Variability Assessment of Mechanical Properties of Pineapple Leaf Fibers

Maria Fabiana Baldoino Da Paixão
Federal University of Bahia, UFBA
Salvador, Brazil

***Abstract*—Lignocellulosic fibers have been applied to composite materials in order to enhance their mechanical characteristics. Although their economic and environmental benefits have been proven, it is known that these materials can differ in their properties depending on local characteristics of the natural fibers. This study aims to evaluate the variability of the mechanical properties of pineapple leaf fibers (PALFs) from Brazil, India and Malaysia. It was found that pineapple fibers from the same species and region vary in mechanical properties. The species *Cosomus* cultivated in India presented a variation of 59% in tensile strength. Better mechanical behavior of PALFs was observed with an increase of cellulose crystallinity index. In order to define the best application for PALFs in composites it is necessary to evaluate the specific structural characteristics of each species, once their morphological characteristics depend on local planting conditions.**

***Keywords*— Lignocellulosic Fibers; Pineapple Leaf Fibers; PALF, Composites.**

I. INTRODUCTION

Civil industry has a significant participation in the economy. However, it is also responsible for the environmental impacts of extracting and manufacturing construction materials, transporting inputs, carrying out of construction and waste disposal. The current environmental impacts caused by the construction industry have stimulated the development of activities associated with the principles of sustainable construction, such as the adoption of more responsible ways of raw material exploitation and the application of less aggressive materials and constructive techniques to the environment [1].

In order to meet the new needs of the market, there has been an increase in the demand for high performance, more resistant and light materials. As a consequence, composites have become a significant material choice for a vast range of industries, being used in automotive and military applications, furniture and fashion accessories [2].

The composite materials are made by combination of two or more materials of different chemical composition which are necessarily insoluble in each other. They consist of one or more discontinuous phases (defined as reinforcements) dispersed in a continuous phase (matrix) and their properties are influenced by the properties of the constituents, by the distribution and interaction among them, among other aspects [3,4].

Since natural fibers have small cross-sections and cannot be directly used in engineering applications, they are immersed in matrix materials in order to form fiber composites. The matrix phase has the function of connecting the fibers to each other and acting as a mean by which an externally tension applied is transmitted and distributed by the fibers. The final strength of the composite is strongly associated with the magnitude of the adhesive bond between the fiber and the matrix, and a suitable interface is essential for the maximization and transmittance of the matrix tension for the fibers. Once composite materials have been developed for several applications it is fundamental to comprehend physical-mechanical properties of both reinforcements and matrix and also their interaction/interface Adhesion fiber-matrix might be affected by the fiber´s absorption of moistures, so that lignocellulosic can be chemically treated aiming to anchor fibers and matrix and promote a stronger interfacial adhesion [5,3]. These adhesion´s improvements trend to promote an optimums fiber-matrix and increase the durability and mechanical behavior of the composites.

Plant fibers can be considered as interesting, safe and environmentally friend alternatives for the development of new materials. They are process-friendly, have lower specific weight and have good thermal and acoustic insulating properties as well. There are several advantages in the application of natural fibers in composites, such as their low density, low cost, high filling level possible, low energy consumption, high specific properties, biodegradability, and generation of rural/agricultural-based economy [5]. From the environmental point of view, the use of vegetal residues to produce lignocellulosic fibers constitutes an alternative to add value to the composite production process and to minimize the emission of residues [6,7]. However some disadvantages must be considered such as variable quality depending on unpredictable influences as weather and moisture absorption. Furthermore the fluctuation of prices based on harvest results or agricultural politics can limit their industrial application [8].

Among the considered natural fibers for application in composites are coconut [9,10], banana [10], sisal [11] and other ones from agroforestry waste [12].

The pineapple is part of the *Bromeliaceae* family. The cultivated types belong to the genus *Ananas*, which covers several species, the most familiar which is explored for commercial purposes, is *Ananas comosus* [13]. Pineapple is largely cultivated in tropical countries and its availability provides a possibility of exploring their utilization as biodegradables composites for diverse applications.

The main pineapple producers in 2014 were Thailand, Brazil, the Philippines, Costa Rica and India (in decreasing order of production). The pineapple production in 2014 corresponds to 2.64 million tons in Brazil and 1.73 million tons in India and around 0.33 million tons in Malaysia which grows about 130 different species for several uses [14].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

PALF present suitable mechanical properties in comparison with other lignocellulosic fibers such as jute, flax, sisal and others [15,16]. Natural fibers are subdivided by their origins: leaf, bast, seed or fruit. PALF is extracted from the crown, which is discarded by both industry and consumers, enforcing the residue as raw material for application in composites. The pineapple Curauá (*Ananas comosus var. erectifolius*) which is a *bromeliacea* grown in Brazil is already applied as mechanical reinforcement and it is largely used in the automotive industry [17].

The present research aims to evaluate the potential of PALF as reinforcement in composites considering the variability associated to the mechanical properties.

II. METHODOLOGY

Seven pineapple crown fibers from species cultivated in Malaysia (*Moris Gajah*, *Josapine*, *Sarawak*), India (*Cosomus*) and Brazil (*Bromelia sp*. and *Bilbergis sp*.) were considered for this assessment.

A literature review was carried out aiming data about those species, especially results about mechanical tests of fibers together with their chemical analysis. After analyzing the available data, it was studied the relation between the composition of the fibers (content of cellulose, hemicellulose, lignin, ashes) and the measured mechanical properties.

Three mechanical properties were considered for this assessment: tensile strength, Young´s modulus and elongation break. Tensile strength is the capacity of a material to withstand loads tending to elongate. Young's modulus is a measure of the stiffness of a solid material and is defined as the relationship between stress (force per unit area) and strain (proportional deformation) in a material. Elongation break, or fracture strain, is the ratio between the changed length and the initial length after breakage of the sample.

Tensile testing involves pulling a sample with a fixed cross-sectional area with a tensometer at a constant strain (change in gauge length divided by initial gauge length) rate until the sample breaks. The test directly measures the ultimate tensile strength, maximum elongation at break and reduction in area. From these properties, it is then inferred the Young's modulus. Materials like composites, textiles and natural fibers are anisotropics. That is, they have the property of being directionally dependent, which implies different properties in different directions. Therefore, a biaxial tensile test, in which the sample is stretched in two distinct directions, must be carried out for PALFs.

Among the bibliography consulted, articles that use biaxial tensile testing were selected. It was also regarded the methods of sample preparation and eventual pretreatment of the fibers [18]. Although no alkaline treatment was applied to the fibers, different processes were made to obtain the fibers - measures, cuts, scrapes, sieving, manual selection, calender, and fiber bond. All fibers were washed and dried in order to extract possible impurities.

III. RESULTS AND DISCUSSIONS

A. *Geographical variability of mechanical properties*

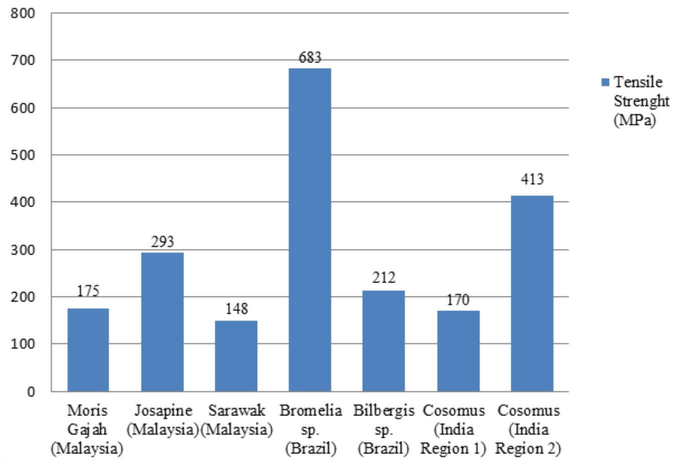
Seven samples of pineapple cultivars from different planting conditions - India, Malaysia and Brazil - were analyzed on mechanical properties. The results presented significant variations tensile strength, Young´s modulus and elongation at break, as showed in Table 1.

TABLE I – TENSILE STRENTH, YOUNG´S MODULUS, ELONGATION AT BREAK.

Author	PALF	Tensile strength (MPa)	Young´s modulus (GPA)	Elongation at break (%)
[19]	*Moris Gajah* (Malaysia)	174.89	7.45	0.52
	Josapine (Malaysia)	293.08	18.94	1.41
	Sarawak (Malaysia)	148.44	10.46	1.05
[20]	*Bromelia sp.* (Brazil)	638.00	41.59	2.05
	Bilbergis sp. (Brazil)	212.00	15.42	1.99
[21]	*Cosomus* (India Region 1)	170	6.21	3
[17]	*Cosomus* (India Region 2)	413.00	6.50	1.60

The *Bromelia* and *Bilbergis* species cultivated in Brazil presented tensile strength values of 638 Mpa and 212 Mpa respectively, representing a 67% of discrepancy from each other. Samples from India presented a variation in tensile strength of 59% observed even in the same species – *Cosomus*. Graph.1 shows the variability of this parameter among the different species considered.

Graph.1: Comparative of tensile strength for each specie



B. *Effect of content and structural characteristics of the fibers on mechanical properties*

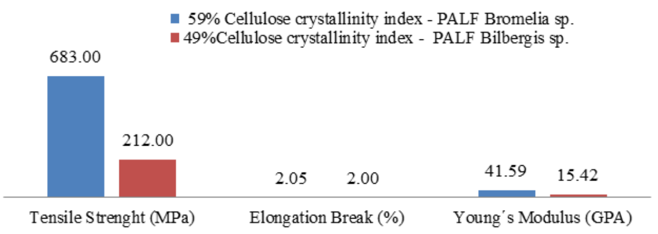
The main chemical constituents of PALFs are cellulose (70–82%), lignin (5–12%), and ash (1.1%). However climatic conditions, age, and the digestion process influence not only the structure of fibers but also the chemical composition which are strongly associated with their mechanical behavior [5,15,16,22].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 01, January-2017

The properties of plant fibers can be correlated with some structural parameters that vary from one natural fiber to another. Plants have tissues that provide mechanical and mechanical support. The cells that constitute tissues are responsible for absorbing internal and external forces that are transmitted to the plant structures, resisting to tensile, compressive and bending stress and also torsional strength. The cells are formed by a crystalline microfibrils based on cellulose, that are connected to a complete layer by amorphous lignin and hemicellulose. Multiple layer of cellulose-lignin/hemicellulose stick together to form a multiple-layer-composite, the cell. The cell walls differ not only on their composition (ration between cellulose and lignin/hemicellulose) but on the orientation (spiral angle) of cellulose microfibril. The spiral angle of the fibrils and the content of cellulose generally determine the mechanical properties of the cellulose-based natural fibers [28]. So that cellulose is the main structural component of lignocellulosic fibers since it provides resistance and stability to cell walls and fiber as a whole. The cellulose present in the vegetable fibers forms long chains that are organized three-dimensionally in the microfibrils, giving the fiber a degree of crystallinity that can improve mechanical properties of fibers [4,5,23,24].

The PALF samples from Brazil *Bromelia sp.* and *Bilbergis sp.* were analyzed aiming to correlate the cellulose crystallinity index and the mechanical properties. Results are shown in Graph.2.

Graph.2: Comparative of mechanical properties X cellulose crystallinity index

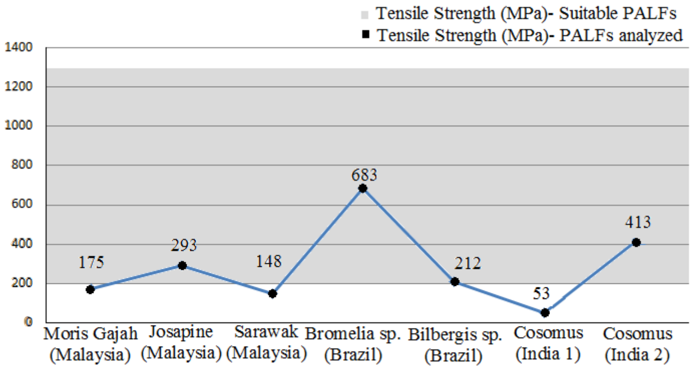


It was observed that the cellulose crystallinity index had improved the mechanical behavior of PLAFs submitted to compressive strength. The contained cellulose in vegetable fibers forms long chains in the microfibrils that give the fiber a degree of crystallinity. This arrangement can be considered an ordered phase, alternated with amorphous phases in the cellular structure of the fiber. Superior mechanical properties of PALFs can be associated with its high degree of cellulose crystallinity [4,15,16,23,24].

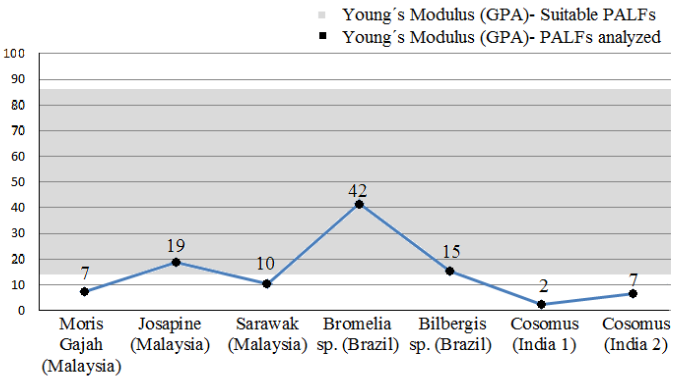
In previous research [4] were studied 18 varieties of pineapple cultivars (*Ananas* genres) aiming to evaluate their applicability to polymer composites reinforcements. The mechanical properties, together with thermogravimetry, indicated that the 18 PALFs are suitable to be used as a fibrous reinforcement in polymer composites. The mean composite values of the elastic modulus varied from 15 to 86GPa and the tensile strength between 212 and 1309MPa.

The seven samples studied in this research were evaluated to their suitability on polymer composites reinforcement based in correlations to previous studies. In terms of materials science and engineering, and in order to serve as a mechanical reinforcement in polymer composites, the fibers must have values of tensile strength and elastic modulus higher than those of the polymers used as matrix [4]. Graph. 3 and 4 show the mechanical properties of seven samples analyzed in this research in comparison to an optimum range of tensile strength and Young´s modulus of PLAFs applied as reinforcement in polymer composites [4].

Graph.3: Comparative of tensile strength - Suitable PALFs X PALFs analyzed



Graph.4: Comparative of Young´s Modulus - Suitable PALFs and PALFs analyzed



The pineapple cultivars *Sarawak* from Malaysia and *Cosomus* from India (sample for region 1) presented lower values on tensile strength comparing to the optimum values suggested. The pineapple cultivars *Moris Gajah* (Malaysia), *Sarawak* (Malaysia), *Cosomus* (India, region 1), *Cosomus* (India, region 2) had lower Young´s modulus than the average suitable to polymer reinforcement.

IV. CONCLUSIONS

In this research it was demonstrated that the mechanical behavior of PALF varies not only from region to region, but also on similar species cultivated in the same region, evidenced by the species *Cosomus* cultivated in India presenting a variation of 59% in tensile strength. Those variabilities belonging to plant materials suggest different possibilities of use for each variety.

It was evidenced that the structural characteristics of the fibers (such as the cellulose content) interfere in the mechanical behavior, being observed the increase of the mechanical properties of the fibers with the increase cellulose crystallinity index. It is important to point out that the morphological characteristics of the natural fibers depend on local planting conditions (soil, temperature, hydration), and it is necessary to evaluate the specific structural characteristics of each species in each growing region, aiming the most suitable applications for these fibers.

Despite the impossibility to determine the fibers studied as suitable to polymer composite reinforcement only based in comparison results, it is important to reinforce that each group of PALFs can be better explored in order to match the different applications of composite materials.

REFERENCES

[1] C.G. Roth, C.M. Garcias, “Construção civil e a degradação ambiental,” Desenvolvimento em Questão, vol.13, pp. 111-128, Jun 2009.

[2] V.P. Silva, “Compósitos poliméricos de fibras curtas de sílica/silicona,” Compinas, UNICAMP, 2005.

[3] W.D. Callister, “Ciência E Engenharia de Materiais: Uma Introdução,” 5th ed. LTC: Livros Técnicos e Científicos Editora S. A., 2000, pp. 359-376.

[4] A.R.S. NETO, “Estudo de fibras de folhas de abacaxis (gênero Ananas) e sua utilização em compósitos biodegradáveis com matriz de poli (ácido lático) (PLA),” São Carlos: UFSCar, 2014.

[5] S. Mishra; A.K.; Mohanty, L.T. Drzal, G. Hinrichsen, “A Review on pineapple leaf fibers, sisal fibers and their biocomposites,” Macromolecular Materials and Engineering, vol. 283, pp. 955-974, November 2004.

[6] K.S. Prado, M.A.S. Spinacé, “Characterization of Fibers from Pineapple's Crown, Rice Husks and Cotton Textile Residues,” Materials Research, vol. 18, pp. 530-537, June 2015.

[7] D. Puglia, F. Sarasini, C. Santulli, J.M. Kenny, “Manufacturing of Natural Fiber/Agrowaste Based Polymer Composites”. In: “Green Biocomposites”. Springer International Publishing, 2017, pp. 125-147.

[8] J. Biagiotti, D. Puglia,J.M. Kenny, J. M, "A review on natural fibre-based composites-part I: structure, processing and properties of vegetable fibres," Journal of Natural Fibers, vol. 1, pp. 37-68, November, 2004.

[9] C.L. Hwang, V.A. Tran, J.W. Hong, Y.C. Hsieh, “Effects of short coconut fiber on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites”. Construction and Building Materials, vol. 127, pp. 984-992, November 2016.

[10] K.S. Kumar, I. Siva, N. Rajini, J.W. Jappes, S.C. Amico, “Layering pattern effects on vibrational behavior of coconut sheath/banana fiber hybrid composites”. Materials & Design, vol. 90, pp. 795-803, January 2016.

[11] A. Orue, A. Jauregi, U. Unsuain, J. Labidi, A. Eceiza, A. Arbelaiz, “The effect of alkaline and silane treatments on mechanical properties and breakage of sisal fibers and poly (lactic acid)/sisal fiber composites”. Composites Part A: Applied Science and Manufacturing, vol. 84, pp. 186-195, May 2016.

[12] T. Väisänen, A. Haapala, R. Lappalainen, L. Tomppo, “Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review”. Waste Management, vol. 54, pp. 62-73, August 2016.

[13] UNCTAD - United Nations Conference on Trade and Development. http://unctad.org/en/Pages/Home.aspx. Acessed in December 2016.

[14] FAOSTAT- Food and Agriculture Organization of the United Nations Statistical Database. Crops database. http://faostat3.fao.org/browse/Q/QC/S. Acessed in October 2016.

[15] L.U. Devi, S.S. Bhagawan, S. Thomas, "Dynamic mechanical analysis of pineapple leaf/glass hybrid fiber reinforced polyester composites," Polymer composites, vol. 31, pp. 956-965, August 2009.

[16] L.U. Devi, S.S. Bhagawan, S. Thomas, "Mechanical properties of pineapple leaf fiber-reinforced polyester composites," Journal of Applied Polymer Science, vol. 64, pp. 1739-1748, November 1996.

[17] A.L. Leão, I.S. Machado, I. S., S.F. Souza, L. Soriano, "Production of curauá (Ananas Erectifolius LB SMITH) fibers for industrial applications: characterization and micropropagation," In VI International Pineapple Symposium, 822, pp. 227-238, November 2007.

[18] N. Venkatachalam, P. Navaneethakrishnan, R. Rajsekar, S. Shankar, “Effect of Pretreatment Methods on Properties of Natural Fiber Composites: A Review”. Polymers & Polymer Composites, vol. 24(7), pp. 555-566, August 2016.

[19] A. R. Mohamed, S. M. Sapuan, M. Shahjahan, A. Khalina, “Characterization of pineapple leaf fibers from selected Malaysian cultivars,” Journal of Food, Agriculture & Environment, vol. 7, pp. 235-240, January 2009.

[20] A.K. Bledzki, J. Gassan, “Composites reinforced with cellulose based fibres,” Progress in Polymer Science, vol. 24, pp. 221-274, May 1999.

[21] A.K.Mohanty, M. Misra, G. Hinrichsen, "Biofibres, biodegradable polymers and biocomposites: an overview," Macromolecular materials and Engineering, vol. 276, pp. 1-24, March 2000.

[22] R.M.N. Arib, S.M Sapuan, M.M.H. Ahmad, M. T. Paridah,H.K. Zaman, "Mechanical properties of pineapple leaf fibre reinforced polypropylene composites," Materials & Design, vol. 27, pp. 391-396, December 2004.

[23] A.R.S. Neto, M.A.M. Araujo, F.V.D. SouzaA, L.H.C. Mattoso, J. M. Marconcini, “Characterization and comparative evaluation of thermal, structural, chemical, mechanical and morphological properties of six pineapple leaf fiber varieties for use in composites,” Industrial Crops and Products, vol. 43, pp.529-537, May 2013.

[24] A.R.S. Neto, M.A.M. Araujo, R.M.P. Barboza, A.S. Fonseca, G.H.D. Tonoli, F.V.D. Souza, L.H.C. Mattoso, J.M. Marconcini, “Comparative study of 12 pineapple leaf fiber varieties for use as mechanical reinforcement in polymer composites,” Industrial Crops and Products, vol. 64, pp. 68-78, February 2015.