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A short review of recent engineering applications of natural fibres

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Abstract. Many researchers and industry players are investigating possible uses of natural fibres in order to raise environmental consciousness, preserve nature, and benefit social economy. In the composite business sector, there are several advantageous natural fibre sources open up for a variety of applications. It is worth noting that the performance of natural fibre-reinforced composites may be customized by natural fibre treatment and hybridization. An equilibrium between environmental consequences and desired performance as well as cost-effectiveness may be accomplished by developing composites depending on the product needs. However, some limitations, including their hydrophilic nature and their tendency to absorb moisture during processing, severely restricts natural fibres' potential for use as reinforcements in polymer composites. Thus, the key discoveries provided in the extant literature are reviewed in this brief overview, with an emphasis on the qualities of natural fibres and their recent progress in several engineering areas.

Keywords: natural fibre; natural fibre composites; biocomposites; engineering application; hybrids

1. Introduction

Natural fibres (NF) are gaining popularity for a variety of reasons, including their potential to replace synthetic fibre-reinforced plastics at a cheaper cost while improving sustainability; Table 1 summarizes their benefits and drawbacks. Globally, the demand for reinforcing fibres in the composite sector exceeds 95%. However, natural fibre composites for interior automobile components are limited due to their inferior mechanical properties and poor interface characteristics. Emerging methods for the application of surface treatments, chemicals, and coatings, on the other hand, improve these qualities. Aside from the benefits listed above, natural fibres have constraints in terms of moisture absorption, adhesion, fire resistance, strength, and weather dependency, which affects their uniformity [1].

Table 1. Advantages and disadvantages of NFs

Advantages	**Disadvantages**
Low density with high specific strength	Low durability
Renewable resource, greenness	High moisture absorption
Low processing costs	Low impact strength
Less abrasive damage to processing equipment	Low processing temperatures
Biodegradability	

NFs are moderately hydrophilic, with a raw base, and physicochemically diverse. Additionally, they have issues with supply continuity and homogeneity. These properties have an effect on the interfacial adhesion of the fibre matrix in the composite. Poor interfacial bonding leads to the mechanical flaws of composites [2]. The fundamental weakness of NFs is the presence of hydroxyl (–OH) groups in their structure, notably cellulose, which comprises repeated glucose units in plants as well as hemicellulose sections. When NFs are exposed to high humidity, their hydroxyl groups connect to water molecules through a chemical reaction called hydrogen bonding (–H) [1].

NFs have various advantages, including availability, low cost, good acoustic damping, facile process, minimal carbon footprint, and biodegradability [3]. Some researchers provide evidence indicating evident benefits, such as the fact that NFs are less expensive and take less energy to create than standard reinforcing fibres such as glass and carbon [4]. NFs, on the other hand, have drawbacks owing to their inconsistent characteristics and quality. These fibres exhibit more physical and mechanical property variability, high sensitivity towards humidity and high processing temperature, and lesser durability and strength [3], [5]. Hence, this review will present an extensive overview of the current development of various NFs in various engineering applications.

2. Natural fibres classification

The term "natural fibre" refers to any type of fibre found in plants (cellulose fibres), animals (protein fibres), and minerals in nature (asbestos, chitin, and chitosan). NFs are flexible materials with a high tensile strength and a wide aspect ratio [1]. While cellulosic resources such as cotton, wood, grain, and straw are plentiful, not all of them are suitable for use in textiles or other industrial fibres. The locations that provide the most frequent NFs for reinforcing composites are listed in Table 2. The cellulose fibre market was valued at US$26.04 billion in 2019 and is predicted to reach US$49.49 billion by 2026, growing at an 8.36 percent CAGR during the forecast period. Furthermore, Asia has produced the majority of the world's cellulosic fibre output. Aside from economic considerations, the weight, softness, elasticity, abrasion resistance, and surface features of a fibre dictate its suitability for business needs [6].

Table 2 Production of NF types by region

Fibre type	Cultivation region
Abaca	The Philippines, Malaysia, Uganda, Bolivia, Ecuador
Bamboo	Asia, South America, India
Coir	India, Sri Lanka, the Philippines, Malaysia
Cotton	Southern parts of North America
Flax	Malaysia, the EU, Canada, Argentina, the Russian Federation, Ukraine, India
Hemp	Serbia, Croatia, China, the Philippines, Central Asia, the Russian Federation, Ukraine, the EU
Henequen	Mexico
Jute	India, China, Bangladesh, Egypt, Guyana, Jamaica, Ghana, Malawi, Sudan, Tanzania
Kenaf	Iraq, Tanzania, Jamaica, South Africa, Cuba, Togo, Thailand, India, North America, South America
Ramie	China, Brazil, Thailand, Japan, the USA, Honduras, Mauritius
Sisal	Central and South America, Africa, Indonesia, West Indies, India
Softwood kraft	The EU, North America

As illustrated in Table 3, NFs may be divided into three categories based on their origin: animal, mineral, and plant [4], [5]. Plant fibres are the most widely acknowledged by the industry and the most thoroughly studied by the scientific community. This is attributed mostly to the short growing time, renewability, and increased availability [5]. NFs are made up of cellulose, hemicellulose, and lignin, and they may be derived from the bast, leaf, seed, fruit, wood, stalk, and grass/reed. Leaf and bast fibres are well-known high-performance fibres. Because fibre-source plants can be grown in abundance to meet demands, there is a surplus of fibres that might be used for composite reinforcement [1]. As a result of their abundance, NFs are the best candidate to replace traditional structural materials.

Table 3 Natural fibre classification [4]

Cellulose/ Lignocellulose	Wood	Hardwood, Softwood
	Stalk	Wheat, Maize, Oat, Rice
	Bast	Flax, Hemp, Jute, Kenaf, Ramie
	Leaf	Abaca, Banana, Pineapple, Sisal
	Seed	Cotton, Kapok
	Fruit	Coir
	Grass/Reed	Bamboo, Corn
Animal	Wool/Hair	Cashmere, Horse hair, Goat hair, Lamb wool
	Silk	Mulberry
Mineral	-	Asbestos, Ceramic fibres, Metal fibres

Certain physical and mechanical qualities of NFs, such as fibre structure, cellulose content, intrinsic angle, and degree of polymerization, are determined by their chemical and physical composition [7]. Table 4 displays the physical and mechanical properties of several natural and synthetic fibres. The main problem of NFs is that they swell due to moisture build up, resulting in poor coupling with the composite fibre matrix [8]. NFs are less mechanical by nature than synthetic fibres. The poor mechanical characteristics of high-performance materials are a significant disadvantage in their manufacture. Aside from these advantages, NFs have a downside in that they are hydrophilic [5], which causes them to absorb more moisture and become more susceptible to damage or deterioration.

Table 4. Properties of selected natural fibres and synthetic fibres [4]

Fibre	Density (gcm^{-3})	Diameter (μm)	Length (mm)	Tensile strength (MPa)	Failure strain (%)	Young modulus (GPa)	Moisture content (%)
Abaca	1.5	10–30	4.6–5.2	430–813	2.9	31.1–33.6	14
Alfa	1.4	-	350	188–308	1.5–2.4	18–25	-
Bamboo	1.25	25–88	1.5–4	270–862	1.3–8	17–89	11–17
Bagasse	1.5	-	-	290	-	17	-
Banana	1.35	12–30	0.4–0.9	529–914	5–6	27–32	10–11
Coir	1.2	7–30	0.3–3	175	15–25	6	10
Cotton	1.21	12–35	15–56	287–597	2–10	6–10	33–34
Flax	0.6-1.4	5–38	10–65	345–1035	1.2–3.2	50–70	7
Hemp	1.48	10–51	5–55	700–1110	1.6–4.5	30–70	8
Jute	1.3	5–25	0.8–6	393–773	1.5–3.1	26.5–55	12
Kenaf	1.45	12–36	1.4–11	295–930	1.6–6.9	22–53	6.2–12
Pineapple	0.8-1.6	8–41	3–8	400–1627	1–14.5	60–82	14
Ramie	1.5	18–80	40–250	560–938	2.5–3.8	24.5–128	12–17
Sisal	1.5	7–4	0.8–8	511–855	2.0–3	9.4–22	11
Silk	1.3	-	Continuous	100–1500	15–60	5–25	-
Sugar palm	1.29	-	-	15.5–290	5.7–28.0	0.5–3.37	-
Wool	1.3	-	38–152	50–315	13.2–35	2.3–5	-
E-glass	2.5	-	Continuous	2000–3500	0.5	70	-
S-glass	2.5	-	-	4570	2.8	86	-
Aramid	1.4	-	-	3000–3150	3.3–3.7	63.0–67.0	-

3. Recent engineering applications of natural fibres

Composites have evolved as a novel material class that allows for the synergistic combination of several materials' features to improve a desired property for an application. When compared to synthetic fibres, NFs have a substantial advantage in terms of high specific characteristics (property to density ratio) among the various possibilities for composing them. Another advantage is the abundance of natural sources or remains. They are low in production cost and biodegradable, giving natural fibre composites a sustainable aspect [9]. Their interaction with the matrix will result in high-performance composites

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with applications in a variety of industries, including automotive, aeronautic, construction, medical, and other industries.

a. Automotive industry

Natural fibre composites have been used in the automobile industry since the 1940s, when Henry Ford created the first composite components in a car using hemp fibre [10]. Natural fibre composites are mostly utilized for interior components like dashboards, door panels, parcel shelves, seat cushions, backrests, and cabin linings, with relatively little utilization of natural fibre composite parts for external applications [11]. Due to the obvious increased need for lightweight and ecologically acceptable materials, natural fibre-based composites have tremendous promise in the automobile sector. According to studies, natural fibre composites can lead to greater cost and weight reduction of an automobile component [11]. In addition, the light weight of the components leads to reduced fuel consumption, biodegradability, and fewer greenhouse emissions, which are some of the key reasons for the use of NFs.

b. Aviation industry

Due to their superior mechanical qualities combined with their low weight, lightweight constructions built of composite materials have grown in popularity [18]. To date, synthetic fibre-reinforced composites based on carbon/glass/aramid fibres have been effectively employed in many components of aircrafts. This is because of their great rigidity and strength [12]. Natural fibre-reinforced composites, on the other hand, have piqued the interest of researchers in recent years due to benefits such as biodegradability, low density, and cost-effectiveness when compared to synthetic fibre-reinforced composites. In the near future, they have the potential to be used in aviation applications.

As parts of the aircraft such as the tailplane and wing leading edge, among other things, must withstand the low velocity impact damage caused by bird strikes, hailstones, runway debris, and other causes, it is necessary to understand the behaviour of these composites to impact damage and how various parameters significantly influence the impact properties and damage/failure mechanism of these composites to low velocity impact loads [13]. In another study [14], researchers developed natural fibre-based thermoset and thermoplastic skins for use as airplane interior panels, claiming that each kilogram of weight reduction saves 0.02–0.04 kg of fuel per hour in a typical commercial aircraft. The weight reduction associated with thermoplastic resin panels also correlates to a reduction in CO_2 emissions.

c. Maritime industry

Since ancient times, NFs have been used in marine applications, such as ropes, lashings, and sails [15]. Using locally accessible fibre resources, primitive timber rafts were tied together using ropes and twine. The raft was built from balsa logs tied together with inch and a quarter hemp rope, securely knotted, as is stated in Thor Heyerdahl's (1950) famous account of the Kon-Tiki voyage (crossing the Pacific by raft). The deck was built with split bamboos plaited with bamboo reeds, while the open cabin was built of bamboo canes, plaited bamboo reeds, and bamboo slats, with roof tiles made of overlapping banana leaves. The masts and rudder were made of mangrove wood, and the sails were made of plain-woven canvas, most likely using hemp yarn.

Natural fibre composites have lately presented a solution for the production of fibre composite boats and surfboards with increased eco-profiles, but they have uncertain environmental stability. In comparison to synthetic fibres, the current selection of NFs for maritime applications is motivated by cost, sustainability, and carbon footprint reduction [15]. The use of NFs over synthetic fibres often leads to reduced composite stiffness, which is an important feature in mechanical designs. As a result, it is useful to investigate the mechanical qualities and eco-profiles of natural and synthetic fibres.

d. Packaging

Petroleum-based thermoplastics are widely employed in a variety of applications, most notably packaging. However, their use has led to a significant increase in pollutant emissions. The packaging business is one area where NFs offer potential. Biodegradable polymer reinforcement with NFs is the next logical step in the packaging industry's quest for ecologically responsible, cost-effective solutions [16]. The primary aims of using NFs in packaging are to improve stiffness and strength, reduce weight, and save money by decreasing the polymer content. Furthermore, when mixed with biodegradable polymers, NFs allow the packaging material's biodegradability to be preserved. Several manufacturers have already begun to employ natural fibre composites in place of traditional plastic packaging materials [17]. This highlights the fact that natural fibre composites could offer greater impact qualities and can be employed in rigid packaging with good biodegradability properties.

4. Conclusion

Natural fibres and their composite-based products are gaining popularity in a variety of engineering industries due to their light weight and exceptional mechanical qualities. Conversely, previous petroleum-based composites usually cause substantial environmental problems due to non-biodegradability at the end of their lifetime. Natural fibre and bio-composite materials, on the other hand, are biodegradable and have promising future applications in the automotive, aerospace, maritime, packaging, and other industries due to their low cost and high specific mechanical properties.

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