BENDING TESTS IN EPOXY COMPOSITES REINFORCED WITH FIQUE FIBERS*

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Abstract
Environmentally correct composites, made from natural fibers, are among the most investigated and applied today. In this paper, we investigate the mechanical behavior of epoxy matrix composites reinforced with continuous fique fiber, through bending tensile tests. Specimens containing 0, 10, 20 and 30% in volume of fique fiber were aligned along the entire length of a mold to create plates of these composites, those plates were cut following the ASTM standard to obtained bending tests specimens. The test was conducted in a Instron Machine and the fractured specimens were analyzed by SEM, the results showed the increase in the materials tensile properties with the increase of fiber amount.
Keywords: Polyester composite; Fique fiber; Mechanical behavior.

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1 INTRODUCTION

Synthetic fiber reinforced composites have been in these past decades dominating many high tech, such as the aerospace and defense related areas [1]. Carbon fiber components for jet planes and aramid armor for soldier protection are known examples of these expensive but effective composites. Other industrial sectors like the automotive (2), sporting, leisure and civil construction are also investing in synthetics that are, by contrast, simpler and less expensive like the glass fiber composites. Even though the high-tech composites still stand as top competitors, in their areas, the simpler glass fiber composites are now being replaced by natural fiber composites [1,3]. The reasons for this preference combines environmental, economical and technical aspects that increasingly favor natural fiber, mainly those lignocellulosic extracted from plants, against synthetic ones as composite reinforcement.

Environmental aspects are related to the fact that natural fibers are renewable, recyclable and biodegradable. Moreover, their composites require comparatively less energy to be processed. These combined aspects results in carbon dioxide neutrality of the natural fiber in contrast to synthetic fibers that contribute to global warming through their positive emission of CO_2 [2,4]. The economical advantage of lignocellulosic fibers is their significantly lower prices in confront with glass fiber, which is the cheapest among the synthetic fibers.

Technical aspects could also be in favor of the natural fibers that are softer and, consequently, less abrasive to processing equipments. Furthermore, for some lignocellulosic fibers, the mechanical properties can be superior to the corresponding one of glass fiber composites [1,4]. This is the particular case of lignocellulosic fibers that have received a surface treatment to improve adhesion to a polymeric matrix [4].

Natural fibers also present drawbacks in relation to the use as composite reinforcement. The high moisture adsorption at surface owing to the hydrophilic characteristic of the fiber causes incompatibility with hydrophobic polymeric matrices [5].

According to Wambua et al. [1], the most important problem for the composite strength is the fiber/matrix adhesion. Since the matrix has to transfer an applied load to the reinforcing fibers through interfacial shear stress, a good bond between the matrix and the fiber is required. An effective bond may be achieved by different fiber´s surface treatments [6,7]. Among these treatments, the less expensive is an alkali attack with sodium hydroxide solution, known as mercerization [8].

Previous works demonstrate that the incorporation of lignocellulosic fibers in polymeric matrix gives rise to composites with mechanical resistance directly proportional of the fiber content, where these fibers act as reinforcement for matrix due to their high mechanical properties. Therefore, the objective of this study was to evaluate the mechanical properties of epoxy matrix composites reinforced with continuous and aligned fique fibers in the bending test.

2 EXPERIMENTAL PROCEDURE

The basic material used in this work was the fiber extracted from the leaf of fique plant (*Furcraea Andina),* Figure 1(a), supplied by a producer in Colombia. No treatment was applied on fique fibers, Figure 1(b).

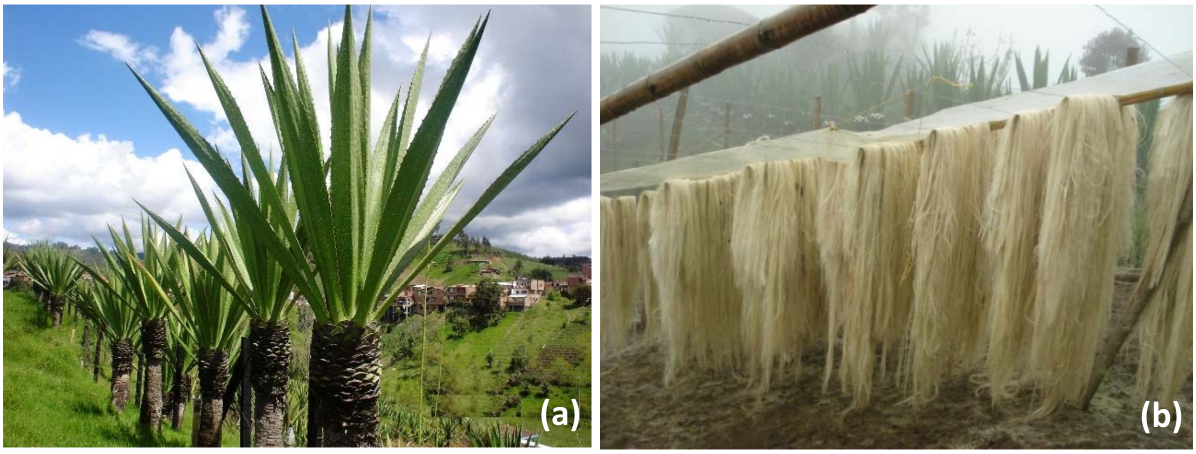

Figure 1. Fique plant (a) and its fibers (b).

The as received fibers of fique were cleaned and dried before use. The composites with 0, 10%, 20% and 30% in volume of aligned fique fibers were manufactured through accommodation of the fibers in a rectangular mold 152 x 122 x 10 mm and soaked with epoxy resin to complete the cavity, the procedure origins plates with were cut following the ASTM standard and the samples were three points bend tested in a model 5582 Instron machine with 100 kN of capacity at a strain rate of 1.6 x 10^{-2} s^{-1} and a span-to-depth ratio of 9. The fracture surface was sputter coated with gold, then examined in a Shimadzu SEM operated at 15 kV. Secondary electron images were collected to reveal details on the fracture surface.
The flexural strength, σ_f, were calculated by the following equation:

$$\sigma_m = \frac{3F_m L}{2bd^2} \quad (1)$$

where F_m is the maximum resistance force, L the distance between supports, and the extension associated with maximum force, the width b and d the thickness of the specimen.

3 RESULTS AND DISCUSSION

A typical flexural force *vs*. deflection curve directly obtained from the machine acquisition data program are shown in Figure 2. In this figure it should be noticed that the flexural curve for the fique fiber reinforced composite specimens display limited plastic deformation. Indeed, after the first linear elastic part of the curves in Figure 2, a drop associated with the rupture occurs gradually, followed by some sharps, indicating that maybe some fibers were been pulled out of the composite, and after this, they were getting fixed again in the matrix, rising the resistance for a short time.

ISSN 1516-392X

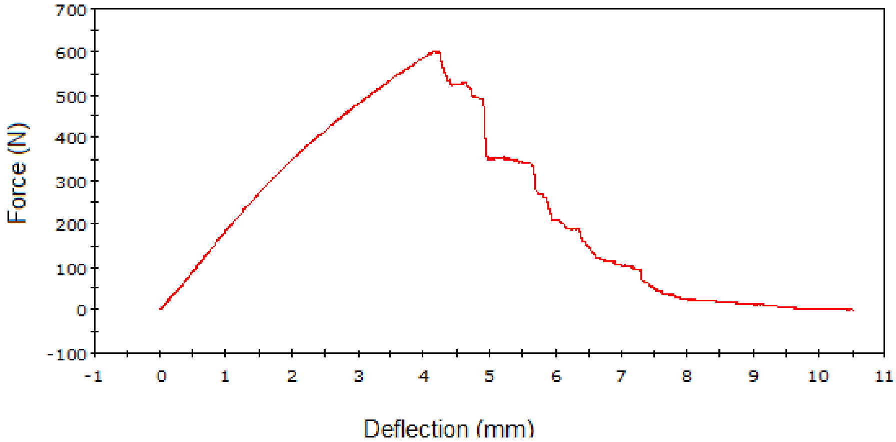

Figure 2. Typical force *vs*. deflection curve for flexural test of epoxy composite with 20% of volume fraction of fique fibers.

From curves such as the ones shown in Figure 2, the flexural strength (maximum bend stress) was calculated for each amount of fiber in the material. Table 1 presents these values for composites with different volume fraction of fique fibers. It is important to observe in this table that the flexural strength tends to increase with the amount of incorporated fique fibers.

Table 1: flexural results for the epoxy composites reinforced with bamboo fibers.

Volume Fraction of fibers (%)	Flexural Strength (MPa)
0	33.90 ± 16.99
10	43.80 ±12.13
20	55.09 ± 18.11
30	82.21 ± 12.78

From the results in Table 1, a curve of the variation of flexural strength with the volume fraction of fique fibers is presented in Figure 3. From this curve, some relevant comments should be made regarding the flexural behavior of bamboo fiber reinforced epoxy composites. Within the error bars, Figure 3 the flexural strength increase continuous, in a linear way, with the volume fraction of incorporated fique fibers. The results presented in Figure 3 indicate that the incorporation of fique fibers can make the epoxy matrix composite commercially stronger [11-13].

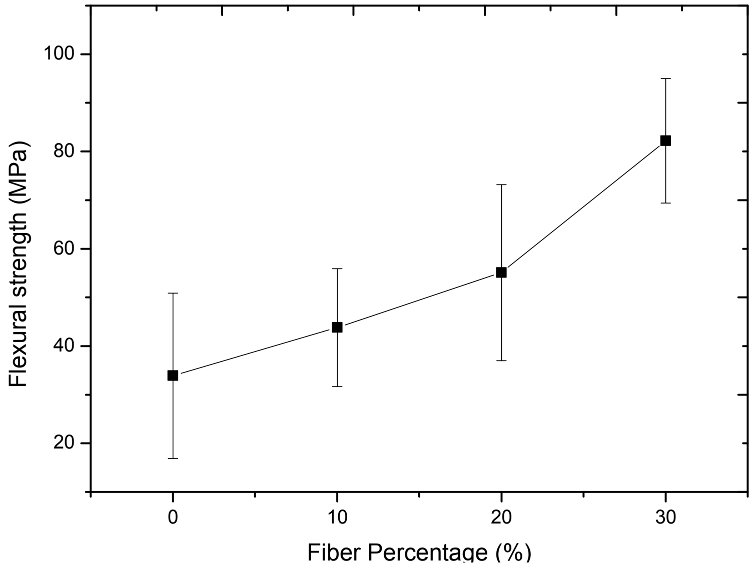

Figure 3. Variation of flexural strength with the volume fraction of fique fibers reinforcing epoxy matrix composites.

Figure 4 shows the typical macroscopic aspect of representative ruptured composite specimens with different volume fraction of fique fibers. In this figure it can be noticed that the fracture tends to be transversal to the specimen's axis in principle, but, the important feature to notice is that the majority of the specimen present a plastic deformation with the participation of some fibers pullouts from the matrix (9-14), the specimens doesn't even present a total fracture. Above any amount of fiber volume fraction, visual evidence of fiber participation in the fracture exists. The fact that individual fibers are sticking out of the fracture surface for specimens with 10, 20 and 30% in Figure 4, indicates that a separation process between the fiber and the matrix is occurring. This can be attributed to fiber/matrix interaction and is a consequence of the relatively weak interface of the fique fiber with respect to the epoxy matrix.

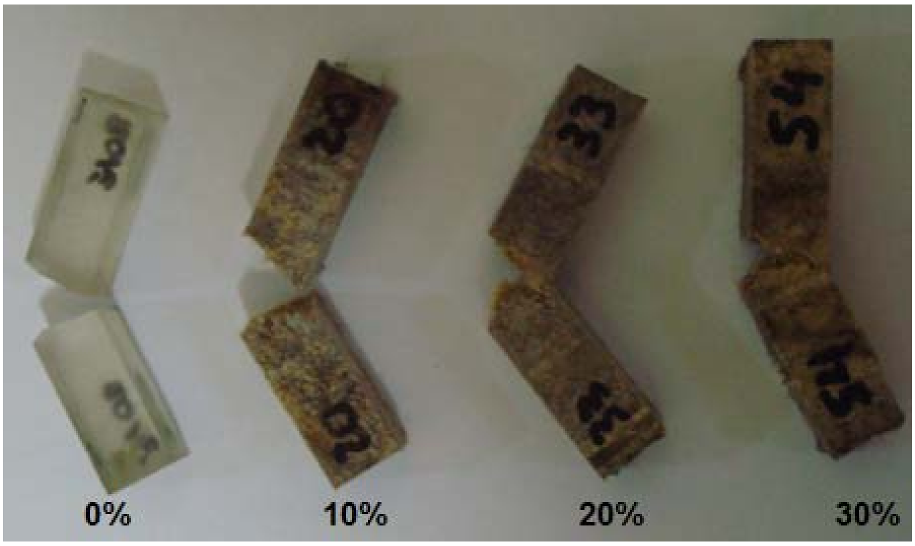

Figure 4. Macroscopic aspect of ruptured epoxy composite specimens with different volume fraction of fique fibers.

The weak relation between the fiber/matrix is also an indication that transversal cracks are being arrested while other longitudinal cracks propagate through the interface. During the flexural test, this longitudinal mode of rupture allows the

specimen to bend until the flexible fique fibers being are broken. For the 10 to 30% specimens in Fig 4, the fracture is not perfectly transversal as compared to the 0 specimen.
As final comments, it is relevant to emphasized that continuous and aligned fique fibers improve the strength of epoxy matrix composites in any volume fraction. With lower amounts of fibers, cracks propagate transversally through the brittle epoxy matrix with limited interference of the relatively fewer fique fibers. On the other hand, above 20% in volume fractions, cracks are effectively arrested by the fique fiber what causes the participation of the stronger fibers in the rupture mechanism, which contributes to a higher strength of the composites.

4 CONCLUSIONS

- Epoxy matrix composites reinforced with continuous and aligned fique fibers show an improvement in the strength as compared to the pure epoxy matrix.
- This improvement show a continuous line and can be assumed as a linear growing in the flexural strength with the consideration of the errors bars.
- The macroscopic analysis of the specimens after the test revealed that above 20%, transversal cracks are effectively arrested by the fibers. As a consequence, longitudinal propagation through the weak fiber/matrix interface results in an efficient contribution to the relatively stronger fique fiber to elevate the flexural strength of the material and creating difficulty to the final composite rupture, which then occurred at higher strength.

Acknowledgements

The authors thank the support to this investigation by the Brazilian agencies: CNPq, CAPES, FAPERJ and TECNORTE/FENORTE.

REFERENCES

1. P. Wambua, I. Ivens, I.Verpoest, “Natural fibers: can they repalce glass and fibre reinforced plastics?”, *Composites Science and Technology*, 63 (2003) 1259-1264.
2. R. Zah, R. Hischier, A.L. Leão and I. Braun, “Curaua fibers in the automobile industry – A sustainability assessment” *J. Cleaner Production*, 15 (2007) 1032-1040.
3. K.G. Satyanarayana, J.L. Guimarães, F. Wypych, “Studies on lignocellulosic fibers of Brazil. Part I: Source, production, morphology, properties and applications”. *Composites: Part A*, 38, (2007) 1694-1709.
4. A.K. Mohanty, M. Misra and G. Hinrichsen, “ Biofibers, biodegradable polymers and biocomposites: an overview”, *Macromolecular Mat. And Engineering*, 276/277 (2000), 1-24.
5. A. Vasquez, J. Riccieri, L. Carvalho, “Interfacial properties and initial step of water sorption in uniderectional unsaturated polyester/vegetable fibre composites”. *Polymer Composites*, 20 (1999) 29-27.
6. J. Gassan, A.K. Bledzki, “Effect of cyclic moisture absorption/desorption on the mechanical properties of silanized jute-epoxy composites. *Polymer Composites*, 20(4) (1999) 604-611.
7. J. Rout, M. Misra, S.S. Tripathy, S.K. Nayak, A.K. Mohanty, “The influence of fibre treatment on the performance of coir-polyester composites”, *Comp. Sci. Technol*., 61 (2001) 1303–1310.

ISSN 1516-392X

8. A.P. Kumar, R.P. Singh, B.D. Sarwade, “Degradability of Composites, Prepared from Ethylene-Propylene Copolymer and Jute Fiber under Accelerated Aging and Biotic Environments”. *Mat. Chemistry and Physics*, 92 (2005) 458-469.
9. T.G.R. Portela, F.P.D. Lopes, R.L. Loiola, S.N. Monteiro, E.A. Carvalho, “Evaluation of the diameter influence on the tensile strength of buriti fibers by the Weibull method” (in Portuguese), Proceedings of the 64th Annual Meeting of the Brazilian Society for Metallurgy, Materials and Mining, (Belo Horizonte, MG, Brazil, July 2009) 1-10.
10. S.N. Monteiro, F.P.D. Lopes, L.C. Motta, L.S. Marques, T.G.R. Portela, “Statistical analysis to characterize the uniformity of mechanical properties of butiti fibers”. Proceedings of the Characterization of Mineral, Metals & Materials, TMS 2009, (San Francisco, CA, USA, March 2009) 1-8.
11. N.S.S. Santos, C.G.B.T. Dias, E.M.S. Sanches, C.A.C. Zavaglia, E.L. Albuquerque, “Microstuctural and mechanical characterization of miriti fiber for utilization as reinforcement on polymeric composites” (in Portuguese), Proceedings of the Brazilian Congress on Materials Science and Engineering – 18 CBECIMAT (Porto de Galinhas, PE, Brazil, November 2008) 3565-3573.
12. T.G.R. Portela, L.L. Costa, F.P.D. Lopes, S.N. Monteiro, “Characterization of fibers from different parts of the buriti palm tree”, Proceedings of the Characterization of Mineral, Metals & Materials, TMS 2010 (Seattle, USA, February 2010) 1-8.
13. T.G.R. Portela, L.L. da Costa, N.S.S. Santos, F.P.D. Lopes, S.N. Monteiro “Tensile behavior of lignocellulosic fiber reinforced polymer composites: Part II buriti petiole/polyester” Rev. Mater., 15(2) (2010) 216-222.
14. W.D. Callister Jr., Materials Science and Engineering – An Introduction, 5 ed., (New York, NY: John Wiley & Sons, 2000).