

Natural Fibers

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Natural fibers are flexible filaments extracted from renewable sources, with complex properties due to the wide variations in the chemical and structural composition of cellulose, lignin, hemicellulose, fatty acids, pectins, and other structures linked by intermolecular hydrogen bonds and forces of Van der Waals forming microfibrils with parallel arrangement.

Keywords: natural fibers ; biocomposites ; polymer

1. Natural Fibers as a Sustainable Alternative to Reinforce Residual Polymers

Natural fibers are flexible filaments extracted from renewable sources, with complex properties due to the wide variations in the chemical and structural composition of cellulose, lignin, hemicellulose, fatty acids, pectins, and other structures linked by intermolecular hydrogen bonds and forces of Van der Waals forming microfibrils with parallel arrangement. They are used in different fields of engineering as reinforcing elements that provides resistance to tension and bending, rigidity, and modulus of elasticity ^{[1][2][3]} forming a remarkable bioengineering material that is of interest for their multiple uses and applications across a wide range of products with pleasing value; they differ from the initial materials, which is related to the nature of the fibers, crystallinity, and insolubility; however, the elaboration of these composite materials in the melt process can present drawbacks such as the viscosity, which can become very high, especially when the fiber content is greater than 50% by weight; Mazzanti et al. ^[4] stated in their research that if the capillary is too narrow, the pressure can become too high and the use of lubricants promotes the sliding of the wall, which can alter the viscosity measurements if researchers do not account for wall slip appropriately ^{[5][6]}.

In natural fibers, the compounds as a whole are held together by the collective function of cellulose, hemicelluloses, lignin, and pectin as matrix; on average, fibers are mainly composed of cellulose (60 to 80%), lignin (5 to 20%), and around 20% moisture ^[7]; these percentages can vary according to the type and origin of the fibers ^[2]. Next, the chemical composition of natural fibers are analyzed in **Table 1** using data from different investigations since their understanding allows us to predict and infer their thermal and mechanical performance ^[3], coupled with the economic and environmental problems that can be solved with this alternative when they are linked to new bio-based compounds.

Table 1. Chemical composition of some natural fibers.

Natural Fibers	Scientific Name	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractive (%)	Ashes (%)	Author, Year
Sugar cane	<i>Saccharum officinarum</i>	46.6–45.1	25.5–25.0	20.7–14.1	29.4–2.7	8.0–2.6	^{[1][8]}
Pineapple	<i>Ananas comosus</i>	81.2–45.0	50.0–12.3	30.0–3.4	—	—	^{[9][10]}
Banana	<i>Musa paradisiaca</i>	60.0–10.0	19.0–16.0	19.0–5.0	9.6–2.0	11.0–1.2	^{[10][11]}
Hemp	<i>Cannabis sativa</i>	72.0–68.0	15.0–10.0	10.0–3.0	—	5.8–2.3	^{[12][13]}
Coconut	<i>Cocos nucifera</i>	53.0–43.0	14.7–1.0	45.0–38.4	—	—	^{[13][14][15]}
Jute	<i>Corchorus capsularis</i>	72.0–60.0	22.1–13.0	15.9–13.0	—	3.0–2.5	^{[12][13]}
Oil palm	<i>Elaeis guineensis</i>	45.0–28.2	18.8–12.7	49.5–9.4	7.13–2.0		^{[16][17]}
Wheat	<i>Triticum</i>	43.2–60.5	34.1–20.8	22.0–9.0	—	5.7–5.6	^{[18][13]}
Kenaf	<i>Hibiscus cannabinus</i>	65.7–63.5	17.6–15.3	21.6–12.7	4.0–2.0	2.2–1.0	^{[1][19]}

Natural Fibers	Scientific Name	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractive (%)	Ashes (%)	Author, Year
Flax	<i>Linum usitatissimum</i>	81.0–70.0	20.6–16.7	10.0–3.0	—	—	[12][14]
Ramie	<i>Boehmeria nivea</i>	73.0–69.8	14.0–9.6	3.9–1.6	—	—	[15][19][20]
Sisal	<i>Agave sisalana</i>	75.0–65.0	13.9–10.0	10.0–7.6	—	1.0–0.4	[13][21][22]

1.1. Cellulose

Cellulose is the major structural component of natural fibers. It is a linear biopolymer composed exclusively of β -glucose molecules linked together by 1,4 bonds that impart good resistance, rigidity, structural stability, porosity, and elasticity to the fiber [7]. This polysaccharide is composed of crystalline and amorphous microfibrils helically aligned along the fiber [12] and is resistant to hydrolysis and oxidizing agents, which can partially degrade in strong acid catalyzed media [23].

1.2. Hemicellulose

Hemicellulose is a structure of straight branched chains composed of the various, most-abundant polysaccharides of lower molecular weight that form a branched chain, including β -glucose, mannose, galactose, or xylose, and the acetyl groups that contain side groups, giving rise to their noncrystalline nature, with a medium degree of polymerization through the covalent bonding of these compounds and by ionic and hydrophilic interactions; it is responsible for the thermal and biological degradation of the fiber through moisture absorption [24], which can be easily hydrolyzed by dilute acids and bases [12].

1.3. Lignin

Lignin is a key component in the fiber structure due to the complexity of its molecular structure. It is an amorphous and cross-linked three-dimensional polymer that acts as a natural binder of the individual fibers—filling the spaces between the pectin, hemicellulose, and cellulose [1][25]—composed of an irregular matrix of linked hydroxy and methoxy substituted phenylpropane units [7], which is responsible for stiffness, producing a structure resistant to impact and stress [13]. It is hydrophobic, resists acid hydrolysis, is soluble in hot alkali, easily oxidizes, and is responsible for radiation degradation despite being thermally stable.

1.4. Pectin

Pectin is an anionic polysaccharide complex that provides flexibility to the fibers since its structure is highly branched [23]; it is a structural acid heteropolysaccharide that is composed of modified glucuronic acid and rhamnose residues. The structural integrity of the plant is enhanced by the pectin chains that often cross-link with calcium ions [7].

Finally, there are extractives and ashes in a lower proportion, with great influence on the properties and processing of natural fibers, since they act as protectors; inhibit the attack of acids; and belong to different classes of organic and inorganic chemical compounds, respectively, which are extracted by washing the fibers with water or organic solvents prior to their binding in the polymeric biocomposite.

2. Properties of Natural Fibers and Their Wide Potential as Reinforcements in Residual Polymers

Natural fibers have a number of physical and chemical properties depending on the content of cellulose, lignin, hemicellulose, and pectin, which make them excellent materials along with their renewability and biodegradability, being a common practice to eliminate lignin and pectin to improve the reinforcing effect of natural fibers in biocomposites [26].

Natural fibers when used as reinforcements in biocomposites, in addition to representing environmental benefits, reduction in energy consumption, insulation properties and acoustic absorption [27][28], also have essential mechanical properties, as evidenced in **Table 2**, with average variations ranging from 1.25–1.5 g/cm³ for density, 320–520 Mpa for tensile strength, 22–48 Gpa for tensile modulus, and 7–25% for elongation before break; additionally, the investigations of Nurazzi et al. [29], Nagaraj et al. [30], and others related flexural strength, modulus of elasticity, thickness swelling, and water absorption as important properties when evaluating them as polymeric reinforcements.

Table 2. Physical and mechanical properties of some natural fibers.

Natural Fibers	Density (g/cm ³)	Endurance Traction (Mpa)	Tension Module (Gpa)	Elongation at Break (%)	Author, Year
Wood	0.50–1.4	130–64	70–7	—	[31][32]
Flax	1.5–1.4	650–250	70–27	3.2–2.3	[33][34][29][31]
Hemp	1.6–1.4	690–630	70.0–45	3.0–1.6	[14][35][36]
Jute	1.5–1.3	773–325	55–26	2.5–1.5	[34][31][37]
Coconut	1.5–1.2	180–146	6–3	30.0–27.5	[33][14][31]
Cotton	1.6–1.5	310–191	12–5	8.0–7.0	[34][31][36]
Sisal	1.2–1.5	430–335	22–9	8.0–2.5	[33][29][36]
Kenaf	1.5–1.4	930–641	53–36	1.6–3.5	[30][38][39]
Bamboo	1.1–0.6	140–600	89–48	—	[34][38][40]

The mechanical properties in natural fibers are lower than in synthetic fibers; they can be improved or equalized by surface modification techniques ^[41] (as presented below), in addition to the low density, which is one of the properties that makes them more attractive for different purposes and engineering applications, such as in construction, aeronautics, and automobiles ^{[42][43]}. On the other hand, it should be noted that the resistance of the fiber depends on the load imposed on the fiber, the weight ratio of the fiber, the cultivation process, the manufacturing or modification process, and the manufacturing methods of the reinforced polymeric matrices ^[44].

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