v. 4, n. 20, 2024

Journal of
Engineering
Research

NEW LOW-DENSITY NATURAL FIBERS USED IN COMPOSITES: A REVIEW

Antonio Ricardo Grippa Satiro
Advanced Materials Laboratory, UENF,
Campos dos Goytacazes, RJ
http://lattes.cnpq.br/0529000071673226

Noan Tonini Simonassi
Advanced Materials Laboratory, UENF,
Campos dos Goytacazes, RJ
http://lattes.cnpq.br/0091760384705916

Sergio Neves Monteiro
``Instituto Militar de Engenharia`` (Military Engineering Institute), Rio de Janeiro, RJ
http://lattes.cnpq.br/2962183322412029

Eduardo Atem de Carvalho
Advanced Materials Laboratory, UENF,
Campos dos Goytacazes, RJ
http://lattes.cnpq.br/2617773687973315

Felipe Perissé Duarte Lopes
Advanced Materials Laboratory, UENF,
Campos dos Goytacazes, RJ
http://lattes.cnpq.br/1944239448019813

Elaine Aparecida Santos Carvalho Costa
Advanced Materials Laboratory, UENF,
Campos dos Goytacazes, RJ
http://lattes.cnpq.br/2265929820644777

Abstract: The growing demand for new materials has made it possible to highlight the use of natural lignocellulosic fibers in the manufacture of composite materials. These fibers, coming from vegetable sources, are characterized by the predominant presence of lignin and cellulose in their composition. The composition of these fibers provides a low-density characteristic compared to other materials, which is an extremely advantageous property in materials engineering. Therefore, in this article, a document review research was carried out to present some lignocellulosic fibers that are being researched to be applied as reinforcement in polymer composites. Focusing on the low-density characteristic, some fibers, their compositions and their main properties were presented. In this review article, it was possible to observe that fibers from curauá, elephant grass, straw and corn stalk have low density combined with good mechanical properties. Another relevant factor observed is that extraction methods and the demand for fibers are factors that limit the large-scale use of the fibers presented here.
Keywords: curauá, elephant grass, corn straw, corn stalk

INTRODUCTION

The growing demand for sustainable materials has intensified interest in natural fibers and their application in polymer composites. Among natural fibers, which are derived from renewable sources, fibers extracted from plants, also called lignocellulosic fibers, have gained prominence [1,2].

The properties of natural fibers, which are incorporated into the polymer matrix, play a crucial role in the effectiveness of composites, as the increase in mechanical strength, tenacity and flexibility directly influences the performance of the final composite [3].

Lignocellulosic fibers generally have a low density when compared to other materials, resulting in low-density composites, which in turn stand out for their ability to combine mechanical resistance and durability with a reduced mass. This characteristic makes them attractive in applications that require resistant but also light materials [4,5].

For a natural fiber to be effectively used as reinforcement in composites, some requirements must be considered before its use. One of the first crucial requirements is the mechanical resistance of the natural fiber. To give the composite desirable structural properties, the fiber must have a strength capable of withstanding significant loads [6,7]. Furthermore, the elastic modulus of the fiber needs to be compatible with the matrix material, ensuring a uniform distribution of loads and avoiding discontinuities that are harmful to the integrity of the composite [8,9].

Certainly, one of the most important characteristics is that the fiber must have low density to preserve the lightness characteristics of the final material, expanding its applicability in sectors that require weight reduction, providing attractive specific properties [10,11].

NEW LOW-DENSITY NATURAL FIBERS

The definition of these fibers lies in the complexity of their lignocellulosic composition that guarantees the fibers a low-density characteristic when compared to other fibers [12,13]. Lignin, providing strength and stability, intertwines with cellulose, which, in turn, offers tenacity and lightness.

This combination provides unique properties that highlight them as versatile materials in materials engineering [11,14]. In this context, fibers from curauá, elephant grass, corn stalk and corn straw are gaining prominence in research into composites.

Figure 1: a) curauá [15], b) curauá fiber [16], c) corn straw, d) corn straw fibers [17], e) elephant grass [18], f) elephant grass fiber [19], g) corn stalk [20], h) corn stalk fibers [21]

The chemical composition of the fibers is directly responsible for guaranteeing their physical and mechanical properties, therefore the chemical compositions of curauá fibers, corn straw, corn stalk and elephant grass are presented in Table 1.

Composition of fibers	Curauá (%)	Corn Straw (%)	Corn Stalk (%)	Elephant Grass (%)
Cellulose	73,60	46,15	35,00	29,90
Lignin	7,50	3,92	35,00	21,10
Hemicellulose	9,90	33,79	25,00	20,20
Pectin	-	-	-	-
Wax	-	-	-	-
Moisture	-	-	-	-
Ashes				7,20

Table 1: Composition of natural fibers [4,22,23,24]

PHYSICAL AND MECHANICAL PROPERTIES OF NATURAL FIBERS

The choice of a natural fiber for a specific application is influenced by its physical and mechanical properties. Understanding these properties is crucial to determining the best choice.

DIAMETER

Fiber diameter is a parameter that can vary greatly depending on the type of natural fiber and can affect several mechanical and physical properties, including strength, flexibility, water absorption and density. Furthermore, a larger cross-sectional area also allows for a greater occurrence of defects in the fiber [25].

In general terms, fibers with smaller diameters tend to have greater flexibility and resistance, on the other hand, fibers with larger diameters are more rigid and less resistant. It is also possible to say that there is a relationship between the diameter of the fibers and their density [26].

DENSITY

Density is one of the important mechanical properties of natural fibers. It refers to the mass per unit volume of the fiber and is normally expressed in grams per cubic centimeter. Density is influenced by several factors, including the chemical composition of the fiber, the degree of maturation, the processing method and the presence of impurities [27,28].

In general, natural fibers have relatively low densities compared to other synthetic materials. This characteristic is important because density directly affects other mechanical properties of fibers, such as specific strength and specific stiffness [28].

TENSILE STRENGTH OF FIBERS

Tensile strength is an important mechanical property of natural fibers that measures the fiber's ability to withstand tension before breaking. This property is directly related to the fiber's ability to withstand loads or tensile forces along its length [6,7].

Tensile strength is influenced by several factors, such as the internal structure of the fiber, its chemical composition, density, humidity, as well as the conditions under which the fiber is processed and treated [29].

YOUNG'S MODULUS

Young's modulus is an important mechanical property for describing the elastic behavior of materials, including natural fibers. This property is a measure of the stiffness of the material and represents the relationship between the applied stress and the resulting elastic deformation [30,31]. For natural fibers, Young's modulus varies widely depending on their chemical composition, structure and processing method [8,9].

The properties of curauá fibers, corn straw, corn stalk and elephant grass are presented in Table 2.

Properties	Natural fibers			
	Curauá	Corn straw	Corn stalk	Elephant grass
Diameter (μm)	50 - 230	133	-	70 – 400
Medium density (g/cm³)	0,57 - 1,34	0,34	0,30	0,81
Tensile Strength (MPa)	117 – 3000	160,49 ± 17,12	33,4 – 34,8	185
Young's Modulus (MPa)	11,5 – 87,23	4,57 ± 0,54	4,10 – 4,50	7,40

Table 2: Properties of natural fibers [17,22,24,32,33,34,35,36,37,38,39]

METHODS FOR EXTRACTING NATURAL FIBERS

The extraction of fibers from plant sources to reinforce polymer matrices is a crucial step. This step requires the careful choice of extraction methods that preserve the properties of the fibers.

CURAUÁ

The process begins with the strategic harvesting of mature curauá leaves. Generally, the leaves are harvested by hand to avoid damaging the fibers. The leaves are cleaned and ground to break down the bark and binders. Then, the fibers are washed, subjected to impact and immersed in water to remain hydrated and prevent them from breaking easily. In order to obtain cleaner fibers, it is recommended to repeat these steps several times. To reduce the time spent in these steps, it is possible to first wash the fibers in a chemical mercerization process. Manual shredding requires precision to ensure fibers are preserved in their ideal shape and length.

The extracted fibers go through a cleaning process to remove any remaining impurities. Drying in the sun is essential to prevent fiber decomposition and fungal growth [40,41,42].

CORN STALK

The process begins with harvesting the corn, followed by carefully separating the stalk from the cobs and leaves. The culms are cut to the desired size and shape. The pieces of culm are then dried in an oven or exposed to the sun for 2 or 3 days. Later, after drying, the outer husk of the dried stalks is removed, resulting in the desired corn stalk fibers. After extraction, the fibers are carefully cleaned to remove impurities and then classified based on criteria such as length and thickness [43,44].

CORN STRAW

The first step involves carefully harvesting the corn stover. After harvesting, the straw is separated from the corn cobs. Then, the straw is cut into thin segments, facilitating the next steps of the process. The straw pieces are then subjected to an alkalization process followed by an enzymatic treatment. Proper drying is crucial to prevent mold development and to ensure fibers do not have excess moisture, which could compromise their quality and durability. After extraction, the fibers are carefully cleaned to remove impurities [44,45].

ELEPHANT GRASS

The extraction of elephant grass fibers begins with the harvesting of the elephant grass. The upper and lower parts of the grass are removed to obtain the finest and best quality fibers, also removing the leaves. In the second stage, the culms are cut, removing the knots and drying in the weather without direct sun exposure for at least a week.

Next, the culms are cut lengthwise along their length and immersed in water for up to 10 days, making the fibers more malleable and easier to separate. This step can be replaced by a chemical extraction process using NaOH. A mechanical extraction process is then used, applying impact and scraping, obtaining the elephant grass fibers. The extracted fibers are then cleaned, dried and stored [35,46].

CONCLUSION

It was possible to observe that low-density natural fibers, including curauá, elephant grass, corn stalk and corn straw, have promising characteristics and properties for materials engineering. The diversity of these fibers offers a wealth of options in creating low-density composites, aligning with demands for lightweight and resilient materials.

Curauá, with its resistance and versatility, stands out as a valuable option, while elephant grass, with its abundance and relevant mechanical properties, proves to be a sustainable alternative. The inclusion of corn stalks and corn straw highlights not only the effectiveness of these fibers, but also the importance of fully utilizing agricultural resources.

The sustainable approach in the extraction and application of these fibers not only reduces dependence on non-renewable materials, but also contributes to mitigating environmental impact. Furthermore, the low density of these fibers results in lightweight composites with good resistance.

The fiber extraction processes are basically manual, which results in low production efficiency and a final value that is not competitive. Constant improvement in extraction and processing methods for these natural fibers is essential to further boost their acceptance and application on an industrial scale.

REFERENCES

[1] KERNI, L. *et al.* A review on natural fiber reinforced composites. Materials Today: Proceedings, v. 28, p. 1616–1621, 2020.

[2] VIGNESHWARAN, S. *et al.* Recent advancement in the natural fiber polymer composites: A comprehensive review. Journal of Cleaner Production, v. 277, p. 124109, 2020.

[3] MARINHO, N. P.; NASCIMENTO, E. M.; NISGOSKI, S.; et al. Caracterização física e térmica de compósito de poliuretano derivado de óleo de mamona associado com partículas de bambu. Polímeros, v. 23, n. 2, p. 201–205, 2013.

[4] CHOKSHI, Sagar *et al.* Chemical composition and mechanical properties of natural fibers. Journal of Natural Fibers, v. 19, n. 10, p. 3942-3953, 2022.

[5] TAMANNA, T. A. *et al.* Characterization of a new natural fiber extracted from Corypha taliera fruit. Scientific Reports, v. 11, n. 1, p. 1–13, 2021.

[6] KRISHNAN, A.; XU, L. R. Effect of the interfacial stress distribution on the material interfacial shear strength measurement. Experimental Mechanics, v. 50, p. 283-288, 2010.

[7] KU, Harry *et al.* A review on the tensile properties of natural fiber reinforced polymer composites. Composites Part B: Engineering, v. 42, n. 4, p. 856-873, 2011.

[8] BLEDZKI, A. K.; GASSAN, J. Composites reinforced with cellulose based fibres. Progress in polymer science, v. 24, p. 221–274, 1999.

[9] ZHAN, Jianghu *et al.* Review on the performances, foaming and injection molding simulation of natural fiber composites. Polymer Composites, v. 42, n. 3, p. 1305-1324, 2021.

[10] KARIMAH, Azizatul *et al.* A review on natural fibers for development of eco-friendly bio-composite: Characteristics, and utilizations. Journal of materials research and technology, v. 13, p. 2442-2458, 2021.

[11] MORTAZAVI, Sayed Majid; MOGHADAM, Meghdad Kamali. Introduction of a new vegetable fiber for textile application. Journal of Applied Polymer Science, v. 113, n. 5, p. 3307-3312, 2009.

[12] MONTEIRO, Sergio Neves *et al.* Natural lignocellulosic fibers as engineering materials - An overview. Metallurgical and Materials Transactions A, v. 42, p. 2963-2974, 2011.

[13] YANG, Jianlei; CHING, Yern Chee; CHUAH, Cheng Hock. Applications of lignocellulosic fibers and lignin in bioplastics: A review. Polymers, v. 11, n. 5, p. 751, 2019.

[14] BRODEUR, Gary *et al.* Chemical and physicochemical pretreatment of lignocellulosic biomass: a review. Enzyme research, v. 2011, 2011.

[15] ZUKOWSKI, Bartosz *et al.* Mechanical Properties of Hybrid PVA–Natural Curaua Fiber Composites. Materials, v. 15, n. 8, p. 2808, 2022.

[16] MACIEL, Natalia de Oliveira Roque *et al.* Comparative tensile strength analysis between epoxy composites reinforced with curaua fiber and glass fiber. Journal of materials research and technology, v. 7, n. 4, p. 561-565, 2018.

[17] SARI, Nasmi Herlina *et al.* The effect of water immersion and fibre content on properties of corn husk fibres reinforced thermoset polyester composite. Polymer Testing, v. 91, p. 106751, 2020.

[18] PEREIRA, A. V. *et al.* BRS Capiaçu: cultivar de capim-elefante de alto rendimento para produção de silagem. Embrapa, comunicado técnico 79, Juiz de Fora, p. 6, 2016.

[19] REDDY, K. Obi *et al.* Chemical composition and structural characterization of Napier grass fibers. Materials letters, v. 67, n. 1, p. 35-38, 2012.

[20] GRAFFITTI, Matheus Santos. Desempenho da cultura de milho em função de arranjos espaciais. Dissertação de mestrado. Programa de Pós-Graduação em Ciências. Universidade de São Paulo. 2020.

[21] CHEN, Zining *et al.* Properties of asphalt binder modified by corn stalk fiber. Construction and Building Materials, v. 212, p. 225-235, 2019.

[22] CHONG, Ting Yen, *et al.* The potentials of corn waste lignocellulosic fibre as an improved reinforced bioplastic composites. Journal of Polymers and the Environment, v. 29, n. 2, p. 363-381, 2021.

[23] KOLO, Sefrinus Maria Dolfi; WAHYUNINGRUM, Deana; HERTADI, Rukman. The effects of microwave-assisted pretreatment and cofermentation on bioethanol production from elephant grass. International Journal of Microbiology, v. 2020, p. 1-11, 2020.

[24] SARI, Nasmi Herlina *et al.* Characterization of the chemical, physical, and mechanical properties of NaOH-treated natural cellulosic fibers from corn husks. Journal of Natural Fibers, v. 15, n. 4, p. 545-558, 2018.

[25] JAAFAR, J. *et al.* Important Considerations in Manufacturing of Natural Fiber Composites: A Review. International Journal of Precision Engineering and Manufacturing - Green Technology, v. 6, n. 3, p. 647–664, 2019.

[26] AMOY NETTO, Pedro *et al.* Correlation between the density and the diameter of fique fibers. In: Materials Science Forum. Trans Tech Publications Ltd, 2016. p. 377-383.

[27] GUAN, J.; FANG, Q.; HANNA, M. A. Selected functional properties of extruded starch acetate and natural fibers foams. Cereal chemistry, v. 81, n. 2, p. 199-206, 2004.

[28] STEVULOVA, Nadezda *et al.* Characterization of manmade and recycled cellulosic fibers for their application in building materials. J. Renew. Mater, v. 7, p. 1121-1145, 2019.

[29] MOHANTY, A. K.; MISRA, M.; DRZAL, L. T. Natural fibers, biopolymers, and biocomposites. CRC Press, 2005.

[30] COSTA JUNIOR, Antônio Eufrazio da. Estudo das propriedades térmicas e mecânicas de biocompósitos com matriz polimérica derivada do lcc suportados em fibras de bambu. 2012. Dissertação de Mestrado. Programa de Pós-Graduação em Química. Universidade Federal do Ceará.

[31] HOLANDA, Elisângela Bezerra das Neves. Morfologia e propriedades mecânicas da fibra de sisal unidirecional e em sobreposição de compósito com resina epóxi. 2013. Dissertação de Mestrado. Programa de Pós-Graduação em Engenharia Mecânica. Universidade Federal do Rio Grande do Norte.

[32] CARVALHO, Leila Maria Coelho; CASAGRANDE, Michelé Dal Toé. Mechanical behaviour of reinforced sand with natural curauá fibers through full scale direct shear tests. In: E3S Web of Conferences. EDP Sciences, 2019. p. 12003.

[33] MELIANDE, Natalin Michele *et al.* Curaua–Aramid Hybrid Laminated Composites for Impact Applications: Flexural, Charpy Impact and Elastic Properties. Polymers, v. 14, n. 18, p. 3749, 2022.

[34] RAMAKRISHNAN, S. *et al.* Theoretical prediction on the mechanical behavior of natural fiber reinforced vinyl ester composites. Appl. Sci. Adv. Mater. Int, v. 1, n. 3, p. 85-92, 2015.

[35] RAO, K. Murali Mohan *et al.* Tensile properties of elephant grass fiber reinforced polyester composites. Journal of Materials Science, v. 42, p. 3266-3272, 2007.

[36] SANJAY, M. Ra; ARPITHA, G. R.; YOGESHA, Basavegowda. Study on mechanical properties of natural-glass fibre reinforced polymer hybrid composites: A review. Materials today: proceedings, v. 2, n. 4-5, p. 2959-2967, 2015.

[37] SIMONASSI, Noan Tonini; BRAGA, Fabio Oliveira; MONTEIRO, Sergio Neves. Processing of a green fiber-reinforced composite of high-performance curaua fiber in polyester. JOM, v. 70, p. 1958-1964, 2018.

[38] VÄISÄNEN, Taneli *et al.* Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review. Waste management, v. 54, p. 62-73, 2016.

[39] YAN, Libo; CHOUW, Nawawi; JAYARAMAN, Krishnan. Flax fibre and its composites–A review. Composites Part B: Engineering, v. 56, p. 296-317, 2014.

[40] DE FREITAS, Ana E. M. *et al.* Curauá fiber from plants produced by tissue culture: thermal, mechanical, and morphological characterizations. Cellulose, v. 30, n. 5, p. 2841-2858, 2023.

[41] SIMONASSI, N. T. Compósitos de alto desempenho de matriz epóxi reforçada com fibras naturais de curauá: caracterização e estudo de parâmetros de processamento. Tese (Doutorado) Programa de Pós-Graduação em Ciência dos Materiais, Instituto Militar de Engenharia, Rio de janeiro, 2019.

[42] ZUKOWSKI, Bartosz *et al*. Effect of moisture movement on the tensile stress–strain behavior of SHCC with alkali treated curauá fiber. Materials and Structures, v. 53, p. 1-11, 2020.

[43] PEÑA, L. *et al.* Mechanical behavior of thermo-mechanical corn stalk fibers in high density polyethylene composites. Journal of Biobased Materials and Bioenergy, v. 6, n. 4, p. 463-469, 2012.

[44] TABAN, Ebrahim *et al.* Acoustic absorption characterization and prediction of natural coir fibers. Acoustics Australia, v. 47, p. 67-77, 2019.

[45] YILMAZ, Nazire Deniz. Effects of enzymatic treatments on the mechanical properties of corn husk fibers. Journal of the Textile Institute, v. 104, n. 4, p. 396-406, 2013.

[46] KUMARA, N. Ravi *et al.* Tensile strength of elephant grass fiber reinforced polypropylene composites. International Journal of Applied Engineering Research, v. 4, n. 11, p. 2363-2369, 2009.