Comparative Analysis of the Tensile Properties of Polyester to Epoxy Matrixes Composites Reinforced with Hemp Fibers

MANTOVANI, D. P. [a], ROHEN, L. A.[a], NEVES, A. C. C.[a], VIEIRA, J. S. [a], PONTES, L. A. P. [a], VIEIRA, C. M. F. [a], MARGEM, F. M.[b], MONTEIRO, S. N. [c]

a. State University of the Northern Rio de Janeiro, UENF, Advanced Materials Laboratory, LAMAV; Av. Alberto Lamego, 2000, 28013-602, Campos dos Goytacazes, Brazil

b.Faculdade Redentor Rodovia BR 356. n° 25 Itaperuna RJ - 28.300-000

c.Instituto Militar de Engenharia , IME, Praça Gen. Tibúrcio, nº80 Urca, Rio de Janeiro - RJ, 22290-270

Abstract

This present work consists in comparing the tensile properties of polyester and epoxy matrix composites reinforced with hemp fibers. According to ASTM D-638-14 the matrix, polyester and epoxy reinforcing specimens reinforced with different volumes of hemp, 0%, 10%, 20% and 30% fibers were made and suitably tested by a universal machine INSTRON model 5582 of the LAMAV / UENF. The epoxy matrix composites reinforced with 30% of fibers presented tensile strength, of 53.08 MPa, while those of polyester matrix, 25.44 MPa. The elastic modulus, epoxy matrix composites, in a volume of 30%, was 1.75 GPa and the polyester matrix 4.05 GPa. The tests showed comparatively that the resistance of the epoxy reinforced with hemp fiber composites is superior to the composites of polyester matrix. However, the stiffness of these polyester / hemp fiber composites is higher than the epoxy / hemp fiber ones. The determination of the mechanical properties of these new composites materials contributed to the search for new sustainable materials, economically viable and technologically advanced.

Keyword*: tensile properties, composites, polyester, epoxy, hemp fibers.*

1. Introduction

The interest in using polymeric composites reinforced with lignocellulosic fibers grows in proportion to the worldwide concern with the preservation of the environment and the use of the renewable materials. Just as a search for natural fibers that properly replace synthetic ones such as fiberglass, has been made increasing expressively (Da Silva et al. 2008). Many of these new materials are already being applied in the aerospace, leisure, construction, sports, packaging and automotive industries (Ku et al. 2011).

Polymeric composites are structural molding materials, formed by a continuous polymeric phase called matrix, which is reinforced by a discontinuous reinforcing phase. The discontinuous phase, or reinforcement, usually consists of fibers which may be glass, aramid, carbon, natural lignocellulosic or animal origin, depending on the final application (Aquino et al. 2005). The continuous phase, matrix, is generally composed of a resin, which may be derived from thermoplastic or thermosetting polymers

(Adamian et al. 2009). Among the advantages of using polymer composites are: low weight, corrosion resistance and high temperatures and excellent mechanical properties when compared to conventional engineering materials (Agarwal and Broutman, 1990).

Most of the polymer matrices used in composites are thermosetting resins, being epoxy, phenolic and polyester resins the most important, since they are polymers in addition to a high thermal resistance, those composites have a better dimensional stability than thermoplastics. The polyester resins in addition to a low cost also have satisfactory mechanical properties, widely used as matrix of composites reinforced with glass fibers (Hage, 1989, Goodman, 1998). The epoxy resins have a higher cost, being very used in aerospace applications because of their better mechanical properties and better resistance to moisture than polyesters (Strong, 1989) .

Natural fibers have many special properties that make them an attractive alternative to traditional materials such as: stiffness, impact resistance, flexibility, good thermal and electrostatic properties, biodegradability, economic viability, improved energy recovery, reduced tool wear, low density, less skin and respiratory irritation, which makes them an interesting sustainable resource as reinforcement of composite materials (Sgriccia et al. 2008, Dhakal et al. 2007). But the use of natural fibers as a booster or substitute is still a challenging issue as they are neither regular in shape nor in dimensions and show a relatively inferior mechanical performance to synthetic fibers. Despite all the drawbacks mentioned regarding the use of natural fibers as reinforcement of composite materials, the main argument in favor of the use of these fibers as reinforcement is their low density, which allows the achievement of high levels of specific properties. Hemp fibers are extracted from the stem of the *Cannabis* plant and consist in a very resistant lignocellulosic fiber (Koguchi, 2014). In general this fiber is composed of cellulose, hemicellulose, lignin, pectin, fats and waxes (Thakur et al. 2014). The high cellulose content in the walls of the hemp fibers makes this an interesting renewable raw material for reinforcement in composites and concrete (Salentijn et al. 2014).

Generally, the tensile properties of the composites are improved by the addition of fibers to a polymeric matrix, since the fibers have much higher strength and stiffness values than those of the matrices, bonding greater stiffness to a material of higher ductility (Ku et al. 2011, Mostefai et al. 2015). The literature reports many studies on the use of hemp fibers as reinforcement of different polymer matrix, such as polyester and epoxy. Sébe et al. (2000), evaluated the mechanical behavior of the composites of matrix polyester reinforced with hemp fiber, prepared using the Resin Transfer Molding (RTM) technique under flexion and impact. Rouison et al. (2005), studied the optimization of the Resin Transfer Molding process (RTM) in the preparation of polyester composites reinforced with hemp fibers. Already, Scarponi et al. (2009) characterized epoxy matrix composites reinforced with hemp fibers, molded by Resin Transfer Molding (RTM), and their performance against impact. Santulli and Caruso (2009) analyzed the architecture of the hemp fiber in the impact properties of epoxy matrix composites reinforced with hemp fiber.

Then, the work analyzed to comparatively analyze the tensile properties of polyester matrix composites with those of epoxy matrix reinforced with hemp fibers in different fiber volume fractions, that contributed to the search for new sustainable materials, economically viable and technologically advanced.

2. Materials and Methods

2.1 Materials

As reinforcement of the specimens, hemp fibers were purchased from the company Desigan Natural Fibers. The Figure 1 illustrates the aspect of the fibers used in this work.

Fig.1. General aspect of hemp fiber

As matrixs of the composites were used:

- unsaturated orthophthalic polyester resin hardened with 0.5% methyl ethyl ketone primer purchased from ResinPoxy LTDA;

- bisphenol A diglycidyl ether epoxy resin (DGEBA) with triethylene tetramine hardener (TETA) in the stoichiometric ratio corresponding to phr = 13 (13 parts hardener per 100 parts resin), purchased from ResinPoxy LTDA.

According to the ASTM D 638-14 suitable samples were prepared for the tensile test. In this process was used a steel matrix with the dimensions 5.8 X 76.7 X 4.5 mm, in the shape for tensile test. The Figure 2, shows this mold:

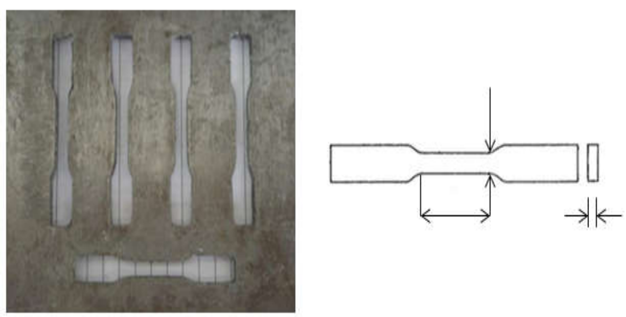

Fig.2. Metal matrix for tensile test

2.2 Methods

The hemp fiber was characterized by its diameter and length. Initially, 100 fibers were randomly selected from the purchased lot. These had their length measured with the aid of the caliper. Their diameters were obtained through a Nikon model 6C profile projector in the LAMAV / UENF, shown in Figure 3.

Fig.3. Nikon Profile Projector used to measure fiber diameters

Each fiber had its diameter measured individually on the profile projector at five distinct points along its length. For each fiber the diameter was measured in five positions, at 0 ° and after the rotation of 90 °, in order to obtain the most varied possible dimensions. At the end, the diameter and length were analyzed statistically.

The specimens used in this test were made initially placing the different volumetric concentrations of hemp fibers, 0%, 10%, 20% and 30%, continuously and aligned within the steel matrix. Both the polyester and epoxy resin, still in liquid form already added to their hardeners, were poured onto the fibers within the matrix. The curing process of the samples was done for 24 hours under pressure and at room temperature. These samples were tensile tested by an INSTRON, model 5582 LAMAV / UENF universal machine. From the results by the Instron machine, the calculation of maximum tensile stress (σm) and tensile modulus (E) of the specimens were obtained through the following equations (Callister, 2007):

$$\sigma = \frac{F}{A} \quad (1)$$

$$E = \frac{\sigma}{\varepsilon} \quad (2)$$

Where:

F Applied force (N)

A Area of the specimen

E Yong Modulus (GPa)

σ Applied tensile

ε Longitudinal elastic deformation of specimen

3. Results and Discussions

The fibers that had their lengths measured with pachymeter and their diameters using the Nikon profile projector which allowed the statistical evaluation of the diameter and length of the samples. In this evaluation the lengths of the 100 fibers and their diameters were schematically divided into intervals associated to their frequencies, as can be observed in the Figure 4.

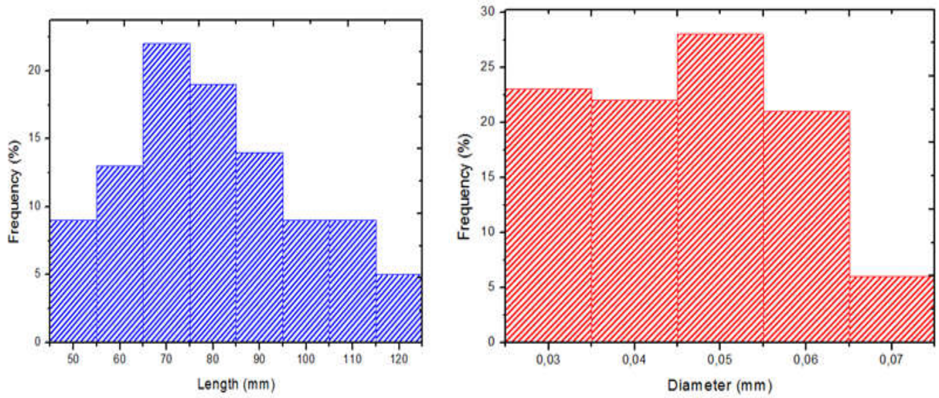

Fig. 4. Statistical distribution of the length and diameter of the hemp fibers

Based on the histogram an average length of 76.6 mm and an average diameter of 0.042 mm were calculated for the hemp fibers investigated.

After the tensile test on a universal machine INSTRON, model 5582 of the LAMAV / UENF, some preliminary data such as the ratio between the force (N) applied as a function of the elongation (mm) of the tested samples were obtained initially by the software of the machine. These can be seen in Figure 5.

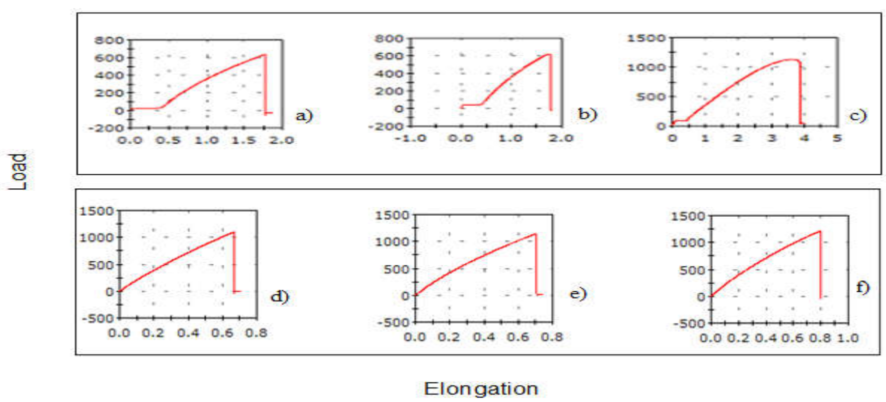

Fig. 5. Load curves vs. Elongation, obtained in the tensile test of the polyester matrix a) 0% reinforced with hemp fibers at b) 10% and e) 30% and of epoxy matrix d) 0% reinforced with hemp fibers at e) 10% and f) 30%.

Analyzing these preliminary data it's noticed that as expected the tensile curves of the polyester matrix and the epoxy matrix, it has a linear behavior, typical of brittle materials, that when they reach the maximum resistance point, they suddenly break. With the addition of fibers, this linear behavior is modified in the 30% fiber content the maximum strength load is higher than at 0% and 10% fiber, in both the polyester and epoxy matrix samples.

To obtain these results, the data were applied to the equations (1) and (2) what made it possible the calculation of representative values in tensile strength and elastic modulus of these new materials. The table 1 shows the tensile properties values of the epoxy and polyester reinforced composites with different volume fractions of hemp fibers incorporated.

Table 1. Tensile Strength of the epoxy and polyester composites reinforced with differents the amount of hemp fibers.

Amount of Hemp Fiber (Vol. %)	Tensile Strength Epoxy composite (MPa)	Tensile Strength Polyester composite (MPa)
0	28.99 ± 6.58	23.29 ± 4.81
10	37.43 ± 3.29	15.38 ± 6.33
20	45.56 ± 6.73	24.85 ± 7.81
30	53.08 ± 3.28	25.44 ± 5.35

Figure 6 plots the results of tensile strength of the epoxy composites and polyester composites in function of the volume fraction of hemp fibers incorporated.

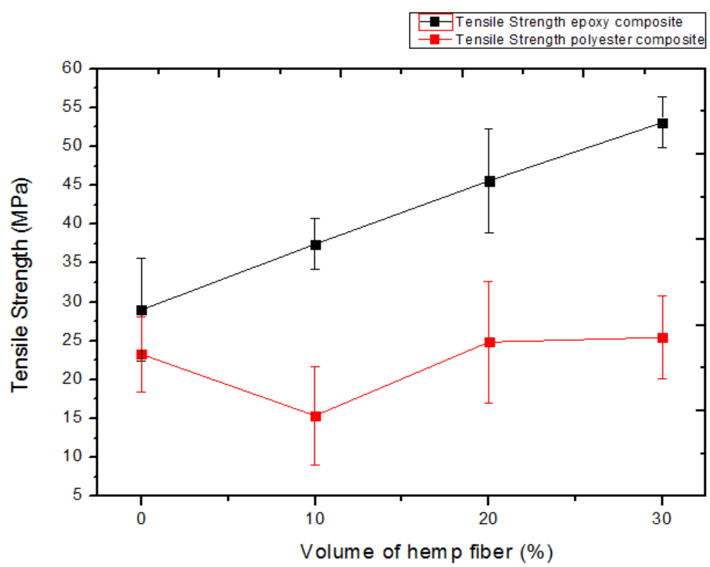

Fig. 6. Tensile strength variation with the amount of hemp fiber in the epoxy and polyester composites

In this figure it should be noticed that both the composite tensile strength and stiffness significantly increase with the volume fraction of hemp fiber incorporation into the epoxy matrix. The values of tensile strenght to the polyester composites could be adjusted to a linear increase of hemp fibers volume fraction in the matrices. However, the values of tensile relation, as this one what demonstrates an increase of the tensile strenght of the composites by the strenght of the epoxy composites showed that this material is more resistant than the polyester composites.

Table 2 shows the average values of the Elastic Modulus of epoxy and polyester composites with different amounts of hemp fiber investigated.

Table 2. Elastic Modulus of epoxy and polyester composites with different amounts of hemp fiber

Amount of Hemp Fiber (Vol. %)	Elastic Modulus Epoxy composite (GPa)	Elastic Modulus Polyester composite (GPa)
0	0.83 ± 0.23	3.35 ± 0,98
10	1.88 ± 0.16	2.98 ± 0,87
20	1.70 ± 0.05	2.60 ± 0.82
30	1.75 ± 0.13	4.05 ± 0,96

Figure 7 plot the results of the Elastic Modulus of the epoxy and polyester composites with different amounts of hemp fiber investigated.

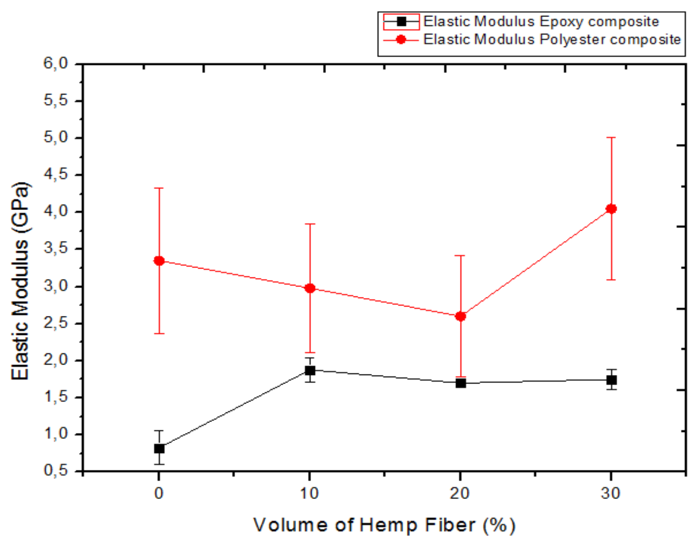

Fig. 7. Elastic Modulus of the epoxy and polyester composites in function different amounts of hemp fiber

The Elastic Modulus variation in Fig 7 could also be adjusted to a linear relation and demonstrates a relevant increase in it values with the increase of fibers in the matrix in the both epoxy and polyester composites. On the other hand, the elastic modulus of the polyester composites shown better results than that of the epoxy composites, which demonstrates that these composites presented greater stiffness when compared the polyester ones.

4. Conclusion

The incorporation of continuous and aligned hemp fibers significantly increases the tensile properties of the composites analyzed.

Epoxy composites reinforced with hemp fibers showed higher tensile strength than polyester composites reinforced with hemp fibers. Futhermore, these polyester matrix composites presented higher stiffness compared to the epoxy ones.

The analysis of the tensile strength of this new material, contributed to the search for new sustainable and technologically advanced materials.

5. Aknowelegements

The authors thank the support provided by the Brazilian agencies: CNPq, CAPES, and FAPERJ

6. References

Adamian, R., Medina, V., Weisz, J. (2009). Novos materiais: tecnologia e aspectos econômicos. Rio de Janeiro: COOPE- UFRJ.

Agarwal, B. D., Broutman, L. J. (1990) Analysis and performance of fiber composites. New York [etc.]: John Wiley & Sons, 1(2).

Aquino, R. G. M. P., Almeida, J. R. M., Monteiro, S. N. (2005) Análise do compósito de piaçava/ resina poliéster, como substituto da madeira. In: 60º Congresso Anual da Associação Brasileira de Metalurgia e Materiais- ABM, Belo Horizonte-MG, 1484-1492.

ASTM, Internacional Standard Test Methods for Tensile Properties of Plastic. (2002) ASTM D 638-14. United States.

Callister JrWD.Materials Science and Engineering. (2007) 7. ed. New York: John Wiley & Sons.

Da Silva, R. V., Aquino, E. M. F., Rodrigues, L. P. S., Barros, A. R. F. (2008) Desenvolvimento de um compósito laminado híbrido com fibras natural e sintética. Revista Matéria: 13 (1): 154-161.

Dhakal, H. N., Zhang, Z. Y., Richardson, M. O. W. (2007) Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. Composites Science and Technology, 67: 1674–1683.

Goodman SH. Handbook of Thermoset Plastics (1998). 2. ed. New Jersey: Noyes Publications.

Hage, Jr. E. (1989) Compósitos e Blendas Poliméricas, Campinas: Instituto Latino Americano de Tecnologia e IBM.

Koguchi, T. C. (2014) Uma planta, muitas discussões. Ler e Saber, 2(2): 6-17.

Ku, H., Wang, H., Pattarachaiyakoop, N., Trada, M. (2011) A reviewon the tensile properties of natural fiber reinforcedpolymercomposites. Composites: Part B: (42): 856-873.

Mostefai, N., Hamzaoui, R., Guessasma, S., Aw, A., Nouri, H. (2015) Microstructure and mechanical performance of modified hemp fiber and shiv mortars: Discovering the optimal formulation. Materialsand Design, 84: 359–371.

Rouison, D., Couturier, M., Sain, M., MacMillan, B., Balcom, B. J. (2005) Water absorption of hemp fiber/unsaturated polyester composites. Polymer Composite; 26: 509-525.

Salentijn, E. M. J., Zhang, Q., Amaducci, S., Yang, M., Trindade, L. M. (2014) New developments in fiber hemp (cannabis sativa L.) breeding. Industrial Crops and Products; 68: 32-41.

Santulli, C., Caruso, A. P. (2009) Effect of fibre architecture on the falling weight impact properties of hemp/epoxy composite. Journal of Biobased Materials and Bioenergy;3:291–7

Scarponi, C. , Pizzinelli, C. S., Sanchez-Saez, S., Barbero, E. (2009) Impact load behavior of resin transfer molding (RTM) hemp fibre composite laminates. Journal of Biobased Materials and Bioenergy; 3:298–310.

Sébe, G., Cetin, N. S., Hill, C. A. S., Hughes, M. (2000) RTM Hemp fibre- reinforced polyester composites. *Applied Composite Materials*, 7: 341-349.

Sgriccia, N., Hawley, M. C., Misra, M. (2008) Characterization of natural fiber surfaces and natural fiber composites. Composites: Part A; 39: 1632–1637.

Strong, A. B. (1989) Fundamental of composite: Materials,Methods, and applications. Dearborn, Michigan: Society of Manufacturing Engineeres.

Thakur, V. K., Thakur, M. K., Grupta, R. K., Prasanth, R., Kessler, M. R. (2014) Green Composites from Natural Resources. 1 ed. Iowa- USA: Taylor e Francis group.