



Composite Materials and Their Fiber Reinforcement Technology in Aerospace Field

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Abstract: The need to reduce the overall weight of aeronautical and space structures while preserving or even improving their performances make the research and development in the field of advanced composite materials necessary for the advancement of aerospace technologies. This paper provides an overview of composite materials and their fiber reinforcement technology in aerospace field. We discuss the reasons for aircraft manufacturers and airlines to use composites and illustrate the definition of composite material. Then, we list the advantages and disadvantage of composite materials and cite different fiber reinforcement technologies of carbon fibers, aramid fiber, UHMWPE, etc. At last, we summarize the present and future applications of composites materials in aerospace and other civil fields. A conclusion is drawn that in the future, composite materials are set for their development, while continually decreasing its costs is still an important task.

Keyword: Composite materials; Fiber reinforcement; Aerospace; Carbon fiber

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1 Introduction

There is a revolution underway in commercial aircraft manufacturing today, to be summed up in a word: composites. Aircraft manufacturers have many good reasons to use composites and for airlines to want composites to be used in their fleets. Composite materials achieve relatively better strength than

traditional metallic materials, reducing aircraft weight and thus relative fuel consumption. Composites are also more resistant than metal to fatigue situations, or repeated take off/landing cycles, resulting in fewer costly inspections over the course of the aircraft's lifespan and more time spent in the air making profit^[1]. Nowadays, advanced composite materials are able to supersede aluminum and other metallic materials and comprise the main structure of modern aircrafts^[2-3].

On the other hand, artificial satellites and other space structures are exposed to very different environments from atmospheric conditions: ultra-vacuum, atomic oxygen corrosion, cosmic rays, meteorites / space debris collisions, heat circulation, etc. With accordance to these factors, therefore, the selection of structural materials on spacecrafts must refer to the strength-to-mass ratio, modulus-to-mass ratio, heat conductivity, stability of dimensions, release of gas, etc., encouraging the use of composite materials^[4].

2 Composite Material

2.1 The Definition of Composite Material

Composite material is a material that consists of strong carry-load materials embedded in a somewhat weaker material. The stronger material is commonly referred to as reinforcement and the weaker material the matrix. The reinforcement provides the strength and rigidity that is needed and which helps to support the structural load^[1].

2.2 The Advantages and Disadvantages of Composites Materials

Compared with traditional metal materials, the

composite material can reduce the weight by 20% - 50%. It has high impact resistance and can reduce accidental damage to the engine pylon for engine control and fuel line. The damage tolerance is very high which can improve the accident survivability. Galvanic corrosion, which will occur when two dissimilar metals are in contact (particularly in humid marine environments), is avoided (e.g. non-conductive fiberglass will not have this problem).

However, the composite materials have higher recurring, nonrecurring, and material costs. Damages of composite materials are less easily detectable, and repairs are more difficult than metal structures. Composite materials need to be isolated to prevent adjacent aluminum part from galvanic corrosion.

3 Fiber Reinforcement Technology

3.1 Carbon Fiber

The performance of a composite material system

Table 1. The IFSS of four single fiber-microdroplet composites

Filament	IFSS (MPa)	Increase (%)
As-received T300	42.62	—
T300 rinsed by acetone	18.37	-56.9
T300 treated by thionyl chloride	56.19	31.84
CNT/CF	106.55	150

further enhance the performance of the carbon fiber composite^[7].

In aircraft environment, the absorbed water molecules in polymer composite materials are known to have significant effects on physical and chemical properties of the matrix as well as the final performance of composite structures, especially in long-term operations. In some researches, the fibers embedded in the matrix were assumed to serve as a barrier to the penetrating water molecules^[8].

3.2 Aramid Fiber

Aramid fiber composites have plenty of applications in the automotive industry. Aramid-filled composites are used in parts such as gears, door check arms, head lamp adjustor parts, and sensor housings. In many of these applications, the use of polytetrafluoroethylene (PTFE) in conjunction with aramid fibers is capable of providing superior wear and lower friction coefficients. Some research has shown through SEM that aramid composites form a transfer film during adhesive wear, which is important in yielding excellent wear properties^[9].

depends critically on the interfacial characteristics of the reinforcing fibers and the matrix. It has been found that the interfacial strength between carbon fibers (CFs) and the matrix in a polymeric composite could be greatly improved by growing carbon fiber nanotubes (CNTs) onto the surfaces of CFs^[6].

Researches show that the IFSS of the epoxy composite reinforced by CNT/CF is as high as 106.55 MPa, which is 150% higher than that of the as-received T300 fiber composite (Table 1). And the main interfacial reinforcing mechanisms of this novel composite could be characterized by chemical bonding, Van der Waals binding, mechanical interlocking, and surface wetting (Figure 1)^[6].

Moreover, obtaining thinner optimized composite has been made possible by having a host material of higher complex permittivity. Other electromagnetic wave absorbing fillers could also be added to

An analysis was developed for the flexural strength in three-point loading of a rectangular unidirectional composite beam reinforced by aramid fibers. The behavior of the material was assumed to be linearly elastic in tension and perfectly plastic in compression. The results indicate that non-linear compressive stress-strain characteristics significantly affect material behavior under flexural loading, and there is a significant shift in the position of the neutral axis at midspan^[10].

Research results also suggest that ultrasound waves can effectively improve the interface of aramid fiber/epoxy composites through activating the surface of fibers and producing the interface interlock. The obvious advantage of ultrasound treatment is that it can be applied easily and directly in the winding process of fibers, without decreasing the tensile strength of fibers^[11].

3.3 UHMWPE

Ultrahigh molecular weight polyethylene (UHMWPE) fiber is the new generation of high-performance fiber after carbon fiber and aramid

fiber. UHMWPE fibers have a number of excellent properties: for example, high strength (tensile strength as high as 30.8cN/dtex) and modulus, excellent toughness, chemical resistance and impact, low moisture absorption, good wave transmission, and electrical insulation. UHMWPE fiber is considered the ideal reinforcing fiber with high performance and lightness. Unfortunately, however, the UHMWPE fiber is chemically inert and has low surface energy; this disadvantage leads to poor interfacial adhesion in UHMWPE fiber-reinforced composites, which, along with the poor heat-resistance and creep-resistance, limits the application of UHMWPE fiber. To improve the fiber-matrix adhesion and more efficiently deploy UHMWPE fibers, hybrid of UHMWPE fiber and other high-performance fibers, such as carbon fibers and aramid fibers, is needed. Thereby, their exceptional toughness and extremely good resistance to chemical attack can be better utilized to compensate for the shortcoming of other fiber composites^[13-14].

Based on the difference in crystallinity and melting point of UHMWPE fibers and simple HDPE, there is a thermal window of about 20 °C in which these composites could be manufactured. With respect to the high viscosity of thermoplastic PE in this thermal window, the key element to attain high mechanical properties is achieving the highest impregnation of the fibers through control of the processing conditions such as temperature, pressure, and time, as well as retaining a high degree of fiber orientation. To this end, several routes have been developed up to now—for instance, hot compaction, powder impregnation, solution impregnation, film stacking, etc^[16].

4 The Present and Future Applications of Composites Materials

Composite materials can provide a much better strength-to-weight ratio than metals: sometimes by as much as 20% better, which secures their extensive use in Aerospace and other fields. The lower weight results in lower fuel consumption, emissions, and enhanced aerodynamic efficiencies and lower manufacturing costs because of fewer riveted joints. The aviation industry was naturally attracted by such benefits when composites first made an appearance, but it was the manufacturers of military aircraft who initially seized upon the opportunity to exploit their

use to improve the speed and maneuverability of their products^[3].

Satellites nowadays are comprised of thousands of composite material parts. Japanese satellites use a considerable amount of composite materials, which ensures dimensional stability and rigidity in the first place, deploying carbon fiber (T30) as the main reinforcement. As per the manufacture of the cylindrical solar panel, aramid fiber composites (KFRP) have electrically insulating properties; the Double-Kel frame of the space station, which is centered above NASA and has an orbital inclination of about 28.50 km from Earth, and the Canadian-made Mobile Operation Controller (Maniu-Plator) are made of CFRP^[4-5].

The challenge for being able to drive scale to volume and decrease cost, however, is also presented. For example, having a cable weighing 69% lighter is appealing, but it has to be produced and formatted at an appropriate cost that can be broadly used by aircraft engineers. So, in the future, developing composite materials driving up the output, decreasing cost and eventually getting broadly used across the entire industry will be of more importance.

5 Conclusion

The aerospace manufacturing field nowadays becomes increasingly demanding of high-performance materials that demonstrate even tougher physical capacities but can be run at a much lower cost than traditional metallic materials. As a solution, composite materials, which consist of strong carry-load materials (mostly specific fibers) embedded in a somewhat weaker material (mostly epoxy), are adopted.

This novel pattern of utilizing materials to manufacture specific structures has a number of advantages and disadvantages implying the future of it: composite materials. Some of the advantages include weight reduction, oriented design, and high impact and damage tolerance, while some of the disadvantages are higher recurring and non-recurring costs, non-visible damage, and more difficult repair processes.

Previous literatures addressing the theories and technologies underlying composite materials are found. On the most common carbon fiber, aramid fiber, and UHMWPE fiber composites, particular

physical traits on macroscopic and microscopic levels account for the reason for their outstanding performances and possible limitations of use. The lock between carbon fibers and the epoxy matrix produced by the bonding of carbon nanometer tubes gives carbon fiber composites very impressive designable capacities; aramid fibers yield interfacial interlock, which is important for the composite's wear-resistance and special wave transmission properties; UHMWPE fibers possess high tensile strength, and the transition film formed on UHMWPE composites also leads to wear-resistance properties of UHMWPE composites, while its low surface energy is responsible for its poor bonding strength. These properties have some implications on specific uses of UHMWPE.

Lastly, based on the review of present and future applications of composite materials, we find that the future of composite materials is promising, while further reduction in cost is necessary for its development. Uses of composites have long been adopted by aircraft manufacturers and seen in space structures as well as militaries, and nowadays there are common uses of advanced composite materials in civil fields. As discussed earlier, however, advanced composite materials are relatively high in both recurring costs and non-recurring costs. With the cost of manufacturing and operation being the prominent factor to be considered in most fields (especially for aircrafts and airlines), future use of composite materials have to see an overall reduction in cost while continually advancing onto new technologies. More experimental research definitely needs to be conducted on this topic.

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