

Introduction to Composite Materials and their Application and use in Aircraft and Unmanned Aerial Systems (UAS)

Sofema Aviation Services (SAS) www.sassofia.com considers the different composite materials and their applications in aviation.

Introduction

Composite materials are multi-component materials made from two or more different constituents that, when combined, produce a material with properties different from and superior to those of the individual components.

- The individual components maintain their physical identities in the final product, and the new material's properties are the result of both components' combined action.

There are two main categories of constituents in composite materials:

- The matrix
 - The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions
- The reinforcement.
 - The reinforcements impart special mechanical and physical properties to enhance the matrix properties.

Composite materials have a wide range of applications within due to their high strength-to-weight ratio, corrosion resistance, and ability to be formed into complex shapes.

There are currently several types of composite materials used in the aviation industry:

Carbon Fiber Reinforced Polymer (CFRP)

Carbon fibers are known for their high tensile strength, high chemical resistance, high-temperature tolerance, low thermal expansion, and low weight. These features make CFRP a perfect material for aviation use. The Boeing 787 and Airbus A350 primarily use CFRP in their structure. CFRP's superior strength-to-weight ratio allows for increased payload capabilities.

The lightweight nature of CFRP together with good corrosion resistance can lead to a longer lifespan for aircraft components, reducing the frequency of replacement. (also means that aircraft require less fuel to fly)

- Carbon Fiber Reinforced Polymer (CFRP) has seen increasing use in the aviation industry due to its unique and advantageous properties.
- CFRP is an extremely strong material, which is much lighter than traditional materials used in aviation like aluminum or steel.
- CFRPs are resistant to corrosion which can supports to a longer lifespan for aircraft components, reducing the frequency of replacement.

- The flexibility of CFRPs allows for innovative and efficient design shapes, which can lead to aerodynamic advantages.

Considerations

- One of the most significant disadvantages of CFRP is the high initial cost.
 - Production of CFRP components is more expensive than traditional materials, largely due to the cost of the carbon fiber itself and the specialized manufacturing processes.
- CFRP can be more susceptible to certain types of damage, like impact damage, and these can be harder to detect than in metal structures.
- This necessitates more sophisticated and thus costly non-destructive testing techniques.
- Repairs to CFRP structures can be more complex and time-consuming than those for metal components.
- While the upfront cost of using CFRP in aviation is high, the long-term savings can be substantial due to less maintenance, lower fuel costs, and the extended lifespan of the aircraft.

Note - The need for specialized training to handle and repair CFRP structures could increase the operational costs.

Glass Fiber Reinforced Polymer (GFRP)

Glass fibers are a cheaper alternative to carbon fibers. Although they are heavier and less rigid than carbon fibers, they have excellent tensile strength and are non-magnetic and more flexible. They are often used in secondary aircraft structures.

- GFRP is a composite material made of a polymer matrix reinforced with glass fibers.
- The glass fibers provide strength and stiffness to the polymer, which provides the shape and protects the fibers from damage and environmental effects.

Considerations

- GFRP has high strength-to-weight ratio which makes it ideal for aviation applications where reducing the weight of an aircraft can lead to fuel savings and increased payload.
- Unlike traditional metallic materials, GFRP does not corrode, making it an excellent material choice for parts exposed to harsh environmental conditions, like wings and fuselages.
- GFRP is an insulator, which makes it useful in applications where electrical conductivity could be a problem, such as in radar domes (radomes) or near avionics equipment.
- GFRP can be molded into complex shapes, allowing more design freedom for engineers and designers. This can result in more aerodynamic shapes, reducing drag and improving fuel efficiency.
- The production and processing of GFRP can be more expensive than traditional materials, moreover repairing GFRP can be more difficult than repairing metals.

- Special techniques are required, and it's often harder to detect damage in GFRP structures.

Note - GFRP has different thermal expansion characteristics than metals, which can cause problems when it's used alongside metallic components.

Aramid Fiber (Kevlar)

Aramid fiber, commonly known by the brand name Kevlar, is a synthetic material characterized by high strength, light weight, and resistance to heat and chemicals. In the aviation industry, aramid fibers are utilized in various components due to their unique properties, contributing significantly to the overall safety, durability, and performance of aircraft.

- High strength-to-weight ratios, high toughness, and good resistance to impact and abrasion.
- Aramid fibers are frequently used in the construction of composite materials, which are extensively used in aircraft structures such as wings, fuselage, and tail. These composite materials offer high strength-to-weight ratios and excellent fatigue resistance.
- Aramid fiber is a common material for aircraft tires, providing superior resistance to wear and heat compared to conventional materials.
- The fibers' electrical neutrality makes them perfect for the construction of radomes (the protective structures that house radar equipment on aircraft), as they don't interfere with signal transmission.
- The heat resistance property of aramid fiber makes it a perfect choice for some engine components, including containment systems for turbine engines.
- Kevlar is used in the cockpit door to offer ballistic protection and resist unauthorized access to the cockpit.

Considerations

- Aramid fibers have high tensile strength, also incredibly durable and can withstand harsh environmental conditions, which is essential in aviation applications.
- Aramid fibers are resistant to heat and various chemicals, making them suitable for use in high-temperature areas like engines.
- Aramid fibers do not interfere with radio waves, making them ideal for the construction of radomes and antennae.
- Aramid fibers are more expensive than many other materials used in the aviation industry. The high cost can be prohibitive, especially for smaller companies or less critical applications.
- Repairing composite materials made with aramid fibers can be complex, requiring specialized knowledge and equipment.
- Aramid fibers are sensitive to ultraviolet (UV) radiation, which can degrade the material over time.
 - This requires the application of protective coatings, adding to the maintenance requirements.

Important Note - Damage to aramid fiber composites can be difficult to detect without specialized equipment, as the damage may not be visible on the surface.

Boron Fiber Composites

Boron fiber composites are used in aircraft and aerospace applications because of their high strength and stiffness, high temperature stability, light weight, and high energy absorption. They are often used in wing and tail assemblies.

Considerations

- Boron fiber composites exhibit excellent strength-to-weight and stiffness-to-weight ratios, which are crucial in aerospace applications.
 - They are frequently used in structural components of aircraft where high strength and rigidity are required, such as wings, fuselages, and engine components.
- Boron fiber composites resist heat exceptionally well, which makes them suitable for engine components and other parts exposed to high temperatures.
- The composites also exhibit a low coefficient of thermal expansion, (a crucial trait for aircraft materials, which are subjected to extreme temperatures during flight)
- The composites' high strength and thermal resistance mean they can handle the stresses of flight over extended periods, reducing the frequency of component replacements.
- Boron fibers can be woven into various shapes and sizes, offering flexibility in aircraft design.
- Boron fiber composites are costly to produce, mainly due to the energy-intensive production process of boron fibers and the complex procedures to manufacture composite parts.
- Damage to composites can be difficult to detect and repair. Special techniques and equipment are typically required.
- Despite their high strength, boron fiber composites can be brittle and may fail suddenly under high stress without deformation, unlike metals that may yield and deform before breaking.

Ceramic Matrix Composites (CMCs):

Ceramic Matrix Composites (CMCs) have gained significant attention in the aviation industry due to their unique properties and potential benefits. CMCs are advanced materials that combine ceramic fibers with a ceramic matrix, resulting in a material that exhibits enhanced mechanical, thermal, and chemical properties. CMCs can withstand high temperatures and harsh conditions better than metals, making them an excellent choice for engine components. They are lighter and stronger than metals and have better high-temperature strength.

Considerations

- CMCs can withstand extremely high temperatures, making them suitable for applications in the hot sections of aircraft engines, such as turbine blades and combustors.
- CMCs offer a high strength-to-weight ratio, making them lighter than traditional metallic materials.
- CMCs possess excellent mechanical properties, including high strength and stiffness, enabling them to withstand significant loads and stresses.
- CMCs are highly resistant to chemical corrosion, which is crucial in harsh environments like aircraft engines where exposure to combustion gases and other corrosive agents is common.
- CMCs have low thermal conductivity, allowing them to act as effective thermal barriers, reducing heat transfer and improving overall efficiency.
- CMCs can withstand temperatures above what traditional metallic materials can tolerate, allowing for improved engine performance and increased efficiency.
- CMCs require specialized manufacturing techniques, making their production more complex and potentially increasing costs.
- While CMCs possess excellent strength, their fracture toughness can be lower compared to metallic materials.
- CMCs may require specific repair techniques and maintenance procedures, which can be more challenging and costly compared to traditional materials.

Typical Use of CMC,s

- CMCs are used in the hot sections of gas turbine engines, such as turbine blades, turbine shrouds, combustors, and nozzle components.
 - Their high-temperature resistance and lightweight properties contribute to improved engine performance and efficiency.
- CMCs can be used in the exhaust systems of aircraft engines to withstand high temperatures and provide thermal insulation.
- CMCs are employed in aircraft braking systems and clutches due to their excellent heat resistance and wear properties.
- CMCs can be used in thermal protection systems for re-entry vehicles, enabling them to withstand the extreme heat encountered during atmospheric re-entry.

Metal Matrix Composites (MMCs)

MMCs are composed of a metal combined with a ceramic or another metal. MMCs combine the ductility and toughness of metals with the strength and stiffness of ceramics, providing resistance to wear, high-temperature strength, and thermal conductivity. MMCs are often used in brake systems of aircraft.

MMC's present challenges in terms of cost, repairability, and processing. Thus, their use in aviation must be evaluated on a case-by-case basis, considering all these factors.

Considerations

- MMCs can withstand the high-temperature and high-stress environment inside an aircraft engine.
- MMCs are also used in the construction of airframes due to their light weight and high strength.
- MMCs can also be used in the landing gear due to their ability to withstand high mechanical stresses and strains.
- MMCs possess excellent thermal properties, including resistance to thermal expansion and high-temperature endurance, crucial for engine components and avionics.
- MMCs are typically harder and more resistant to wear than traditional materials, which can extend the life of components.

Special Considerations

- The manufacturing processes for MMCs are often complex and require advanced technologies, which can be costly.
- Repairing MMCs can be challenging due to their complex structures. This can result in high maintenance costs and increased downtime.
- MMCs are generally harder to machine than conventional materials due to their high hardness and strength. Special tooling and techniques are often needed.
- The quality of MMCs can vary depending on the specific manufacturing process used, and small variations can have significant effects on the material properties.

Next Steps

Sofema Aviation Services (www.sassofia.com) offers the following 2 day course - Composite Material TAP Testing for Aviation Inspectors