https://www.sworldjournal.com/index.php/swj/article/view/swj33-01-044
DOI: 10.30888/2663-5712.2025-33-01-044

UDC 621.791.9

UNDERSTANDING COMPOSITE MATERIAL PROPERTIES FOR AEROSPACE ENGINEERING APPLICATIONS

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Abstract. *The authors explore a range of composite materials utilized in aviation, evaluating their advantages and disadvantages. The contemporary aerospace industry requires materials that enhance the functional and technological characteristics of aerospace equipment while optimizing operational, maintenance, and disposal costs. One solution is the use of polymer composite materials (PCM). As new demands for operational performance emerge, there is a growing need for materials that improve technical specifications by reducing weight. The research goal is to describe the types of polymer composite materials used in the aerospace industry.*

Keywords: *polymer composite materials, carbon fiber, glass fiber, organoplasties,* boroplastics.

Introduction

The aerospace industry, as a high-tech sector, currently faces stringent requirements for the production of rocket, space, and aviation technology. The momentum for the development of aviation materials has accelerated due to the way the aerospace industry is expanding. It is generally known that use of polymeric composite materials (PCM) in any branch of industry is a sign of high scientific, technical and qualitative level of its development. Improvement of ergonomic qualities of leisure time items, medical equipment along with economic efficiency, reliability and structural life results in increasingly bigger volumes of PCM implementation especially in the aircraft and rocket manufacturing [1-2]. The primary motivating factor is cost reduction via lighter construction and longer-lasting aircraft parts/structures. Improved mechanical qualities in the materials used to make lightweight aircraft frames and engines can enhance payload, extend flight range, and improve fuel efficiency i.e., all of which immediately lower aircraft operating costs [3]. Consequently, aerospace enterprises continually adapt to the latest scientific advancements, modernizing their production processes. The adoption of polymer composite materials (PCM) has significantly improved the functional attributes of aerospace vehicles.

The use of PCM is driven by the desire to enhance the capabilities of aircraft while simultaneously reducing density without compromising strength. These materials are characterized by superior strength and resistance to elevated temperatures and vibrations compared to alternatives. Importantly, they enable substantial reductions in vehicle weight, consequently lowering operational costs.

Polymer Composite Materials in the Aerospace Industry

Polymer composites are increasingly utilized in the automobile and aerospace industries for weight reduction, improved performance, and environmental sustainability [4, 5, 6]. Fiber-reinforced plastics (FRP) play a crucial role in the automobile industry, offering weight reduction potential, high specific strength, and stiffness (Alberto, 2013) [7]. Polymer composites provide advantages over steel in terms of weight reduction, styling flexibility, tooling cost reduction, rust resistance, noise reduction, and higher damping properties [8, 9].

The aerospace industry has seen a rise in the use of polymer composites for various components like tail fins, elevators, fuselage fairings, spoilers, and ailerons, leading to weight reduction and cost savings [10]. Research in advanced polymer composites is expanding, with a focus on recyclability, mechanical properties, reduced weight, and extended shelf life for future automotive applications [11].

Aerospace materials must meet specific requirements such as being lightweight, high strength, having good fracture resistance, and high damage tolerance [6, 12]. The aerospace industry's focus on lightweight materials is driven by the need to reduce operational costs, particularly fuel consumption, which accounts for a significant portion of aviation expenses.

Materials and structures are fundamental to the development of modern aerospace systems, impacting various stages of an aircraft's life cycle from design to disposal [6, 9, 7]. This highlights the continuous evolution and importance of materials in the aerospace industry. Fiber-reinforced polymer composite materials are increasingly favored for aerospace applications, particularly as primary structural materials [13]. In

2024, glass fiber composites are among the most widely used PCM. Glass fiber products feature enhanced electrical insulation properties, significantly extending their lifespan even under extreme environmental conditions (temperature range from -60 to +170 degrees Celsius) while reducing the risk of corrosion. This material also improves the radio transparency of aircraft fairings.

Another common PCM is carbon fiber. Its fibrous structure redistributes internal stresses and prevents the propagation of small cracks. This characteristic makes it more appealing than metal products, as it prolongs the lifespan of the equipment without repairs and enhances safety (used in manufacturing bodies, antenna reflectors, trusses, and various internal and external structures). Carbon fiber can reduce the mass of a spacecraft by up to 15%, being five times lighter than steel and nearly 1.8 times lighter than aluminum.

These properties have made carbon fiber one of the most utilized materials in the aerospace sector. Epoxy polymer matrices serve as the foundation for most PCM in the production of aerospace vehicles, equipment, and components.

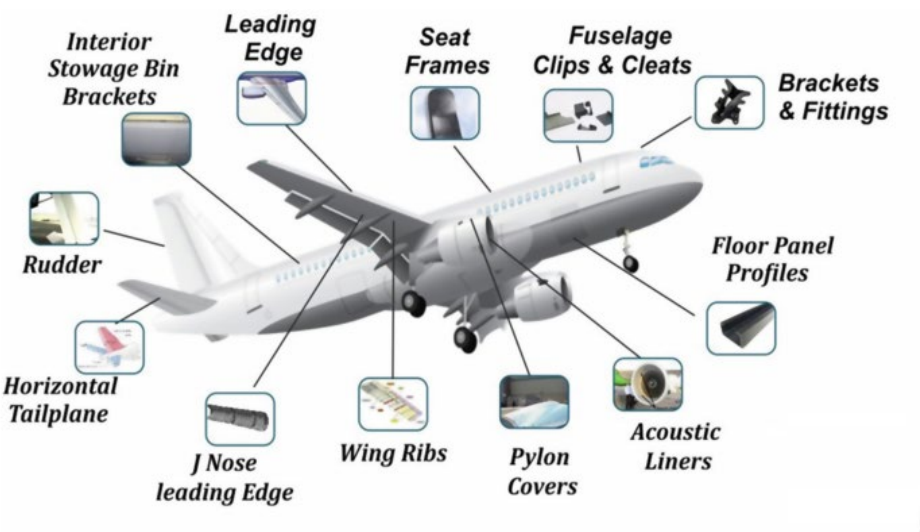

Figure 1 - Advanced Polymer Composite for Aerospace Engineering Applications [18].

Main text

Currently, aircraft manufacturing companies are actively using composite materials. This technology allows for a reduction in the overall mass of the structure and significantly lowers operational costs.

Composite materials (composites) are multi-component materials typically consisting of a plastic base (matrix) reinforced with fillers. The combination of heterogeneous substances leads to the creation of a new material whose properties differ from those of each of its components. The use of composite materials enables a reduction in the weight of the airframe of an aircraft by 30–40% [14-16] compared to the weight of an airframe made from traditional metallic materials. Let's take a closer look at these composite materials. Carbon fiber reinforced plastics are composite materials that use carbon fibers as a filler. Depending on the processing mode and the raw materials used, the resulting carbon fiber can have various structures. The main advantage of carbon fiber reinforced plastics is their low density combined with a high modulus of elasticity. Carbon fiber materials are very lightweight yet strong. All carbon fiber composites conduct electricity well, which somewhat limits their areas of application.

Table 1 - Comparative properties of various structural materials

Material	Density, p, kg/м^3	Strength, $\sigma_в$, MPa	Modulus of elasticity, E, GPa
Carbon fiber	1 500	1 200	170
Boroplastic	2 000	1 200	270
Organoplastic	1 300	2 000	95
Fiberglass	2 000	2 000	70
Aluminum alloys	2 700	600	70
Titanium alloys	4 500	1 100	110
Steel	7 800	2 100	200

Carbon composites are used to manufacture high-temperature components in rocket technology and high-speed aircraft, as well as brake pads and discs for high-speed airplanes and reusable spacecraft, along with electric thermal equipment.

Boron plastics are composite materials that contain boron fibers as fillers, embedded in a thermosetting polymer matrix. The binders in boron plastics are typically epoxy resins, polyamides, or other polymers, primarily thermosetting ones. Boron plastics are characterized by high values of elastic modulus, fatigue strength, and other mechanical properties, along with low creep in the direction of fiber orientation. When exposed to water, lubricants, and atmospheric factors for extended periods (up to 10 years), the mechanical properties of boron plastics decrease by no more than 10–15%. They are widely used in aerospace and aviation to reduce the weight of heavily loaded components. Currently, in aircraft manufacturing, the use of composite materials with boron alloys accounts for 15–20% due to expensive production methods, leading aircraft designers to prefer carbon composites [15-17].

Organic plastics are composites in which the fillers are organic, synthetic, and, less commonly, natural and artificial fibers in the form of bundles, threads, fabrics, etc. In thermosetting organic plastics, the matrix is usually made of epoxy, polyester, and phenolic resins, as well as polyimides. Organic plastics have low density, relatively high tensile strength, high resistance to impact and dynamic loads, but at the same time low compressive and bending strength. They find wide application in many fields, including aircraft manufacturing.

Glass plastics are polymer composite materials reinforced with glass fibers, formed from melted inorganic glass. The matrix used is most often thermosetting synthetic resins (phenolic, epoxy, polyester, etc.) as well as thermoplastic polymers (polyamides, polyethylene, polystyrene, etc.). These materials possess quite high strength, low thermal conductivity, and excellent electrical insulation properties, in addition to being transparent to radio waves. Glass plastic is a relatively inexpensive material widely used in aviation, as well as in construction, shipbuilding, and radio electronics.[14].

The use of composite materials allows for the creation of lighter structures for aircraft, which increases altitude, flight range, and speed. These materials are reliable, significantly impact fuel savings, and require lower maintenance costs. However, the technologies for their production remain expensive to this day.

Summary

Polymer composite materials are widely used in the aerospace sector, from small component manufacturing to the creation of spacecraft bodies. The trend toward increased PCM application necessitates detailed studies and data collection on the behavior of various material types under environmental conditions and extreme situations. Predictive efforts require thorough examination and classification of technological defects, which in turn forms the basis for implementing preventive measures to mitigate the occurrence of such defects, accounting for their impact on manufactured equipment and products, and describing acceptable thresholds for these defects' characteristics.

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