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Application of carbon fiber composite materials in aircraft

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Abstract. Carbon fiber composite is a material with excellent mechanical properties. Compared with other high-performance fiber materials, carbon fiber composites have the advantages of high strength and high modulus even at ultra-high temperatures. In addition, the carbon fiber composite material also has excellent electrical and thermal conductivity and electromagnetic shielding performance. Carbon fiber composites are widely used in the aircraft manufacturing industry due to their incomparable performance with other composite materials. In recent years, the amount of carbon fiber composite materials in newly developed aircraft products has reached more than 50%. This paper aims to explore the application of carbon fiber in aircraft, and to reflect the importance of carbon fiber composite materials by comparing models that use composite materials and models that do not use composite materials. The study explores the application of carbon fiber composite materials in aircraft through a comprehensive literature analysis and review. Key findings indicate significant advantages of these materials in enhancing aircraft performance, including reduced weight and increased strength. The paper also discusses the challenges in manufacturing and environmental impacts, offering insights into future research directions for sustainable aviation technologies.

Keywords: Carbon fiber composite material, Aircraft structure, Excellent performance

1. Introduction

In 1879, Edison used cellulose fibers such as bamboo, flax or cotton yarn as raw materials to first produce carbon fibers and obtained a patent. However, the mechanical properties of the obtained fibers were very low at that time, and the process could not be industrialized, so it failed to develop. In the early 1950s, due to the development of cutting-edge technologies such as rockets, aerospace and aviation, new materials with high specific strength, high specific modulus and high temperature resistance were urgently needed. Filament, this process laid the foundation for the industrialization of carbon fiber. Carbon fiber material, a high-performance inorganic fiber material, was originally only used in the field of national defense and military due to its high production cost and complicated production process. Due to the improvement of production process and technology, its price has become very affordable. Therefore, it is widely used in various fields. Through the study of literature, this paper has a new understanding of the process, classification and advantages of carbon fiber composite materials, and summarizes the development of carbon fiber composite materials in recent years. Various applications of carbon fiber composite materials in civil aviation aircraft are also discussed in this paper. This research delves into the transformative role of carbon fiber composite materials in aircraft manufacturing, a field that has seen significant advancements in recent years. The

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use of these materials is pivotal in developing lighter, stronger, and more efficient aircraft, aligning with industry demands for sustainable and cost-effective aviation solutions. This study not only contributes to academic research but also aids industry practitioners in understanding the evolving landscape of aircraft materials.

2. Carbon fiber composite material

2.1. Manufacturing method of carbon fiber composite material

The fabrication process of carbon fiber composites involves several key steps, resulting in a high-strength, lightweight material [1]. It begins with precursor materials, usually polyacrylonitrile (PAN) or pitch-based fibers, which are subjected to a series of treatments to align and strengthen the carbon structure.

Precursor Materials: Polyacrylonitrile fibers are the most common precursor, chosen for their ability to yield high-quality carbon fibers. The Polyacrylonitrile fibers undergo stabilization, where they are heated in the absence of oxygen to lock in the desired carbon structure. Alternatively, pitch-based fibers, derived from coal or petroleum, are also used and require less processing.

Carbonization: In this step, the stabilized Polyacrylonitrile or pitch-based fibers are exposed to extremely high temperatures in an inert atmosphere. This process eliminates non-carbon elements and transforms the fibers into a high-carbon content structure. The result is a material with exceptional mechanical properties and high thermal stability.

Matrix Infusion: Carbon fibers are then combined with a matrix material, often a polymer resin like epoxy, in a process called matrix infusion. The matrix serves to bind and protect the carbon fibers, providing structural integrity to the composite. This step can be achieved through various methods, including hand layup, resin transfer molding (RTM), and autoclave processing. The choice of fabrication technique impacts the properties of the carbon fiber composite. Autoclave processing, involving high pressure and temperature, leads to composites with excellent strength but is time-consuming and costly. RTM produces composites with good mechanical properties at a lower cost, suitable for large-scale production. Hand layup offers flexibility in design but can result in variability in composite quality.

2.2. Advantages and disadvantages of carbon fiber composite materials

Carbon fiber composites offer many advantages that make them ideal for the aerospace industry [2]. Chief among these benefits is their excellent strength-to-weight ratio, which allows for strong structures without excessive weight. This characteristic is especially beneficial in the aerospace sector, where lightweight components can improve performance and fuel efficiency. In addition, carbon fiber composites have very good corrosion resistance, ensuring long durability even in harsh environments. It is good for extending the service life of the aircraft and also eliminates the need for frequent maintenance of the aircraft engine. Another key advantage is its design flexibility. Carbon fiber can be designed into a variety of complex shapes, aircraft designers can use the flexibility of carbon fiber to design a more favorable shape for the aircraft, such as supersonic aircraft overture, its wings and nose shape is very different from other aircraft, its wingspan is lower, while the fuselage is very narrow. This allows for better supersonic flight. If other materials were used, there would be no way to easily create the shape that the designers wanted.

However, carbon fiber composites have some limitations. The manufacturing process is complex and often labor-intensive, involving precise control of temperature, pressure and resin infusion. This complexity adds to production time and costs, making carbon fiber composites more expensive than traditional materials such as steel or aluminum. In addition, the specialized equipment and expertise required for manufacturing results in higher overall costs. Environmental concerns are another drawback. The production of carbon fiber involves energy-intensive processes, and the resins used in composites often come from non-renewable resources. In addition, recycling carbon fiber composites

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is challenging because separating and reusing the fibers is technically demanding and may result in lower-quality materials.

3. Application of carbon fiber composite materials in aircraft

3.1. Application of carbon fiber composite materials in subsonic aircraft

Carbon fiber composites have revolutionized the aerospace industry and are used extensively in subsonic aircraft, especially commercial airliners. These advanced materials offer a range of benefits that help improve performance, efficiency and safety [3]. One of the main applications of carbon fiber composites in subsonic aircraft is the construction of structural components. Carbon fiber-reinforced polymer composites are used to make a variety of parts, including wings, fuselage sections, empennages and interior components. The Airbus A380 and Boeing 787 are two prime examples of subsonic aircraft that use carbon fiber composites to achieve superior performance and handling advantages [4].

The Airbus A380 is a double-decker wide-body airliner known for its enormous capacity and luxurious features. While the A380’s structural components are primarily traditional aluminum, it does use carbon fiber composites in specific areas. For example, the A380’s horizontal stabilizer is partially made of composite materials. Improves the overall aerodynamic performance of the aircraft [5].

The Boeing 787, on the other hand, was a revolutionary aircraft that highlighted the use of carbon fiber composites. About 50 percent of the 787’s primary structure, including the fuselage and wings, is made of carbon fiber-reinforced polymer composites [6]. This remarkable integration of composite materials offers many advantages. The reduction in aircraft weight contributes to improved fuel efficiency, which reduces operating costs and reduces environmental impact. The use of composite materials also allows for greater cabin pressurization and humidity control, improving passenger comfort on long-haul flights. In addition, the innovative design enabled by composite materials contributes to improved aerodynamics, further optimizing fuel consumption and performance. Both the Airbus A380 and Boeing 787 demonstrate the benefits of using carbon fiber composites in subsonic aircraft, significantly improving efficiency, passenger experience and overall aircraft performance.

3.2. Application of carbon fiber composite material in supersonic aircraft

Concorde is a supersonic airliner jointly developed and produced by British Aircraft Corporation and Air France. It was commissioned in 1976 and remained in operation until it was decommissioned in 2003. Concorde was designed to fly faster than Mach 2 [7]. Concorde’s nose and wing leading edges are equipped with carbon-carbon composites to withstand the high temperatures generated by air friction during supersonic flight. These composites have excellent heat resistance, allowing aircraft to safely withstand the heat caused by air compression [5]. While Concorde’s main structural components were primarily made of aluminum alloys, the aircraft’s engineers explored the use of composite materials to improve performance. Composite materials are considered for applications such as auxiliary structural elements and interior components, and composites are used in structural elements such as fuselage and landing gear doors. Helps reduce weight and improve fuel efficiency. Concorde’s fuselage is a slender design, with the integration of advanced materials such as carbon fiber composites, which help reduce drag and optimize aerodynamic efficiency at supersonic speeds.

3.3. Problems in the use of carbon fiber composite materials

While carbon fiber composites offer many advantages, their use is not without certain problems and negative impacts. These issues stem from all stages of the composite’s life cycle, from production to end-of-life disposal, and require careful consideration to mitigate their negative impacts.

The production of carbon fiber is a complex process that includes high temperature carbonization. This can lead to significant carbon emissions that contribute to the global greenhouse effect. Carbon fiber precursor materials, such as PAN, require chemical treatments and processes prior to use, which

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may generate hazardous wastes and cause environmental pollution. Carbon fiber composites are known to be difficult to recycle. Their complex composite structure makes separating and recycling the fibers and resins a technically demanding process, which can make recycling too costly, leading some companies to opt out of recycling, resulting in pollution of the environment from their discarded materials [8].

Some of the resins used in carbon fiber composites may release volatile organic compounds during the manufacturing and curing process, causing air pollution and potential health hazards. Although carbon fiber composites are durable, their long service life may result in slower replacement cycles, delaying the introduction of more environmentally friendly materials and technologies [5]. Disposal of carbon fiber composite components at the end of their life cycle can be problematic due to their non-biodegradable nature. If not managed properly, these components can create long-term waste in the environment. Efforts are underway to address these environmental concerns and promote more sustainable practices in the use of carbon fiber composites. Researchers are exploring recycling methods, alternative raw materials, and improved resin formulations to minimize environmental impacts. As technology advances, it is possible to develop more environmentally friendly manufacturing processes and improve the recyclability of these materials, ultimately minimizing their negative impact on the environment.

4. Conclusion

In summary, this paper explores the multifaceted role of carbon fiber composites in advancing aircraft technology, focusing on their applications, benefits, limitations, and environmental considerations. Carbon fiber composites have become a transformative force in aviation, revolutionizing the design and performance of subsonic and supersonic aircraft. The integration of carbon fiber composites offers significant advantages, particularly their superior strength-to-weight ratio, corrosion resistance, and design flexibility. These properties have enabled the creation of lighter, more fuel-efficient airplanes that can fly longer distances while reducing their environmental impact. The use of carbon fiber composites has extended to critical components such as structural elements, leading edges, control surfaces and even thermal protection systems. The importance of carbon fiber composites in aviation cannot be overstated. They not only improve efficiency and performance, but also drive innovation in aerodynamic design and passenger comfort. This study underscores the crucial role of carbon fiber composites in advancing aircraft technology. While offering substantial benefits like weight reduction and strength enhancement, these materials also pose manufacturing and environmental challenges. Future research should focus on innovative recycling techniques and sustainable production methods to mitigate these challenges, paving the way for greener aviation technologies.

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