Chapter 1
Green Composites Reinforced with Natural Fibers: A Review on Mechanical Properties

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Abstract The rapid development of modern social economy, the acceleration of industrialization, and the increasingly serious environmental problems have severely restricted the sustainable development of social ecology. At present, the public's awareness of environmental protection has been greatly improved, and the development and application of green materials have received more and more attention. In order to improve the utilization efficiency and quality of green composite materials, the first step is to clarify the concepts and characteristics of green materials, then grasp the value and development trend of green materials, and finally analyze their applications in-depth to make green composite materials possible. Green material is a new material concept, so its advantages and value must be clarified in the application process in order to fully develop and use green materials, so as to better serve social development. Natural fiber is a diverse and renewable resource. Its availability and satisfactory mechanical properties make it a potential substitute for man-made fibers and can be widely used in various fields. However, natural fibers still have some inherent deficiencies such as hydrophilicity and variability. Physical and chemical treatments are used to improve the mechanical properties of natural fibers, thereby improving the properties of natural fiber composites. This study gives a detailed overview of these sustainable and renewable natural fiber composite materials. The general characteristics of natural fibers used in green composites will be reviewed, including types, sources, properties, as well as improved methods. Furthermore, the application of natural fibers composites in various fields is studied.

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A. Ismail et al. (eds.), *Advanced Maritime Technologies and Applications*,
Advanced Structured Materials 166,
https://doi.org/10.1007/978-3-030-89992-9_1

Keywords Green composite · Natural fiber · Mechanical properties · Treatment · Application

1.1 Introduction

Green composite material refers to a material with environmental protection performance, good environmental performance, easy to recycle and reuse, meet the needs of energy saving and consumption reduction, and has a small impact on the environment during product processing. In terms of the characteristics of green materials, in metallurgy and chemical industries related to the preparation of engineering materials, the acquisition of green composite materials is green, which can effectively reduce energy consumption and improve environmental protection. Green composite materials have relatively little impact on the environment during product processing and manufacturing, and they also have environmental protection characteristics during use, which can effectively reduce the adverse effects on human health. The recycling of green materials, while saving resources and protecting the environment, facilitates enterprises to strengthen cost control and improve material production efficiency, which is of great significance to the maintenance of the comprehensive benefits of enterprises [1]. High-performance composite materials mainly refer to a class of composite materials that are compounded with high-performance reinforcing fibers and a high-performance resin matrix that can meet high-end applications such as aerospace. Its advantage lies in its comprehensive performance, especially its lightweight and high strength, which can greatly enhance the structural quality when used as a structural material. High-performance composite materials were successfully developed in the 1960s [2]. They were first used in airplanes. Now they have rapidly developed into energy, transportation, ships, automobiles, chemicals, machinery, and other fields. For more than half a century, the mainstream of the development of high-performance composite materials has been carbon fiber reinforced resin-based composite materials. Due to the diversity of fiber types, some fibers can be directly extracted and processed for use, such as cotton fiber and hemp fiber. However, other plant fibers need to use solvents to dissolve the cellulose fibers in the plant, remove impurities, and then use special equipment to draw out the filaments to crystallize and sample them before they can be used [3].

1.2 Properties of Green Composites Reinforced with Natural Fibers

A composite material is a combination of two or more materials with different chemical or physical properties to create high-performance materials. The reinforced material has high strength and low density, while the matrix material has toughness and ductility, so the composite material can have a variety of properties [4]. Composites using reinforced materials are the most widely used polymer composites today. There are many materials in the world that can enhance polymers. These structural materials are based on polymers and are completely covered with reinforcing materials. Without these reinforcing materials, the polymer will provide relatively poor mechanical properties. In the research of polymer composites, natural fibers have been widely studied for their use as reinforcement materials. The properties of composite materials are generally attributed to the high strength and high modulus of the fibers and are reinforced by the matrix, which acts as a load transfer medium between the two phases [5].

In the past, extracting natural fibers from nature and replacing traditional high-strength synthetic fibers to form a new type of green composite materials has always been the research object of sustainable green development [6]. As reinforcement materials, natural or bio-fibers are embedded in a green composite polymer matrix to form the dispersed phase and to increase the strength and stiffness of the composites as it carries the stress and loads imposed on the prepared composite [7]. Natural fibers play an important role in the field of sustainable green composite technology due to their availability and satisfactory mechanical properties. These plant fibers are biodegradable, renewable, cheap, recyclable, and friendly to the environment and humans. These properties and characteristics make it a potential substitute for glass, carbon, and other manmade fibers.

The most important characteristic feature of materials used in various applications is depending on their performance. The properties of materials usually depend on the isotropy and anisotropy of the material [8]. The characteristics of natural fiber composite are different because the source of the fiber and the humidity conditions are different [9]. Multiple physical and chemical factors, such as properties of constituent materials, fiber and matrix content, fiber length and orientation, cell dimensions, the physical profile of the contact surface, interlinear shear strength, and interfacial chemical bonding strength, can influence the mechanical behavior of natural fiber reinforced polymer composite materials [10]. In order to be able to apply various natural fibers to composite materials and improve their performance, it is important to understand various fiber properties. Table 1.1 summarizes the properties of some natural and synthetic fibers.

Natural fibers normally have a lower density than synthetic fibers, so they are lighter. However, in terms of mechanical properties, most natural fibers are weaker than manmade synthetic fibers such as glass or carbon. Compared with synthetic E glass fiber, hemp and flax natural fibers have good mechanical properties as given in Table 1.1, such as tensile strength and specific modulus, making it possible to become a substitute for synthetic fibers. In the mechanical characterization of fibers, the concept of length becomes particularly important. This is also the focus of composite materials and directly affects the aspect ratio of reinforced materials. In fact, for composite materials, the quality of the stress transfer between the fiber and the matrix is closely related to the individualization of the fiber and the interface area. The individualization of the fiber and the interface area is directly affected by the ratio of reinforcement length or diameter [13]. Then, the elongation at break increased with

Table 1.1 Basic properties of natural fiber and synthetic fibers [11, 12]

Fiber type	Density (kg/m^3)	Young's Modulus (GPa)	Tensile Strength (MPa)	Elongation (%)	Moisture content (%)	Microfibrillar angle (°)	Cellulose (wt%)	Length (mm)	Diameter (μm)
Flax	1420–1520	75–90	750–940	1.2–1.8	8–12	5–10	62–72	5–900	12–600
Hemp	1470–1520	55–70	550–920	1.4–1.7	6.2–12	2–6.2	68–74.4	5–55	25–500
Jute	1440–1520	35–60	400–860	1.7–2	12.5–13.7	8	59–71.5	1.5–120	20–200
Kenaf	1435–1500	60–66	195–666	1.3–5.5	–	–	31–72	–	–
Ramie	1450–1550	38–44	500–680	2–2.2	7.5–17	7.5	68.6–85	900–1200	20–80
Sisal	1400–1450	10–25	550–790	4–6	10–22	10–22	60–78	900	8–200
Bamboo	600–1100	11–32	140–800	2.5–3.7	–	8–11	26–65	1.5–4	25–40
Coir	1150–1220	4–6	135–240	15–35	8	30–49	32–43.8	20–150	10–460
Cotton	1520–1560	7–12	350–800	5–12	7.85–8.5	46	82.7–90	10–60	10–45
Carbon HS	1800–1840	225–260	4400–4800	1.8–4.8	–	–	–	–	< 17
E-glass	2550–2600	72–85	1900–2050	0.0	–	–	–	–	< 10

the microfibril angle. If all the microfibers are aligned along the fiber direction and a tensile load is applied, the tensile modulus of the natural fiber composite material will be higher [6].

1.3 Mechanical Properties of Natural Fibers Composites

Matrix and fiber properties are both important to improve the mechanical properties of composite materials. Plant fiber composites have excellent mechanical properties, such as flexibility, strength, rigidity, and modulus, and are durable and easy to manufacture complex parts. Compared with metal, the overall strength and weight characteristics of plant fibers are very advantageous, and they can be easily made using a molding process [14]. Polymer composites reinforced with natural fibers (such as jute, hemp, and kenaf) have excellent mechanical and dynamic mechanical properties that are not inferior to steel and aluminum, which makes them widely used in various fields such as automotive industry, aerospace industry, and construction industry [15]. Improvements to natural fibers can enhance the mechanical properties of natural fibers, thereby increasing their strength and structure. The basic structure of the reinforced material is strengthened, and the composite will be strengthened and improved. The properties of composite materials are affected by many aspects, including fiber orientation, fiber strength, fiber physical properties, fiber interface bonding characteristics, and so on [9]. The mechanical efficiency of natural fiber composites depends on the interface provided by the fiber matrix and the stress transfer function, where stress is transferred from the matrix to the fibers. Plant fibers can be defined as fibers with high mechanical properties, which are characterized by a tensile strength generally higher than 200 MPa [12].

The flexural, tensile, and impact properties of untreated sisal fiber reinforced green polyethylene composites were evaluated by de Castro et al. Traditional green high-density polyethylene (HDPE) derived from sugar cane ethanol was used as the matrix of the composite material. The results show that green polyethylene reinforced with untreated sisal fibers can achieve higher flexural modulus, flexural strength, tensile strength, and ultimate strain compared to unreinforced traditional polyethylene [10]. Some studies have shown that the combination of plant fiber and glass fiber can improve the tensile, flexural, and impact strength of the material. The mechanical properties of the hybrid composite material can be enhanced by adding a relatively small amount of glass fiber to the pineapple leaf fiber or sisal fiber reinforced polyester matrix [16]. The study also observed that the water absorption rate of the hybrid composite material was lower than that of the composite material without hybridized. If jute fiber is added to polylactic acid (PP), the mechanical properties (such as tensile strength) of natural fiber composites are even better than the pure matrix [9].

Natural fiber reinforcement still faces some problems, and its variability increases the uncertainty of its consistent performance and negatively affects the green composite [12]. The nature of plant fiber depends on its chemical composition and growth conditions, so any planting factors and extraction technology may affect the quality of natural fiber. The water absorption of plant fibers is a big problem in composites. They easily absorb water and cause de-bonding of the fiber and matrix interface, and it will cause swelling and performance degradation in a humid environment. Plant fibers can have a good chemical interaction only with hydrophilic resins through the formation of hydrogen bonds. For hydrophobic resins, the compatibility of the fibers at the interface with the matrix is a problem, and the wettability of the fibers will become poor, which will cause interface defects, and ultimately leads to stress concentration and failure points in the composite material. Therefore, the method of improving fiber wettability and interfacial adhesion is an important step for improving the performance of bio composite materials. Then, plant fiber has a fast degradation rate, poor on thermal stability, thermal degradation, and flame resistance. This will affect the durability and heat resistance of composite materials.

1.4 Improvement in Mechanical Properties of Natural Fibers

The properties of natural fibers are related to the mechanical properties of composite materials. The shortcomings of natural fibers include the hydrophilicity and water absorption, thermal degradation in the fibers, poor adhesion between the fibers and the matrix, etc. Therefore, physical and chemical methods can be used to improve mechanical properties and compatibility with polymers caused by the hydrophilicity of natural fibers [17]. The structural properties of natural fibers are changed and the mechanical bonding between polymer and fiber by the physical methods such as sputtering, stretching, corona discharge, low-temperature plasma, and thermal treatment. Chemical methods can improve the adhesion and mechanical properties of natural fiber polymers. These treatments of the fiber result in structural and surface changes, thereby enhancing the mechanical properties of the fibers. Kapatel, 2019 [18] evaluated the mechanical and physical properties of green composite materials by performing alkali surface treatment on different percentages of jute fabric as a reinforcement. The results showed that 10% to 15% alkali treatment of jute fabrics enhanced the fiber matrix adhesion and impact strength, and water absorption was reduced and achieved the excellent performance of the composite material. Fiber quality is affected by the fiber extraction process. The use of biotechnology to facilitate the extraction process can improve the fiber quality and reducing fiber damage [19]. Fiber quality has an impact on mechanical properties. The surface properties of the fibers can be improved by dewaxing (degreasing), acetylation, bleaching, delignification, and chemical grafting [17]. The antifungal and hydrophobic properties of natural fibers like jute can be achieved through acetylation and provide greater stability. The physical and mechanical properties of natural fibers can also be changed by graft copolymerization. Jute propylene composites can be treated with cardanol-formaldehyde to improve the mechanical properties and reduce water absorption. After treatment with ethylenediamine and hydrazine, the moisture absorption rate

Table 1.2 Natural fiber treatment [17]

Treatment process	Natural fiber	Outcomes
Acetylation	Flax fibers	Tensile strength and flexural strength increased
Silane treatment	Flax fibers	Improvement in hydrophobic and mechanical properties
Sodium chlorite treatment	Jute fibers	Significant improvement in tensile strength young's modulus and extension at break
Treatment with metha acrylate	Jute fibers	Improvement in flexural and tensile strength
Mercerization	Jute fibers and flax fibers	Reduction in moisture regain due to better interface and improvement in
Peroxide treatment	Ramie fibers	Decrease in moisture regain
Benzoylation	Sisal fibers	Surface modification and improvement in hydrophobicity
Plasma treatment	Sisal/Hemp fibers	Surface modification and improvement in hydrophobicity
Lysine-based diisocyanate (LDI) Treatment	Bamboo fiber	Moisture absorption reduced and adhesion between fiber and matrix improved
Alkalization (KOH and NAOH treatment)	Coir fiber	Eliminate open hydroxyl group that tends to bond with water molecule and also dissolve hemicellulose

of jute fiber is also reduced [20]. Some methods of improving the fire resistance of cellulosic materials have been patented, especially when cellulosic materials are used in polymer composites. The cellulosic material is treated with an aqueous mixture of alkali metal or ammonium hydroxide and alkaline earth metal or aluminum metal salt while preparing the mixture. The treated cellulosic material has self-extinguishing properties, and its thermal stability, fire resistance, interface heat resistance, antioxidants, resistance to UV damage, and other chemical agents have been improved [21]. Table 1.2 shows the reinforcement treatment of natural fibers to improve the properties of natural fiber composites.

1.5 Conclusion

Composites that are made from natural fibers mainly consist of animal fibers and plant fibers. Animal fibers are abundant in protein; therefore, it is also known as protein fiber. On the other hand, plant fibers are formed by both cellulose and various nutrients. Plant fibers can also be further classified as soft and hard fibers due to plants having different variations of stems. High-performance-reinforcing fibers and high-performance resin matrix can be compressed together to form high-performance composite materials. An example of this would be carbon fiber which are commonly used in the automotive industry. As the type of fiber varies, so does the method of extracting and processing it varies. For example, some fibers can be directly extracted and processed while plant fibers will require solvents. Natural fibers are a major factor regarding sustainable green composite technology, they are also eco-friendly as they are biodegradable, renewable, cheap, and recyclable. Materials that are formed by green composites along with natural or synthetic fibers are used in various applications depending on their performance. Natural fibers have generally lower density compared to synthetic fibers. However, natural fibers are generally weaker compared to synthetic fibers. Improving natural fibers will allow an increase in strength and structure. This will also significantly improve its effects on green composites as it suffers from unreliable consistent performance due to its variability. Various physical and chemical methods are used to improve their mechanical properties as their structural properties are changed. As mentioned above, using natural fibers are absurdly eco-friendlier than synthetic fibers as synthetic fibers are the by-products of non-renewable resources. Natural fiber composites are favorable in automotive and building industry due to their low-density property and low cost of production. In addition to that, the textile industry is one of the minor industries that will benefit from using natural fiber composites. In fact, silk that is a protein fiber is considered to be the world's luxurious fabric material. In other words, natural fibers and synthetic fibers has their respective strengths and weaknesses. However, in our current day and age, natural fibers should be widely used as they preserve our environment while providing us alternative methods in carrying out our daily necessities.

Acknowledgements The authors would like to thank anonymous reviewers for their input and SEGi University for providing platform to perform this study.

References

1. Oh JM, Biswick TT, Choy JH (2009) Layered nanomaterials for green materials. J Mater Chem 19(17):2553–2563
2. Zald MN (1969) The power and functions of boards of directors: a theoretical synthesis. Am J Sociol 75(1):97–111
3. Lopes GP (2015) The Sino-Brazilian principles in a Latin American and BRICS context: the case for comparative public budgeting legal research. Wis Int'l LJ 33(1):1–45
4. Dixit S, Goel R, Dubey A, Shivhare PR, Bhalavi T (2017) Natural fibre reinforced polymer composite materials—a review. Polym Renew Resour 8(2):71–78
5. Sangregorio A, Guigo N, van der Waal JC, Sbirrazzuoli N (2019) All 'green' composites comprising flax fibres and humins' resins. Compos Sci Technol 171:70–77 (Aug 2018)
6. Lau KT, Hung PY, Zhu MH, Hui D (2018) Properties of natural fibre composites for structural engineering applications. Compos B Eng COMPOS PART B-ENG 136:222–233

7. Karim Z, Afrin S, Husain Q, Danish R (2017) Necessity of enzymatic hydrolysis for production and functionalization of nanocelluloses. Crit Rev Biotechnol 37(3):355–370
8. Reddy TRK, Kim HJ, Park JW (2016) Renewable biocomposite properties and their applications. Comp Renew Sustain Maters (IntechOpen, London, UK), pp 177–197
9. Mohammed L, Ansari MNM, Pua G, Jawaid M, Islam MS (2015) A review on natural fiber reinforced polymer composite and its applications. Int J Polym Sci. https://doi.org/10.1155/2015/243947
10. de Castro BD, Fotouhi M, Vieira LMG, de Faria PE, Rubio JCC (2021) Mechanical behaviour of a green composite from biopolymers reinforced with sisal fibres. J Polym Environ 29(2):429–440
11. Dicker MPM, Duckworth PF, Baker AB, Francois G, Hazzard MK, Weaver PM (2014) Green composites: a review of material attributes and complementary applications. Composites Part A Appl Sci Manuf 56:280–289
12. Ray D, Sain S (2017) Plant fibre reinforcements. In: Biocomposites for high-performance app. Woodhead publishing https://doi.org/10.1016/B978-0-08-100793-8.00001-6
13. Bourmaud A, Beaugrand J, Shah DU, Placet V, Baley C (2018) Towards the design of high-performance plant fibre composites. Prog Mater Sci 97:347–408 (July 2017)
14. Ramesh M, Palanikumar K, Reddy KH (2017) Plant fibre based bio-composites: sustainable and renewable green materials. Renew Sust Energ Rev 79(May):558–584
15. Bhardwaj S (2017) Natural fibers composites—an opportunity for farmers. Int J Pure Appl Biosci 5(5):509–514
16. Mishra S, Mohanty AK, Drzal LT, Misra M, Parija S, Nayak SK, Tripathy SS (2003) Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. Compos Sci Technol 63(10):1377–1385
17. Lalit R, Mayank P, Ankur K (2018) Natural fibers and biopolymers characterization: a future potential composite material. Strojnicky Casopis 68(1):33–50
18. Kapatel PM (2021) Investigation of green composite: preparation and characterization of alkali-treated jute fabric-reinforced polymer matrix composites. J Nat Fibers 18(4):510–519
19. Sorieul M, Dickson A, Hill SJ, Pearson H (2016) Plant fibre: molecular structure and biomechanical properties, of a complex living material, influencing its deconstruction towards a biobased composite. Mater. https://doi.org/10.3390/ma9080618
20. Gupta MK, Srivastava RK, Bisaria H (2015) Potential of jute fibre reinforced polymer composites: a review. Int'l J Fiber and Textile Res. 5(3):30–38
21. Zaman A, Huang F, Jiang M, Wei W, Zhou Z (2020) Preparation, properties, and applications of natural cellulosic aerogels: a review. Energy Built Environ 1(1):60–76