Chapter 14
Hybrid Biocomposites: Utilization in Aerospace Engineering

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1 Introduction

Aerospace engineering develops the aircrafts and spacecrafts. Though metals are extensively employed in the building of aerospace structures, new materials such as composites are promising for aerospace engineering.

Wood was the first structural material employed in aircrafts due to its good strength-to-weight ratio and easily shaping into beams for wings, fuselage, and other structures. In 1903, Wright brothers used timber covered with fabric to build the mainframe of their aircraft. Nowadays, wood is not utilized in modern aircraft. However, wood is employed in ribs and spars of the mainframe of small aircraft because of its lightness, toughness, stiffness, and strength. Wood has low density, fracture toughness, Young's modulus, and tensile strength in comparison to other kinds of aerospace materials. Owing to its low density, the specific mechanical properties of wood are like aluminum alloys and most magnesium alloys. Wood has some properties that make it inferior to composites and metals as an aircraft structural material. Disadvantages of wood are given in Table 14.1.

Composition and structure of wood affect the properties of wood used for aircraft material. Greenwood has high water and is not appropriate for aircrafts since it is heavy, soft, and vulnerable to attack from fungi. Therefore, wood must be dried between 2 and 10 years at room temperature. When wood dries, the density decreases owing to evaporation of moisture. The drying of wood causes the increment in the longitudinal stiffness and strength since the cellulose fibrils pack more closely together into space occupied by water molecules (Mouritz, 2012a). The density of timber should be measured prior to building an aircraft to provide the total weight

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Table 14.1 Disadvantages of wood

Lower toughness, stiffness, and strength
Anisotropic mechanical properties
Defects causing the reduction in the strength
Hygroscopic nature resulting in shrinking, swelling, and changing density and mechanical properties under atmospheric humidity, which can cause loosening of bolted connections especially propeller flange bolts and warping of the airframe under harsh conditions
Vulnerable to attacking from fungus, insects, and other microorganisms when employed without surface protection and chemical treatment

within the design limit. Employing denser wood in an aircraft is more useful to longitudinal properties than the radial and tangential properties.

Wood in aircraft is often utilized as a laminated plywood made from birch, gabon, mahogany, or spruce to decrease the problems of anisotropy. Timber sheets are bonded with durable and high-strength adhesives. Wood is appropriate for using aircraft structures carrying low loads.

The most significant parameters to be taken into consideration in the design of aircraft interior parts are density, recyclability and reusage potential, energy and other resource need for manufacturing, and toxicity of materials. Selecting of materials used in aircrafts depends on the location and product of usage. For instance, the materials for outer aircraft structure such as wings and nose cone must have excellent fire resistance, while fire resistance is not mandatory requirement for interior structures (Arockiam et al., 2018).

Some properties such as excellent corrosion resistance, high ductility, low cost, and low density make polymers beneficial as aircraft materials. Polymers also are utilized as an adhesive for joining aircraft parts to obtain high strength without utilizing fasteners such as screws and rivets. But polymers cannot be employed alone in structural applications due to their low creep resistance, fatigue life, stiffness, and strength. Another issue for using of polymers in aircraft industry is softening. A polymer for aircraft component should not exceed a temperature of approximately 80% of heat deflection temperature (HDT). HDT is a capability of polymer to resist deformation under load at elevated temperature to prevent distortion.

Polymers and their composites are flammable and release fumes, heat, and smoke when they burn. Therefore, their using is depended on the safety standards in the aircraft industry. In recent years, flame-retardant additives such as halogenated or phosphorus compounds are incorporated into polymers to enable their use in the aircraft industry (Gopi et al., 2017).

Polymerization is the chemical process by which monomers (small molecules) are joined to make macromolecules and can be separated into two kinds: addition and condensation polymerization. Addition polymerization includes the linking of monomers into the polymer chain by a chemical reaction. Condensation polymerization involves two or more different kinds of molecules that generate a molecular chain-done combinations of beginning molecules. Examples of aerospace polymers fabricated by condensation polymerization are epoxy resin, used as matrix phase of carbon fiber composite structures and as structural adhesive and phenolic resin, used inside aircraft cabins for fire resistance (Mouritz, 2012b). Epoxy resin is the most used thermoset in aircraft components owing to its good durability in hot and wet environment, high strength, and low shrinkage. However, it should not be employed in cabins due to its bad fire performance. Phenolic resin meets fire regulation. Cabin interiors, furniture, and internal fitting in aircraft are made by phenolic resin and glass fiber/phenolic composite.

In composite materials, thermoplastic polymers give some advantages such as higher fracture toughness, better impact resistance, and higher operating temperatures over thermoset polymers. But thermoplastic polymers must be operated at high temperature that make them expensive to fabricate aircraft structures. The most employed thermoplastic polymer group in aircraft structures is polyketones including polyetherketone (PEK), polyetheretherketone (PEEK), and polyetherketoneketone (PEKK) (Mouritz, 2012b). Polymers such as PEEK can be used for the fabrication of composite parts in aeronautical applications at high temperatures (Benyamina et al., 2021). Polycarbonate (PC), polyetherimide (PEI), polyphenylene sulfide (PPS), and polysulfone (PSU) thermoplastic polymers are also utilized in aircraft industry. Impact-resistant, scratch-resistant, tough, and transparent polymers are appropriate for aircraft canopy and window. Acrylic such as polymethyl methacrylate (PMMA) and PC are the most often employed thermoplastics in aircraft windows. Acrylic polymers are lighter, tougher, and stronger than window glass. PC is tougher and stronger than acrylic polymers and is employed as high impact resistance is desired such as canopy and cockpit window due to the hailstones and birds collision risk especially during landing and takeoff. Therefore, PC windows present the flight crew with security against severe impacts.

The using of thermoset polymers in aircraft industry is larger in comparison to the using of thermoplastics. Bismaleimides, cyanate esters, and polyimides thermoset polymers are employed in aircraft structures operating at temperatures above performance limit of epoxy resin (Mouritz, 2012b).

Elastomers are not appropriate for employing in aircraft components due to low strength and stiffness. Using of elastomer is restricted to nonstructural aircraft components that want elasticity, flexibility, and low stiffness such as aircraft tire, gasket, and seal. Elastomers employed for tires include carbon black filler to improve wear resistance and tensile strength. Elastomers can degrade and erode in harsh conditions such as high temperatures, and the most dramatic example of degradation of an elastomer was the space shuttle *Challenger* accident. *Challenger* space shuttle exploded 1 min after takeoff on January 28, 1986, causing seven astronauts dead. The space shuttle is equipped with twice rocket boosters that generate an enormous amount of thrust that throws the main vehicle into space during takeoff. Without boosters, the shuttle would not be able to produce enough thrust to overcome Earth's gravitational force. The boosters are made of hollow metal cylinders, with a joint connecting the cylinders including two O-rings done with an elastomer. The elastomer must form a tight seal to prevent hot gases leakage from the rocket engine during takeoff. Several factors caused the *Challenger* accident; one of the elastomer O-rings in a booster rocket did not form a tight seal because of cold air during takeoff. This resulted in hot combustion gases (above 5000 °F) inside the rocket engine to rapidly degrade the elastomer O-ring, allowing propellant to escape and ignite, thereby detonating the space shuttle (Mouritz, 2012b).

A structural adhesive is high strength, elastic modulus, and toughness glue employed in aircraft for joining components. Elastomers, thermoplastics, and thermosets possess adhesive properties. Toughening agents such as rubbers are mixed with adhesive to enhance fracture toughness. Structural adhesive must possess low shrinkage when cured to eliminate the residual tensile stress in the joint. Structural adhesive must be resistant to degradation in the environment. Aviation fuel, hydraulic fluid, solvent, and water can attack the bonding; thus, durable adhesives must be utilized. Employing structural adhesives for bonding aircraft structures rather than mechanical fasteners has some advantages. Structural adhesive diminishes the cost and weight of fasteners in aircraft parts. Structural adhesive also reduces fatigue cracking in metal connections due to the elimination of the required drilled holes for fasteners that are areas for the beginning of fatigue cracks. Structural adhesive presents a more uniform stress distribution in the bonding. Bonded joints are lighter than mechanically fastened joints. Bonded joints also cause a smooth surface. Adhesives are present as pastes or films. Film adhesives are employed in bonding aircraft parts since they give higher strength than paste adhesives. Epoxy resin is the most often utilized structural adhesive due to high strength, the capability to adhere to most surfaces, and long-term durability over a wide range of environments and temperatures. Silicone is employed when high toughness is required, while polyimide and bismaleimide are employed when a high-temperature adhesive is wanted. Acrylic resin, inorganic cement, urethane, and phenolic resin are other kinds of adhesives utilized for bonding aircraft components. Hot-melt adhesive is thermoplastic or thermoplastic elastomer that melts when heated, and it is not used in highly loaded aircraft components. Pressure-sensitive adhesive is elastomer that is not cross-linked, and it is not suitable for bonding aircraft structures owing to its low strength.

Radar is employed for aircraft detection and tracking, and it is very important for traffic management in aviation. However, in military operations, it is a problem since they want aircraft must attack its target and escape undetected. Passenger airliners can be detected by radar due to their cylindrical shape and bumps. Metals and composites utilized in aircraft are strong reflectors of electromagnetic waves and thus can be detected by radar. But detection of composite is not as easy as metal. Radar-absorbing material is polymer based employed to the surface of stealth military aircraft to decrease radar cross section, making them difficult for the detection by radar.

Polymer composites are employed in the engine components, airframe, furniture, and internal fittings of aircraft. Polymer composites utilized in aerospace components must meet some requirements such as excellent dimensional stability over a wide range of temperatures, good fatigue performance, high-fracture toughness, high-impact energy to bear sudden impacts of bird strikes, high strength, light weight, and resistance to corrosive environments (fuel and lubricant) and also provide shielding of electromagnetic waves. Good fatigue performance increases the lifetime of aerospace components and safety and decreases the maintenance frequency and cost. Structural health monitoring of damage in the aerospace structures is important for composites used in aerospace industry so as to perform maintenance on time, which causes the reduction in the maintenance cost and enhancement of the safety of aerospace components (Rana & Fangueiro, 2016). Wing box needs high-strength fibers in composite structures. Control surfaces require high-stiffness fibers. Structures requiring both high strength and stiffness such as fuselage and wing need intermediate modulus fibers. Carbon fiber-reinforced polymer composite is suitable for aircraft structures (such as ribs, spars, stringers, wing box) and jet engine parts due to the stiffness of carbon fiber. Carbon fiber-reinforced polymer composite has better corrosion resistance and fatigue properties than metals, and it is employed for doors, fuselage, interior components, tail, and wing in aircrafts (Mouritz, 2012c). Carbon nanotube-reinforced polymer composite is an advanced material that allows a structure to be lightweight, high temperature resistance, and a high strength-to-weight ratio (Nurazzi et al., 2021a). Glass fiber-reinforced polymer composite is utilized rarely in aircraft structures due to its low stiffness. However, its lower cost in comparison to carbon fiber-reinforced polymer composite causes using in some applications at aircraft industry. Therefore, it is mostly used in secondary structures including aircraft fairings, inside cabins for fittings, furnishing, and helicopter structures such as cabin shell. Due to its low dielectric properties, glass fiber-reinforced polymer composite is employed when transparency to electromagnetic radiation is significant such as aerial covers and radomes (Mouritz, 2012c). Radome is dome-shaped components, radar transparent, protecting radar antennas from aerodynamic loading such as impact from bird strike. Materials with high toughness and low dielectric constant are employed for aircraft radome (Haris et al., 2011). Overhead luggage storage containers and partitions are manufactured with glass fiber phenolic resin composite because of its good flammability resistance, low cost, and lightweight. E-glass and S-glass kinds of glass fibers are employed in aircraft applications. E-glass has lower cost and lower strength than S-glass resulting usage in aircraft cabin fittings. Higher strength of S-glass composite causes the use in structural components. Aramid fiber composites are utilized for parts that require impact resistance against high-speed projectiles such as for ballistic protection on military aircraft and helicopter due to absorption of large amount of energy during fracture. Aramid fiber composites are suitable for radomes owing to their good dielectric properties. High vibration damping properties make aramid fiber composites suitable for helicopter engine housings to diminish vibration from the rotor blades reaching the cabin. Aramid fiber composites have high stiffness and strength in tension. However, compression strength of them is low, which is not suitable to use in aircraft components exposed to compression loads (Mouritz, 2012c).

The desire of lightweight materials such as fiber-reinforced polymer composites in aerospace industry is huge due to the rising of gas and oil prices. It is declared that fuel costs about 50% of operational costs and using fiber-reinforced polymer composites in Boeing 787 contributes over 20% more fuel efficiency (Njuguna et al., 2012). Aircrafts with lightweight materials can burn less fuel, thus carrying higher loads or travel longer distances. In summary, polymer composites have an important influence on aerospace structures, by giving cheaper, faster, and safer transportation. In addition, lower consumption of fuel without compromising the flight performance will cause to drop the greenhouse gases emission. Composite parts utilized in aircraft applications are exposed to impact damage such as bird strike, hailstones, and runway debris causing a drop in load-carrying capability, stability, and structural stiffness.

1.1 Natural Fibers and their Composites

Natural fibers have been used since ancient times; ancient Egyptians mixed wheat straw with Nile River's mud to fabricate brick in order to obtain stronger bricks and to keep their houses cool during summer (Mansor et al., 2019). Natural fibers possess some pros such as abundance, biodegradability, low density, low cost, recyclability (Das et al., 2017; Nurazzi et al., 2021b), nonabrasiveness, renewability, sustainability, and vibration damping. However, most natural fibers are flammable and thermally unstable at low temperature (200–300 °C) releasing fume, heat, and smoke when they burn, limiting their applications in aerospace industry (Chai et al., 2012). Also, they have high moisture absorption, low mechanical properties, and poor dimensional stability. To overcome these weaknesses, several methods such as halogenated and nonhalogenated flame retardants, copolymerization, grafting, layered silicates, nano fillers (Rashid et al., 2021), and synergistic utilize of natural fiber (Rashid et al., 2021; Suriani et al., 2021a) and fire retardant have been employed (Rashid et al., 2021; Suriani et al., 2021b). Therefore, it is mandatory to develop hybrid biocomposites which are thermally stable and flame resistant while simultaneously possessing moderate mechanical properties for aerospace applications. Natural fibers are generally hybridized with glass fiber for enhancing mechanical and physical properties.

Natural fiber-based composites (biocomposites) provide carbon dioxide (CO_2) emission reduction, competitive cost, recycling, and sustainability, and the use of biocomposites in the aerospace industry has been increasing. Environmental problems are rising because of industrialization that directly influences the ecosystem by increasing environmental pollution, fossil fuel costs, greenhouse effects, and global warming problems. Natural fiber-based composites are environmentally friendly and a good alternative to costly materials. Due to this, the demand of natural fiber-based composites in aerospace industry is increasing.

In hybrid composites, two or more kinds of reinforcing materials were added to a polymer matrix to obtain the synergistic influence of all fibers on the overall properties of hybrid composites (Fu et al., 2002). The weakness of one component can be balanced by the properties of another. Hybrid composites of glass fiber/carbon and Kevlar fibers were employed in aircraft components such as engine cowlings, engine pylon fairings and wing-body fairings (Baker et al., 2000). Unidirectional glass-carbon/epoxy hybrid composite was used in helicopter rotor blade (Mouritz, 2012d). Polyetherimide (PEI)/graphene oxide-multiwalled carbon nanotube hybrid nanocomposite films can be integrated into flexible electronic devices for a variety of potential applications in the aerospace and defense industries (Ahmad et al., 2020). It was declared that goat hair and banana fiber-reinforced epoxy hybrid composites laminates fabricated by the hand layup could be used in the aerospace applications (Rao et al., 2020).

This chapter reviewed the application areas of polymers, biocomposites, and hybrid biocomposites in aerospace industry. Some of the used polymers, polymer composites, and hybrid composites in aircraft industry are summarized in this chapter.

2 Components of Aircraft Structure

External shape of an aircraft is determined by fuselage, tail, and wing (Fig. 14.1). Components of aircraft structure are made of a wide variety of materials and are joined with bolts, rivets, screws, and adhesives or welding. Aircraft structural components are designed to resist stress or carry a load.

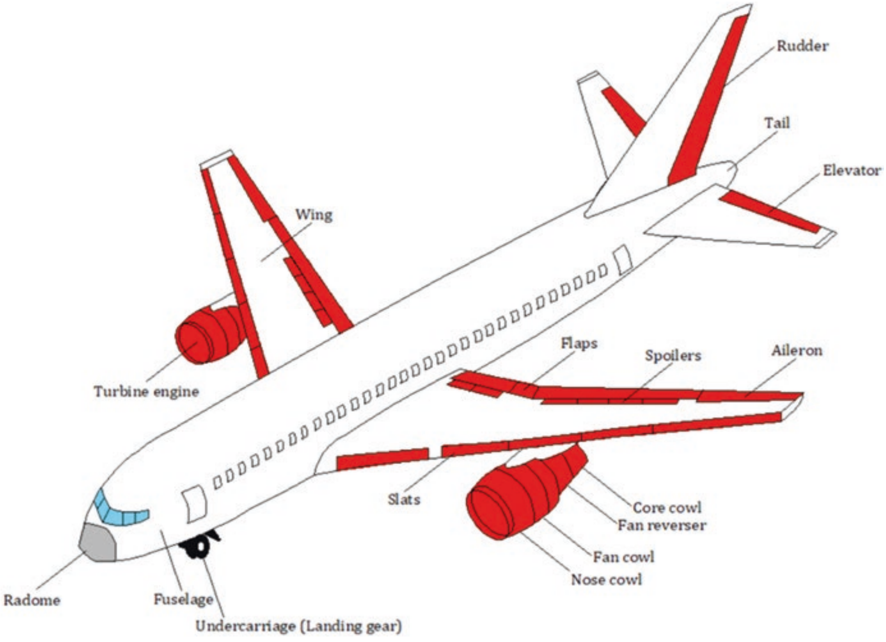

Fig. 14.1 Components of aircraft structure

2.1 Fuselage

Fuselage carries load and all parts are connected to it. Therefore, it must have low weight, must have high stiffness and strength to resist loads, and must be able to withstand bending moments, cabin pressurization, and torsional loads. In transport airplane, the fuselage is near cylindrical or cylindrical, with tail and nose sections, while in modern airplane, the fuselage has a skin attached to the stringers and hoop-shaped frames (Ghori et al., 2018).

2.2 Wing

Wing of an aircraft provides lift and is attached to fuselage by strong bolts. Wings carry loads and act as fuel tank. In most airplane, the wing skin is multifunctional. It determines shape, carries heavy and torsional loads, behaves as a fuel tank, and helps easy inspection and maintenance. Often, the entire airplane wing is fabricated with metal or a mixture of metal and composites (Ghori et al., 2018). Carbon fiber-reinforced plastic is used to make the wing in recent years.

2.3 Tail

Tail provides control and stability in three directions: lateral (left and right), longitudinal (before and after), and vertical (down and up). The horizontal tail with elevator is utilized for lateral axis rotation (pitch) of an aircraft. The vertical fin with rudder is employed for vertical axis rotation (yaw) of an aircraft. Ailerons are utilized for longitudinal axis rotation (roll) of an aircraft. Stability in yaw is provided by the fin. When the airplane needs to yaw, the rudder changes direction. Stability in pitch is provided by the tailplane. When the airplane needs to climb or descend, the elevators change direction. If the position of gravity center changes or the speed of the airplane is varied, the elevator position required to keep level flight will vary. That’s why a small extra control surface is added to each major surface to allow the pilot to trim the airplane. Carbon fiber-reinforced plastic is used to make the tail in recent years.

2.4 Undercarriage

Undercarriage (landing gear) provides shock absorbers during landing and provides smooth taxiing; however, it has no function during flight. Therefore, it should be as small and lightweight as possible. Because of heavy weight present in the aft and fore, large bending moments form in the center. To diminish these bendings, a strong keel beam is installed that decreases the landing gear. During the landing of an airplane, a large amount of heat is occurred, and the shock must be diminished to dissipate this heat. This could be obtained by the existence of disc brakes that increase the friction between the friction material pads (Ghori et al., 2018). Carbon/glass epoxy skins are used to make the landing gear door in recent years.

3 Natural Fiber-Based Composites (Biocomposites)

Biocomposites could be divided into two categories: partially (synthetic polymers + natural fibers or natural polymers + synthetic fibers) and completely (natural polymers + natural fibers) biodegradable composites (Fig. 14.2). Partially biocomposites are prepared from mixing of traditional petro-based nonbiodegradable polymeric materials such as epoxy, polyester, polyethylene (PE), polypropylene (PP), and polystyrene (PS) with natural fibers. Completely biocomposites are developed from natural fibers and natural matrices or synthetic biodegradable matrices such as poly(lactic acid) (PLA). They are completely degradable, sustainable, eco-friendly (Nair et al., 2014), and more environmentally friendly, and they have lower CO_2 footprint (Farag, 2017). They come from the earth, and they can go back into the earth and composted in organic soil with no residue when they are disposed after being utilized (Nair et al., 2014). Completely biocomposites can be prepared by

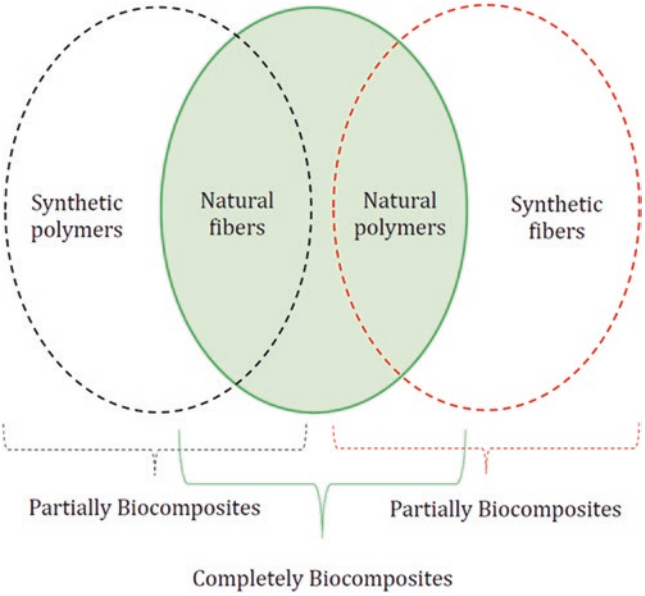

Fig. 14.2 Type of biocomposites

utilizing the traditional manufacturing methods (compounding, compression molding, extrusion, filament winding, hand layup, injection molding, and mixing) that have been employed for composites composed of synthetic fibers and synthetic polymers (Farag, 2017). The possible application of completely biocomposites for aerospace interior parts employing cotton fiber and polyurethane matrix was investigated by Eloy et al. (2015). Results demonstrated that the feasibility of replacing synthetic composites with completely biocomposites in aviation interior applications is to obtain better end-of-life performance and achieve "green airplane" efforts in the future.

Natural fibers such as banana, bamboo, coconut, cotton, hemp, flax, jute, palm, silk, sisal, and wheat are abundant, and they are good and effective reinforcement in polymer matrices (Siva et al., 2012). High specific strength and modulus of natural fiber-based composites can provide use in structural applications such as aircraft and spacecraft (Bharath & Basavarajappa, 2016; Hassan et al., 2010). Natural fibers obtained from animals and plants (Mansor et al., 2019; Omran et al., 2021) have some pros such as biodegradable, high strength-to-weight ratio, low density, low cost, more environmentally friendly, recyclable, renewable (Ilyas et al., 2021; Mansor et al., 2019), and sustainability. Resistance to impact damage is mandatory for composites employed in aerospace applications (Goriparthi et al., 2012). However, low thermal stability of both natural fibers and polymers restricts the application of biocomposites in the areas requiring high thermal stability such as aircraft materials (Sim et al., 2013). Also, low dimensional stability, low mechanical property, and hydrophilic nature of natural fiber give some challenges in the use of polymer composites for higher load-bearing components in aircrafts. To diminish the negative effects of polymer composites with natural fiber, hybridization process is implemented.

Waste of natural fibers is being burnt, affecting the environment negatively. Instead of burning and wasting natural fibers, they could be employed with polymers to develop composites. This endeavor protects the environment and can provide income.

Biocomposites possess low fire resistance; therefore, their safe use in aerospace industry is a question mark (Rashid et al., 2021). Low fire resistance of it is owing to lignin contents of natural fiber in biocomposites (Manfredi et al., 2006). Because flammability is becoming main issue in aviation sector, a new biocomposite that possesses the ability to behave as a self-extinguisher is under investigation. Fire hazard in aviation industry has been known ever since Wrights brother fabricated the aircraft (Karunakaran et al., 2016).

Advantages and disadvantages of employing natural fiber-based composites in aerospace industry are summarized in Table 14.2.

There are some criteria that natural fiber-reinforced composites must meet to employ them for aviation applications (Chandrasekar et al., 2018). These criteria are presented in Table 14.3.

Table 14.2 Advantages and disadvantages of employing natural fiber-reinforced composites in aerospace industry

Advantages	Disadvantages
Density of natural fiber-based composites is lower as compared to synthetic fiber-based composites causing an increment in the load capacity of aircraft structure	The properties of natural fibers are not consistent. Their properties change with harvesting area, harvesting time, intensity of sunlight, rain, and soil type
High specific stiffness and strength of composites can enable more aerodynamic design of complex shapes	Natural fibers have poor compatibility with polymers. Most polymers are nonpolar (hydrophobic); however, natural fibers are polar (hydrophilic)
Corrosion problems are not observed with composites, diminishing the maintenance cost	Moisture sorption tendency of natural fibers causes a drop in mechanical properties
They are fully biodegradable	Natural fibers possess poor thermal stability
Natural fibers have low cost. By adding natural fiber into polymers, the overall fabricating cost of an airplane structure can be decreased.	
Extraction of natural fibers is simple and requires unskilled labor	
Fabricating of natural fiber-based composites does not cause any health problems for the operators	

Table 14.3 Criteria that natural fiber-reinforced composites must meet to employ them for aviation applications

High specific stiffness and strength
Flame retardancy
High moisture resistance
Good interfacial bonding among natural fiber and polymeric matrix to bear different kinds of loads encountered in airplane flight

The main aims of aircraft sector are to decrease carbon dioxide emission, cost, and fuel consumption; hence, the implementation of natural fibers as reinforcement in polymer composites gains more interest in aerospace sector. Aircraft interior parts (such as decking, flooring, seats) and exterior body panels can be manufactured with natural fiber-based polymer composites. Nowadays, biocomposites are used from relatively small, lightly loaded components to heavily stressed structures.

Phenolic resin and woven flax were used to manufacture cabin interiors panels (Anandjiwala et al., 2008). Kenaf fiber gives similar stiffness to glass fiber and low dielectric constant; thus, it is suitable for radome applications (Haris et al., 2011). It was calculated that ramie fiber-reinforced composite reduced the weight of wing box by 12–14% with respect to 7000 series aluminum alloy; however, increment in the weight with flax- and hemp fiber-reinforced composites was found (Boegler et al., 2014).

4 Hybrid Biocomposites

“Hybrid” comes from Greek and Latin (Kaiser et al., 2014). In hybrid composites, two or more kinds of reinforcing materials are added to a polymer matrix (Fu et al., 2002) to obtain the synergistic influence of all fibers on the overall properties of hybrid composites. Weakness of one component can be balanced by the properties of another. Hybridization of synthetic and natural fiber is an environmentally friendly and economically feasible solution (Alsubari et al., 2021; Jawaid & Abdul Khalil, 2011; KC et al., 2018; Panthapulakkal & Sain, 2007). Hybrid composites of two natural fibers are less common in comparison to hybrid composites of natural/synthetic fiber. It was declared that oil palm and sisal fibers were good combination for hybrid composites because of high toughness of oil palm and high tensile strength of sisal (Jacob et al., 2007). It was concluded that palmyra palm leaf stalk fiber/jute fiber-based hybrid polyester composites could be a potential replacement in place of natural/synthetic fiber composites (Shanmugam & Thiruchitrambalam, 2013). Hybrid composites cause excellent impact resistance, good corrosion, and fatigue resistance in aerospace industry. The most important benefit is weight reduction in the range of 20–50% (Jamir et al., 2018). Sisal/banana/coconut sheath fiber-based polyester hybrid composites were developed via compressing molding to determine the mechanical properties (flexural strength, flexural modulus, tensile strength, and tensile modulus) and vibration properties (damping and natural frequency). It was found that stack sequence affected the vibration and mechanical properties. Alkali-treated sisal/coconut sheath/banana combination was the optimal hybrid composite and could be used for interior components of aerospace applications (Senthilkumar et al., 2017).

Two categories for design of hybrid composites are available: interlayer and intra-layer (Fig. 14.3). In intra-layer, both kinds of fibers are mixed in a single layer. In interlayer, each layer is done with a single fiber kind. Interlayer hybrid includes subcategory of skin-core hybrids, which are generally employed in aerospace parts (Shahzad & Choudhry, 2017). In interlayer configuration, layers of two fiber kinds are stacked on top of each other. This is the cheapest and simplest method to

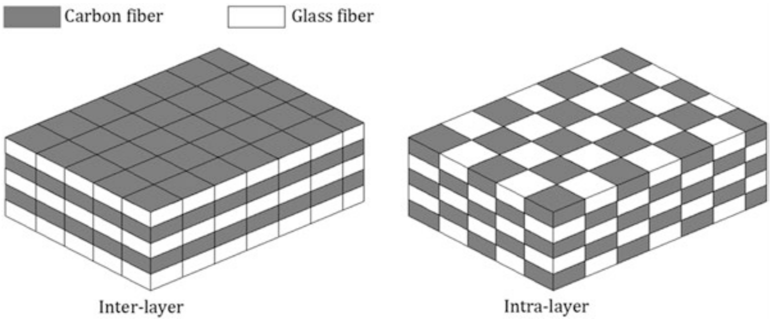

Fig. 14.3 Interlayer and intra-layer hybrid of glass-carbon fibers

produce a hybrid composite. Mixing of different fiber kinds in one layer characterizes intra-layer hybrid composites, causing higher dispersion of fibers as well as a more complex manufacturing process.

5 Manufacturing of Polymer Composites for Aerospace Engineering

Composites for aerospace applications are fabricated with two forms: laminate and sandwich composites (Fig. 14.4). Multiple layers of fiber and resin bonded together create laminates. Carbon fiber epoxy resin laminate composites are employed in heavily loaded aircraft structures (Mouritz, 2012c; Yokozeki et al., 2008) and

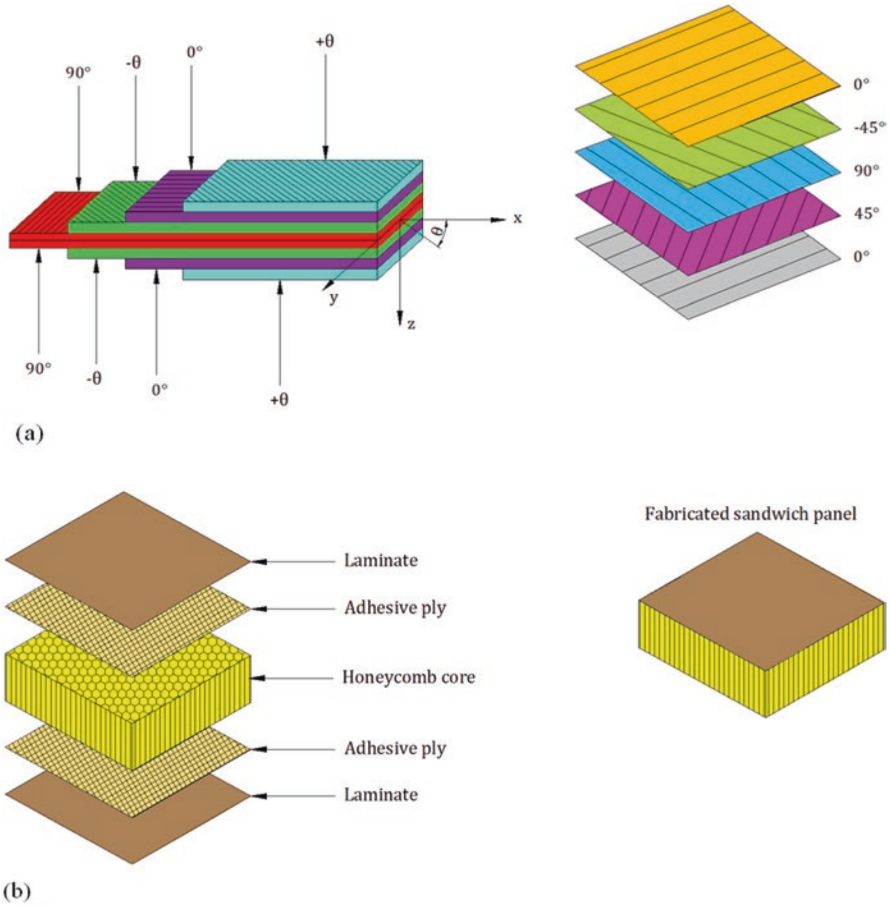

Fig. 14.4 (**a**) Laminate and (**b**) sandwich composite

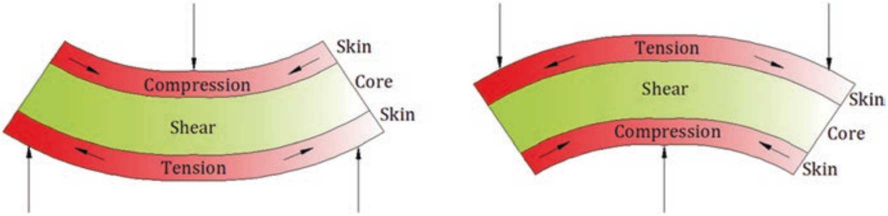

Fig. 14.5 Basic loading of sandwich composite

fuselage. In sandwich composites, thin face skins are bonded to a thick core material with an adhesive film. Under bending, the skins carry compression loads and in-plane tension while the core is exposed to shear (Fig. 14.5). Aluminum honeycomb is the most used core material in aircraft components since it has a lightweight cellular honeycomb structure providing high shear stiffness. Using of polymer foams such as polyetherimide (PEI) and polymethacrylimide (PMI) instead of aluminum honeycomb is rising in the aircraft sector because of their good durability and high temperature properties. Sandwich composites are utilized in lightly loaded aircraft structures requiring high resistance to buckling and bending. Sandwich composites are used for control surfaces (such as ailerons, flaps) and vertical tailplanes.

One of the most common forms of failure for composite materials is delamination. Delamination is a kind of layer deformation in laminated composite materials because of continuous stress and pressure on composite material. This type of failure may cause poor performance during the usage of these materials (Suriani et al., 2021a).

Manufacturing of composite can be separated into two kinds basing on how the polymer is combined with fiber: resin infusion processes such as filament winding (Fig. 14.6), resin film infusion (Fig. 14.7), resin transfer molding (Fig. 14.8), vacuum-bag resin infusion (Fig. 14.9), and prepreg-based processes including autoclave curing (Fig. 14.10), automated fiber placement (Fig. 14.11), and automated tape layup. In filament winding, cylindrical components are manufactured by winding continuous fiber tows over a stationary or rotating mandrel. Drive shafts, missile launch tubes, motor cases, and pressure vessels are fabricated with this process. Resin film infusion is suitable for producing relatively large structures because of its good drapability and near zero void content in comparison to autoclave cured parts (Rout et al., 2021). Moderate size of composite components such as fan blade of engine, rib, and spar for midsection fuselage and empennage is fabricated by resin transfer molding. Resin transfer molding can manufacture high-fiber volume amount composites, resulting them a good candidate for primary aircraft structures that need high fatigue, stiffness, and strength properties. Resin transfer molding is a closed molding process consisting of two molds with inner surfaces possessing the shape of final part. Fabric is placed in cavity between mold and stacked in the desired thickness and direction and then sealed and clamped. It is completely filled with resin injected at low pressure into the mold through a pump. Finally, the mold

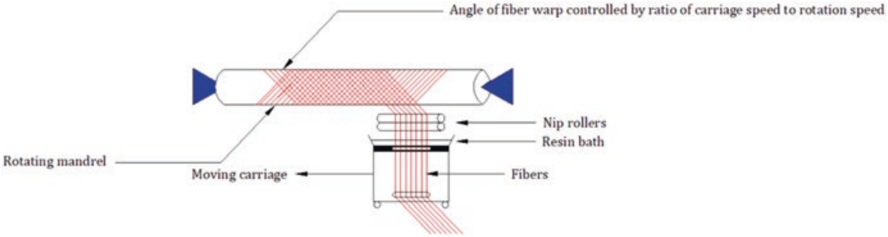

Fig. 14.6 Filament winding

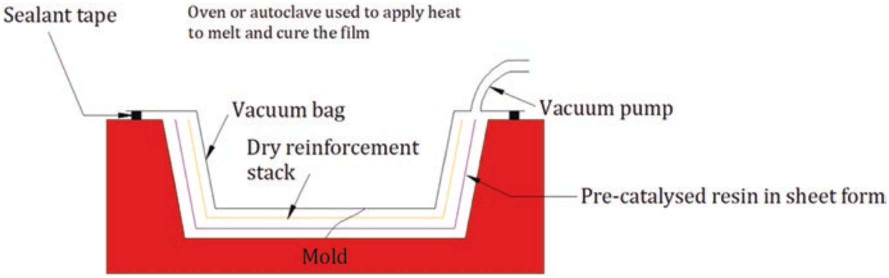

Fig. 14.7 Resin film infusion

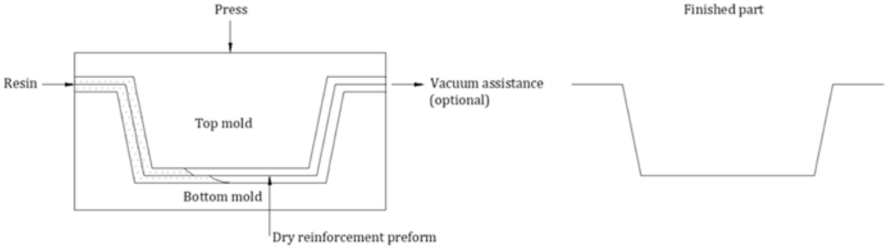

Fig. 14.8 Resin transfer molding

is heated to harden the polymeric matrix to form a solid composite and then trimmed of edge. Vacuum-bag resin infusion fabricates carbon-epoxy structural components. High-quality composites with high fiber amount are obtained with autoclave process which is suitable for primary and secondary parts for helicopters and aircrafts. Automated fiber placement is employed in the automated fabrication of large airplane parts from prepreg such as cowls, ducts, pressure tanks, nozzle cones, fuselage barrels, and spars. Automated tape layup is an automated process utilized to lay up prepreg tape in the manufacturing of composite airplane parts such as carbon-epoxy prepreg components. Near-net shape is obtained by the most manufacturing processes for composites. This is one of the advantages of fabricating with composites instead of metals. After manufacturing, only hole drilling for fasteners or trimming to eliminate excess material from the edges is required (Aisyah et al., 2021; Mouritz, 2012c).

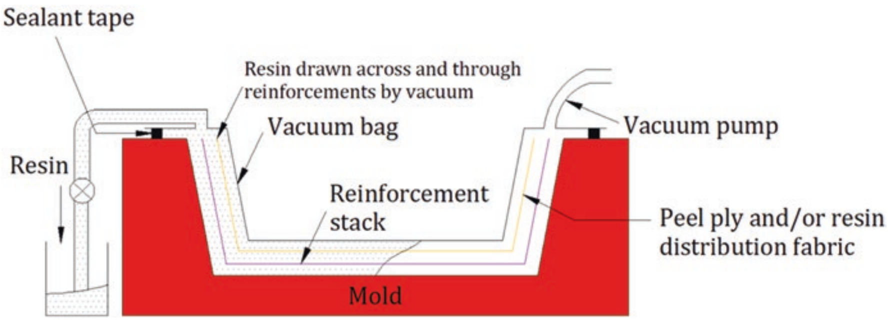

Fig. 14.9 Vacuum-bag resin infusion

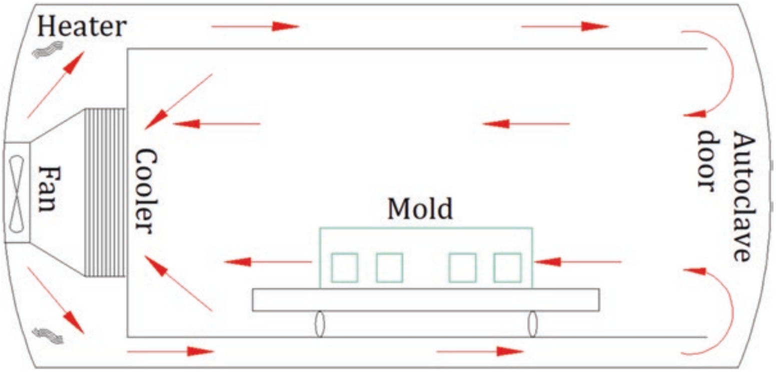

Fig. 14.10 Autoclave curing

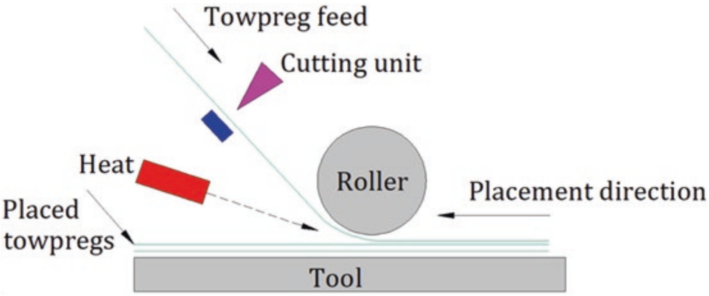

Fig. 14.11 Automated fiber placement

6 Applications of Hybrid Biocomposites in Aerospace Engineering

A wing is a structural beam which is exposed to altering moments and stresses owing to air turbulence, flight maneuver, and its weight and stresses from the gear during takeoff and landing. Moreover, bottom and top surfaces of the wing are alternately exposed to tension and compression (Mansor et al., 2019). Therefore, wings should be resistant to high forces, and composite materials with high strength can be good choice for these aerospace structures.

The existence of two different fibers caused good wettability, reducing void formation at the fiber-matrix interface and giving hybrid composites with high strength and stiffness (Islam et al., 2017), which could be suitable for the usage in aerospace applications of hybrid biocomposites.

Kenaf fiber-reinforced acrylonitrile butadiene styrene (ABS) with nanoclay hybrid biocomposite is able to self-extinguish and has efficient fire extinction, which can be applied in secondary structures of airplane with advantages such as biodegradable self-extinguishing, lightweight, and cost-effective biocomposite. It was declared that ABS/kenaf fiber (50/50) with 1% nanoclay formulation was applicable for confined spaces in aircraft (Karunakaran et al., 2016).

Impregnation of ceramic sheets into kenaf fiber-reinforced PP biocomposite could improve both inflammability and mechanical properties, causing the use in aerospace applications of hybrid biocomposites (Sim et al., 2013).

Sisal-glass fiber PP biocomposites caused a drop in volumetric coefficient of thermal expansion from 30 to −30 °C and improved moisture resistance showing that hybrid biocomposites expose lower dimensional change when subjected to alternating atmospheric condition (KC et al., 2018). They may be suitable for the use in aerospace applications of hybrid biocomposites.

7 Conclusions

Polymer composites utilized in aerospace components must meet some requirements such as excellent dimensional stability over a wide temperature range, good fatigue performance, high-fracture toughness, high-impact energy to bear sudden impacts of bird strikes, high strength, lightweight, and resistance to corrosive environments (fuel and lubricant) and also provide shielding of electromagnetic waves. Biocomposites have been developed by the researchers in recent years owing to rising pressure on the protection of the environment. Poor interface, moderate to lower mechanical properties, and moisture intake are some drawbacks of biocomposites for partial or full change with synthetic composites. To overcome these drawbacks, hybridizing, blending two or more reinforcements instead of single reinforcement in a polymeric matrix, is widely employed nowadays. Therefore, in this chapter, the works about hybrid biocomposites and their applications in the aerospace industry are reported. Aircraft interior parts (such as decking, flooring, seats) and exterior body panels can be manufactured with natural fiber-based polymer composites.

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