% lighter than the traditional material. In addition, Japan has recently developed the technology of replacing aluminum alloy with carbon fiber to manufacture compressor impellers, which not only shorter the response lag time, but also achieves 48% weight reduction.

Globally, BMW has become one of the first enterprises to realize the large-scale application of carbon fiber in mass production vehicles, which has promoted the technological innovation of carbon fiber in the automotive field. Through deep cooperation with carbon fiber companies such as SGL and Mitsubishi Rayon, and relying on the production network distributed in three countries and five places, BMW has effectively reduced the manufacturing cost of carbon fiber and laid the foundation for large-scale application. From the i3, i8 to the new 7 Series, BMW continues to explore the path of mass production of carbon fiber body. Each BMW i3 uses about 200,300 kg of carbon fiber composite material, and the weight reduction effect is 250,350 kg, with a total vehicle mass of only 1,224 kg. The lightweight nature of the carbon fiber body significantly improves the vehicle's performance and range, while saving about $1,299 in battery cost. The successful mass production of BMW i3, i8 and the new 7 Series fully demonstrates the feasibility of carbon fiber for mass production applications in the automotive industry. However, given that the cost of carbon fiber is still at a high level, automobile manufacturers need to comprehensively consider the pricing power and market acceptance of vehicles when applying carbon fiber in practice.

Domestic manufacturers are also making breakthroughs in the field of carbon fiber for automotive use. In joint research with the Chinese Academy of Sciences, Chery developed the composite material system, structural part design and rapid prototyping process for the Erize 7 model, and completed the verification and evaluation of the material and structural part performance. This series of innovations has made carbon fiber composite materials widely used in this model, and achieved good lightweight effect and vehicle performance improvement.

4. Conclusion

Overall, the excellent properties exhibited by carbon fiber composites are a key factor driving the growth of the

market; sound green and low carbon development mechanisms coupled with awareness of the positive impact of green and light vehicles can directly contribute to the growth of the market. In addition, fuel-efficient vehicles are environmentally friendly, have high driving range, can run on alternative fuels, and use advanced fuel technologies. Hybrid vehicles, battery-powered vehicles, plug-in hybrids, and pneumatic electric vehicles are some of the fuel-efficient vehicles favored by consumers. These light vehicles make heavy use of composite materials, which directly increases the demand for the market during the forecast period. Although the cost reduction of carbon fiber may not happen immediately, the application of carbon fiber in automotive lightweighting will become more economically viable with technological advances, production scale up, application of automation and robotics, development of recycling and reuse technologies, policy and market incentives.

Disclosure statement

The authors declare no conflict of interest.

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