

Polymer Nanocomposites: Cutting-edge Material for the Aviation Sector

Rama Sharma*

Abstract

Due to current market demands and a need to produce structural materials for use in both military and civilian aircraft more efficiently, the aerospace industry is always pushing for higher productivity. The design and manufacturing of aeronautical components in the present and the future are heavily reliant on materials of the polymer composite class. The building of many airplane components uses polymer composites, which are generally helpful. Based on their mechanical characteristics, these materials may be used in airplane building. Throughout maintenance cycles, replacing metal parts and components with polymer composite-based parts is becoming more and more common in both commercial and recreational aviation. Polymer composite-based components are quickly replacing metal parts during maintenance cycles in both private and commercial aviation. In aircraft applications, carbon fiber is typically the most commonly utilized polymer composite. The aerospace industry has used fiber-reinforced polymers (FRP) composite materials to create extremely strong, lightweight, and thermally resistant materials for aircraft structures. The use of composite materials in the production of various aerospace components has led to significant weight reduction roughly 30% around the world. Aeronautic applications of composites encounter a number of difficulties, including the need for high precision and low volume. Consequently, the development of expensive technologies is required.

Keywords: Polymer nanocomposites, aerospace industry, carbon fiber, fiber-reinforced polymers, challenges

INTRODUCTION

Due to its many applications, polymer composite materials need to have their strength, stiffness, density, and cost reduced even more. Since these materials are essential to the manufacturing sector, more research is required to determine how to make these properties sustainable (1–4). Multiple monomers are frequently found in composite materials; one monomer may be found in the matrix phase, while the other monomer may be present as a fiber or particle (5). Composite materials, whether synthetic or natural, have been made employing the fiber form of these monomers in a range of industries, including mechanical, aerospace, automotive, biomedical, and marine (6–8).

*Author for Correspondence

Rama Sharma

Associate Professor, Department of Chemistry, GLA University, Mathura, Uttar Pradesh, India

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The use of polymer composite materials has several advantages over steel in the transportation and automotive industries. Firstly, they produce weight 20% to 40% lighter than steel; secondly, the flexibility of the deep drawn panel's styling reduces the need for steel metal stamps; thirdly, they reduce tooling costs by 40% to 60%; fourthly, they save overall assembling costs by minimizing the amount of time required consolidating parts; fifthly, they are very resistant to rust, dents, and scratches; Sixthly, they have stronger damping qualities and less noise, vibration, and harshness; Finally,

because the polymer composite material has a higher specific energy absorption than other materials, applying new process improvements can result in a safer construction as well as added value to the finished product (9).

Since then, more modern polymeric composite materials have replaced thermoset and thermoplastic materials in the manufacturing and automotive sectors. In order to handle these new materials, compounds are, for instance, extending their manufacturing line; in addition, concentrations of fiber and nanocomposite are being offered as substitutes for large fabricators and specialist compounds (10). In addition to being offered as new additions to the supply chain, emerging novel polymer materials are also being compounded in novel ways using new technologies. Various polymer composites are integrated into structural elements including semi-structural headliners and floor modules through the use of modularization (11).

Weight is a crucial design factor for machines that weigh more than air, and automakers have been working to increase the weight ratios of their vehicles (12). In order to accomplish this significant advancement in weight reduction, polymeric composite materials were employed. There are now three main types of these materials in use: aramid-, fiberglass-, and carbon-reinforced epoxy (13). There are now three main types of these materials in use: aramid-, fiberglass-, and carbon-reinforced epoxy (14). The aerospace industry has been using polymer composites for more than 20 years, and this has increased application and prompted the creation of novel composite materials (15).

Generally useful, polymer composites are used in the construction of numerous spacecraft and aviation components (16). Several components of passenger airlines, military planes, space shuttles, hot-air balloon gliders, and gondolas are among them (17). Additional uses for these materials may be seen in the entire aircraft assembly, including the wings of the Beech Starship, the propellers, seats, instrument enclosures, and helicopter rotor blades (18). It is crucial to remember that the mechanical characteristics of these materials determine how they are used in aircraft building. For instance, carbon fiber has the special ability to become brittle and fatigued. Rolls-Royce made the discovery in the 1960s and used it to build the inventive compressor blades or wings for the RB211 jet engine, however these failed miserably as a result of bird strikes (19). According to Hedayati and Ziaei-Rad (2014)(20), aluminum wings have been utilized as a substitute because of their metal fatigue lifetime. Carbon fiber is dramatically improving every day, despite being far less predictable. Particularly in the building of the Advanced Tactical Fighter's wings, boron performs admirably (21). In order to build light bulkhead fuel tanks and floors with a high degree of rigidity, DuPont (2016) (22) owns the well-known patented product Aramid fibers, better known as Kevlar.

Through its experimental research program, Boeing has successfully swapped out 11,000 metal parts in a helicopter for 1500 polymer composite parts (23). In both commercial and recreational aircraft, polymer composite-based components are quickly replacing metal parts during maintenance cycles. According to Tang and Hu (2017)(24), carbon fiber is generally the polymer composite that is employed in aerospace applications the most. The following are some advantages of employing carbon fiber in the aerospace industry: (1) a 20%–50% weight reduction in quotes; (2) simple assembly of intricate component parts through the use of automated layup equipment and rotational molding techniques (3) With tapering thicknesses and reinforced apparel, UP designs can rearrange the mechanical characteristics of carbon fiber in a novel way. (5) Polymer composites' thermal resilience does not change even at greater temperatures; for instance, it may quickly expand or shrink at 35,000 feet of runway between 900F and 2670F (6) Its high damage tolerance increases its accident survivability; (6) It has been noted that monocoque (single-shell)-molded structures guarantee greater strength at a significantly lower weight; (7) nonconductive fiberglass is an additional carbon fiber substitute that can be utilized; (8) it removes combination fatigue issues; and (9) it shields planes, thereby reducing the likelihood of unintentional accidents. Carbon fiber makes comprise the engine pylons that are used in the fuel delivery lines and engine control panels.

AIRCRAFT'S EXTERIOR AND INTERIOR PARTS

The aerospace industry has used fiber-reinforced polymers (FRP) composite materials to create extremely strong, lightweight, and thermally resistant materials for aircraft structures. These materials exhibit remarkable mechanical, electrical, and tribological characteristics (25). Heat- and flame-resistant aircraft body sections, such as interior panels, have been fabricated using thermoplastic and natural fiber reinforced thermoset. They have also taken the place of traditional sandwich panels and are simply disposed of and recyclable (26). Conversely, FRP composites are used in many different aircraft applications. Its outstanding mechanical and lightweight structure is the main cause of this. The primary drawback of FRP is that it is less recyclable than natural fiber/bio composites, which are more widely used in the aerospace sector. Additionally, they are less expensive and readily biodegradable (27).

Signal Transmission

The usage of composite structures made of natural fiber in airplanes does away with the requirement for separate wires to serve as communication device transmitters. The method works by applying a voltage to any one of the composite's layers, which then directly transfers electricity to other electrical devices via the fiber composite (28).

The Hubble Space Telescope Antenna

The Hubble space telescope antenna demonstrates that P100 graphite fiber has a low coefficient of thermal expansion and great stiffness when it is distributed across a 6061-aluminum matrix composite material. As a result, the antenna of the Hubble space telescope experiences higher gain (29).

Aircraft Parts

There is a 12%–14% weight decrease when using ramie fiber composites to build airplane wings (30). Furthermore, hybrid kenaf/GF-reinforced polymer composites have outstanding mechanical properties and are resistant to rain erosion, according to Ghori et al. (2018)(31). The use of carbon fiber reinforced silicon carbide in aircraft brake design improves the material's resistance to high temperatures, up to 12000C, according to Dos Santos et al. (2016) (32).

Safety

Utilizing an ablative composite material with zirconia fiber for thermal protection increases the safety of the spacecraft. Significant mechanical qualities and a robust resistance to high temperatures are also present in this material. According to reports, a composite material containing 30% zirconium fiber had a bend strength of 19.33 MPa at a temperature of 1400 °C. Likewise, a ceramic protective layer has developed as a result of the eutectic melting reaction, which adds another 13.05 MPa of bending strength (33).

MANUFACTURING OF SUSTAINABLE POLYMER COMPOSITES

The two types of fiber reinforced polymer (FRP) manufacturing techniques utilized in airplanes are open molding and closed molding. Since this type of mold is often one-sided, the gel coat and laminate are pre-exposed to the environment during the open molding process. The composite is treated in a vacuum bag or a two-sided mold set when it is closed molding. The composite product can be made from the outside to the inside thanks to open molding. Large parts are also produced by open molding, and the maximum size of each part that may be handled is limited. Furthermore, it involves labor-intensive, low-volume, low-cost procedures, and emissions may pose a significant issue. The best substitute that satisfies emission regulations is closed molding. It can also reliably produce better parts at a bigger volume. Moreover, labor expenses are decreased, finishing work is completed with less waste, and parts are automated without the need for molds. The fibers are immediately drained from the creel board and run into a resin bath in both the open and closed molding processes to impregnate them with the resin. After the fibers are saturated, any extra resin is removed by passing them through a predie cast, and at last the composite takes on its final, distinct shape.

An alternative method is to mold the pultruded composite part's final cross section using the curing die. The resin can also be solidified by applying heat to the component through the use of a curing die. This will guarantee that the finished profile composite is removed from the die with a specific amount of force. This reduced composite production strategy necessitates new die cross-sectional area due to changes becoming increasingly significant. Because the process is typically mechanized, labor costs are reduced and the resulting composite components are of superior quality and reliability. The uses of this technology are largely determined by the constant, limited cross-sectional area that it produces for the composite components. Although the pultrusion technique has not been used much in the aerospace sector or its environs, it is highly effective in producing standardized profile beams for aerospace-related civil engineering projects (34).

Currently, robotics is being employed in the production of polymer composites; this trend is growing more quickly and will undoubtedly become a new technology in the future. Reduction of the final size and low faults of the final composite formed are the obvious benefits of adopting robots as an automated process in polymer composite manufacture. Furthermore, a significant decrease in the quantity of feed material utilized occurs, and labor expenses are also taken into account. Automated fiber placement (AFP) machines are a potential method of producing polymer composites. They use robotics to deposit fibers in numerous pre-impregnated layers of "slit tape," which also makes it possible to successfully cut and clamp at the end of a single tow. The robotic head is heated just before being put on a compacted substrate with the aid of a specialized roller, and it adheres to a predetermined fiber route tow. Because robot technology works so well, AFP machines have also produced excellent productivity because of their ability to handle complex geometries. It is now used in the production of window square boxes for the Boeing 787 fuselage, which are chopped longitudinally to create two "C" sections for wing spars. Enterprises like Electro Impact have included their production techniques with intriguing potential for designing airplane structures in the future. These systems incorporate several industrial processes as well. By integrating the robot head and strategically placing the fiber, for instance, the manufacturing process guarantees the creation of integrated and blended structures with fewer joints and connectivity. Integrated orthogrid and isogrid composite panels, which are now exceedingly difficult to construct on an economically feasible big scale, have also been made viable by structural engineers through the use of these approaches, which enable the creation of more efficient structures (35).

PROSPECTS OF ECO-FRIENDLY POLYMER COMPOSITES FOR AIRPLANES

The market for increased productivity is always being driven by the aerospace industry's requirement and desire to perform better when it comes to producing structural materials for use in both military and commercial aircraft. One such class of materials that is heavily influencing the design and production of aerospace components both now and in the future is polymer composite materials. These materials' exceptional strength, stiffness-to-density ratios, and great physical qualities make them highly valuable for applications in the aviation and aerospace industries. Composite materials typically consist of stiff, somewhat strong fibers embedded in a rough resin matrix. Naturally occurring composite materials include wood and bone. In wood, cellulose fibers are embedded in a matrix of lignin, whereas in bone, hydroxyapatite particles are spread throughout a matrix of collagen. CFRP and GF reinforced plastics (GFRP) are two more well-known man-made composite materials used in the aerospace sector. Their respective densities make them both extremely robust, fibrous, and rigid. Similarly, their toughness is derived from their brittleness in a polymer matrix. Comprising of low density, high strength, stiffness, toughness, and other complementing features, a new material called a composite can be made simply by combining elements. Another kind of composite material that is now in use in the aerospace and aviation sectors is metal matrix composite. Nonmetallic particles can also be found in some composites that have a metallic matrix. An excellent illustration of this type of composite is the amalgamation of silicon carbide particles with aluminum alloy (36).

The wings, fuselage, flaperons, and rudder of the Eurofighter jet are constructed primarily from polymer composite materials. Seventy-five percent of the jet's external area is composed of tough epoxy

wings (37). In summary, CFRP makes up roughly 40% of the structural components of the Eurofighter jet. The polymer composite by weight of other European fighter jets ranges from 20% to 25%. The composite by weight of the Saab Gripen is between 20% and 25%, but that of the Dassault Rafale jet fighter is 26%. Because their lighter airframes provide better fuel economy and eventually lower operating costs, it is noteworthy that the use of composite materials in commercial transport aircraft has shown to be quite effective (38). Airbus, with its A300 and A310 aircraft, was the first commercial airline to employ composite materials in the rudder's design and construction as of 1983. Furthermore, in 1985, the tail fin is also made of the same composite materials. With the usage of composite fins, the number of parts that were formerly 2000 (excluding the fasteners) using metal fins has been dropped to fewer than 100. Additionally, this has lowered the production cost and overall weight. CFRP face plate has additionally been used in the fabrication of the A310 elevator with a honeycomb core (39). Utilizing the advancements recorded in A310, the entire rear structure of the A320 was designed and built. Moreover, polymer composites (GFRP) have been utilized in the construction of additional tail parts, such as nacelles, flap-track fairings, main gear leg fairing doors, ailerons, deflectors, flare/fuselage fairings, wheel doors, and trailing-edge bottom access panels (40,41).

BUSINESSES' INITIATIVES TO USE COMPOSITES IN AIRPLANES

Significant weight savings roughly 30%—have been achieved through the global use of composite materials in the production of various aerospace components. The adoption of these technologies has opened the door for the creation of increasingly intricate airplane parts, like fuselages with significant weight reductions. The production of integral components is necessary, even if the curing and cobonding procedures currently face new difficulties. This is especially true for the fuselage, which includes several cuts, highly curved pieces, out-of-plane loadings, and load transmission through bulkheads. The resin becomes weak in its attachment to the direction of load reduction when it is forced to pressurize tanks or other locations of triaxial stress during construction. Despite the development of high strain fibers and tougher resins, as previously noted, the success of cost reduction strategies will be a major factor in the rise of polymer composites as airplane structural materials. With any luck, the people working on this technology will soon concentrate on end-to-use intermediate items that will increase the parts' cost-effectiveness and resistance to damage while also improving their hygrothermal performance. These improvements should include the creation of multidirectional preforms, grid compartments, and reinforcements, as well as the manufacturing of stitched hybrids employing RTM and resin infusion molding, which will replace the costly and time-consuming autoclave molding of prepregs. One of the new and highly significant sectors in the aerospace industry is the use of novel composite materials and structures. Other practical uses and clever applications of the passive structure design concept are carried out. According to Joel et al. (2019)(40), this has resulted in the employment of piezoelectric sensors and actuators as well as fiber optics following laboratory experiments. The ideal materials for these kinds of applications are polymer composites. These include smart surface control, surface modification for aerodynamic flow control, monitoring structural health, and regulation of vibration and noise. Extra safety precautions and better performance are also offered by these uses.

Aiming to design fuselage structures, thermoplastic composite is being used. It is a tremendous advancement from the past, despite only being discovered recently. It has made sense to employ this crucial step in a single-aisle aircraft's fuselage, mainly because single-aisle aircraft's fuselage skin thickness is lower than that of twin-aisle aircraft. The primary problem has been the adoption of thinner skin utilizing standard composite materials and procedures, resulting in excessive weight and cost associated with composites. This is because the original intention was to create an M&P combination for the fuselage that would result in skin thickness that was reasonably thin and inexpensive (40).

CHALLENGES

High accuracy and low volume requirements in the automotive and aeronautic industries provide one of the difficulties for the application of composite materials. So, costly technologies must be developed in order to ensure that automotive and aeronautic composites become more desirable for high volume

commercial purposes in the near future. That being said, production cycle length and volume will be important considerations (42).

Recycling Process

Composites made of automotive and aerospace materials are more difficult to recycle than composites made of metallic materials. This is the result of three key factors: Fiber-reinforced composite is initially frequently attached to other components with metal fasteners, and it may be challenging to disassemble or debond the components so that they can be recycled separately. Second, due to the fact that composites are a blend of several components that are neither recyclable or melting, it is difficult to remove individual materials from the composites for those parts that are separable. Finally, the absence of appropriate procedures that enable recovered composites to retain their original properties makes recycling composites difficult.

Manufacturing Process

Achieving a competitive pricing for the final product that consumers can afford is a persistent challenge, as is the high expense of the manufacturing method used to make aeronautic composite materials. For instance, it has been claimed that the complexity of the carbon fiber production process drives up the cost of CFRP materials far over that of their component base material. Long-term economic viability of CFRP is compromised by many methods like weaving, noncrimp textiles, and pre-impregnation of fibers, which raise the cost of CFRP over the purchasing power of the consumer. But because they are less expensive to make, GFRPs are more beneficial for a variety of uses in the aviation and aerospace industries.

Techniques for Assessing Damage to Aeronautical Materials

Because composite materials are more ductile than traditional metals, they are linked to a variety of damages. Due to their frequent subsurface location, nonvisible impact damage is the type of composite material damage that is most frequently documented. Nondestructive testing methods are frequently employed for tiny composites found in automobiles. Therefore, its applicability is limited to structural parts where damage evaluation and detection are critical.

TECHNIQUES FOR JOINING AUTOMOBILE COMPOSITE MATERIALS

The overall weight of the constructed cars has generally decreased due to the use of composite materials. In contrast to polymer composites, these materials are frequently utilized in conjunction with other metal components that have superior structural qualities. It is crucial that these various components are joined using a dependable and stable procedure. The composite materials' surface must also be ready for connecting methods. Composite materials cannot be joined using the traditional metal joining method of welding. Joining composite materials to metals or other composites was often quite difficult. Despite being the most used method for combining multimaterial automobile bodywork, adhesive bonding is a highly costly process. The cost will be greatly decreased by using this technique's full automation.

CONCLUSION

The cost of fuel for operating commercial aircraft is rising, thus more study is required to ensure the aviation industry's environmental sustainability. There is legitimate pressure on this business to do better, particularly when it comes to weight loss. Aircraft maintenance should have very simple daily operating costs in order to reduce component use. The industry of aircraft design and construction will most likely be able to reduce operating costs in the near future by using suitable polymer composite materials with notable mechanical and physical properties. There is rivalry going on right now for both missiles and airplanes. The development of composite technology has not stopped, and new varieties like basalt and carbon nanotube forms have been introduced in an effort to increase and expedite the use of composites.

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