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# Green Polymer Composites for Aerospace Engineering Applications : A Review

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***Abstract*— In the last decade, Study on the use of natural fibers as synthetic substitute materials or green polymer composites is growing. The growth of green polymer composites has had a significant impact on polymer composite research and innovation. This rapid growth provides advantages over low-cost synthetic fiber composites and reduces adverse impacts on the environment. Because of its potential, this material is applied in various engineering fields, including in the aerospace engineering. In recent years, various improvements have been made to natural fiber composite materials to improve physical, mechanical and chemical properties. The aim of this review is to highlight trends in the use of natural fiber polymer composites applied to the aerospace engineering. This review article explains the latest research activities regarding green polymer composite fabrication, advantages of green polymer composites, and applications in the aerospace engineering.**

***Keywords—composite, natural fiber, polymer, green, aerospace.***

## I. Introduction

The development of the aerospace engineering is increasingly diverse. The use of advanced materials as part of aircraft is one option. The use of natural fibers as composite materials is an innovation to protect the environment, low production costs, and reduce the weight of objects. The use of natural fibers as composites is usually called Green Polymer Composites. Green polymer composite has the potential to become an alternative material for aircraft, especially for interiors such as trim and panels.

Green polymer composites, sourced from renewable materials like flax, hemp, jute, or bamboo, play a crucial role in diminishing reliance on non-renewable resources, thereby fostering environmental sustainability. The incorporation of natural fibers not only reduces costs, density, and weight but also aligns with eco-friendly principles, minimizing pollution and health risks. Beyond the economic and environmental advantages, the utilization of natural fibers in composite development is noteworthy for their sustainability, serving as renewable raw materials for innovative green products. The biological, chemical, environmental, and economic attributes of these fibers significantly enhance the overall properties of fiber composites, extending their application across various modern uses.

The degradability of natural fibers adds a strong recyclability dimension to fiber composites, supporting the creation of composites featuring natural fibers [1]. Notably, the density of green polymer composites is lower than that of glass fiber at 2.4 g/cm$^3$, resulting in lightweight composites [2]. Previous research underscores that a 1 kg reduction in aircraft weight can lead to a 0.94 kg decrease in carbon emissions for the Boeing 747-400 and a 0.475 kg reduction for the Airbus A330-300. Moreover, it is suggested that cutting 1 kg of carbon emissions can save up to 0.3 kg of aviation fuel [3]. This highlights the potential of employing green polymer composites in aircraft interior materials to reduce overall aircraft weight, thus generating increased interest in the commercial adoption of these composites in the aerospace interiors sector. On the other hand, the use of green polymer composites as aircraft interior materials faces numerous challenges. One of these challenges is the voids within the composite, where these voids impact the properties of the material, necessitating further research [4]. This chapter discusses the current applications of natural fibers as green polymer composites for aerospace engineering. Topics covered include an introduction to present aerospace interior materials, manufacturing, and the benefits the materials offer. Hopefully that this chapter will provide readers with a positive insight, risks of usage and challenges related to the potential use of green polymer composites in aerospace applications and the current performance of aerospace materials, especially in terms of light weight and environmental sustainability.

## II. Green Composite Polymer

Green polymer composites are one of the developments in advanced materials. These composites use natural fibers as fillers or reinforcements for polymer matrices. The reason for choosing natural fibers is their abundance and environmental friendliness. They are eco-friendly and biodegradable, and they reduce the problem of solid waste production when used to replace nondegradable fillers [5]. Due to their inherent properties, natural fibres are flexible. Additionally, natural fibers are easily obtainable and offer low-cost production. Natural fibers contain various components, and these components play a crucial role in determining the strength and quality of the composite. The key components are lignin, hemicellulose, and cellulose. Detail of the structure of natural fibers [6] presented in Fig. 1.

Research on natural fiber composites has advanced significantly. Various types of natural fibers are combined with polymers to achieve desired properties for specific products. [7] state that the density of fiberglass is (2.2 g/cm$^3$), while the natural fibers used in green polymer composites have a density of 0.5 – 1.5 g/cm3 [8-12]. The densities of various natural fibers are presented in Table 2. Green polymer composites are chosen as a material option for aircraft interiors due to their low density. Table 1 illustrates the utilization of various natural fibers in green polymer composites. However, the challenges faced in using natural fibers lie in their inherent characteristics. Natural fibers have weaknesses in thermal resistance, water absorption, and degradability, which need to be innovatively addressed through the choice of matrices to improve these properties [13].

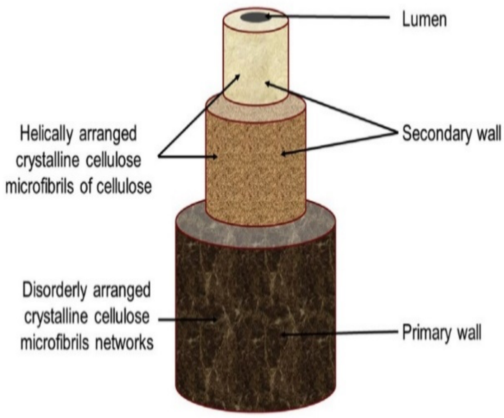


Fig. 1. Structure of Natural Fiber [6]

TABLE I. NATURAL FIBER DENSITY [8-12]

| Fiber | Component | | | |
|---|---|---|---|---|
| | Lignin (%) | Hemi-cellulose (%) | cellulose (%) | Density (g/cm3) |
| Abaca | 7-9 | 15-17 | 56-63 | 1,5 |
| Bamboo | 5-31 | 30 | 26-43 | 0,91-1,26 |
| Bagasse | 15-25 | 32-38 | 25-45 | 1,2 |
| Banana | 5 | 17-21 | 63,83 | 1,35 |
| Kenaf | 22 | 8-13 | 45-57 | 1,25-1,40 |
| Pineapple | 8-11 | 4-6 | 70-75 | 1,44 |
| Rice Husk | - | - | 38-45 | 0,5-0,7 |

TABLE II. RESEARCH ON GREEN POLYMER COMPOSITES

| Reinforcement | Matrix | Source |
|---|---|---|
| Rice husk and Sisal | Polyurethane | [14] |
| Oil palm and jute | Epoxy | [15] |
| Banana and Coconut | Polyester | [16] |
| Sisal and Bamboo | Polyester | [17] |
| Banana and kenaf | Polyester | [18] |
| Coir and jute | Epoxy | [19] |

## III. FABRICATION PROCESS

The natural fibers were reinforced in different forms in the matrix such as long fiber, short fiber, different orientation and mat form. For the fabrication of the fiber composites, various techniques are followed [20]. In recent years, various new fabrication methods were developed based on the composite design and to overcome the manufacturing challenges. Mostly selection of fabrication method depends on the type of matrix material, size and shape of the composite material and end-use or application [21].

Composite from flax fiber using one of the simplest methods, namely the hand lay-up method [22]. The hand lay-up method is a simple method using hands and for natural fiber composites it is usually done per layer of fiber [23]. However, the weakness is that voids and porosity are often found [24]. Study on the fabrication of green polymer composites from flax fiber using the vacuum-assisted resin transfer molding method [25]. The obtained results indicated minimal occurrence of voids and porosity in its micron structure, resulting in excellent strength. The concept of resin transfer molding involves flowing the matrix into an air-free mold to minimize the entry of air. Table 3 shows various fabrication processes of Green Polymer Composites.

TABLE III. VARIOUS FABRICATION PROCESS

| Matrix | Reinforcement | Method | References |
|---|---|---|---|
| Epoxy | Ramie fiber | Vacuum Infusion | [26] |
| Epoxy | Kenaf fiber | Hand lay-up | [27] |
| Epoxy | Flax and bamboo | Vacuum Bag | [28] |
| Polyester | Sisal fiber | Resin Transfer Moulding | [29] |

## IV. ADVANTAGES AND CHALLENGE OF GREEN POLYMER COMPOSITES ON AEROSPACE ENGINEERING

The use of natural fibers as green polymer composites, especially in applications in aerospace engineering, offers many advantages. One of these advantages is lightweight. Natural fiber composites typically have lower density compared to traditional aerospace materials like metals and fiberglass. The density of natural fiber-reinforced polymer composites is lower compared to synthetic fiber-reinforced polymer composites, resulting in an increased payload capacity for the aircraft structure. Notably, green polymer composites are entirely biodegradable, in contrast to the non-biodegradable nature of current synthetic fiber-reinforced polymer composites, which poses significant environmental concerns. The cost of natural fibers is considerably low, offering the potential to reduce the overall manufacturing cost of aircraft structures by incorporating these composites. The extraction of natural fibers is a simple process that can be carried out by unskilled labor, while the manufacturing of synthetic fibers is complex, requiring skilled personnel [30].

Additionally, the production of natural fiber-reinforced polymer composites does not pose health-related issues to workers, whereas working with synthetic fiber composites necessitates stringent safety precautions. Moreover, natural fibers are noncorrosive, and their low specific weight contributes to higher specific strength and stiffness [30]. This reduction in weight contributes to overall weight savings in aircraft, potentially leading to improved fuel efficiency and performance. 1 kg reduction in aircraft weight can lead to a 0.94 kg decrease in carbon emissions for the Boeing 747-400 and a 0.475 kg reduction for the Airbus A330-300. Moreover, it is suggested that cutting 1 kg of carbon emissions can save up to 0.3 kg of aviation fuel [3]. Other advantage is envoironmental sustainability. Natural fibers are renewable resources, and their use in composites aligns with the aerospace engineering growing emphasis on sustainability. This can be especially relevant as the aviation sector seeks to reduce its environmental impact and adopt more eco-friendly materials.

Other advantages of green polymer composites in their mechanical properties is tensile strength. The tensile strength of the composite is needed to withstand the tensile loads that occur. The strength can be improved in airplane, of course there is a lot of loading. Therefore, natural fiber composites are needed that have good tensile strength. The strength can increase if given certain treatments such as alkali chemical treatment. Additionally, it can also be varied in fiber length so that the strength of green polymer composites can be improved.

Previous study explored the impact of coir fiber length on epoxy composites, introducing coir fiber at three different lengths (5 mm, 20 mm, 30 mm) [31]. The findings indicated a significant enhancement in the tensile strength of the composites, with the maximum strength observed in the 30 mm coir fiber composite. Another research discussed the tensile characteristics of phormium fiber within an epoxy matrix, employing both short and long fiber reinforcements at 20% [32]. The long fiber reinforcement exerted a dominant effect on the tensile properties of the short fiber, attributed to the distribution of fibers in the matrix. Variation in tensile strength resulting from alkaline-treated fiber reinforcement in epoxy composites. Alkaline treatment substantially increased both tensile strength and modulus. In comparison to bamboo and linen fibers, flax fiber demonstrated the highest tensile properties [28]. Hemp fiber-reinforced polylactic acid (PLA) composites, highlighting the impact of alkaline treatment. The tensile modulus of the treated composite (85 GPa) exhibited a twofold increase compared to the neat PLA composite (35 GPa) [33]. For natural fiber kenaf composites reinforced with a PLA matrix at a 70% volume fraction, the maximum tensile strength reached 223 MPa. However, beyond 70% fiber volume, the tensile strength declined due to the presence of voids and insufficient matrix [34]. Other research about tensile strength on green polymer composites which has prospect on aerospace interior shown in the Table 4.

Another advantage of using green composite polymer as a material for aerospace engineering is enchance the damping properties. With lower cost for production, green polymer composites offer damping vibration ability. On airplanes, vibrations occur that come from various sources, which have a significant impact on flight safety and comfort. Apart from aircraft engines, vibrations also come from external factors such as weather and air which cause turbulence. The advantage of Natural Fiber Polymer Composites is that it is able to reduce and even dampen vibrations because it contains hemi-cellulose in the natural fiber. [35,36]. Shock-absorbing properties of flax fiber/epoxy polymer materials studied before. They observed that the damping capacity of flax composites was 51% higher than that of glass fiber composites [37]. Sisal fiber also combined effect for sisalbanan fiber length and content on the free vibration and damping properties of polyester composites [38]. They found that an increase in fiber content (50 wt%) affected the vibration and free damping properties more than a change in fiber length, and the authors concluded that this could be due to the fiber has naturally high porosity. Chemical treatment on natural fiber also affect to natural frequency, [39] investigated the impact of sodium hydroxide treatment on the natural frequency and damping characteristics of banana/sisal composite with increased fiber weight percentage. The outcomes of their study revealed elevated natural frequency and damping factors in both banana and sisal-reinforced polymer composites, in contrast to untreated composites. These improvements were attributed to the heightened stiffness of the material resulting from the sodium hydroxide treatment.

In addition to the various benefits and possibilities associated with the application of green polymer composites, there are undoubtedly challenges and risks to contend with. The natural fibers employed in these composites exhibit notable water absorption. Recent investigations focused on understanding the impact of water absorption on the mechanical properties of hybrid polyester composites reinforced with short roselle and sisal fibers. Researchers observed a significant decline in tensile and flexural strength when the material was wet, indicating that moisture exposure adversely affected the fiber's mechanical characteristics [40]. This reduction in mechanical properties is attributed to the presence of hydrophilic chemical elements such as cellulose and hemicellulose in natural fibers, making them susceptible to humidity and moisture [41]. Additionally, natural fibers possess low dielectric constants.

In the aerospace industry, high-performance synthetic fibers like carbon fiber, glass fiber, and Kevlar fiber are commonly utilized. Nevertheless, the growing demand for biodegradable materials has prompted researchers to explore the use of natural fibers. Despite these efforts, a combination of natural and synthetic fibers is still necessary to address the existing challenges, indicating that the complete utilization of natural fibers has not yet been achieved [42].

TABLE IV. TENSILE PROPERTIES OF GREEN POLYMER COMPOSITES

| Fiber | Matrix | Properties | | Source |
|---|---|---|---|---|
| | | Tensile strength (MPa) | Modulus (GPa) | |
| Ramie fiber | Epoxy | 86 | 9,56 | [43] |
| Banana Fiber | Polypropylene | 45,26 | 0,98 | [44] |
| Kenaf Fiber | Epoxy | 30 | 4,5 | [27] |
| Bamboo Fiber | Epoxy | 269 | 16,43 | [45] |
| Flax Fiber | Epoxy | 189,23 | 16,2 | [46] |

## V. APPLICATIONS FOR AEROSPACE ENGINEERING

Green polymer composites with their various advantages have the potential to become products for the interior of aerospace. In the aircraft, there has been a concerted effort to create eco-friendly aircraft interiors utilizing natural fibers. The adoption of green polymer composites for interior components aims to substitute non-renewable resources and potentially harmful materials like glass fibers and phenolic resins. This shift not only enhances fuel efficiency and reduces the carbon footprint, likely due to the decreased weight, but it also underscores the importance of maintaining adequate strength and meeting rigorous safety standards. These safety requirements primarily revolve around fire performance, weight considerations, and other mechanical properties.

For the example, [47] focused on developing commercial panels for cabin interior from woven flax fabric and phenolic matrices. To satisfy airworthiness standards, they put more effort into solving the issues related to strength, moisture absorption, and adhesion between the fiber and matrix. In a contrasting scenario, fibers derived from bast plants like hemp, kenaf, and flax serve as a strengthening component for the internal structures of aircraft. In addition, the production of natural fiber composites has also been pursued, aiming for good thermal resistance for panels in aircraft. Moreover, these natural fiber composites have been patented through a European patent application in 2012 [48]. These eco-friendly composites find application in various indoor components such as seat cushions, cabin linings, and parcel shelves. An innovative application involves the utilization of jute fiber-reinforced polyester/epoxy with red mud for constructing pilots' cabin doors and shutters [49]. Given the critical importance of weight in aviation, natural fiber composites have been employed in constructing the wing box. Comparative analyses have been conducted, contrasting the performance of these natural fiber composite wing boxes with a conventional counterpart made from aluminum alloy. Notably, the use of ramie fiber composites resulted in a weight reduction of approximately 12%-14% [50]. Another utilization within aircraft components involves the implementation of radomes. An aircraft radome takes on a dome-shaped structure designed to shield radar antennas from adverse weather conditions, aerodynamic forces, and potential damage caused by bird strikes. The materials employed for this purpose consist of bamboo fibers, kenaf, and empty oil palm fruit bunches. The process entails blending synthetic fibers with natural fibers, enabling these hybrid composites to enhance both rain erosion resistance and mechanical properties [42].

## VI. CONCLUSION

Green polymer composites composites show promise in aerospace engineering, especially in applications where weight reduction and sustainability are critical. Ongoing research and development are likely to address challenges and expand the use of these materials in various aerospace components.

For the latest advancements and specific details, it's recommended to refer to recent scholarly articles, conference proceedings, and industry publications related to natural fiber for green polymer composites in aerospace engineering.

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