Chapter 16
Recent Advancements in Advanced Composites for Aerospace Applications: A Review

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1 Introduction

The rapid progress in the aerospace industry provides the momentum for the fast advancement of innovative aircraft materials. The aerospace industry comprises aircraft, spacecraft, and the associated design and production processes. The aerospace

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and aviation industries have long been pioneers in the development of new innovative materials frameworks and breakthroughs in their production. The utter pace at which this sector has advanced has been remarkable. However, the rising prices of air travel fuel have supervened in greater demand for lighter materials in the aerospace and aviation industries. In the aerospace sector, about 50% of the operating cost is used in fuel consumption. A heavier system needs extra energy to lift in the skies, thus adding up to the overall cost. Thus, the vital driving factors for aerospace materials progress are reduction in weight, application-specific desires, and minimal cost (Alam et al., 2021a; Ghori et al., 2018; Jayakrishna et al., 2018). Though metals, ceramics, and polymers are primarily used in the manufacture of aerospace structural and other components, developments in materials science, notably in composites science and technology, permitted the advancement of favorable modern materials for aerospace engineering. Composites are the materials system which is formed by blending two elements, namely, matrix and reinforcement, to use the valuable attributes of each component. If the reinforcing component in composite material is two or more than two, then it is referred as hybrid composites. Fiber-reinforced composites (FRCs), which are made by various types of matrices (e.g., ceramic, polymeric, metallic, etc.) with fibrous materials, have recently gained a significant attention in the aerospace industry (Rana & Fangueiro, 2016). The key advantages of composite materials, due to which they are highly in demand in the aerospace sector, are lightweight, optimum stiffness and strength, high fatigue strength, resistance to corrosion, higher fuel efficiency, and improved performance. One of the most useful characteristics of hybrid composite materials is that they could be sandwiched with multiple layers with the fibers laid in different directions, allowing engineers to assemble the parts that meet strength and other mechanical properties requirements (Mouritz, 2012; Saha, 2016). Composite materials have been utilized in the aerospace sector in essential and secondary underlying parts including aircraft wings, floor beams, landing gear doors, fuselage, antenna dishes, engine cowls, rocket motor castings, center wing boxes, pressure bulkheads, vertical and horizontal stabilizers, etc. Some of these aerospace components such as wings, fuselage, landing gear, etc., are considered safety critical (Mouritz, 2012). Opportunities for global composites as a structural component in aerospace industry is represented in Fig. 16.1.

2 Recent Advances in Aerospace Composites

Demand of composite materials are increasing in both military and commercial aircraft design and manufacturing. Attributes such as escalating air travelers, increase in tourism, rise of low-budget carriers, and rising concern for airplane fuel efficiency remain likely to propel the flea market demand. The manufacturers are seriously investing in exploration and development to revolutionize lightweight and economical composites for aerospace industry with superior strength-to-weight

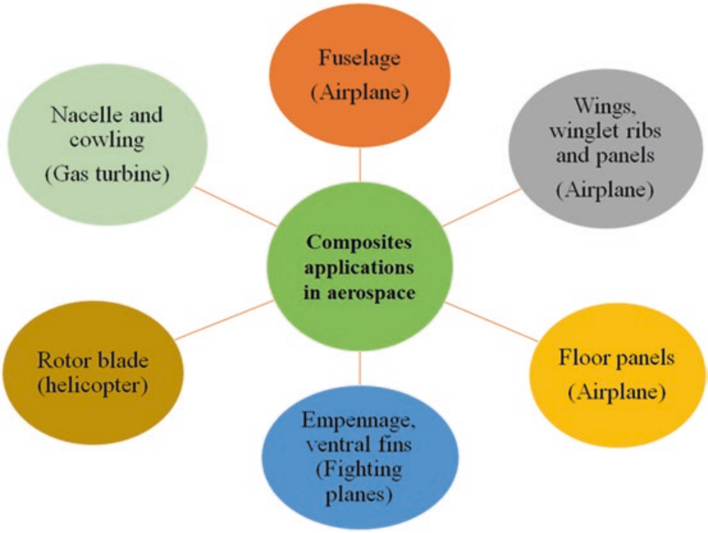

Fig. 16.1 Applications of composite materials in aerospace industry

ratio and outstanding impact strength. Additionally, the fuel costs likely to be nearly 30% of the carrier costs, and the new aircrafts are produced to reduce the fuel costs with improved and fuel-effective aerospace composites. Recent advancements in the composite material have highly influenced the aerospace industry, due to increment in flying performance.

Modern commercial airplanes, such as the Boeing 787 and Airbus A350, used a significant amount of composites to replace heavier metal elements to reduce fuel consumption. As an illustration, Boeing has raised usage of composite materials by a very considerable amount, from 1% (747) to 50% (new 787) of the structural weight of an aircraft (Mouritz, 2012; Zhang et al., 2018). Figure 16.2 depicts the trends in usage of composite materials in Boeing series aircraft.

The composite materials market is estimated to attain an estimated $39.4 billion by 2025, and it was declined in 2020 due to global financial recession led by COVID-19. However, market witnessed recovery in the year 2021, and it is forecasted to reach an estimate $39.4 billion by 2025 by a CAGR of 2% to 4% from 2020 to 2025 (Kazmierski, 2011). Figure 16.3 illustrates the trends and forecast for the global composites market. Composites have seen a significant increment material in the latest Boeing models, whereas aluminum-based alloys have seen a drop.

However, the COVID-19 virus outbreak has negatively impacted every industry including aircraft industry, leading to closure of aircraft manufacture and cancellation of fresh orders. The worldwide air traffic dived to nearly standstill in the mid-2020, thus influencing the aerospace industry market. Thus, diminished air traffic combined with the shutdown of airplanes manufacturing services will adversely affect the overall market size.

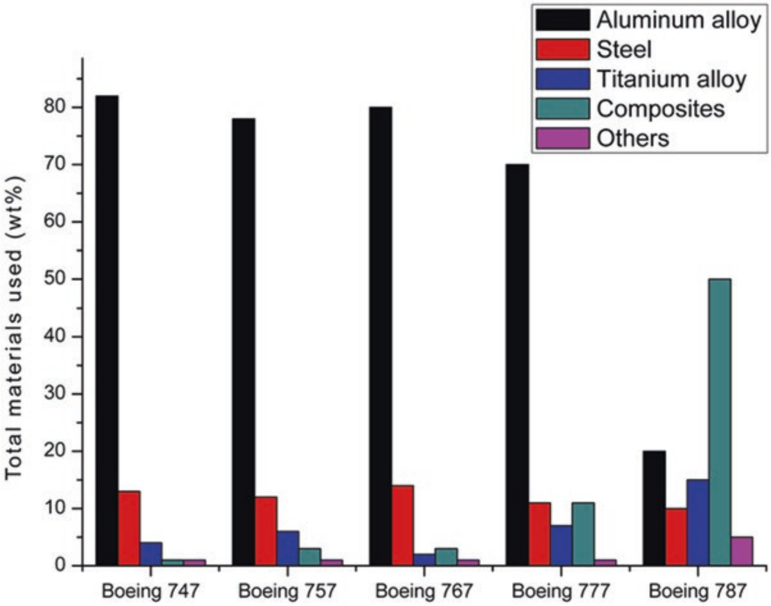

Fig. 16.2 The total amount of materials utilized in the Boeing series airplanes (Zhang et al., 2018)

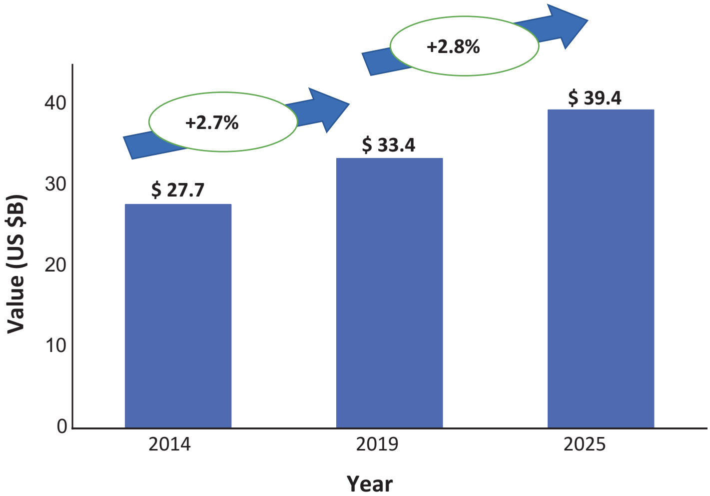

Fig. 16.3 Trends and forecast of global composites for the years 2014 to 2025 (Kazmierski, 2011)

2.1 Polymer Composites in Aerospace Industry

Polymer is a broad term which refers to a wide range of plastics, adhesives, and elastomers. The thermoplastics, thermosets, and elastomers are the three primary types of polymers. The most common thermoplastics-utilized aircraft composite are polyether ether ketone (PEEK), polyphenylene sulfide (PPS), polysulfone (PSU), polyetherimide (PEI), and polycarbonate. The most widespread use for polymers is as a matrix phase of polymeric composites (Alam et al., 2017, 2020b; Ahmed et al., 2021). Composites for aerospace applications are produced in two fundamental material forms: sandwich and laminate composites. Applications of polymer composite materials are increasing in both military and commercial aircraft design and manufacturing. Polymeric materials have significant pros over the common metallic materials that are utilized in various aerospace components (Al-Oqla & Salit, 2017). One of the vital characteristics of polymer-based composites is being lightweight while offering specific strength, resulting in an overall weight reduction of roughly 20%–50%, and save energy due to lightweight consequently leading toward sustainability (Masood et al., 2021; Yusuf et al., 2021a, 2021b). Other features include the capacity to process materials quickly, meet high dimensional stability requirements, lower thermal expansion, and have good fatigue and fracture resistance (Alam et al., 2015; Begum et al., 2020). Modern air force fighter aircraft have lowered 30% of their weight utilizing polymer composite materials (Khandelwal & Rhee, 2020; Njuguna, 2016). The polymer-based composites contribute up to 80% in advanced launch vehicles designed for satellites and consist of numerous essential satellite components as the honeycomb structures, cylinder support structures, equipment panels, antennas, solar array substrates, etc. The rocket motor housing of the space shuttle's solid booster contains 30 tons of epoxy-graphite composites (Saba et al., 2014).

The use of fiber-polymer composites has been preceded by the passenger and military aircraft, particularly with fighter planes and helicopters. Carbon fiber-epoxy composites have been utilized in the fuselage and wings to improve the structural efficiency and minimize the weight. The 35% composite materials (carbon fiber-poxy and carbon fiber-bismaleimide) were used as structural material in the F-35 Lightning II as depicted in Fig. 16.4. The carbon, aramid fiber, and glass-based composites with improved service life has been used in rotor blades and fuselage of helicopters. A cross-sectional view of sandwiched type composite rotor blade made up of carbon and glass fibers is presented in Fig. 16.5.

The composite material utilized as a structural component in Airbus and Boeing aircraft is summarized in Table 16.1.

Although the application of composites is now common in commercial aircraft. The larger amount of FRPs have been used in the A380 Airplane manufactured by the European Airbus consortium. The panels of the wing trailing edge are composed of carbon and glass fiber-reinforced polymer composites utilizing a modern resin film infusion method (RFI), in which a resin film, layered between carbon and glass fabric layers, as soon as the laminate is laid up, melts once the heat is employed.

Figure 16.6 depicts the composites structural components of A380 airbus. Fiber-metal laminates (FML) are lightweight materials composed of thin bonded sheets of metal and fiber-polymer composite. This combination produces a material which is lightweight, better strength, and the higher fatigue resistant than the monolithic metal and has superior damage tolerance and impact strength than the composite

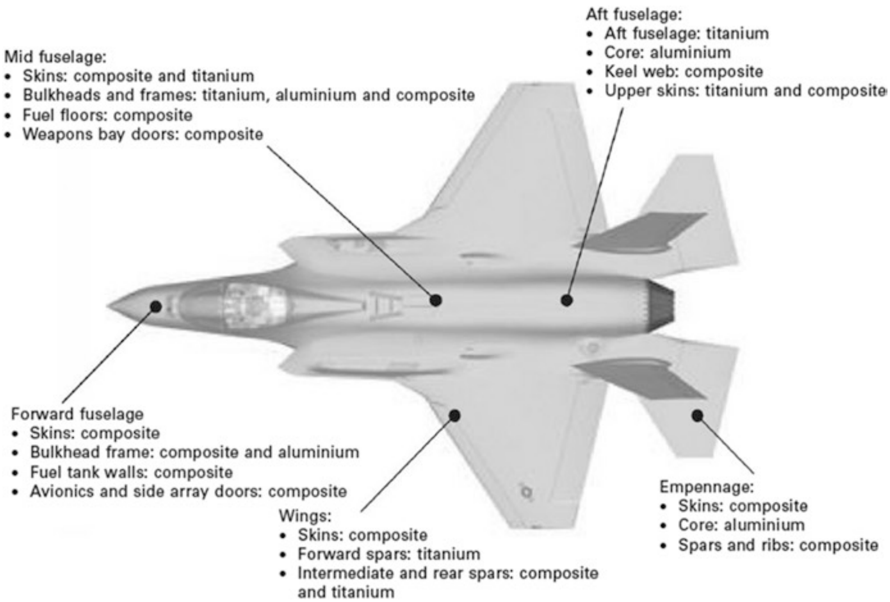

Fig. 16.4 Utilization of composites in the fighter aircraft F-35 Lightning II (Mouritz, 2012)

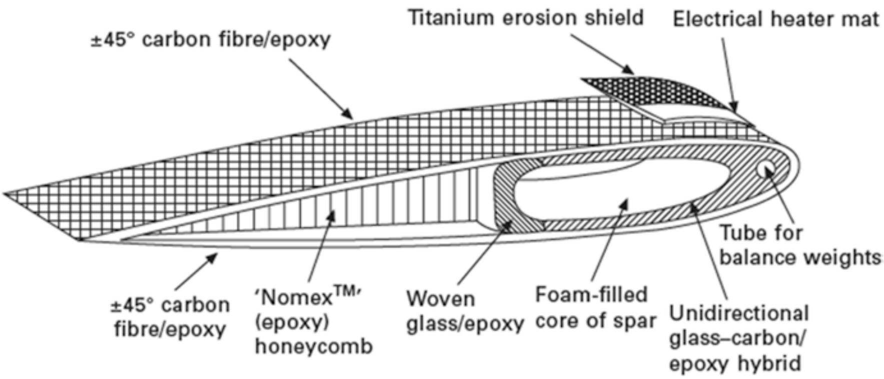

Fig. 16.5 Rotor blade of helicopter made up of sandwich composite material (Mouritz, 2012)

(Vogelesang & Vlot, 2000). The A380 fuselage crown is made up of a hybrid aluminum/glass-reinforced polymer system (GLARE) as shown in Fig. 16.7, which reduces weight, improves damage tolerance, and extends fatigue life (Alderliesten & Benedictus, 2008; Soutis, 2019).

Current civil aviation technologies have focused on replacing secondary structures with fiber composites reinforced with carbon, Kevlar, glass, or a combination of these materials. The matrix material is a thermosetting epoxy system with a 125 or 180 °C curing system and becoming more popular because of its superior resistance to environmental damage. The Boeing 757, 767, and 777, as well as the Airbus

Table 16.1 Airbus and Boeing airliners composite components (Mouritz, 2012)

Composite components	Airbus	Boeing
Fuselage and nose component		
Fuselage	A380	B787
Belly fairing	A380	
Rear pressure bulkhead	A340–600, A380	
Floor beams	A350, A400M	B787
Keel beam	A340–600, A380	
Nose cone	A340–600, A380	B787
Wing and empennage components		
Wing beams	A350, A380	B787
Wing skins	A350, A380	B787
Horizontal stabilizer	A340, A350	B737, B777
Vertical tailplane	A350, A380	B737, B777
Wing box	A380, A400M	B787
Engine components		
Nacelles	A340, A380	B787
Reversers	A340, A380, A350	B787
Reverser details	A380 (gutter fairing) A320 (reverse doors) A380 (reverse doors) A340 (reverse doors)	B787
Fan blades		B787
Cone spinners		B787

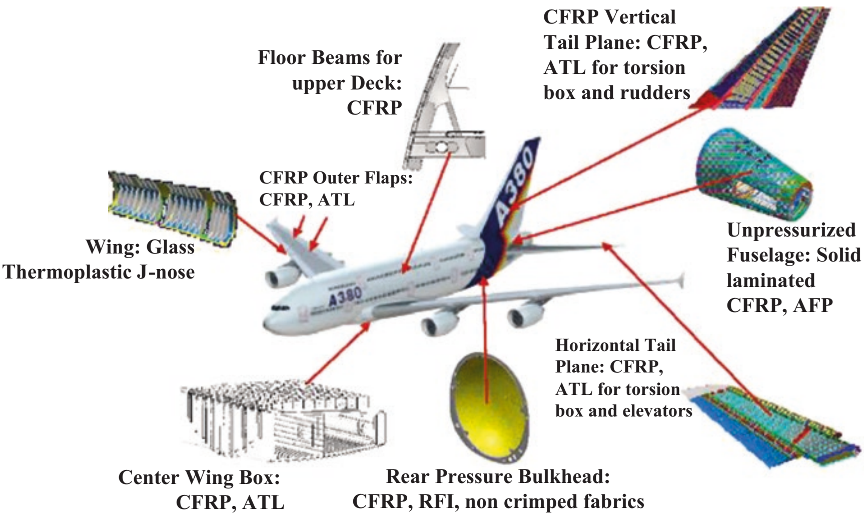

Fig. 16.6 The usage of polymer composites in Airbus A380 (Zhang et al., 2018)

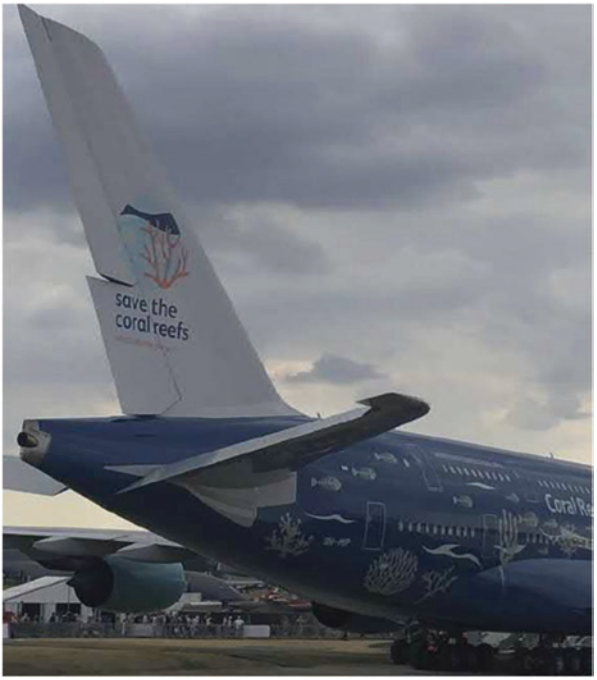

Fig. 16.7 A380 composite tail assembly (empennage) with glare fuselage crown (Soutis, 2019)

A310, A320, A330, and A340 airplanes from Europe, are typical examples of widespread applications of composites in this fashion. The A310 contains a vertical stabilizer (8.3 m high by 7.8 m wide), a major aerodynamic and structural component, manufactured entirely from carbon fiber composite with a total weight savings of nearly 400 kg as compared to the monolithic Al alloy unit previously utilized. Furthermore, the CFRP fin box has only 95 parts (without fasteners) against more than 2000 parts in the metal unit, thus making it much easier to manufacture. The use of CFRP achieved new height with the Airbus model A350 XWB, which retains the usage of composites across the structure with total of 52% by weight. The wing of the aircraft is mostly made up of carbon fiber (CF), that includes the upper and lower covers, gauging 32 m in length and 6 m wide, enabling them among the largest single aircraft parts ever manufactured from CF (Mallick, 2007; De Rosa, et al., 2008). The A320 has increased the usage of composites to the flat stabilizer in add-on to the variety of panels and secondary structural parts, resulting in an 800 kg weight reduction over Al alloy skin production. As an indication of the advantage of such weight reduction, it has been projected that 1 kg decrease in weight saves more than 2900 L of fuel each year. Airbus continues to use advanced composites from nose to tail in the A320neo narrow-body airliner, which was deployed by Lufthansa on January 25, 2016, with enhanced fuel efficiency and significantly decreased noise and emissions (Paiva et al., 2009; Wang et al., 2011; Pimenta & Pinho, 2011).

Similarly, the fuselage, wings, doors, tail, and interior of the new Boeing 787 Dreamliner are made up of nearly 50% composite materials by weight (80 percent by volume). It was the world's first composite airliner due to its all-composite fuselage (its first flight was before the A350). Each fuselage barrel is made in one piece (about 45 feet long), obviating the necessity for more than 50,000 fasteners in traditional airplane construction. However, considerable assembly faults with the composite fuselage portions were identified, resulting in lengthy delays in the aircraft's delivery to the customer. Other technological concerns that needed to be handled are electromagnetic risks such as lightning strikes, because the polymer substance cannot conduct electric energy. Another key concern, primarily for the operator, will be damage assessment, as previously stated, which happens primarily internally and is challenging to detect. Soutis and coworkers have demonstrated the possibility of using a linear array of piezoelectric transducers for the detection of delamination and other modes of damage in composite plates (Diaz Valdes & Soutis, 2000; Diamanti et al., 2004, 2007; Soutis, 2005).

Polymer composites has been utilized in gas turbine engine parts including the front fan case, fan blades, nacelle, outlet guide vanes, nose cone, bypass ducts, spinner, and cowling as depicted in Fig. 16.8. However, the use of polymer composites is limited to engine parts which are required to operate lower temperature (<150 °C) to prevent heat distortion and softening.

Fig. 16.8 Gas turbine engine nacelle and cowling made up of composite material (Mouritz, 2012)

2.2 *Metal Composites in Aerospace Industry*

The aluminum industry has a long history of improving the performance of aerospace alloys and composites. Aluminum alloy serves as matrix in particulate alloy-based metal matrix composites (MMC), and the reinforcements are usually in the form of micron or nanoparticles (Alam et al., 2020a). Aluminum alloy-based composites have always been at the forefront of the research among metal matrix composites, and Al-based composites continued to exist as the most viable candidate to be investigated to make aircraft components sustainable (Ahmed et al., 2021; Alam et al., 2021b; Haider et al., 2015; Shozib et al., 2021; Surappa, 2003). This culminated in the advancement and continuous implementation of high-strength 7XXX alloys in commercial airplanes, for example, 7075, 7150, 7055, and 7449, chronologically as per the order of application (Seshappa & Anjaneya Prasad, 2020; Verma & Vettivel, 2018; Warner, 2006). The 7000 series of aluminum alloys exhibit higher strength relative to other aluminum alloy grades and are chosen for the manufacture of upper wing skins, vertical/horizontal stabilizers, and stringer (Boyer & Padmapriya, 2016; Dursun & Soutis, 2014; Sahu & Sahu, 2020). The fatigue resistance and compressive strength are important factors in the design of structural components of the upper wing (Williams & Starke, 2003). Table 16.2 shows a few of the key materials used in the aircraft's primary and secondary structural components. Because of their high strength-to-weight ratio, good machinability, and comparatively lower cost and higher strength, aluminum alloys like the 7075-T6 are commonly used in aircraft structures. The upper wing skin of the aircraft is made up of 7075-T7751. The aluminum alloys of 7000 series have also been heat treatable, and the Al-Zn-Mg-Cu variants engulf the highest strength to all aluminum alloys (Wanhill, 2013; Zhang et al., 2018). In view of aircraft design factors which is

Table 16.2 Types of major materials for structural and secondary components of aircraft (Saha, 2016)

Aluminum alloys	Titanium	Graphite composites	Fiberglass panels
Wing skin	Main landing gear beam	Floor panels	Rudder
Wing stringers	Inboard carriage	Main deck sidewall panels	Elevators
Wing spar web	Hydraulic tubing	Main deck ceiling panels	Floor panels
Wing spar chords	Lavatory attach fittings	Overhead storage bins	Upper and lower trailing edge panels
Wing ribs	Torque link	Winglet ribs and panels	Wing to body fairing
Wing channel events	APU fire wall		Ailerons
Wing to body chords	Inboard flap fitting		Spoilers
Fuselage skin			Trailing edge flap segments

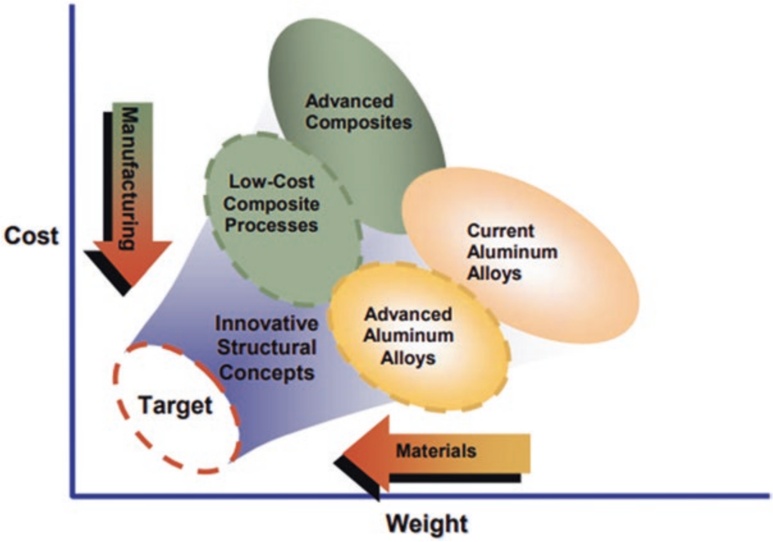

Fig. 16.9 Schematic diagram of cost-weight factors for selection of materials (Warren, 2004)

shown in schematic Fig. 16.9, there seem to be significant cost and weight problems for both aluminum and composites (Warren, 2004).

The applications of composites in the commercial aircraft industry has accelerated. In the 1972, Airbus started utilizing composite materials with considerable success for vertical fins for its A300 series aircraft (Marsh, 2014). In December 2009, a crucial development milestone achieved, as the second largest composite fuselage portion for A350 XWB as shown in Fig. 16.10, was completed in Hamburg, Germany (Marsh, 2010). Airbus Hamburg is liable for fuselage advancement and ultimate assembly, with an associate plant by producing some carbon fiber panels. Center fuselage manufacture takes place at the Aerolia (formerly Airbus) site in Saint-Nazaire, France, applying upper and lower casings offered by Spirit AeroSystems Inc. in North Carolina, USA. Nevertheless, Boeing also progressively made big changes in 2007 in the commercial aircraft industries by utilizing more than 50% composite materials in its new 787 aircraft, with 20% weight saving and better fuel economy (Puttegowda et al., 2018).

The A350 model has a wing and center wing box that significantly consist of composite (nearly 80%) than on earlier Airbus aircraft, and the fabrication arrangements reveal this. With mainstream manufacturing of the wings taking place in the UK, Airbus has increased its capability at Broughton, North Wales, with a new 46, 000 square meter plant devoted to A350 XWB wing production. Wing layout and manufacturing go on at the Airbus UK site at Filton, Bristol. Manufacturing of the lower wing shells of the model A350 XWB is depicted in Fig. 16.11.

One notable application is the two ventral fins on the F-16 Fighting Falcon (Mouritz, 2012), which are located on the fuselage just behind the wings as depicted in Fig. 16.12.

Fig. 16.10 Fuselage section made up of composites for the A350 XWB in Hamburg, Germany (Marsh, 2010)

Fig. 16.11 Manufacture of lower wing shells of A350 XWB model (Marsh, 2010)

2.3 Ceramic Composites in Aerospace Industries

In aerospace industry, ceramics materials are primarily utilized in engine and exhaust systems, thermal control shields, and frameworks for hyper flying objects. Ceramics and ceramic-based composites that can endure high temperatures like 1600 °C are utilized to produce lightweight turbine elements that prerequisite less cooling air, for example, vanes, nozzles, blades, and combustion liners and components for the exhaust system that improve acoustic reduction and take a long-life recognition to their corrosion and abrasion resistance. Ceramic-based materials for aerospace applications comprise oxides (e.g., alumina), non-oxides (e.g., borides, carbides, and nitrides), glass ceramics, and ceramic matrix composites (e.g., SiC, TiC, Al_2O_3 composites). These materials are described by dimensional permanence

Fig. 16.12 Aluminum-SiC composites utilized in the ventral fins (circled) and fuel access doors of the F-16 Fighting Falcon (Mouritz, 2012)

over a span of temperatures and are improved to have excellent chemical resistance and mechanical strength. Ceramic matrix composites (CMC), for instance, silicon carbide (SiC), titanium carbide (TiC), silicon nitride (Si_3N_4), and aluminum nitride (AlN) matrix composite, have been extensively studied (Arif et al., 2017; Sommers et al., 2010) in current years due to their attractive characteristics, for example, high-temperature steadiness (to survive at higher operating temperature at 1500 °C), extraordinary hardness (22 GPa for Al_2O_3-based composite), and good corrosion resistance. Ceramic matrix composites are typically utilized in high-temperature segments in aircraft like exhaust nozzle. Ceramic matrix composites (CMCs)-containing products were utilized in an aircraft engine named as Leap in the year 2016. This engine was mounted in different aircraft model including the famous Boeing 737 Max. Carbon fiber-reinforced silicon carbide has been explored as an option for aircraft brakes, where the temperatures could approach 1200 °C in emergency brake situations (Fan et al., 2016). Despite their advantages, MMCs have been shown to have poor fracture toughness (Walker et al., 2011). To address this shortcoming, some studies (Ahmad et al., 2015; Baig et al., 2018; Liu et al., 2013) have focused on incorporating nanomaterials such as the graphene and carbon nanotubes (CNT) to enhance the fracture toughness of ceramic-based composites. Nevertheless, Ahmad et al. (2015) stated the consequences of CNTs on the fracture toughness of ceramic matrix composite (CMC) are not consistent. The authors deem that graphene nanoplatelets (GNPs) are an effective substitute for CNTs in ceramic composite due to the comparable mechanical properties and well dispersibility to CMC. Walker et al.'s study showed that adding 1.5 vol percent graphene to a Si_3N_4 ceramic composite increased fracture toughness by 235%. The content of graphene platelets, on the other hand, should be limited at a crucial value. For instance, Liu et al. (2013) described the fracture toughness of alumina ceramic composite improved to 4.49 MPa $m^{1/2}$ when graphene quantity increased from 0 to 0.38 vol% and subsequently dropped to 3.53 MPa $m^{1/2}$ when the content of graphene touched up to 1.33 vol%. Other uses of ceramics in the aerospace engineering include bearings, brakes, seals, and other wear-resilient components, automated thermal management structures, armor for helicopters, lightweight optical parts (e.g., silicon carbide mirrors), radiators for deep space vehicles, and windshield coatings. Ceramic components for the aerospace sector frequently have complex shapes, which has prompted the advancement of innovative forming technologies like 3D printing.

3 Challenges in the Development of New Advanced Aerospace Materials

3.1 Corrosion

One of the immense challenges in developing advanced materials for aerospace is corrosion. Corrosion is the chemical degradation of materials because of their reaction to the surroundings (Shaw & Kelly, 2006). Various types of corrosion developed in structural material, for instance, pitting corrosion, uniform corrosion, galvanic corrosion, crevice corrosion, can cause breakdown of parts when the left behind materials cannot sustain the applied loads. Based on the estimate, just up to 30% of the corrosion loss be able to be prevented by corrosion inhibition methods (Kesavan et al., 2012; Khan et al., 2020a). Various researches have examined the corrosion behaviors of various materials, allowing for the simple selection of materials for usage in various adverse environmental conditions. As a result, methods for preventing corrosion of structural materials have been devised, with coating being the most studied (Khan et al., 2020b; Shozib et al., 2021). The purposes of the coating are (1) to offer a regional corrosion barrier, (2) perform as a sacrificial anode, and (3) deliver solute ions (Presuel-Moreno et al., 2008). However, traditional corrosion coating has problem in supplying effective corrosion inhibitors. Therefore, the flaws cannot be protected by the transfer of inhibitor via the liquid corrosive stage (Ilevbare, 2000). Even though some more materials such as cerium sulfate (Kozhukharov et al., 2012), graphene (Chauhan et al., 2020), and oxides of rare earth elements (Chauhan et al., 2020) have been explored to enhance the protective performance, the mechanism of corrosion behavior and prevention method needs to be further studied and explored.

3.2 Stress Corrosion Cracking (SCC) and Hydrogen Embrittlement (HE)

Stress corrosion cracking (SCC) is deemed as extremely dangerous failure process as it can trigger gradual crack progression under a secure loading condition. When the size of crack approaches the critical value, the crack caused by SCC under the secure loading can bring about the abrupt breakdown of materials. SCC is caused by tripartite interaction, namely, mechanical stress, corrosive environment, and vulnerable alloy (Winzer et al., 2005). The processes of SCC and HE are pertinent because hydrogen primarily appears at the prongs of cracks in a wet atmosphere (Raja & Shoji, 2011). The deportment of SCC and HE in some vulnerable metallic materials, like steels (Shu et al., 2012), Mg, and Al-based alloys (Uematsu et al., 2012), have been extensively explored. Mg possesses great intrinsic dissolution propensity, whereas the contaminations and the second phase can behave as the regional cathodes to hasten corrosion by local galvanic, which promotes the vulnerability of Mg-based alloys to SCC. It is established that the separation of Mg along edges of grain can accelerate the hydrogen entry, expedite the transfer of hydrogen, and offer sites for grain border embrittlement by hydrogen chemosorption (Vasudevan & Doherty, 2012). Mg dispersing into Al generates the extremely anodal β phase of Al_3Mg_2, which may enhance the propensity of Al-based alloys to SCC (Scotto D'Antuono et al., 2014). To avoid HE and SCC, some techniques have been explored in current years to enhance cracking resistance (Shu et al., 2012). Guo (2010) investigated some alloying components in Mg-based alloys and concluded that the Mn element positively affects the increment of SCC resistance. Peng et al. (2011) stated that SCC resistance could be enhanced with the escalation of size and gap between grain boundary precipitates (GBP) by lowering the proliferation rate and the intensity of atomic hydrogen. Analogous techniques like hypothetical and quantum mechanical models, current nano-research, and atomistical inspections have been established to examine the mechanism of SCC and HE.

3.3 Fretting Wear

Surface interactions and relative motion between the various engine components are responsible for the fretting wear. Fretting wear is triggered by small-amplitude (<100 μm) oscillatory motion between two contact parts (Tucker & Lindsey, 2002). Fretting wear be able to initiate cracks on the ravaged surface and decrease the fatigue life of the respective components (Tucker & Lindsey, 2002). Fretting wear appears in both aircraft engine parts and structural components such as the bolted connection, bearing shaft, and blade-disc assemblies (Majzoobi et al., 2011). Several researchers have performed tests looking for removal of the undesired fretting wear of aerospace materials. The most extensively studied technique is surface modification, for example, modification in hardness of the surface and adhesion

(Amanov et al., 2012; Zalnezhad et al., 2013). The difference in hardness among two mating duos can significantly influence the fretting wear. Sarhan et al. examined the relation of fatigue life and hardness on a hard anodized Al7075-T6 aerospace alloy. The outcomes revealed that fatigue life of the alloy was improved by improving the surface hardness to 393 HV in lower-stress regions (Sarhan et al., 2013). In another study, it is stated that toughness and bonding strength have more effect as compared to friction factor on fretting wear resistance of graphite-like carbon-coated Ti-based alloys (Du et al., 2014). Even though various materials have been examined for fretting behavior, the general theory explaining fretting behavior and prevention is still in its early stages. Further research should focus on the mechanism of fretting and the development of more effective strategies for reducing fretting resistance.

4 Conclusion and Future Developments

Aerospace materials have a significant impact on design, fabrication, in-service performance, and reliability. Every aspect of the airplane is affected by materials, including price, design selections, weight, performance of the flight, power of the engine and fuel efficacy, maintenance time during service, repair, and recycling and discarding at the end-of-life. The five most important types of structural materials are alloys of aluminum, Al-based composite, fiber-polymer composites (mainly carbon fiber-epoxy), high-strength steels, and titanium alloys. These materials contribute for more than 80% of the structural mass in most military and commercial aircraft. Fiber-metal laminates, magnesium alloys, and ceramic matrix composites are among the other materials utilized in modest amounts in the airframe and engines. In aerospace engineering, choosing the optimum material to meet the desired property requirements of an airplane component is crucial. Many design criteria are considered during materials selection of an aircraft, including whole-of-life ease of production; structure weight; operational efficiency; tolerance against fatigue and damage; electrical, thermal, radar absorption, and electromagnetic properties; and robustness against corrosion and other destructive processes.

The present review demonstrates that significant development has been made in the advancement of both aerospace structural materials and engine materials. For many years, Al-based alloys have been the leading choice in this industry due to their lightweight and well-known mechanical characteristics. The usage of composites (PMCs, MMCs, and CMCs) as an aerospace material has risen in recent years due to improved mechanical properties such as higher stiffness and specific strength as compared to Al-based alloys. However, the normal carbon fiber polymer matrix composites are more prone to suffer as of stress concentration. Furthermore, various obstacles limit the usage of Mg-based alloys, Ti-based alloys, and steels in specific aerospace applications. The decisive factor for aircraft engines necessitates the materials to offer appropriate densities, mechanical properties, and corrosion resistance at elevated temperatures. Ti-based alloys are the dominant materials in the compressor area, where temperatures range from 500 to 600 degrees Celsius. The high-temperature (1400–1500 °C) turbine portion is made primarily of nickel-based superalloys. Challenges encountered in the advancement of recently advanced composites are corrosion, fretting wear, stress corrosion cracking, and hydrogen embrittlement.

In the outlook, particular mechanical characteristics and challenges such as corrosion, SCC, and fretting wear, will be the key drivers in the advancement and choice of next-generation aircraft structure materials. The airframe materials will be led by several materials, for example, aluminum-based alloys, steels, Ti-based alloys, and advanced composites. The following three areas should be the focus of future aircraft materials research: (i) Develop new advanced composites with excellent mechanical properties by various approaches, including refinement in microstructure, impurities control, and heat treatment processing; (ii) develop novel approaches such as composition alteration, microstructure control, and coating, to meet the challenges of metal alloys and polymers. Adopt more efficient stoppage technique for fretting wear of metal alloys, extra efficient forecast, and prevention approaches for corrosion, HE, and SCC of Mg-based alloys steels and Al-based alloys; (iii) develop hybrid composite materials by reinforcing two or more reinforcement in metal or polymer matrix. The future of aircraft engine materials will be centered on how to survive increased engine temperatures while maintaining adequate mechanical features. The following topics should be the focus of future material development: (i) further improvement in high-temperature resistance of Ti-based alloys by monitoring phases by alloying and heat treatment processing; (ii) develop innovative aerospace composites consuming self-healing polymers and other light metals; (iii) and develop the cutting-edge CMC with high fracture toughness by seeing through the augmented content of fibers and reinforcement like graphene nanoplatelet.

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