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c0010 Biocomposites for aerospace engineering applications

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s0010 10.1 Introduction

p0010 The use of new biological materials for the replacement of synthetic and harmful materials has been shown to offer enormous advantages (Hasan et al., 2021). Natural fibers are easily and affordably obtained from renewable resources and their incorporation and reinforcement with artificial materials can easily be achieved (Olaniyan & Adetunji, 2021). These bio-based materials have excellent biomedical applications due to their favorable biological and physical characteristics. The use of conventional synthetic polymers for composite applications has significant adverse environmental implications (Adetunji et al., 2023a, 2023b, 2021; Pugazhenthi & Anand, 2021). Biodegradable, biocompatible, and natural polymer materials have the potential to effectively replace their conventional polymer equivalents, thereby resolving a number of environmental issues (Adetunji et al., 2023c). Based on the material choice, processing techniques have a significant impact on composite performance (Verma et al., 2022). Bio-based composite materials that are highly sustainable and renewable are being developed for use in marine, automotive, and aerospace applications (Adetunji et al., 2023d). Many of these composites contain parts that have less of an environmental and carbon footprint. It is important to evaluate these biocomposites' long-term durability because their structural components may be subject to a variety of situations. Aerospace and aeronautics are highly technologically advanced sectors that were early adopters of new production processes like computer-aided design and manufacture. The biocomposites of naturally renewable resources with desired tune properties like acoustic, vibration, and electrical behavior can be used in aerospace vehicles (Fig. 10.1) (Bachmann et al., 2021). In this industry, attention is also growing on innovative natural/bio-based materials along with carbon fiber composites. Increased passenger traffic contributed to the aircraft industry's ongoing growth. As a result, this

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f0010 **Figure 10.1** Different aspects of biocomposites in aerospace engineering applications. *Source:* From Bachmann, J., Yi, X., Tserpes, K., Sguazzo, C., Barbu, L. G., Tse, B., Soutis, C., Ramón, E., Linuesa, H., & Bechtel, S. (2021). Towards a circular economy in the aviation sector using eco-composites for interior and secondary structures. Results and recommendations from the EU/China project ECO-COMPASS. *Aerospace, 8*(5). https://doi.org/10.3390/aerospace8050131.

industry is likely to attract investors in the near future, which will encourage competitiveness in the production of bio-based materials that are useful for structural design, aerodynamics, fluid flow, navigation, instrumentation, robotics, propulsion, combustion, and many others. Hence, different companies in the aviation sector must adopt the use of new technologies for the production of parts in the aerospace industry if they don't want to lag behind their competitors.

s0015 10.2 Materials and methods

p0015 A number of parts of aerospace vehicles have been made by using different materials including biocomposites through different methods. The antenna cover, which shields aircraft radar antennas from aerodynamic stresses, weather, hits from flying objects, and radar transparency, has a dome-shaped structure (Jamal et al., 2014). Materials for small airplane enclosures frequently have great durability and low

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dielectric constants. Aircraft structures are frequently made of high-strength fibers such as glass, carbon, and aramid in composite materials. The production of ecologically friendly technologies, however, is of greater importance to modern civilization (Blockley & Shyy, 2010). The demand for biodegradable materials has fueled the use of natural fibers. These bio-based composites have similar mechanical characteristics to synthetic fibers, such as biodegradability, low cost, and lightweight. Panel pieces are produced via vacuum packaging (Brunton et al., 2021). The vacuum bag method requires a flexible bag to be placed over the composite layer, sealed, and with all air sucked system from the bottom. Infusion of vacuum is used to create the dielectric cover. Biofiber is advised for usage in airplane coverings due to its low dielectric constant. Epoxy and hybrid fiber glass−kenaf laminates have been made using natural kenaf fiber (Tavares et al., 2020). A high-performance epoxy biocomposite covering material was developed using biosilica generated from agricultural waste (rice husks), and its viscoelasticity, thermal conductivity, and hydrophobic behavior were assessed (Karthigairajan et al., 2021). The production of a high-performing biocomposite coating material for use on aircraft air ducts was investigated in a study (Wang et al., 2020).

p0020 A thermochemical technique was used to produce the ultrafine biosilica particle, and amino-silane was used to modify the surface. According to viscoelastic data, the addition of 4% by volume of silane-modified biosilica resulted in a maximum storage modulus of 7.2 GPa, a loss factor of 0.51, and a glass transition temperature of 91°C. In contrast to 4 vol% silane-treated biosilica, which had a maximum thermal conductivity of 0.18 w/mK, 4 vol% biosilica in epoxy as received had a maximum thermal conductivity of 0.3 w/mK. Similarly, biosilica treated with silane (4 vol%) maintained a greater contact angle of 85 degrees, according to the results of the experiment involving contact angles. It was able to use this high-performance epoxy biocomposite coating material as an air duct coating material for passengers on flights to enhance air quality and reduce flow heat loss. In addition, the coating on the air channels increases the life span of the final product, including the rivets and welds. The material's thermal disintegration patterns, volatile emissions, and danger of spontaneous combustion were studied to standardize a recently produced green biocomposite based on marine, automobile, and aviation fire safety requirements. The freshly created green biocomposite was thermally characterized in the study with the goal of evaluating its thermal stability, identifying potential gaseous emissions, and establishing its lower flammability limit (LFL). To enhance the thermal profile of the green biocomposite, which is composed of 38% bioepoxy and flax fiber, an intumescent fire-retardant coating composed of ammonium polyphosphate-tris(2-hydroxyethyl) isocyanurate (APP-THEIC) and boric acid (BA) was applied (Biswal et al., 2019). The thermal stability of the newly produced material was assessed using the thermogravimetric analysis (TGA) technique. An analytical pyrolyzer connected to a gas chromatograph and mass spectrometer (Py-GC-Ms) was used to record the gaseous emissions from the green biocomposite at four chosen temperatures: 350°C, 550°C, 750°C, and 900°C. The species generated during pyrolysis were identified on the pyrograms using quantitative structure−property relationship (QSPR), and their LFL was

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computed. The accident risks of new materials were determined using NFPA 704 ("Standard System for the Identification of the Hazards of Materials for Emergency Response" is a standard maintained by the US-based National Fire Protection Association). Based on its thermal decomposition profile, degradation temperature, gaseous emissions, and lowered flammability limit, the green biocomposite developed in the study was described (Bahrami et al., 2020). Utilizing an intumescent fire-resistant coating (IFR) improves the material's fire resistance, and its final degradation temperature was close to 800°C. A new green biocomposite needs to be tested on a medium scale to evaluate its thermal degradation profile (Azeredo et al., 2010). According to a QSPR examination of gaseous emissions created by the pyrolysis of green biocomposite, LFL decreases with rising temperatures up to 750°C. According to the research on the toxicity of gaseous emissions, material heated over 350°C emits a sizable amount of phenol, which is dangerous to health. In a study, the flammability characteristics of composites composed of nanoclay and copolymer of acrylonitrile-butadiene-styrene (ABS) reinforced with kenaf fiber are examined. Natural fiber is one of the prospective materials that can be coupled with thermoplastics as a composite because of its appealing qualities, such as strength and lightness. Underwriters Laboratory 94 Horizontal Burning (UL94 HB), smoke density measurements, and limiting oxygen index (LOI) tests are used in a study to assess the material's flammability features (Karunakaran et al., 2016). The Federal Aviation Regulations (FAR) are complied with via these flammability tests. The presence of nanoclay with an efficient composition of ABS copolymer (ABS plastic) reinforced with kenaf fibers improved the burning capabilities of the material by reducing the formation of char on the material's surface, according to the results of UL94 HB and smoke density tests. As a result, less smoke is created, and the burning rate is decreased. The LOI test, on the other hand, showed that this material requires less oxygen to burn when exposed to fire, which prevents the enhancement of burning capabilities. The formation of barriers and the rate of flame propagation on the surface of the biocomposite material are stimulated as a result of the burning of nanoclay. Overall, these experimental results imply that this biocomposite material can self-extinguish and has effective fire-fighting capabilities. With significant benefits including cost-effectiveness, lightness, and biodegradable self-extinguishing biocomposite, the special synergism that was found from the acquired results is likely to be utilized in secondary aircraft structures (Brodeur et al., 2002).

s0020 10.3 Biocomposites for aerospace engineering applications—recent advances

p0025 Biocomposites are widely used by engineers in industries like aerospace. Fiber-reinforced composites for aircraft constructions must adhere to some of the strictest standards for their physical, chemical, electrical, thermal, and mechanical qualities among a wide range of structural applications (Gopi et al., 2017). Despite the many

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benefits of green composite materials, there are still some issues. Natural fibers have a lesser degree of homogeneity than glass and carbon, are less compatible with traditional resin systems, and have a propensity to absorb moisture. The performance of the composite solution must therefore be improved through preprocessing and modification. Numerous industrial applications use natural fiber−reinforced biocomposites because of their many benefits, which include superior mechanical properties, low production costs, renewability, and biodegradability. According to conventional definition, an aviation airfoil is a radar-transparent dome-shaped structure that shields the aircraft's radar antennae from aerodynamic stress, the outside environment, and bird strikes. Small aircrafts frequently have their skin made of materials with a high resistance and low dielectric constant. Composite materials composed of high-strength fibers such as fiberglass, carbon, and aramid are often used in airplane structures today (Renner et al., 2021). Natural fibers are now being used more frequently, nonetheless, as a result of the demand for biodegradable materials. Natural fibers share many mechanical properties with synthetic fibers and are also lightweight, affordable, renewable, and biodegradable. Sandwich structures with honeycomb cores are renowned for having a high flexural stiffness and greatly enhancing stiffness at a lower weight. They are frequently used in aircraft as fundamental structural components, as well as for flooring and interior decoration. High-performance aluminum and aramid are typical materials for honeycomb core applications, while fiberglass, carbon fiber, Nomex, and polymer-reinforced Kevlar are used in other industries. The increased need for natural fiber−reinforced composite constructions has recently fueled research into natural fiber honeycomb materials. Only a few studies, mostly focusing on the use of randomly chopped fibers, have been reported on the formation of a honeycomb structure using unidirectional fibers as reinforcement. This is primarily due to the fact that the process is challenging and frequently requiring many steps to allow fiber organization and curing. When using unidirectional fibers, which are stronger than randomly chopped fibers, a one-step procedure with vacuum infusion and a mold design is presented that encourages fiber alignment in the direction of the honeycomb fill (Manan et al., 2016). International civil aviation has grown dramatically over the past 20 years. Revenue passenger kilometers (RPK) or revenue passenger miles (RPM), the unit of measurement used to determine airline rates, normally doubles every 15 years. Over the next 20 years, air travel is anticipated to increase by 4.3%−4.8% annually, with Asia Pacific serving as the primary driver of percentage growth. Currently, the world's civil aviation is responsible for 2% of all man-made carbon dioxide (CO_2) emissions. The aviation industry has been challenged to contribute to reducing emissions through the International Civil Aviation Organization's (ICAO's) four innovation pillars, which include sustainable fuel, operations and infrastructure, product technology, and economic measures. Technology and biofuels are anticipated to have the biggest effects on attaining carbon-reduction goals. The aviation sector uses biojet fuel and biocomposite, which helps it become more sustainable and lowers CO_2 emissions than the conventional materials (Chen et al., 2019). Up to five recognized processes exist now for making biojet fuel, and each one provides a synthetic fuel with improved fuel

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efficiency, reduced CO_2, and soot emissions. The sustainability of the airplane is increased by using biocomposites rather than composite fibers derived from nonrenewable resources. The use of sustainable, renewable resources will be crucial to the advancement of biocomposites and their use in airplanes. Although biomass recovery is required to reduce aviation's environmental impact, cost is still a major consideration. Fossil fuel availability will decline, which will result in a rise in the price of products derived from them. Whether or not biomass is renewable and sustainable will determine whether or not items made from it are used in the aviation industry. The supply of raw materials must be sustainable if the aviation industry is to continue growing and uphold the high safety standards for which it is known (Curran et al., 2004). One potential mitigation strategy to lessen the environmental effects of the aviation industry has been the use of organic materials rather than fossil ones. Natural fiber polymer composites, which have shown improved environmental performance in the automobile industry, are currently being investigated as a weight-saving option for aircraft (Gomez-Campos et al., 2021). The study compares specific flax-based composite panels intended for airplane interior trim (such as bulkhead panels, tables, and baggage compartments) with a fiberglass composite core and epoxy honeycomb and quantifies the environmental impact of each. The assessment expanded the system to consider what happens to the leftover waste materials when flax fibers, used as reinforcement in biocomposite material, are transformed into technical textiles. The results demonstrated that the panels' overall environmental performance for usage in the aerospace industry is most significantly influenced by their weight (Rashid et al., 2021). In terms of climate change and marine eutrophication, the biocomposite panel fared better than the traditional panel when only panel manufacturing was taken into account (Curto et al., 2021). Flame retardant (FR) was also discovered to be a significant component in the environmental consequences of biomass. These advantages were insignificant when taking into account the whole life cycle of the panels because of the bio-based panels' larger weight (14%) and the fact that they are still in the prototype stage. Romero-Fierro et al. (2022) reported that the use of polymers has impacted technology and science with applications in the generation of macromolecular biomaterials. The authors described polymer-nanocomposite as an excellent bio-based material in aerospace industry owing to the favorable characteristics like thermal and mechanical resistance, lightness, corrosive resistance, radiation, magnetic, and conductivity. Their use involves design optimization processes for faster, safer, and cheaper applications in transportation. The authors demonstrated that the aerospace industry requires the use of materials like polymer composites with excellent resistance against heat, electromagnetic interference, corrosion and increased durability, conductivity, lightness, and low cost. They reported many advantages of biocomposites including enhanced mechanical properties such as modulus and stiffness, high structural and thermal stability, promising electrical and magnetic properties, noise damping, hydrophobicity, lower density, easy to produce, and low filler content. The authors further demonstrated that in aerospace industry, flame retardancy and thermal stability are the key properties that must be met by the material. They revealed that differential scanning calorimetry and TGA are the two important

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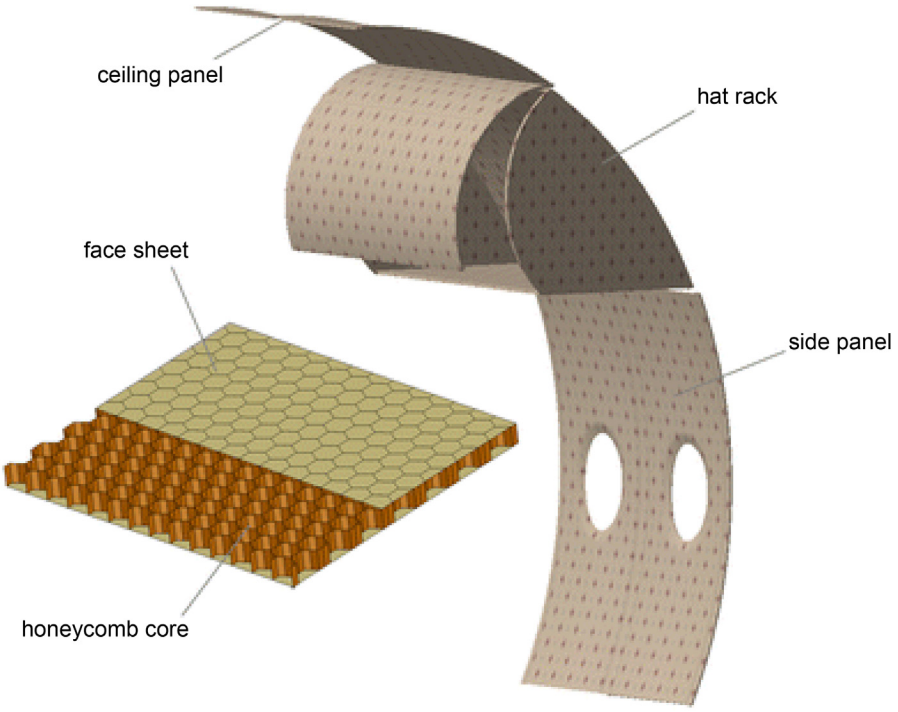
techniques utilized for the determination of thermal behavior in polymers. Biocomposites utilization in aerospace are important aspects of planning, accreditation, development, and maintenance operation of aircraft structures. Notably in the aerospace industry, electronic devices are affected by different transmitters being utilized for navigation, satellite propagation, and communication resulting in the production of electromagnetic interference within the environment. Thus, biocomposites are excellent materials that can protect and shield the aircraft from different electromagnetic radiation and pollution resulting in high performance. In aerospace painting and coating, biocomposites improve deicing, superhydrophobic, great water repellency properties, and antiicing requirements, particularly in polar climate conditions. Biocomposites are also good piezoelectric materials for aeronautical monitoring sensors in the aerospace industry. Farhan et al. (2022) reported that there is an increasing demand for very light materials with improved physiochemical characteristics like toughness and strength in aerospace industry. The authors emphasized the importance of polymer matrix-based composite materials that are biodegradable and hybrid in nature. The authors revealed that recently increased attention has been seen in the application of hybrid biocomposites in the aerospace industry. This may be due to increased investment in air travel and improved technology. Thus the materials utilized in the aerospace sector will determine the success that will be achieved. Materials commonly utilized in this sector must be strong and light with less environmental concerns. Hybrid biocomposites have also gained attention in lower acoustic signature, sound absorbing, and noise testing. The interior parts of aerospace vehicles (Fig. 10.2) can be made by using biocomposites with favorable properties including flammability, heat release, smoke and toxicity, and other benefits of natural fibers, for example, acoustic damping (Bachmann et al., 2018).

p0030 Recently, a large number of polymer nanocomposites with required properties have been shown to have great potential to be used in aerospace engineering applications. Table 10.1 summarizes a few important nanocomposites with their properties and applications in the field.

s0025 10.4 Limitation and market demand limitations

p0035 Traditional petroleum-based materials can be replaced with more cost-effective and sustainable biocomposites (Madyaratri et al., 2022). These composite materials do, however, have drawbacks that might restrict their range of use, like increased flammability when exposed to heat flow or flame initiators. Therefore, efforts to lessen the flammability of biocomposites are ongoing. The combustion of bio-based composites in buildings has the potential to result in scenarios that are dangerous and result in significant material and human losses. To strengthen the fire resistance of biocomposites and other materials, FR additives are frequently utilized (Mngomezulu et al., 2014). Lignin has been looked into for use as a low-cost, environmentally friendly FR addition to produce high-performance biocomposites

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f0015 **Figure 10.2** Biocomposites made interior parts of aerospace vehicles.
Source: From Bachmann, J., Yi, X., Gong, H., Martinez, X., Bugeda, G., Oller, S., Tserpes, K., Ramon, E., Paris, C., Moreira, P., Fang, Z., Li, Y., Liu, Y., Liu, X., Xian, G., Tong, J., Wei, J., Zhang, X., Zhu, J., . . . Yu, T. (2018). Outlook on ecologically improved composites for aviation interior and secondary structures. *CEAS Aeronautical Journal, 9*(3), 533−543. https://doi.org/10.1007/s13272-018-0298-z.

with enhanced engineering and fire qualities (Renner et al., 2021). By creating sustainable FR systems based on renewable raw materials, it is possible and promising to produce biocomposites with improved fire resistance, reduced negative environmental effects, and improved health and safety performance. There hasn't been much research done on the flammability of biopolymer composites reinforced with natural fibers (Idumah & Hassan, 2016). The scant usage of biopolymer composites and blends in a variety of technical disciplines, where the risk of fire and human danger is a severe issue, as well as the dearth of published scholarly works on the topic, are indications of their requirement. Therefore, it is crucial to deepen our understanding of biopolymers' flammability and help widen the scope of their potential applications. Bio-based products are utilized in the packaging business, and the usage of biocomposites in the electronics and transportation (automotive and aerospace) sectors has greatly expanded recently. However, components used in these applications must adhere to high flammability regulations (Haris et al., 2011). Nanocomposites and biocomposites, which have recently gained a lot of

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t0010 **Table 10.1** Summary of aerospace applications of polymer nanocomposites.

Application of nanocomposite	Polymer matrix	Reinforcement	Properties
EMI shielding	PVDF	Fe_3O_4/carbon	Lightweight
	PLA	Ag	Multiple scattering
	Epoxy resin	Iron, cobalt, nickel, and iron oxide	High strength and nonheavy
	PPy	$Ba_{0.6}Sr_{0.4}Fe_{12}O_{19}$	Low cost and resistant
	PAN and PU	Ni-Co	Intrinsic conductivity and magnetism
	PLAUs	Fe_3O_4	Shape recovery in a magnetic field
	Epoxy resin		CNTs
	Epoxy resin	EDFe_3O_4-CNTs/rGF	High EMISE value
	PANI	$CoFe_2O_4$	Anticorrosive properties
	PU	MHAPs	Anticorrosive properties
Coatings and paints	Epoxy-PANI	GONs	Anticorrosive and antifouling properties
	Poly(ethylene glycol) methyl ether methacrylate-co-glycidyl methacrylate	Fe_3O_4	Antifrosting property
	PVDF-HFP	SiO_2/CNTs	Antiicing and superhydrophobic properties
Structural health monitoring	PMDS	PZT	Superior piezoelectric behavior

CNTs, carbon nanotubes; EMI, electromagnetic interference; PANI, polyaniline; PLA, polylactic acid; PPy, polypyrrole; PU, polyurethane, PVDF, polyvinylidene fluoride; PVDF-HFP, poly(vinylidene fluoride-co-hexafluoropropylene, PAN, polyacrylonitrile; GONs, graphene oxide nanosheets (GONs; MHAP, magnetic hydroxyapatite nanoparticles; PZT, lead zirconate titanate; EMISE, empirical mean integrated squared error; PMDS, polymer matrix composite engineering; PLAU, polylactide-based polyurethane shape memory nanocomposites.

Source: From Romero-Fierro, D., Bustamante-Torres, M., Bravo-Plascencia, F., Esquivel-Lozano, A., Ruiz, J. C., & Bucio, E. (2022). Recent trends in magnetic polymer nanocomposites for aerospace applications: A review. *Polymers, 14*(19). https://doi.org/10.3390/polym14194084.

interest for their distinctive features, are the most significant of numerous polymer composite materials. The fundamental benefits of using biocomposites instead of petroleum-based goods unquestionably affect current development trends and provide guidance for additional study and application of polymer composites. Biocomposites are created and sold at a quick clip on the global market. The rising range of uses for new and enhanced materials, as well as the increased interest in

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and demand for these kinds of materials, are some of the reasons behind this (Masek & Kosmalska, 2022). Composites made of bio-based polymers are already utilized in a number of industries. This specifically applies to the transportation and building industries as well as packaging in the broadest sense. For instance, bionanocellulose, commonly referred to as bacterial cellulose, is a naturally occurring polymer with unique features that is widely used, particularly in a variety of medical applications (Abdur Rahman et al., 2023). The domain of composites composed of natural fibers, which are mostly made of organic compounds including cellulose, hemicellulose, and lignin, is also thoroughly studied. The popularity of biopolymers appears to be influenced by aspects such as functionality, processing requirements, and price. According to Fowler et al. (2006), there is still great space for development in both the quality and production efficiency of cellulosic composites. Before it can quickly replace current materials in an industrial setting, the material must be enhanced still further. In various investigations, the production, characteristics, and high-end uses of bacterial or plant nanocellulose are frequently contrasted. Biocomposites pose a challenge to fiberglass-reinforced composites, particularly in the building and automotive sectors (Brunton et al., 2021). To combine biofibers from nonrenewable and renewable sources with polymer matrixes to create a composite that is competitive with synthetic composites, special consideration must be given to the biofiber−matrix interface and novel processing techniques (Vinod et al., 2020). Polypropylene composites reinforced with natural fibers have seen commercial success in the automobile sector. This is because they are made from petroleum-based materials and the polymer matrix is not biodegradable, natural fiber−polypropylene or natural fiber−polyester composites are not sufficiently environmentally friendly. Combining natural fibers with polymers made from renewable resources can help solve many environmental issues. So-called green biocomposites are continuously produced by fusing biopolymers made from renewable resources with biofibers, such as cellulosic plastics, polylactides, starch plastics, polyhydroxyalkanoates (bacterial polyesters), and soy-based plastics.

s0030 10.5 Conclusions and recommendations

p0040 Biocomposites are renowned for having environmentally benign-ness, lightweight, chemical resistance, thermostability, and stronger mechanical qualities than the traditional composite materials. But there are existing research gaps in the usage of biocomposites in the aerospace sector, particularly in determining the potential spectrum of application. The utilization of appropriate biocomposites is responsible for the majority of triumphs in the aerospace industry. Biocomposites with high mechanical strength, durability, flame retardancy, chemical resistance, and thermal stability have been used in aerospace applications for lightweight spacecraft structures, coatings against harsh space environments, and the development of microelectronic subsystems. However, to explore their full potential, much more research and industrial involvement are essential through multidisciplinary collaborations. AU:1

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References

Abdur Rahman, M., Haque, S., Athikesavan, M. M., & Kamaludeen, M. B. (2023). A review of environmental friendly green composites: Production methods, current progresses, and challenges. *Environmental Science and Pollution Research*, *30*(7), 16905−16929. Available from https://doi.org/10.1007/s11356-022-24879-5, https://www.springer.com/journal/11356.

Abu Bakar, N., Sultan, M. T. H., Azni, M. E., & Ariffin, A. H. (2019). *Investigation of the mechanical properties of Napier-grass-reinforced composites for the aerospace industry* (pp. 321−334). Elsevier BV. Available from http://doi.org/10.1016/b978-0-08-102290-0.00014-3.

Adetunji, C. O., Ogundolie, F. A., Mathew, J. T., Inobeme, A., Olotu, T., Olaniyan, O. T., Ijabadeniyi, O. A., Ajiboye, M. D., Ajayi, O. O., Dauda, W., Ghazanfar, S., & Adetunji, J. B. (2023d). Graphene-based nanomaterials for targeted drug delivery and tissue engineering. In *SourceNovel Platforms for Drug Delivery Applications*, (277-288). Woodhead Publishing.

Adetunji, C. O., Olaniyan, O. T., Anani, O. A., Inobeme, A., & Mathew, J. T. (2021). Environmental impact of polyurethane chemistry. In *Journal Polyurethane Chemistry: Renewable Polyols and Isocyanates*, (393-411). Academic Press. American Chemical Society.

Adetunji, C. O., Olaniyan, O. T., Dare, A., & Adeniyi, M. J. (2023a). Nanomaterials derived from marine actinomycetes. *Next Generation Nanochitosan*, 117−124.

Adetunji, C. O., Olaniyan, O. T., Dare, A., Adeniyi, M. J., Ajayi, O. O., Adetunji, J. B., Akinbo, O., Inobeme, A. (2023b). Nanochitosan derived from marine fungi. Academic Press. Next Generation Nanochitosan, 105−110.

Adetunji, C. O., Olaniyan, O. T., Inobeme, A., Bodunrinde, R. E., Wike, N. Y., Palnam, W. D., Adetunji, J. B., Ozolua, P. O., Farid, A., Ghazanfar, S., Adeyomoye, O., Akram, M., Chukwu, C. V., & Yerima, M. B. (2023c). *Application of Nanotechnology for the Bioengineering of Useful Metabolites Derived from Algae and Their Multifaceted Applications. Next-Generation Algae: Volume II: Applications in Medicine and the Pharmaceutical Industry* (pp. 285−320). John Wiley & Sons, Inc.

Azeredo, H. M. C., Mattoso, L. H. C., Avena-Bustillos, R. J., Filho, G. C., Munford, M. L., Wood, D., & McHugh, T. H. (2010). Nanocellulose reinforced chitosan composite films as affected by nanofiller loading and plasticizer content. *Journal of Food Science*, *75*(1), N1−N7. Available from https://doi.org/10.1111/j.1750-3841.2009.01386.x.

Bachmann, J., Yi, X., Gong, H., Martinez, X., Bugeda, G., Oller, S., Tserpes, K., Ramon, E., Paris, C., Moreira, P., Fang, Z., Li, Y., Liu, Y., Liu, X., Xian, G., Tong, J., Wei, J., Zhang, X., Zhu, J., … Yu, T. (2018). Outlook on ecologically improved composites for aviation interior and secondary structures. *CEAS Aeronautical Journal*, *9*(3), 533−543. Available from https://doi.org/10.1007/s13272-018-0298-z.

Bachmann, J., Yi, X., Tserpes, K., Sguazzo, C., Barbu, L. G., Tse, B., Soutis, C., Ramón, E., Linuesa, H., & Bechtel, S. (2021). Towards a circular economy in the aviation sector using eco-composites for interior and secondary structures. Results and recommendations from the EU/China project ECO-COMPASS. *Aerospace*, *8*(5). Available from https://doi.org/10.3390/aerospace8050131.

Bahrami, M., Abenojar, J., & Martínez, M. Á. (2020). Recent progress in hybrid biocomposites: Mechanical properties, water absorption, and flame retardancy. *Materials*, *13*(22). Available from https://doi.org/10.3390/ma13225145.

To protect the rights of the author(s) and publisher we inform you that this PDF is an uncorrected proof for internal business use only by the author(s), editor(s), reviewer(s), Elsevier and typesetter MPS. It is not allowed to publish this proof online or in print. This proof copy is the copyright property of the publisher and is confidential until formal publication.

Bhat, A., Budholiya, S., Raj, S. A., Sultan, M. T. H., Hui, D., Shah, A. U. M., & Safri, S. N. A. (2021). Review on nanocomposites based on aerospace applications. *Nanotechnology Reviews*, *10*(1), 237–253. Available from https://doi.org/10.1515/ntrev-2021-0018, http://www.degruyter.com/view/j/ntrev?rskey = tED3So&result = 1.

Biswal, T., Priyadarsini, M., & Dash, S. (2019). Sustainable biocomposite its manufacturing processes and applications. *Egyptian Journal of Chemistry*, *62*(4), 751–766.

Blockley, R., & Shyy, W. (2010). *Encyclopedia of aerospace engineering*. John Wiley & Sons Ltd.

Brodeur D.R. Young P.W. Blair K.B. 2002, Problem-based learning in aerospace engineering education. ASEE Annual Conference Proceedings. United States. 2109–2116.

Brunton, S. L., Kutz, J. N., Manohar, K., Aravkin, A. Y., Morgansen, K., Klemisch, J., Goebel, N., Buttrick, J., Poskin, J., Blom-Schieber, A. W., Hogan, T., & McDonald, D. (2021). Data-driven aerospace engineering: Reframing the industry with machine learning. *AIAA Journal*, *59*(8), 2820–2847. Available from https://doi.org/10.2514/1.J060131, http://arc.aiaa.org/loi/aiaaj.

Chen, J. T., Abdullah, L. C., & Tahir, P. M. D. (2019). *Biomass valorization for better aviation environmental impact through biocomposites and aviation biofuel* (pp. 19–31). Elsevier BV. Available from http://doi.org/10.1016/b978-0-08-102291-7.00002-2.

Curran, R., Raghunathan, S., & Price, M. (2004). Review of aerospace engineering cost modelling: The genetic causal approach. *Progress in Aerospace Sciences*, *40*(8), 487–534. Available from https://doi.org/10.1016/j.paerosci.2004.10.001.

Curto, M., Le Gall, M., Catarino, A. I., Niu, Z., Davies, P., Everaert, G., & Dhakal, H. N. (2021). Long-term durability and ecotoxicity of biocomposites in marine environments: A review. *RSC Advances*, *11*(52), 32917–32941. Available from https://doi.org/10.1039/d1ra03023j, http://pubs.rsc.org/en/journals/journal/ra.

Farhan, M., Mastura, M. T., Ansari, S. P., Muaz, M., Azeem, M., & Sapuan, S. M. (2022). *Advanced potential hybrid biocomposites in aerospace applications: A comprehensive review*. *Advanced Composites in Aerospace Engineering Applications* (pp. 127–148). Springer International Publishing. Available from https://link.springer.com/book/978-3-030-88192-4, http://doi.org/10.1007/978-3-030-88192-4_6.

Fowler, P. A., Hughes, J. M., & Elias, R. M. (2006). Biocomposites: Technology, environmental credentials and market forces. *Journal of the Science of Food and Agriculture*, *86*(12), 1781–1789. Available from https://doi.org/10.1002/jsfa.2558.

Gomez-Campos, A., Vialle, C., Rouilly, A., Hamelin, L., Rogeon, A., Hardy, D., & Sablayrolles, C. (2021). Natural fibre polymer composites - A game changer for the aviation sector? *Journal of Cleaner Production*, *286*. Available from https://doi.org/10.1016/j.jclepro.2020.124986.

Gopi, S., Balakrishnan, P., Sreekala, M. S., Pius, A., & Thomas, S. (2017). *Green materials for aerospace industries* (pp. 307–318). Elsevier BV. Available from http://doi.org/10.1016/b978-0-08-100793-8.00011-9.

Haris, M. Y., Laila, D., Zainudin, E. S., Mustapha, F., Zahari, R., & Halim, Z. (2011). Preliminary review of biocomposites materials for aircraft radome application. *Key Engineering Materials*, *471*(472), 563–567. Available from https://doi.org/10.4028/http://www.scientific.net/kem.471-472.563.

Hasan, K. M. F., Horváth, P. G., Kóczán, Z., & Alpár, T. (2021). Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites. *Scientific Reports*, *11*(1). Available from https://doi.org/10.1038/s41598-021-83140-0. Available from: http://www.nature.com/srep/index.html.

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Idumah, C. I., & Hassan, A. (2016). Emerging trends in flame retardancy of biofibers, biopolymers, biocomposites, and bionanocomposites. *Reviews in Chemical Engineering*, *32* (1), 115−148. Available from https://doi.org/10.1515/revce-2015-0017, http://www.reference-global.com/loi/revce.

Jamal, Q. M., Majid, D. L., Haris, M. Y., Yidris, N., & Sultan, M. T. H. (2014). Quasi static analysis of a biocomposite aircraft radome. *Applied Mechanics and Materials*, *629*, 78−81. Available from https://doi.org/10.4028/http://www.scientific.net/AMM.629.78, http://www.scientific.net/AMM.

John, M. J. (2018). *Flammability performance of biocomposites*. *Green Composites for Automotive Applications* (pp. 43−58). Elsevier. Available from https://doi.org/10.1016/B978-0-08-102177-4.00002-1, http://www.sciencedirect.com/science/book/9780081021774.

Karthigairajan, M., Nagarajan, P. K., Raviraja Malarvannan, R., Ramesh Bapu, B. R., Jayabalakrishnan, D., Maridurai, T., & Shanmuganathan, V. K. (2021). Effect of silane-treated rice husk derived biosilica on visco-elastic, thermal conductivity and hydrophobicity behavior of epoxy biocomposite coating for air-duct application. *Silicon*, *13*(12), 4421−4430. Available from https://doi.org/10.1007/s12633-020-00772-z.

Karunakaran, S., Majid, D. L., & Tawil, M. L. M. (2016). Flammability of self-extinguishing kenaf/ABS nanoclays composite for aircraft secondary structure. *IOP Conference Series: Materials Science and Engineering*, *152*(1). Available from https://doi.org/10.1088/1757-899x/152/1/012068.

Madyaratri, E. W., Ridho, M. R., Aristri, M. A., Lubis, M. A. R., Iswanto, A. H., Nawawi, D. S., Antov, P., Kristak, L., Majlingová, A., & Fatriasari, W. (2022). Recent advances in the development of fire-resistant biocomposites—A review. *Polymers*, *14*(3). Available from https://doi.org/10.3390/polym14030362, https://www.mdpi.com/2073-4360/14/3/362/pdf.

Manan, N. H., Majid, D. L., & Romli, F. I. (2016). Mould design and manufacturing considerations of honeycomb biocomposites with transverse fibre direction for aerospace application. *IOP Conference Series: Materials Science and Engineering*, *152*(1). Available from https://doi.org/10.1088/1757-899x/152/1/012013.

Masek, A., & Kosmalska, A. (2022). Technological limitations in obtaining and using cellulose biocomposites. *Frontiers in Bioengineering and Biotechnology*, *10*. Available from https://doi.org/10.3389/fbioe.2022.912052.

Mngomezulu, M. E., John, M. J., Jacobs, V., & Luyt, A. S. (2014). Review on flammability of biofibres and biocomposites. *Carbohydrate Polymers*, *111*, 149−182. Available from https://doi.org/10.1016/j.carbpol.2014.03.071, http://www.elsevier.com/wps/find/journaldescription.cws_home/405871/description#description.

Olaniyan, O. T., & Adetunji, C. O. (2021). Biological, biochemical, and biodiversity of biomolecules from marine-based beneficial microorganisms: industrial perspective. *Microbial Rejuvenation of Polluted Environment*, *3*, 57−81.

Pugazhenthi, N., & Anand, P. (2021). Mechanical and thermal behavior of hybrid composite medium density fiberboard reinforced with phenol formaldehyde. *Heliyon*, *7*(12). Available from https://doi.org/10.1016/j.heliyon.2021.e08597.

Rashid, M., Hanus, J. L., Chetehouna, K., Khellil, K., Aboura, Z., & Gascoin, N. (2021). Investigation of the effect of tufts contribution on the in-plane mechanical properties of flax fibre reinforced green biocomposite. *Functional Composite Materials*, *2*(1). Available from https://doi.org/10.1186/s42252-021-00019-z.

Renner, J. S., Mensah, R. A., Jiang, L., Xu, Q., Das, O., & Berto, F. (2021). Fire behavior of wood-based composite materials. *Polymers*, *13*(24). Available from https://doi.org/10.3390/polym13244352, https://www.mdpi.com/2073-4360/13/24/4352.

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Romero-Fierro, D., Bustamante-Torres, M., Bravo-Plascencia, F., Esquivel-Lozano, A., Ruiz, J. C., & Bucio, E. (2022). Recent trends in magnetic polymer nanocomposites for aerospace applications: A review. *Polymers*, *14*(19). Available from https://doi.org/10.3390/polym14194084, http://www.mdpi.com/journal/polymers.

Tavares, T. D., Antunes, J. C., Ferreira, F., & Felgueiras, H. P. (2020). Biofunctionalization of natural fiber-reinforced biocomposites for biomedical applications. *Biomolecules*, *10* (1). Available from https://doi.org/10.3390/biom10010148, https://www.mdpi.com/2218-273X/10/1/148/pdf.

Verma, D., Dong, Y., Sharma, M., & Chaudhary, A. K. (2022). Advanced processing of 3D printed biocomposite materials using artificial intelligence. *Materials and Manufacturing Processes*, *37*(5), 518−538. Available from https://doi.org/10.1080/10426914.2021.1945090, http://www.tandf.co.uk/journals/titles/10426914.asp.

Vinod, A., Sanjay, M. R., Suchart, S., & Jyotishkumar, P. (2020). Renewable and sustainable biobased materials: An assessment on biofibers, biofilms, biopolymers and biocomposites. *Journal of Cleaner Production*, *258*. Available from https://doi.org/10.1016/j.jclepro.2020.120978.

Wang, Y., Ying, Z., Xie, W., & Wu, D. (2020). Cellulose nanofibers reinforced biodegradable polyester blends: Ternary biocomposites with balanced mechanical properties. *Carbohydrate Polymers*, *233*. Available from https://doi.org/10.1016/j.carbpol.2020.115845.

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Abstract

The need to replace synthetic-derived materials has increased significantly due to the recent advancements in natural fiber−reinforced polymer composites in the automotive, gas and oil, construction, electronics, and aerospace industries. However, the widespread use of biomaterials has been limited by their poor flame-retardant (FR) properties. There is an increased demand from automotive and aerospace industries to produce environmentally friendly bio-based materials with non-halogenated self-extinguishing properties. Studies have shown that enhancing the FR characteristics of biomaterials can increase their adaptability in aerospace industry. This chapter focuses on the emerging technologies utilized for biocomposite, biopolymer, and biofiber production and their applications in the aerospace industry.

Keywords: Biocomposite; biopolymers; automotive; flame retardant; aerospace industry