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Review Article

Fostering sustainability: The environmental advantages of natural fiber composite materials – a mini review

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ABSTRACT

In recent decades, natural fiber reinforced composites (NFRCs) have become an attractive substitute for conventional materials such as glass fiber and have attracted considerable interest from researchers and academics, particularly in the context of environmental protection. Environmental factors and their impact on the fundamental properties of renewable materials are becoming an increasingly popular area of study, particularly natural fibers and their composites. While this area of research is still expanding, natural fiber-reinforced polymer composites (NFRCs) have found widespread use in a variety of engineering contexts. Natural fibers (NFs) such as pineapple leaf (PALF), bamboo, abaca, coconut fibers, jute, banana, flax, hemp, sisal, kenaf, and others have many desirable properties, but their development and use present researchers with a number of obstacles. These fibers have attracted attention due to their various advantageous properties, such as lightness, economy, biodegradability, remarkable specific strength, and competitive mechanical properties, which make them promising candidates for use as biomaterials. As a result, they can serve as alternative materials to traditional composite fibers such as glass, aramid, and carbon in various applications. In addition, natural fibers have attracted the interest of an increasing number of researchers because they are readily available in nature and as by-products of agricultural and food systems, contributing to the improvement of the environmental ecosystem. This interest coincides with the search for environmentally friendly materials to replace synthetic fibers used in the construction, automotive, and packaging industries. The use of natural fibers is not only logical but also practical, as their fibrous form can be easily extracted and strengthened by chemical, physical, or enzymatic treatments. This article provides a brief overview of NFRCs, looking at their chemical, physical, and mechanical properties. It also highlights some of the significant advances associated with NFRCs from an economic, environmental, and sustainability perspective. Additionally, it provides a concise discussion of their diverse applications, all with a focus on their positive impact on the environment.

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INTRODUCTION

In recent decades, natural fiber, also known as plant fibers have gained an increasing attention for polymer composites as a possible alternative to traditional polymer composites reinforced with synthetic fibers. Reasons for this include their affordable price and good mechanical properties [1]. There is an increasing focus on the potential to produce biocomposites with minimal environmental impact and a trend towards carbon neutrality. This applies to both thermosets and thermoplastics and has received considerable attention [2, 3]. Since the initial research efforts, the expansion of the natural fiber market into the composites sector has been steadily increasing worldwide. It is reasonable to assume that one or more natural fibers suitable for this purpose can be identified in each global region [4]. Based on assessments carried out between 2011 and 2016, the global output of companies specializing in natural fiber composites is expected to grow by 10% [5]. In particular, the refinement of hybridization processes with aramid, glass, carbon and natural fibers has been the focus of progress in their application in composites. Additionally, there has been an exploration of distinct and more targeted treatments, diverging from the expertise traditionally gained in textile products [5, 6].

The polymer matrix, a critical component of natural fiber reinforced composites (NFRCs), prevents mechanical abrasion and environmental hazards from reaching the fiber surface [7]. The incorporation of resilient and low-density plant fibers in polymer matrix, ensuring robust integration, can result in composites with increased specific strength. This applies to both thermoplastics and thermosets, with recent applications extending to bio-based matrices. Table 1 provides an inventory of globally popular and commercially viable natural fibers, along with total global fiber production. An upward trend in the use of sustainable materials in the manufacture of automotive components [8, 9]. The majority of these NFRCs are composed of sixty to seventy percent NFs, with the remaining portion consisting of adhesive and matrix. A variation of microbes and ecological factors, such as humidity and temperature, influence the degradation of NF in an open environment [10, 11]. There is a significant cause for concern in construction applications regarding the environmental conditions of NFRCs. The degradation of natural fiber components at higher temperatures alters the mechanical properties of the composite [12–14]. These components include cellulose, hemicellulose, and lignin.

This study focused on the characteristics of commercial natural fibers, manufacturing techniques for NFRCs, and their diverse economic, environmental, and sustainability perspectives. Moreover, the future prospects of the NFRCs were discussed.

FIBERS MADE FROM NATURAL SOURCES

Natural fibers (NFs) can be derived from minerals plants, or animals [22]. Within the category of animal fibers, notable examples include protein fibers such as silk, human hair and even wool [23, 24]. Figure 1 illustrates different examples of fiber classification. According to their origin, plant fibers can be classified as stem, stalk, bast, wood, fruit, leaf, grass or seed. Cell walls in plant fibers use randomly oriented hemicellulose and lignin to bind the mostly amorphous cellulose [25]. Amorphous lignin forms a protective layer between the fibers, increasing the strength of the cellulose and hemicellulose network [26]. Hemicellulose formulae a matrix encapsulating the Crystallized cellulose microfibrils and acts as a binder in the cell wall. As shown in Figure 2, the mechanical properties of the fiber are determined by the secondary walls (S2) of the crystalline cellulose microfibrils. When used independently, whether in nanometric or micrometric arrangement, the fiber exhibits excellent tensile strength [26, 27]. Surface modification of polypropylene resulted in improved mechanical properties, indicating that the arrangement had a positive effect [28].

Bast fibers such as sisal, hemp, flax, jute, coir, including kenaf are widely used in polymer based composites due to their uniqe properties such as high tensile properties, low density, low-cost [3,29,30]. In particular, flax, hemp and

Table 1. Global production of natural fibers around the world and their quantities [15–21]

Source of fiber	Leading Countries in Production	Production in the world (10^3 tons)
Abaca	Philippines, Costa Rica, Ecuador	70
Bamboo	India, China, Indonesia	30000
Coir	India, Sri Lanka	100
Flax	Canada, France, Belgium	830
Hemp	China, France, Philippines	214
Jute	India, China, Bangladesh	2300
Kenaf	India, Bangladesh, US	970
Ramie	China, Brazil, Philippines, India	100
Sisal	Tanzania, Brazil	375
Sugarcane bagasse	Brazil, India, China	75000
Cotton	China, India, US	25000

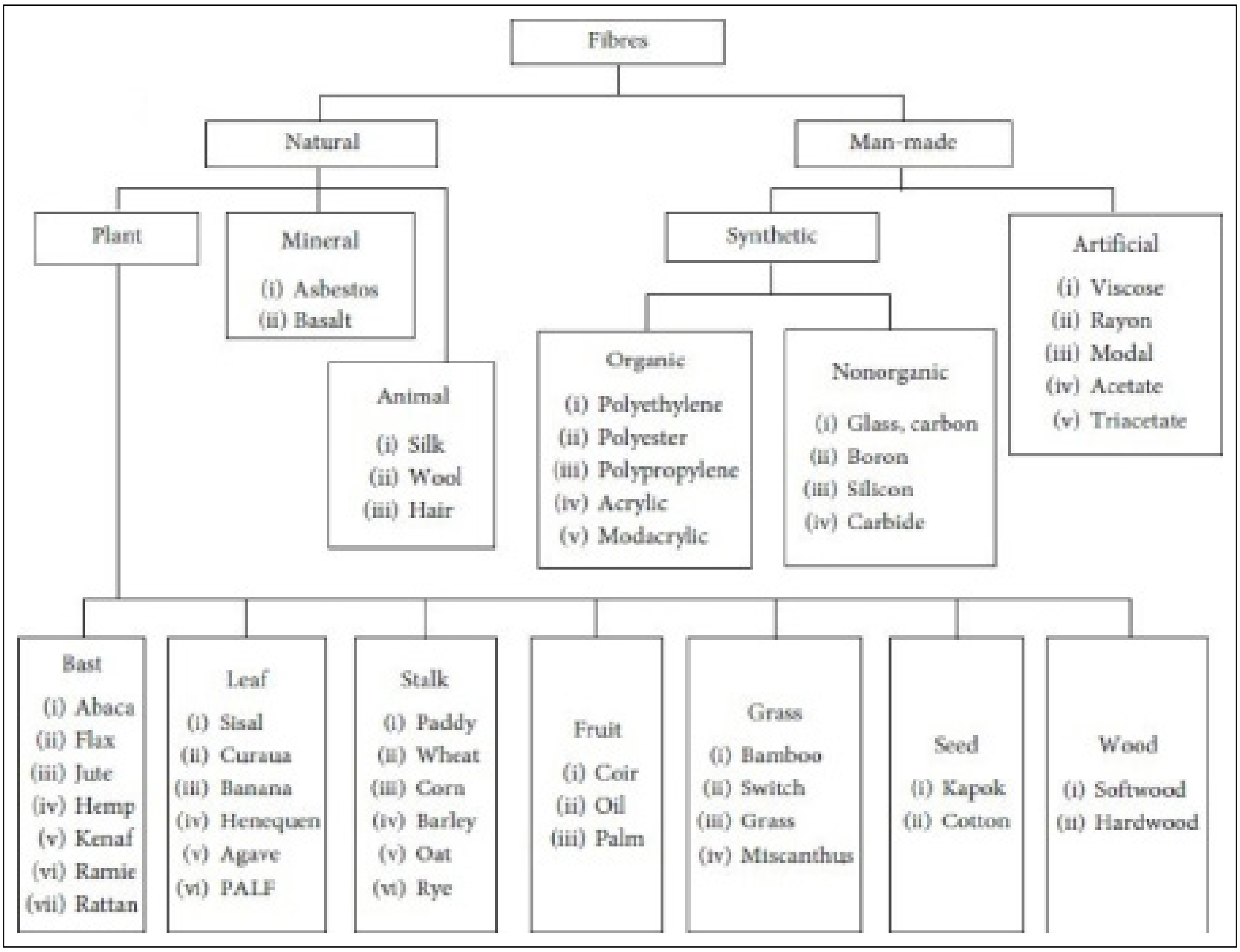

Figure 1. Classification of natural and man-made fibers.

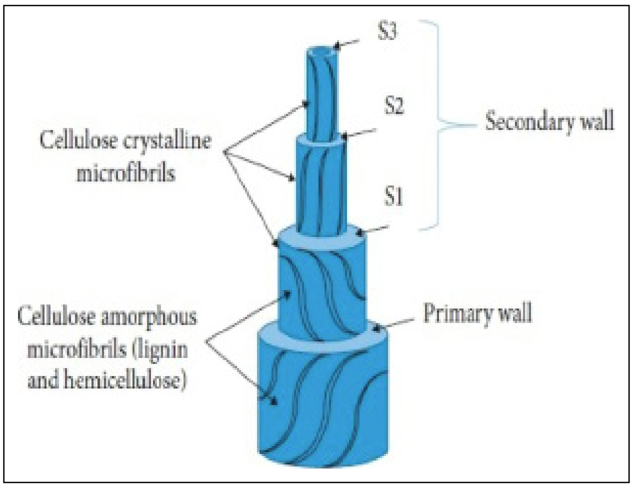

Figure 2. Natural fiber structure [29].

jute were used in polymer composites at an early experimental stage. Over time, however, the scope of research has expanded to include a wide range of species [31]. Jute, grown in South Asian countries and several Latin American countries, is a fiber known for its significant mechanical properties, making it suitable for applications such as ropes and sacks [32]. Flax is the most important and sought-after bast fiber in Europe, although certain varieties are naturally grown in China [33]. The quality of natural fibers depends on geographic conditions such as weather, harvesting time, soil properties. The geographic conditions affects the chemical composition and cellulose crystallinity, which determinees the physical, mechanical, and thermal properties of the polymer composites [34].

The aspect ratio of the fiber is affected by other properties of the fibers include the microfibrillar angle, which is the angle at which the technical (extractable) fiber is formed by winding together the fibers, the dimensions of the lumen and porosity, and the cell length and diameter. Together, these factors affect [33, 35, 36]. All these properties have the potential to influence the mechanical characteristics of the fiber. The mechanical characteristics of various natural based fibers are compared to E-glass synthetic fibers in Table 2. At the composite stage, factors such as fiber extraction, polymer matrix type, interfacial bond performance, distribution of fiber in polymer matrix, manufacturing processes, fiber orientation and porosity emerge as key elements influencing the strength of the resulting composite [8]. In addition, the modulus of natural fibers tends to decrease with increasing diameter, as shown in a previous study [35]. This phenomenon was mainly attributed to the fibrillation

Table 2. Mechanical properties of certain fibers derived from [8]

Fibers	Density (g/cm^3)	Tensile strength (MPa)	Specific tensile strength ($MPa/g.cm^3$)	Stiffness (GPa)	Specific stiffness ($GPa/g.cm^3$)
E-glass	2.5	2000–3000	800–1400	70	29
Wool	1.3	50–315	38–242	2.3–5	1.8–3.8
Chicken feather	0.9	100–203	112–226	3–10	3.3–11
Ramie	1.5	400–938	270–620	44–128	29–85
Flax	1.5	345–1830	230–1220	27–80	18–53
Jute	1.3–1.5	393–800	300–610	10–55	7.1–39
Hemp	1.5	550–1110	370–740	58–70	39–47
Cotton	1.5–1.6	287–800	190–530	5.5–13	3.7–8.4
Sisal	1.3–1.5	507–855	362–610	9.4–28	6.7–20
Silk	1.3	100–1500	100–1500	5–25	4–20

of natural fibers and increase in the percentage of porosity within the fibers [36]. Natural fibers, due to their chemical composition, have a notable drawback for their applications - hygroscopicity. The absorption of moisture adversely affects their properties [37, 38].

Pure microcrystalline cellulose occupies its maximum theoretical density, which is somewhat less than 1.6 g/cm^3, is linked to that of natural lignocellulosic fiber [39, 37]. Natural fibers are undoubtedly less dense than the theoretical maximum due to their high porosity content and cellulose composition [15]. In composites made of natural fibers, the density is significantly lower since the matrix is usually lighter than the fibers. Table 3 displays the densities of commercially used natural based fibers in polymeric composite materials.

The proportions of cellulose, hemicellulose and lignin in natural fibers are the main factors influencing their chemical composition. Cellulose is a naturally occurring molecule that is abundant and degradable. In addition, NFRCs can be biodegraded with other polymers after they have served their useful purpose [44-46]. NFRCs reduce the risk of atmospheric impact and generate positive carbon credits. In this case, NFRCs consist mainly of NFs (60-70%), with the adhesive and matrix making up the remainder [6]. A variety of microbes, as well as environmental factors such as temperature and humidity, influence NF degradation in an open environment. The degradation process involves the breakdown of various fiber components, including hemicelluloses, lignin and cellulose. This allowed for the observation of the overall failure of the mechanical properties of NFRCs [45]. Furthermore, a characteristic that defines the structural potential of the fibers is their degree of crystallinity. Normal fibers often contain very little pectin and waxes, and the amount of residual ash is usually only a few percent. Selected studies reporting structural components of some natural fibers are presented in Tables 4, 5 and 6, respectively.

Coconut is a rigid and decomposable lignocellulosic type of fiber derived from the the outer shell of the coconut fruit, which makes up approximately 25% of the husk. Coconut fiber is also called coir fiber [49]. Coconut (Cocos nucifera) is

Table 3. The density of various natural fibers

Fiber	Density (g/cm^3)	Reference
Abaca	1.5	[38]
Alfa	0.89	[38]
Bamboo	0.6–1.1	[40]
Banana	1–1.5	[41]
Coir	1.25	[1]
Cotton	1.5–1.6	[41]
Flax	1.4	[1]
Hemp	1.48	[1]
Henequen	1.2	[38]
Jute	1.3–1.49	[40]
Kenaf	1.45	[42]
PALF	1.53	[43]
Palm	1.03	[24]
Ramie	1.5	[1]
Sisal	1.33	[1]
Wool	1.3	[41]
Vakka	0.81	[30]

widely grown in tropical countries such as Thailand, Philippines, India, Indonesia, and Lanka. The high amoount of the lignin of coir fibers makes them weather resistant, relatively waterproof durable, and also Chemically changeable. The fibers also have a higher elongation at break. The unique properties of coconut fiber, characteristics such as a low specific gravity and an excellent flexural as well as tensile strength, among others, make it a potential alternative to synthetic fibers such as glass fibers in polymer composites [50]. Tensile properties of plant fibers, tensile modulus along with tensile and impact strength are crtical characteristics for considering the performance in polymer composites. The physical, mechanical, thermal and morphological properties of coir fiber have been reported in the literature [50].

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Table 4. Amount of cellulose in some commercial natural fibers

Source of natural fiber	Cellulose(% by weight)	Reference
Abaca	56–66	[38]
Alfa	45	[38]
Bamboo	30–65	[40]
Banana	62–64	[46]
Cotton	82–7–90	[38]
Flax	71	[47]
Hemp	57–75	[47]
Henequen	60–77.6	[38]
Jute	59–71.5	[40]
Kenaf	45–57	[42]
Ramie	68–91	[47]
Sisal	78	[48]

Table 5. Amount of hemicellulose in several plant fibers

Source of natural fiber	Hemicellulose (% by weight)	Reference
Abaca	20–25	[38]
Alfa	38.5	[38]
Bamboo	30	[40]
Banana	19	[46]
Cotton	5.7	[38]
Flax	18.6–21.6	[47]
Hemp	14–22.4	[47]
Henequen	4–28	[38]
Jute	13.6–20.4	[40]
Kenaf	8–13	[42]
Ramie	5–16.7	[47]
Sisal	25.7	[48]

In composites, several fiber factors may influence the mechanical as well as physical properties. These include fiber length, orientation, dispersion within the polymeric matrix, loading level, and form [51]. The shape and arrangement of the fibers, e.g. continuous fibers, fabric fibers, discontinuous fibers (discrete fibers that are both aligned and orientated in a random manner), flakes and particles, influences the composite's strength [52,53]. The schematic representations of orientation of continuous and discontinuous fibers are presented in Figure 3 [54]. Short fibers are more evenly distributed throughout the matrix, but tend to have a lower stiffness than longer fibers. When the short fibers are used randomly and uniformly in the polymer matrix, the resulting composite has homogeneous strength in all directions. In general, the production process of polymer composites with short fibers are simpler than long fibers. In particular, short-fiber reinforced polymer based composites are more suitable for applications requiring impact resistance [52, 53, 55].

Table 6. Amount of lignin of some commercial natural fibers

Source of natural fiber	Lignin (% by weight)	Reference
Abaca	7–13	[38]
Alfa	14.9	[38]
Bamboo	5–31	[40]
Banana	5	[46]
Cotton	<2	[38]
Flax	2.2	[47]
Hemp	3.7–13	[47]
Henequen	8–13.1	[38]
Jute	11.8–13	[40]
Kenaf	21.5	[42]
Ramie	0.6–0.7	[47]
Sisal	12.1	[48]

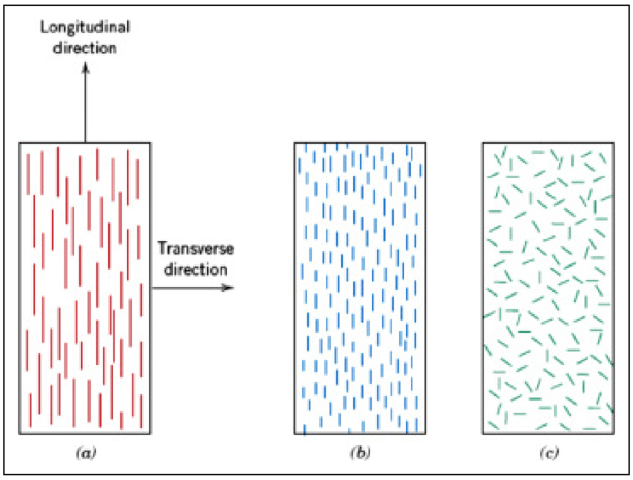

Figure 3. Arrangement of fibers in polymer matrix, **(a)** continuous and aligned, **(b)** discontinuous and aligned, **(c)** discontinuous and randomly oriented fiber reinforced polymer composites [54].

MANUFACTURING METHODS FOR NATURAL FIBER-REINFORCED POLYMER COMPOSITES (NFRCs)

Fiber-reinforced plastics can be produced using a variety of techniques, all based on the idea of polymerization, depending on the geometry of the target component. A collection of research on natural fiber composites produced using a range of production techniques and processes is shown in Table 7.

Hand Layup

The molding process described is a manual process in which fiber-reinforcements are placed by hand and polymer resin is poured over them. An additional layer of fiber-reinforcement is then applied to the surface of the polymer matrix. To ensure a seamless and air-free surface, a lightly pressurized roller is then moved over the layers. This step not only prevents air from being trapped between the layers but also ensures a smooth and uniform surface [75, 78]. After

Table 7. Different composite manufacturing procedures and methods

Method	Composite produced	References
Hand layup	Sisal, jute, and glass fibers with Polyester resin	[56]
	bi-directional jute fiber with epoxy resin	[57]
	Banana fiber with epoxy	[58]
	Glass and sisal/jute fibers with Epoxy	[56]
	Calotropis Gigantea fruit fiber with Polyester	[59]
Spray layup	Rice straw waste in a box made of Kraft paper with a natural rubber seal.	[60, 61]
	Composites using different flax topologies and nanosilica particles	[45, 62, 63]
	Epoxy with coconut sheath fiber	[64]
	Epoxy containing jute and sisal fibers	[65]
Filament winding	Kraft paper and cellulose combine to form cellulose aceto-butyrate (CAB) or natural rubber (NR).	[66]
	Composites reinforced with ramie fiber yarn	[67]
	composites consisting of biopol and jute yarn	[68]
	High density pre-preg polyethylene made of sisal fiber	[69]
	Filament-wound epoxy composites reinforced with natural fibers	[70]
Compression moulding	Composites of cellulose and natural rubber reinforcing short natural fibers made of polyethylene	[71]
	Jute fibers in matrices of polyester and epoxy	[72]
	reinforcement for composites using sisal and banana	[56]
	Natural fibers used to reinforce PLA composites	[73]
	Polypropylene/sugarcane bagasse fibers composite	[74]
Injection winding	Sisal woven fibers with an epoxy matrix modified by natural rubber	[71, 72]
	Vetiver/polypropylene	[75]
	Bamboo-glass fibers/polypropylene hybrids	[76]
	Reinforced polypropylene composites using sugarcane bagasse fibers	[74]
	Reinforced polypropylene with palm fibers	[53, 77]

the initial steps, the manufacturing technique described is repetitive for each polymer matrix and fiber to build up the required layers. This stacking allows for the necessary curing time. The process is particularly suitable for small size composite batches. To facilitate manual handling, the viscosity of the resin must be low, which is often achieved by increasing the diluent/styrene content. However, this adjustment may result in a slight reduction in mechanical properties. A single-sided hand lay-up produces a seamless and better excellence finish to the product. This method offers greater flexibility in material design. However, the trade-off is a longer curing cycle, typically 24 to 48 hours. This time frame is critical to ensure proper curing and to achieve the desired structural integrity and performance of the composite [53,54].

Spray Layup

Spray lay-up is a hand molding technique that is an extension of hand lay-up, similar to hand lay-up. This strategy has attracted much interest, particularly in the field of natural fiber composites [79]. In this technique, a spray gun is used to apply pressurized adhesive and reinforcement into the geometry of chopped fibers. It is possible to spray the reinforcement and matrix material simultaneously or sequentially at various intervals. To release any air entrapped in the layups, a roller is then lightly tensioned as it passes over the sprayed surface. The material is sprayed to the appropriate thickness. Then, it is cured at room temperature for a certain period of time before it is taken out of the mold [80]. This approach preferentially uses low-viscosity matrices; however, low-volume production is the most appropriate manufacturing process, although this choice may affect the mechanical properties of the matrices. The aim is to produce a low-cost composite with an excellent one-sided surface finish [42].

Filament Winding

Depending on the situation, filament winding is often used for both open and closed constructions. Using a mandrel that is swung around a spindle, filaments are wound under stress to create the composite material. By following the axis of the rotating mandrel, a moving eye simultaneously deposits fibers where required. In this way it is possible to produce convex shapes. Low viscosity resins are often preferred [81] and in the case of natural fiber composites, custom grades of epoxy resins have been used [70].

Table 8. Mechanical characteristics of composites reinforced with natural fibers

Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Flexural strength (MPa)	Reference
Abaca	100–980	6.2–20	–	[38]
Bamboo	140–800	11–32	32	[29, 42]
Banana	600	17.85	76.53	[29, 54]
Cotton	400	12	43.3	[1, 93]
Jute	320–800	8–78	45	[42, 68]
Kenaf	930	53	74	[94]
Palm	377	2.75	24.4	[77, 95]
Ramie	500	44	–	[1]
Sisal	600–700	38	288.6	[1]
Henequen	430–570	10.1–16.3	95	[41, 96, 97]

Compression Molding

It is a widely used technique in the field of thermoplastic matrices, especially when dealing with loose chopped fibers, short or long fiber mats and structures that may be very uneven or aligned. This technique can also be used with thermoset matrices. Fibers are usually laid in various configurations with sheets of thermoplastic resin before heat and pressure are applied to form a stronger structure. Typically, the material is heated, placed in an open cavity, reheated and then pressed into the mold. [79, 80, 82].

Injection Molding

The substance contained within a barrel that has been heated an injection molding machine is melted by the combined action of fluctuating temperatures and the frictional motion of the barrel. Following its introduction by an injection nozzle into the mold cavity, the molten plastic solidifies to assume the geometry of the interior structure as it cools. After the components have hardened, the plate is opened, and ejector pins are used to remove the item. A transportable container holds the mold tool in place. Higher volume applications are a good fit for this technique, which produces a clean surface finish. Still, this process's tensile strength is often lower than that of other thermoset systems [83].

MECHANICAL PROPERTIES OF NFRCs

The mechanical characterization of a material includes its response to an applied load, including elastic deformation. These properties not only define the range of use of the material but also influence its durability in everyday applications. To characterize and differentiate between materials and alloys, mechanical properties are essential. The mechanical characteristics of composites reinforced with natural fibers are given in Table 8.

Lignin effectively protects plant fibers from damaging environmental conditions such as humidity and temperature [84, 85], including cellulose, hemicellulose, pectin and wax. Hydrophilicity and exposure to a wide range of weather conditions are two additional factors that shorten the life of NFRCs. However, in humid environments, plant fibers absorb more water and have more voids in their interior, which changes their structure and affects their mechanical and impact properties [83, 85-87]. The NFRCs have become more popular in recent years due to their environmental advantages over synthetic fibers. These advantages include recyclability, biodegradability, energy efficiency and lightweight [88–92].

SUSTAINABILITY OF NFRCs

The "green" term is frequently linked with NFRCs, which are seen as one of the new materials of current use [94, 98–101]. This is because NFRCs break down into their component parts when composites decompose, making them biodegradable [102]. Sustainability, biodegradability, and recyclability can impact the climate in the present and the future [102-105]. The global movement towards eco-friendly materials is generating significant interest as it advocates for stricter regulations and legislation to combat harmful materials. Specifically, NFRCs are being promoted as a green material by the researchers in this context [106, 107]. A significant amount of NFRCs is produced by NFs. Traditional fiber-reinforced composites, like glass, use 54.7 MJ/kg of energy to produce, while NFRCs use just 9.55 MJ/kg [108]. Compared to fiber composites, non-fiber reinforced plastics have a lower environmental impact. Products with eco-friendly features, such as biodegradability and renewability, are seeing increased demand in the market because of their reduced impact on the environment [109-113]. NFs also generate revenue through the production process, which is an additional significant benefit. Also, the land utilized in the production of NF can be repeatedly cultivated. As an example, in addition to fibers, seeds, substances, and oils are produced during the processing of hemp and flax, which have various significant applications, such as the production of nutritional supplements for people [114]. Additionally, the mass that is made can be broken down naturally at the end of its functioning period. For example, a sector of the economy that generates 64.3 billion nuts annually already produces coir strands as a waste product [115-118].

Table 9. Recent applications of some NFRCs [122]

Fiber	Application
Coir	Cases for mirrors, brooms as well as brushes, doors with flush shutters, cushions for seats, upholstery filler, yarns and ropes for nets, and roofing sheets
Cotton	Industries for furniture, textiles, and yarn
Flax	Bicycle frames, decking, fencing, window frames, tennis rackets, and snowboarding
Hemp	Textile, paper, electrical, cordage, and furniture industries
Jute	Construction panels, chipboards, construction materials, door frames and shutters and geotextiles
Kenaf	Mobile device cases, insulation, bags, packing supplies, and bedding for animals
Ramie	Manufacturing of paper, fishing nets, home furnishings, packaging, sewing threads, and clothes
Sisal	The construction industry produces doors, panels, roofing sheets, and other products.

POTENTIAL APPLICATIONS OF NFRCs

The use of NFRCs as a viable alternative to glass fiber, albeit to a lesser extent than carbon fiber composites, has become increasingly widespread in a wide range of engineering applications. Some of their notable advantages are their low specific weight, affordability, biodegradability at the end of life and renewability. NFRCs are becoming increasingly popular in the transportation (vehicle) industries, especially in the case of indoor uses like boot linings, protection against the sun, door panels, seat backs and external underfloor panels [7, 113]. Already in 2004, the BMW Group used approximately 10,000 tons of natural fibers in its manufacturing processes. In addition, the aerospace industry has embraced the use of natural fiber composites for aircraft interior trim [16]. There is increasing evidence that natural fiber composites (NFRCs) can be efficiently converted into load-bearing structural elements suitable for infrastructure and other structural applications [27, 114]. In addition, current research initiatives aim to promote the use of sisal and coconut fiber composites as a substitute for asbestos in roofing components. [44, 79-82]. The environmental impact of NFRCs is lower than that of synthetic fiber-reinforced composites. Due to their biodegradability, lightweight, affordability and lack of environmental impact, natural plant fibers are promising for use in industrial applications [119, 120]. On the other hand, researchers are promoting the use of NFRCs in particular in this context [110]. Hemp, flax and kenaf are natural plant fibers that have many uses, including in the aerospace, automotive, marine, construction and packaging industries [121]. The sports industry, including water sports, is heavily involved in the application of natural fiber composites (NFRCs) due to the improved performance that can be achieved through their use. Table 9 lists some of the advanced manufacturing applications of NFRCs in this sector.

FUTURE PROSPECTS

Natural fibers are a low-cost, lightweight and environmentally friendly substitute for glass fibers in polymer composites and their use is rapidly becoming the norm. NFRCs are used in a wide range of sectors including transportation, energy, construction and domestic appliances. When exposed to high levels of moisture, it is inevitable that the fiber/matrix interface will deteriorate, leading to distortion of dimensional properties and poor stress transfer in all plant fiber composites. In addition, moisture distribution within the composite, temperature, humidity, matrix, and fiber content are some of the many factors that influence moisture uptake. Environmental characterization of NFRCs has become an important and time-consuming component of evaluating the physical characteristics of composites in dissimilar ecological circumstances. This review paper has covered a lot of ground in its discussion of the environmental impact of NFRCs, drawing on a large body of literature. Particular attention has been paid to studies that have investigated the effects of moisture uptake by plant fibers on polymer matrices and how these effects manifest themselves in composite laminates that have undergone impact testing at low, elevated and cryogenic temperatures. Several impact characteristics have been highlighted and addressed. While the NFRCs have made great strides in focusing research studies, there are still some gaps that need to be filled.

CONCLUSION

Natural fibers, also known as plant cellulose fibers, are a novel material that can replace composite materials in various industries. Comparative studies of natural fibers with other reinforced composites have highlighted the environmental benefits of natural fibers, making them more suitable for practical use in industry. As a result, the integration of NFRCs with personal armour technologies has been actively explored by materials scientists and engineers. Each type of natural fiber has different chemical characteristics: bamboo and hemp have higher hemicellulose content, cotton has higher cellulose and kenaf content, and bamboo has higher lignin content. The difference in fiber content by weight contributes to the difference in density between natural and synthetic fibers, promoting environmental sustainability. This has led to the widespread adoption of natural fibers as an alternative to synthetic fibers, not only because of their environmentally friendly properties but also for their applications in the engineering and construction industries, promoting economic growth in rural areas. The motivation for replacing glass fibers with biofibers is the environmental impact, health problems, cost and energy requirements. Natural based fibers are derived from various parts of plants. The study findings suggest that enhancing the properties of composites using natural fibers could offer promising avenues for improving environmental sustainability. The environmental impact of the NFRCs is quite low, making them suitable for various sustainable engineering applications. Numerical tools can be used to help characterize mechanical properties of composites, which enable the design of innovative composites and saving time.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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