Chapter 5
Natural Composites in Aircraft Structures

Lata Samant, Fábio A. O. Fernandes, Seiko Jose, and Ricardo J. Alves de Sousa

5.1 Introduction

Composites consist of two or more physically distinct combinations to produce aggregate properties based on their constituents. These materials have good mechanical properties per unit weight and can be manufactured in any form according to suitability [1]. Multifunctional and eco-friendly composite materials have attracted more researchers and manufacturers to meet the increasing demand of sustainable products. To feed this demand, continuous work has been done on strengthening the ground for composite material.

Green marketing, cleaner production, sustainability, and change of cognitive values of consumers and lawmakers have led to environment-friendly production. Composite materials are being developed and redesigned to improve and adapt conventionally manufactured products while also bringing new products to market sustainably and responsibly [2]. These multifunctional materials have been developed to match the needs of a certain application and offer remarkable physicomechanical properties. Characteristics such as high strength, high modulus, low density, exceptional fatigue resistance, creep resistance, and so on provide design opportunities for the mechanical engineers. Many efforts are being made toward eco-friendly and

L. Samant
G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

F. A. O. Fernandes (✉) · R. J. Alves de Sousa
TEMA: Centre for Mechanical Technology and Automation, Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal
e-mail: fabiofernandes@ua.pt

S. Jose
ICAR-Textile Manufacturing and Textile Chemistry Division, Central Sheep and Wool Research Institute, Avikanagar, Rajasthan, India

M. C. Kuşhan et al. (eds.), *Materials, Structures and Manufacturing for Aircraft*, Sustainable Aviation, https://doi.org/10.1007/978-3-030-91873-6_5

biodegradable materials for the future of composite products because of worldwide environmental agitation and raising awareness of sustainable resources.

The shift toward natural materials in composites has resulted in lower greenhouse gas emissions and a smaller carbon footprint. These are suitable alternatives for substituting or reducing the use of petroleum-based materials [3]. Using natural composite materials that reduce construction waste and increase energy efficiency would be a better solution to the concept of sustainability [4]. Natural composites are, to a certain extent, eco-friendly or green.

Natural renewable resources that reduce carbon footprint are green composites. While materials that have one of the constituents, either fiber or matrix, from no-renewable resources are partly eco-friendly composites [2]. Non-biodegradable predominant fiber-reinforced plastics such as glass, carbon, and aramid fibers reinforced with synthetic thermoplastic and thermosetting resins are hazardous to the environment since they are derived from finite resources [5]. Therefore, to reduce the environmental impact of conventional composite materials, bio-based fibers as reinforcement are getting more attention these days [6].

Advantages of using natural fibers reinforcing materials embrace environment-friendly, low density, low cost, and good mechanical properties [7], Jute [8], coconut [9], hemp [10], pineapple [11, 12], kenaf [13], flax [14, 15], sisal [16], are some important natural fibers used in research and development of the natural fiber composites system. In contrast, natural fiber materials in reinforcements come with some critical shortfall characteristics that are hydrophilicity, poor moisture resistance, and weak fiber/matrix adhesion. But these drawbacks have significant room for improvement using innovative resins, additives, coatings, and surface modification techniques of fibers [17, 18].

Together with the natural fiber flooded market, the approach toward the replacement of a large amount of petroleum-based polymer by natural resins has reduced dependence on petrochemicals, and their cost allows manufacturers to promote a greener product. Bio-resin has a favorable lifecycle profile to the environment that contributed to its emergence in the field of composites. Some of these natural polymer resins are starch, lignin, polylactic acid, furan resins, and super Sap epoxy [19].

In semi-structural and structural applications such as aerospace, vehicles, sports technology, electronics, and plastics, natural fiber-reinforced polymer matrix composites have achieved commercial success. 100% bio-based composites with superior mechanical properties can be made utilizing natural fibers and naturally produced resins, and they can be used for more structural reasons [18]. For instance, Fernandes et al. [15] developed laminate composites based on flax fibers and super Sap epoxy resin to substitute fiberglass laminate composites with matrixes based on synthetic epoxy resin, which showed good impact toughness (Fig. 5.1).

Due to the necessity for enhanced fuel efficiency, corrosion resistance, and fatigue resistance, composite materials are widely employed in the aerospace, marine, and automotive industries [20]. The recent developments in natural composites for aircraft were not the first steps in the use of natural materials for this application. Pioneering work was carried out by the Wright Brothers (1903), who employed wood and natural-based fabrics on their Flyer 1. Wooden structures did

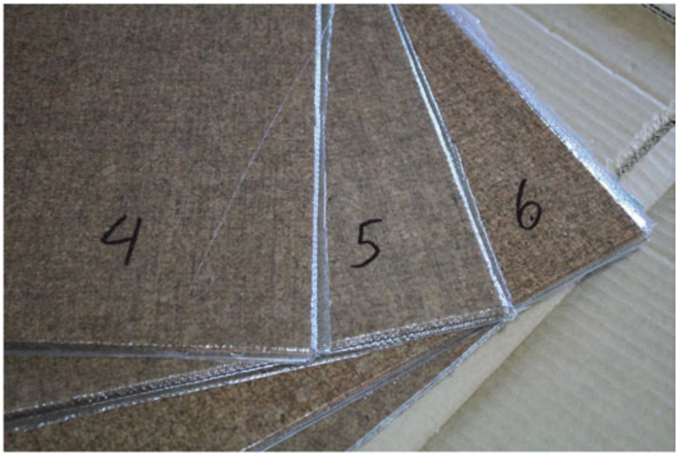

Fig. 5.1 Flax fibers laminates with cured super Sap (bio-based) epoxy resin matrix and cork core

persist until World War II, plywood–balsa–plywood sandwich laminates incorporated in the fuselage of some aircraft [21]. In 1940, balsa-cored sandwich laminates were developed incorporating untwisted flax fibers and having a phenolic resin as the matrix [22]. High strain rate testing of laminate composites has gained significant importance in recent years of material research because these materials are commonly used in lightweight structural applications and there are many cases where the mechanical properties of composite materials are notably reliant on the strain rate. Natural fiber composites have improved in performance thanks to advances in fiber selection, extraction, treatment, interfacial engineering, and composite manufacturing.

5.2 Natural Composites in Aerospace Industry

The first use of composite materials in aircraft was about 30 years ago where boron-reinforced epoxy composite was used for the structure of the tail assembly of the U.S. F14 and F15 fighters. The aerospace industry and manufacturers are relentless in their efforts to improve the performance of commercial and military aircraft as knowledge and technology advances [23]. When it comes to heavier-than-air machines, weight is a major consideration, and designers have worked tirelessly to push the limits of lift-to-weight ratios. Weight loss has been aided significantly by composite materials [24]. The use of metal and alloys-based materials is subsequently replaced by composites for different industrial applications. Fiber–metal laminates such as aluminum/boron/epoxy, titanium/carbon fiber/epoxy, and aramid/aluminum/epoxy are used as aerospace structural material. Although the metal layer is used to improve the impact performance, the rate of moisture absorption increases in the case of fiber metal hybrid composites, presenting also low fracture toughness [25]. On contrary, properties such as high specific strength, stiffness, fracture toughness, good oxidation resistance, and corrosion are some of the reasons for the high demand for composites in the industry [26].

Despite the structural benefits of synthetic fiber composites such as carbon fiber composites and glass fiber composites, they have several drawbacks, including high raw material costs and significant environmental effects due to their non-recyclability and non-degradability. The danger of sustainability and life cycle assessment (LCA) is imposed on aircraft made with these sorts of composites [27]. Stringent regulations and standards have forced the change toward eco-friendliness. The Advisory Council for Aviation Research and Innovation in Europe (ACARE) released the Flightpath 2050 report, which focuses on the use of recyclable and environmentally friendly materials in aviation technologies to reduce carbon emissions and reliance on crude oil-based products [28].

Natural composites used in aircraft have still to overcome several challenges before being widely used in this industry. This is particularly true for critical structural components. Additionally, challenges such as the requirements of safety standards, from fire retardancy to crash safety standards, are barriers to the wider adoption of natural composites by the aerospace industry. Nevertheless, natural fibers have found their way into commercial aircraft, for instance, in-cabin components and other interior components due to their lightweight and strong nature [29].

5.3 Aerospace Component from Natural Fibers

Boeing's 787 Dreamliner, shown in Fig. 5.2, is the first commercial aircraft in which structural materials are made of composite materials rather than aluminum alloys. There has been seen a shift from the use of alloys to the use of synthetic fibers

Fig. 5.2 Usage of composites in Boeing 787 Dreamliner structure [67]. Reprinted by permission from Elsevier

(fiberglass, carbon composites) to the promotion of the green approach of using hybrid composites (natural fibers/synthetic fibers).

As interest in sustainability and "green" interiors grows, a European project called "Cayley" has brought together Boeing Research and Technology Europe (Madrid, Spain), Invent GmbH (Braunschweig, Germany), Aimplas (Valencia, Spain), and Lineo (St. Martin du Tilleul, France) to develop eco-friendly interior panels made of renewable polymers and flax fibers. These interiors are reported to be 35% lighter than carbon fiber/epoxy prepreg tapes [30]. Fiber reinforcements have a broad application spectrum that includes every sort of modern engineering structure. They can be found in a wide range of airplanes, helicopters, spacecraft, boats, ships, and offshore platforms, as well as automobiles, chemical processing equipment, sporting products, and civic infrastructure including buildings and bridges [31]. Flax composites have a high specific tensile and flexural modulus, making them a promising sustainable material for aircraft, transportation, and lightweight building [32]. The mechanical properties of bio-based resin composites with flax fibers as reinforcements can meet the requirements of an aircraft's interior structures [29]. Biodegradable banana fiber and epoxy resin composites are being used for low-strength applications. Considering the advantages of natural fibers, these are being used in aircraft as interlines in the seats, panels, etc. Ramie/PLA composites can be used in aerospace applications to replace composites that use glass fiber and petroleum oil-based resins, improving energy efficiency and solution sustainability [33]. Hemp/epoxy composites can compete with and replace glass/epoxy composites in ultra-light aircraft, thereby broadening the range of environmentally acceptable composites [34]. Coir has the potential to be used as a component in aircraft materials that are impact resistant [35]. Both the bamboo/coir epoxy resin composite and the bamboo/coir epoxy resin composite have superior impact resistance when used together. Hemp, kenaf, flax, and other bast fibers are utilized as reinforcement for aircraft interior structures such as seat cushions, cabin linings, and parcel shelves. Pilots' cabin doors and door shutters are made of jute fiber-reinforced polyester/epoxy [36–38].

In another study, the authors analyzed the dielectric and mechanical properties of five types of natural fibers for radome development viz., banana, bamboo, oil palm, kenaf, pineapple leaf fibers [39]. Hybrid kenaf/glass fiber-reinforced polymer composites showed their potential for this application through their resistance to rain erosion and due to their mechanical performance. More recently, Ilyas et al. [40] also investigated and found the potential application of natural fiber reinforced polymer composites in the radome. These structures are typically manufactured by resin injection molding (RIM).

Boegler et al. [41] found that ramie fiber-reinforced polylactic acid (PLA) and epoxy resin-made wing box could be a sustainable option to replace the conventional aluminum alloy wing box. Natural fiber-based thermoset and thermoplastic panels were found to have the needed flame and heat resistance above conventional sandwich panels [42]. Composites-based high-performance goods must be lightweight while also being robust enough to withstand high loads, such as tails, wings, and fuselages for aerospace structures [43]. The future of the composite industry relies on the material source that can work together following the environmental concerns, with strengthening research on the performance of natural fiber-reinforced composites and their sustainability, it is likely to guarantee their long-term growth, as well as innovative products and new applications on the horizon.

5.4 Natural Fibers in Aerospace Applications and Their Properties

Alonso-Martin et al. [42] patented publication asserts that the aircraft interior panels made from natural fiber-reinforced panels for secondary structure in the cabin would result in a weight reduction of 200–500 kg constituting a reduction of 2500–6500 tons of CO_2 emissions for panels made from inorganic resin. Additionally, during their lifetime, a reduction of 100–250 kg for the thermoplastic resin panels, which corresponds to a reduction of 1300–3250 tones in CO_2 emissions was estimated for panels made of thermoplastic resin. Comparable mechanical properties of kenaf and glass fiber having tensile strength, tensile modulus, and elongation at failure, 930 MPa, 53 GPa, and 53; 1.6%, 2000–3500 MPa, and 70 GPa 2.5–3.0%, respectively, help to improve the rain erosion resistance and mechanical properties for radome applications.

Boegler et al. [41] compared the mass of a wing made of aluminum alloy of the 7000 series (7000–8829 kg) to a wing made of ramie fiber-based composites (7576 kg), which resulted in a weight reduction of the wing box without compromising structural integrity. Sandwich structures were made with diglycidyl ether of bisphenol-A (DGEBA) and glucofuranoside-based trifunctional epoxy (GFTE) matrices cured by curing agent, jute fiber reinforcement, and polymethacrylimide foam as the core for prospective airplane interior flooring applications. The sandwich composites' bending strength and modulus were found to be substantially higher with GFTE than with DGEBA [44].

Bio-composites, rather than nonrenewable composites, improve the plane's sustainability [45]. Bio-composites have a bright future ahead of them and using renewable and sustainable resources is crucial for their integration into aircraft. Biomass valorization is needed for a better aviation environmental footprint. However, as far as falling weight impact properties are concerned, the possibility that offered quite significant results is the use of bio-based thermosets as the matrix for natural fiber composites, such as soy oil methacrylates reinforced with jute fibers [46]. In another example, the application of a hemp fabric/epoxy composite in an electronic rack of a helicopter [47] and Naca cowling of an acrobatic ultralight airplane [34] showed better results. In the case of sisal/polypropylene composites, the addition of magnesium hydroxide and zinc borate offered a satisfactory fire retardancy effect without affecting the mechanical properties [48].

5.5 Natural Resins in Aerospace Applications and Their Properties

The carbon fiber reinforcement offers stiffness and strength to the composite, while the epoxy matrix provides ductility [49]. Carbon fibers and epoxy are unsatisfactory as aircraft structural materials on their own. Natural fibers and epoxy resin, when mixed as a composite, these can produce a high-performance structure with a wide range of desirable qualities.

One of the current priorities in composites incorporating natural materials for aircraft structures is to substitute the traditional epoxies [21]. In addition to new formulations of epoxy resins for the manufacturing of natural composites with superior performance [50, 51], the introduction of nanofillers into bio-based epoxy matrixes has been explored to improve the mechanical properties. Examples of nanofillers incorporated with success are silicon carbide nanoparticles, carbon nanotubes, and nanoclays, which improved the thermal, mechanical, and conductive performance of the cured thermosets [21].

Dinesh et al. [52] created composites of an epoxy matrix, pineapple fiber, and wire mesh with a PF/SS/PF/SS stacking sequence with 1.0vol percent nano-silica, achieving a normalized strength of 98%. Epoxy composites are a superb alternative material for autos, structure, surveillance micro aircraft, and domestic appliance manufacturing industries with high economic value due to their high fatigue and fracture toughness and high penetration resistance against drop load. In comparison to traditional reinforcements, flax-based epoxy has the potential to reach high specific strength [53]. Various types of natural fillers are used with bio-resin to enhance the mechanical strength and reduce the cost of the material and make the resultant material competitive to synthetic composites. In Table 5.1, a few of the natural fillers and bio-resins are mentioned that are being used in the natural fiber composites.

Table 5.1 List of common bio-resins and natural fillers for natural fiber composites

Natural fibers	Natural resins	Natural fillers
Hemp	Soy oil	Nanoclay
Flax	Wheat gluten	Graphite filler
Kraft Pulp	Cashew nut shell	Cellulose nanofibers
PALF	Starch	Rice husk
Cork	Lignin	Wheat husk
Kenaf	Polylactic acid	Coir
Jute	Furan resins	Palm kernel shell
Ramie	Super sap epoxy	Wood chip

5.6 Natural/Synthetic Hybrid Composites for Aerospace Applications

The complete replacement of synthetic fiber composites employed in aircraft by natural solutions is still not possible, mainly due to the disparity of some properties. Therefore, hybrid composites composed of two discontinuous phases, both natural/synthetic fibers, have been the smart way of increasing the natural material content in aircraft composites [36, 54, 55]. Additionally, hybrid composites make it possible to explore demanding applications in the aerospace sector, going beyond interior panels, by developing lightweight hybrid composites for aircraft structural applications.

To achieve excellent properties and improve the sustainability of the solutions, hybrid composites are usually developed through the combination of natural and synthetic materials. These materials with combined properties have extensive engineering applications. In hybrid composite materials, a combination of excellent properties such as tensile modulus, compressive strength, and impact strength can be achieved, which therefore increases the efficiency, performance, and extensibility of the materials.

Hybrid composites are widely used in commercial airplanes. Unlike other vehicles, airplane manufacture places a larger emphasis on safety and weight reduction, which is accomplished by using materials with high specific characteristics [56]. Modern aircraft are designed to meet performance, properties, environmental standards, and safety. A hybrid composite from natural fiber exhibits weight reduction compared to steel/carbon. By exploring these renewable materials, it increases the recyclability percentage of components in the automotive and aircraft. Combined natural and synthetic materials result in environmentally friendly and sustainable components to fulfill the growing demand for composites worldwide [57].

ECO-COMPASS (Ecological and Multifunctional Composites for Aircraft Interior and Secondary Structures) is a Horizon 2020 research and innovation activity (RIA) initiative involving Europe and China. The major goal of this project was to design and test environmentally friendly multifunctional composites for use in the aviation industry. Overall, it focused on the development of environmentally friendly structures for application in aircraft. Figure 5.3 depicts the collection of materials and technologies based on natural composites developed aircraft within the ECO-COMPASS project scope [58].

Although several efforts have been made to incorporate natural fibers in composites, additional research is still necessary to uncover the potential of these natural materials. For instance, although the potential of ramie fibers has not been completely exploited, its high tensile strength is an indicator that it can be used in various products, for example, through its blending with synthetic fibers [59]. According to Romanzini et al. [60], a larger ramie fiber content in hybrid composites resulted in lower weight composites and higher water absorption. By increasing the fiber content, the composites' mechanical properties, such as impact and interlaminar shear strength, were improved. With carbon fiber hybridization, the flexural strength

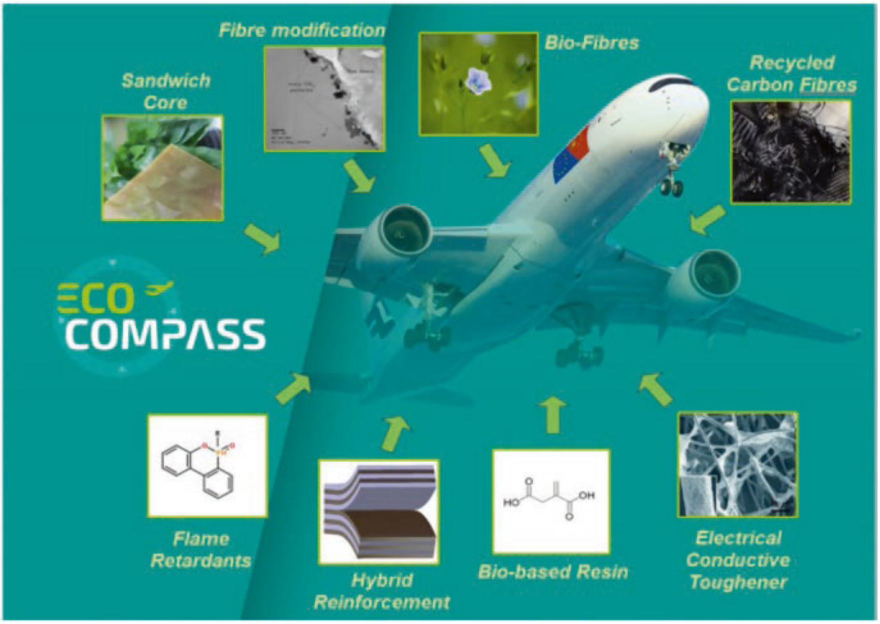

Fig. 5.3 Examples of materials and technologies under investigation in ECOCOMPASS

Table 5.2 Comparison of mechanical properties of bio and synthetic fiber composites

Composite	Tensile strength	References
Carbon/glass/epoxy	58 GPa	[62]
Glass/epoxy	48 GPa	[62]
Carbon/epoxy	110 GPa	[62]
Glass laminate	63 MPa	[63]
Kenaf and glass fiber	65.29 MPa	[64]
Jute and Sisal	66.77 MPa	[65]
Jute and glass fiber	75.68 MPa	[65]
Sisal composite	56.36 MPa	[66]

and modulus of a plain flax/epoxy composite increased from 95.66 MPa to 425.87 MPa and 4.78 GPa to 17.90 GPa, respectively. Carbon fiber hybridization onto flax/epoxy composites can contribute a significant improvement in impact damage behavior and flexural strength and modulus [61]. Brief mechanical properties of bio and synthetic composites are mentioned in Table 5.2 to depict the combined effect to reduce the environmental impact in comparison to completely synthetic composites.

5.7 Conclusions, Challenges, and Future Outlook

Transportation industries functioned to assist mobility of goods and people whether by land, air, or sea, such as automotive, trains, aircraft and ships, etc. Due to the depletion of inorganic materials such as petroleum and other mineral sources, the world is changing, and green materials are at the forefront. As a result, switching to biocomposite materials can meet the expectations for sustainability in the transportation industry by shifting to renewable, recycled, and lightweight materials while taking into account the needs of each type of vehicle. Significant weight reductions can be obtained by switching the materials of some of the heavier vehicle components to high-performance natural fiber composites, contributing to lower fuel consumption and CO_2 emissions.

The ever-increasing carbon footprint and shortage of raw materials push people to think about sustainability, recycling, and the circular economy. As a result, bio-based substitutes are likely to outperform traditional materials. Natural fiber-reinforced composites, particularly those based on bio-based and thermoplastic matrices, are one of the most environmentally friendly materials that could eventually replace glass fiber reinforced plastics (GFRP).

Although the potential of natural composites in transportation has been demonstrated, especially in the automotive sector, the aircraft industry faces many challenges to successfully incorporate these without failing critical requirements. Natural fibers offer advantages and disadvantages when used in composites. They have downsides in terms of performance, behavior in polymeric matrix systems, and processing. Natural fibers' physical qualities do not match in a single fiber or bulk; this inconsistency is a flaw in nature. Depending on the climatic condition, harvesting season, soil conditions, etc., these variations may differ. Additionally, natural fibers have low thermal stability (~200 °C depending on the fiber). Exposure to higher temperatures leads to harmful properties alteration caused by their degradation.

The natural fiber is hydrophilic that constrains its use in the higher ratio in technical applications. The low fiber-matrix adhesion affinity makes the bond weaker and thereby affecting its overall performance. Surface functionalization and treatment of fiber are methods to improve the interface interaction. Sensitivity to humidity and high moisture absorption leads to damage or rupture of the composites. The chemical heterogeneity of the natural fiber makes it a less ideal material for application in aerospace industries. Susceptibility to rotting and high chances of microbial growth can limit its use. These fallbacks can be overcome by modification of the fiber surface and product modifications.

With rising fuel costs and environmental pressure, the aerospace industry, like other industries, is facing sustained implications to improve performance. Understanding the increasing concern for the environment and hike in raw material cost and supply, aircraft production/manufacturing can be reduced by component substitution with comparable alternatives. The aircraft industry ensures that any opportunity to reduce operating costs is explored and exploited wherever possible to be ahead of competitors. Viewing the progress in composite construction techniques, airplanes with high quality and improved mechanical properties can be developed using natural composite materials.

Independently of the nature of the material, currently, reuse and recycle are two main concepts present in any industry since resources are finite. The aerospace industry is no exception, and the management of wastes generated by end-of-life aircraft components must be addressed. Depending on the composite, there are challenges in its disassembly. Natural composites application expansion in aircraft is an active field of research, motivated by the clear environmental benefits, and focused on improving its performance to meet the different types of safety standards.

Acknowledgments This work was supported by the projects UIDB/00481/2020 and UIDP/00481/2020—FCT—Fundação para a Ciência e a Tecnologia; and CENTRO-01-0145-FEDER-022083—Centro Portugal Regional Operational Programme (Centro2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund.

References

1. Sen, T., & Reddy, H. J. (2011). Application of sisal, bamboo, coir and jute natural composites in structural upgradation. *International Journal of Innovation, Management and Technology, 2*(3), 186.
2. Mitra, B. C. (2014). Environment friendly composite materials: Biocomposites and green composites. *Defence Science Journal, 64*(3), 244.
3. Gholampour, A., & Ozbakkaloglu, T. (2020). A review of natural fiber composites: Properties, modification and processing techniques, characterization, applications. *Journal of Materials Science, 55*(3), 829–892.
4. Humphreys, M. (2003). *The use of polymer composites in construction*.
5. Vilay, V., Mariatti, M., Taib, R. M., & Todo, M. (2008). Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber–reinforced unsaturated polyester composites. *Composites Science and Technology, 68*(3–4), 631–638.
6. Santhosh, J., Balanarasimman, N., Chandrasekar, R., & Raja, S. (2014). Study of properties of banana fiber reinforced composites. *Int. J. Res. Eng. Technol, 3*(11), 144–150.
7. Jeyanthi, S., Jeevamalar, J., & Jancirani, J. (2012). *Influence of natural fibers in recycling of thermoplastics for automotive components*.
8. Rana, A. K., Mandal, A., & Bandyopadhyay, S. (2003). Short jute fiber reinforced polypropylene composites: Effect of compatibiliser, impact modifier and fiber loading. *Composites Science and Technology, 63*(6), 801–806.
9. Brígida, A. I. S., Calado, V. M. A., Gonçalves, L. R. B., & Coelho, M. A. Z. (2010). Effect of chemical treatments on properties of green coconut fiber. *Carbohydrate Polymers, 79*(4), 832–838.
10. Gironès, J., López, J. P., Mutjé, P., Carvalho, A. J. F. D., Curvelo, A. A. D. S., & Vilaseca, F. (2012). Natural fiber-reinforced thermoplastic starch composites obtained by melt processing. *Composites Science and Technology, 72*(7), 858–863.
11. Kengkhetkit, N., & Amornsakchai, T. (2012). Utilisation of pineapple leaf waste for plastic reinforcement: 1. A novel extraction method for short pineapple leaf fiber. *Industrial Crops and Products, 40*, 55–61.
12. Jose, S., Salim, R., & Ammayappan, L. (2016). An overview on production, properties, and value addition of pineapple leaf fibers (PALF). *Journal of Natural Fibers, 13*(3), 362–373.

13. Yuhazri, M., & Sihombing, H. (2010). A comparison process between vacuum infusion and hand lay-up method toward kenaf/polyester composite. *International Journal of Basic & Applied Sciences., 10*, 54–57.
14. Bledzki, A. K., Mamun, A. A., Lucka-Gabor, M., & Gutowski, V. S. (2008). The effects of acetylation on properties of flax fibre and its polypropylene composites. *Express Polymer Letters, 2*(6), 413–422.
15. Fernandes, F. A. O., Tavares, J. P., de Sousa, R. A., Pereira, A. B., & Esteves, J. L. (2017). Manufacturing and testing composites based on natural materials. *Procedia Manufacturing, 13*, 227–234.
16. Gupta, M. K., & Srivastava, R. K. (2016). *Properties of sisal fibre reinforced epoxy composite*.
17. Dittenber, D. B., & GangaRao, H. V. (2012). Critical review of recent publications on use of natural composites in infrastructure. *Composites Part A: Applied Science and Manufacturing, 43*(8), 1419–1429.
18. Nair, K. M., Thomas, S., & Groeninckx, G. (2001). Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres. *Composites Science and Technology, 61*(16), 2519–2529.
19. DoroudgarianNewsha. (2016). *High performance bio-based composites: Mechanical and environmental durability*. PhD Thesis. UPC, Departament de Ciènciadels Materials iEnginyeriaMetal·lúrgica.
20. Shekar, H. S., & Ramachandra, M. (2018). Green composites: A review. *Materials Today: Proceedings, 5*(1), 2518–2526.
21. Soutis, C., Yi, X., & Bachmann, J. (2019). How green composite materials could benefit aircraft construction. *SCIENCE CHINA Technological Sciences, 62*(8), 1478–1480.
22. Soutis, C. (2015). Introduction: Engineering requirements for aerospace composite materials. In *Polymer composites in the aerospace industry* (pp. 1–18). Woodhead Publishing.
23. Quilter, A. (2004). *Composites in aerospace applications, aviation pros*. Retrieved from https://www.aviationpros.com/engines-components/aircraft-airframe-accessories/article/10386441/composites-in-aerospace-applications.
24. Johnson, T. (2020). *Composites in aerospace*. ThoughtCo. Retrieved from thoughtco.com/composites-in-aerospace-820418.
25. Vlot, A., & Gunnink, J. W. (Eds.). (2011). *Fibre metal laminates: An introduction*. Springer Science & Business Media.
26. Toozandehjani, M., Kamarudin, N., Dashtizadeh, Z., Lim, E. Y., Gomes, A., & Gomes, C. (2018). Conventional and advanced composites in aerospace industry: Technologies revisited. *Am. J. Aerosp. Eng, 5*, 9–15.
27. Potes, F. C., Silva, J. M., & Gamboa, P. V. (2016). Development and characterization of a natural lightweight composite solution for aircraft structural applications. *Composite Structures, 136*, 430–440.
28. European commission report, Flightpath 2050 Europe's Vision for Aviation. (2011). Retrieved from https://ec.europa.eu/transport/sites/transport/files/modes/air/doc/flightpath2050.pdf.
29. Amiri, A., Burkart, V., Yu, A., Webster, D., & Ulven, C. (2018). The potential of natural composite materials in structural design. In *Sustainable composites for aerospace applications* (pp. 269–291). Woodhead Publishing.
30. Black, S. (2015). *Looking to lighten up aircraft interiors? Try natural fibers!* Retrieved from https://www.compositesworld.com/articles/looking-to-lighten-up-aircraft-interiors%2D%2D-with-natural-fibers.
31. Shrive, N. G. (2006). The use of fibre reinforced polymers to improve seismic resistance of masonry. *Construction and Building Materials, 20*(4), 269–277.
32. Panzera, T. H., Jeannin, T., Gabrion, X., Placet, V., Remillat, C., Farrow, I., & Scarpa, F. (2020). Static, fatigue and impact behaviour of an autoclaved flax fibre reinforced composite for aerospace engineering. *Composites Part B: Engineering, 197*, 108049.
33. Wang, C., Ren, Z., Li, S., & Yi, X. (2018). Effect of ramie fabric chemical treatments on the physical properties of thermoset polylactic acid (PLA) composites. *Aerospace, 5*(3), 93.

34. Scarponi, C. (2015). Hemp fiber composites for the design of a Naca cowling for ultra-light aviation. *Composites Part B: Engineering, 81*, 53–63.
35. Affandi, N. B., Rafie, A. S. M., Basri, S., Romli, F. I., Abdul Majid, D. L. A., & Mustapha, F. (2011). A preliminary study on translational kinetic energy absorption using coconut-fiber (coir) sheets as a potential impact-worthy constituent in advanced aerospace material. In *Key engineering materials* (pp. 1028–1033). Trans Tech Publications Ltd..
36. Arockiam, N. J., Jawaid, M., & Saba, N. (2018). Sustainable bio composites for aircraft components. In *Sustainable composites for aerospace applications* (pp. 109–123). Woodhead Publishing.
37. Gopinath, A., Kumar, M. S., & Elayaperumal, A. (2014). Experimental investigations on mechanical properties of jute fiber reinforced composites with polyester and epoxy resin matrices. *Procedia Engineering, 97*, 2052–2063.
38. Subash, T., & Pillai, S. N. (2015). Bast fibers reinforced green composites for aircraft indoor structures applications: Review. *Journal of Chemical and Pharmaceutical Sciences, 7*, 305–307.
39. Haris, M. Y., Laila, D., Zainudin, E. S., Mustapha, F., Zahari, R., & Halim, Z. (2011). Preliminary review of biocomposites materials for aircraft radome application. In *Key engineering materials* (pp. 563–567). Trans Tech Publications Ltd..
40. Ilyas, R. A., Sapuan, S. M., Norizan, M. N., Atikah, M. S. N., Huzaifah, M. R. M., Radzi, A. M., et al. (2019). Potential of natural fibre composites for transport industry: A review. In *Prosiding Seminar Enau Kebangsaan 2019; Institute of Tropical Forest and Forest Products (INTROP)*; Universiti Putra Malaysia: Bahau, Malaysia; pp. 2–11.
41. Boegler, O., Kling, U., Empl, D., & Isikveren, A. T. (2015). *Potential of sustainable materials in wing structural design*. Deutsche Gesellschaft für Luft-und Raumfahrt-Lilienthal-Oberth eV.
42. Alonso-Martin, P. P., Gonzalez-Garcia, A., Lapena-Rey, N., Fita-Bravo, S., Martinez-Sanz, V., & Marti-Ferrer, F. (2012). *Green aircraft interior panels and method of fabrication*. European Patent EP2463083A2, 13.
43. Balakrishnan, P., John, M. J., Pothen, L., Sreekala, M. S., & Thomas, S. (2016). Natural fibre and polymer matrix composites and their applications in aerospace engineering. In *Advanced composite materials for aerospace engineering* (pp. 365–383). Woodhead Publishing.
44. Niedermann, P., Szebényi, G., & Toldy, A. (2015). Characterization of high glass transition temperature sugar-based epoxy resin composites with jute and carbon fibre reinforcement. *Composites Science and Technology, 117*, 62–68.
45. Chen, J. T., Abdullah, L. C., & Tahir, P. M. (2019). Biomass valorization for better aviation environmental impact through biocomposites and aviation biofuel. In *Structural health monitoring of biocomposites, fibre-reinforced composites and hybrid composites* (pp. 19–31). Woodhead Publishing.
46. Dhakal, H. N., Skrifvars, M., Adekunle, K., & Zhang, Z. Y. (2014). Falling weight impact response of jute/methacrylated soybean oil bio-composites under low velocity impact loading. *Composites Science and Technology, 92*, 134–141.
47. Scarponi, C., & Messano, M. (2015). Comparative evaluation between E-glass and hemp fiber composites application in rotorcraft interiors. *Composites Part B: Engineering, 69*, 542–549.
48. Jarukumjorn, K., & Suppakarn, N. (2009). Effect of glass fiber hybridization on properties of sisal fiber–polypropylene composites. *Composites Part B: Engineering, 40*(7), 623–627.
49. Czél, G., Pimenta, S., Wisnom, M. R., & Robinson, P. (2015). Demonstration of pseudo-ductility in unidirectional discontinuous carbon fibre/epoxy prepreg composites. *Composites Science and Technology, 106*, 110–119.
50. Dai, J., Peng, Y., Teng, N., Liu, Y., Liu, C., Shen, X., et al. (2018). High-performing and fire-resistant biobased epoxy resin from renewable sources. *ACS Sustainable Chemistry & Engineering, 6*(6), 7589–7599.

51. Li, C., Liu, X., Zhu, J., Zhang, C., & Guo, J. (2013). Synthesis, characterization of a rosin-based epoxy monomer and its comparison with a petroleum-based counterpart. *Journal of Macromolecular Science, Part A, 50*(3), 321–329.
52. Dinesh, T., Kadirvel, A., & Hariharan, P. (2020). Role of nano-silica in tensile fatigue, fracture toughness and low-velocity impact behaviour of acid-treated pineapple fibre/stainless steel wire mesh-reinforced epoxy hybrid composite. *Materials Research Express, 6*(12), 125365.
53. Bos, H. L., Van Den Oever, M. J. A., & Peters, O. C. J. J. (2002). Tensile and compressive properties of flax fibres for natural fibre reinforced composites. *Journal of Materials Science, 37*(8), 1683–1692.
54. Jawaid, M. H. P. S., & Khalil, H. A. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate Polymers, 86*(1), 1–18.
55. Sathishkumar, T. P., Naveen, J. A., & Satheeshkumar, S. (2014). Hybrid fiber reinforced polymer composites—A review. *Journal of Reinforced Plastics and Composites, 33*(5), 454–471.
56. Gururaja, M. N., & Rao, A. H. (2012). A review on recent applications and future prospectus of hybrid composites. *International Journal of Soft Computing and Engineering, 1*(6), 352–355.
57. Jawaid, M., & Siengchin, S. (2019). Hybrid composites: A versatile materials for future. *Applied Science and Engineering Progress, 12*(4), 223–223.
58. Bachmann, J., Yi, X., Gong, H., Martinez, X., Bugeda, G., Oller, S., et al. (2018). Outlook on ecologically improved composites for aviation interior and secondary structures. *CEAS Aeronautical Journal, 9*(3), 533–543.
59. Jose, S., Rajna, S., & Ghosh, P. (2017). Ramie fibre processing and value addition. *Asian Journal of Textile, 7*(1), 1–9.
60. Romanzini, D., Lavoratti, A., Ornaghi, H. L., Jr., Amico, S. C., & Zattera, A. J. (2013). Influence of fiber content on the mechanical and dynamic mechanical properties of glass/ramie polymer composites. *Materials & Design, 47*, 9–15.
61. Chapman, M., & Dhakal, H. N. (2019). Effects of hybridisation on the low velocity falling weight impact and flexural properties of flax-carbon/epoxy hybrid composites. *Fibers, 7*(11), 95.
62. Prabhakaran, D., Andersen, T. L., Markussen, C. M., Madsen, B., & Lilholt, H. (2013, July). Tensile and compression properties of hybrid composites—A comparative study. In *Proceedings of the 19thInternational Conference on Composite Materials (ICCM19)* (pp. 1029–1035). Canadian Association for Composite Structures and Materials.
63. Olusegun, D. S., Stephen, A., & Adekanye, T. A. (2012). Assessing mechanical properties of natural fibre reinforced composites for engineering applications. *Journal of Minerals and Materials Characterization and Engineering, 11*(1), 780–784.
64. Sapiai, N., Jumahat, A., & Mahmud, J. (2015). Flexural and tensile properties of kenaf/glass fibres hybrid composites filled with carbon nanotubes. *Jurnal Teknologi, 76*(3).
65. Cavalcanti, D. K. K., Banea, M. D., Neto, J. S. S., Lima, R. A. A., Da Silva, L. F. M., & Carbas, R. J. C. (2019). Mechanical characterization of intralaminar natural fibre-reinforced hybrid composites. *Composites Part B: Engineering, 175*, 107149.
66. Badrinath, R., & Senthilvelan, T. (2014). Comparative investigation on mechanical properties of banana and sisal reinforced polymer based composites. *Procedia Materials Science, 5*, 2263–2272.
67. Georgiadis, S., Gunnion, A. J., Thomson, R. S., & Cartwright, B. K. (2008). Bird-strike simulation for certification of the Boeing 787 composite moveable trailing edge. *Composite Structures, 86*(1–3), 258–268.