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DYNAMIC-MECHANICAL ANALYSIS OF EPOXY COMPOSITES REINFORCED WITH GIANT BAMBOO FIBER (*DENDROCALMUS GIGANTEUS*)[1]

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Abstract

The variation with temperature of the dynamic-mechanical parameters for the epoxy matrix composites incorporated with up to 30% in volume of giant bamboo fiber was investigated. The analyzed parameters were the storage modulus, the loss modulus and the delta tangent. The investigation was conducted in the temperature interval from 25°C to 195°C in a DMA equipment operating at 1 Hz of frequency under a nitrogen flow. The results showed that the incorporation of long and aligned giant bamboo fibers tends to increase the viscoelastic stiffness of the epoxy matrix. By contrast, only minor changes occurred in both the glass transition temperature and the damping capacity of the structure as measured by the tan δ peaks. These are indications that the epoxy molecular mobility is not sensibly affected by interaction with the bamboo fibers in the composites.

Key words: Giant bamboo fiber; Epoxy composite; DMA; Glass transition temperature.

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1 INTRODUCTION

Bamboo is a well-known grass-type plant with a hard and stiff stem, called culm, which can reach, in some species, more than 10 cm in cross section diameter and stand several meters height. Owing to its low density, approximately 0.9 g/cm^3, bamboo culms have been used in house construction from scaffoldings to panels. As an abundant natural resource in tropical and temperate regions, especially in Asia and South America, bamboo is also a substitute for wood and plastics in furniture and lightweight parts of automobile.[(1,2)] The cylindrical shape of the culm is, however, a limitation for its direct use in engineering systems. Consequently, research works have been conducted on bamboo fibers as reinforcement of polymer composites.[(1-12)] According to Shin et al.[(3)] bamboo fiber-epoxy laminates can be made into specific sizes and shapes, preserving the natural microstructural properties. These fiber composites overcome the limitation of the culm's cylindrical macrostructure. Works on the mechanical properties of polymer composites reinforced with culm-stripped bamboo fibers[(3-5,12)] reported mechanical strength and modulus that could vary significantly with the amount of incorporated fiber, the type of polymeric matrix and the fiber disposition (short-cut, continuous, aligned, mat-arranged). In spite of all these efforts, no investigation on the influence of temperature changes was carried out for these composites, particularly on the dynamical mechanical behavior.
Therefore, the objective of this work was to investigate the dynamic mechanical (DMA) behavior of epoxy matrix composites reinforced with up to 30% in volume of continuous and aligned bamboo fibers in a wide temperature interval. This evaluation was carried out through the determination of the temperature dependence of the DMA parameters.

2 EXPERIMENTAL PROCEDURE

The basic material used in this work was the culm of bamboo (*Dendrocalmus Giganteus*) supplied by a producer in the city of Rio de Janeiro. Large bamboo bushes, Figure 1a, occur naturally in the region. Fibers, Figure 1c were manually stripped off from dried culms, Figure 1b with a sharp razor blade. The longitudinal direction of the fiber coincides with that of the culm (Figure 1b), and corresponds to the natural direction of the bamboo fibrils.
The as-stripped bamboo fibers Figure 1c were dried in a laboratory stove at 60 C for 24 hours to remove humidity. In this work, the specimens were made with rectangular cross section, with dimension of 50x13x5 mm, for the DMA, tests. The specimens were fabricated according to the following steps. Initially the bamboo fibers were lay down inside silicone molds with the nominal dimensions, where different volume fractions of 0, 10, 20, 30% of continuous and aligned fibers were used for each specimen. A still fluid epoxy resin was poured into the molds to fabricate the composites. These composites specimens were cured for 24 hours at room temperature.

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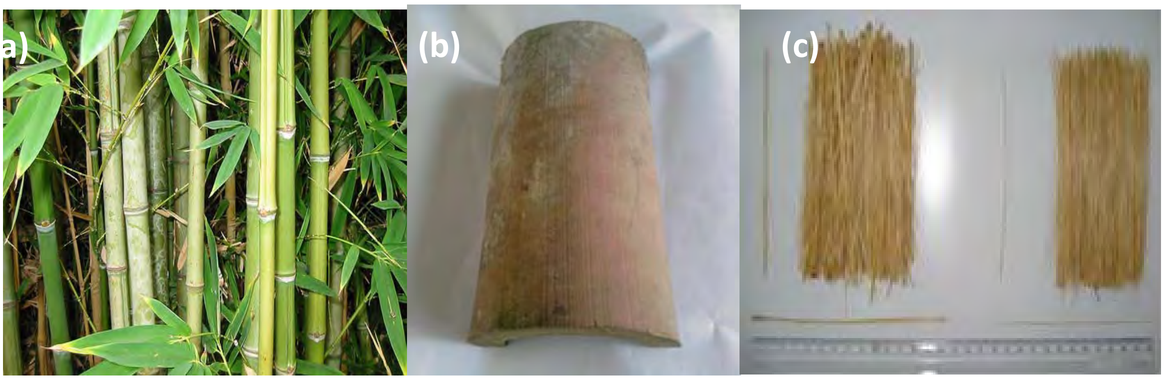

Figure 1. Bamboo trees (a), dried bamboo culm (b) and its fibers longitudinally stripped with different diameters (c).

After curing, each specimen was tested in a Perkin-Elmer equipment operating in a thee points flexural mode at 1 Hz of frequency and heating rate of 3°C/min under nitrogen atmosphere. The storage modulus, E', loss modulus, E", and tangent delta, tan δ, curves were simultaneously registered from 20 to 200°C. In other to complete the curing of the epoxy matrix, two runs were performed for each specimen.

3 RESULTS AND DISCUSSION

In order to evaluate the effect of bamboo fiber incorporation into the epoxy matrix, the composites of bamboo fibers with epoxy matrix prepared were analyzed in the same way as the neat epoxy. Their respective DMA curves are shown in Figures 2 to 4. These figures show only the second run curves for the 10, 20 and 30 vol% of bamboo fiber composites, respectively. Corresponding curves of the first run were not presented, but the results related will be commented afterwards.

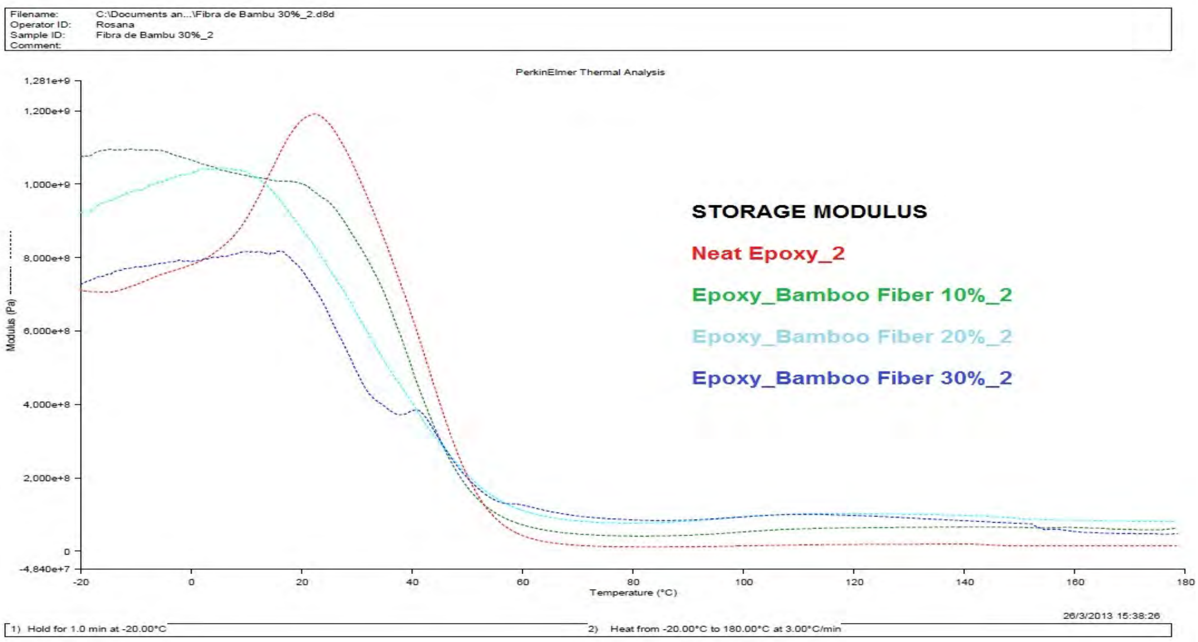

Figure 2. Storage Modulus Curves for 0 to 30% in Volume Fraction of Bamboo Fibers.

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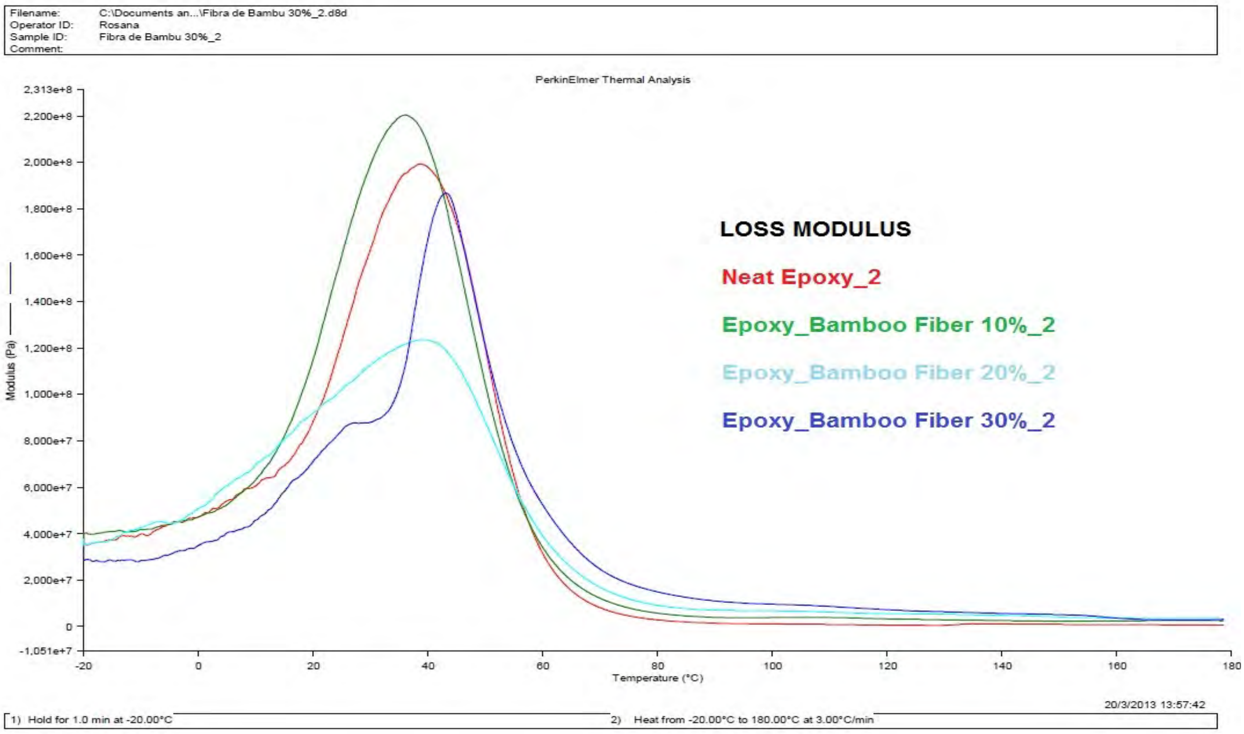

Figure 3. Loss Modulus Curves for 0%to 30% in Volume Fraction of Bamboo Fibers.

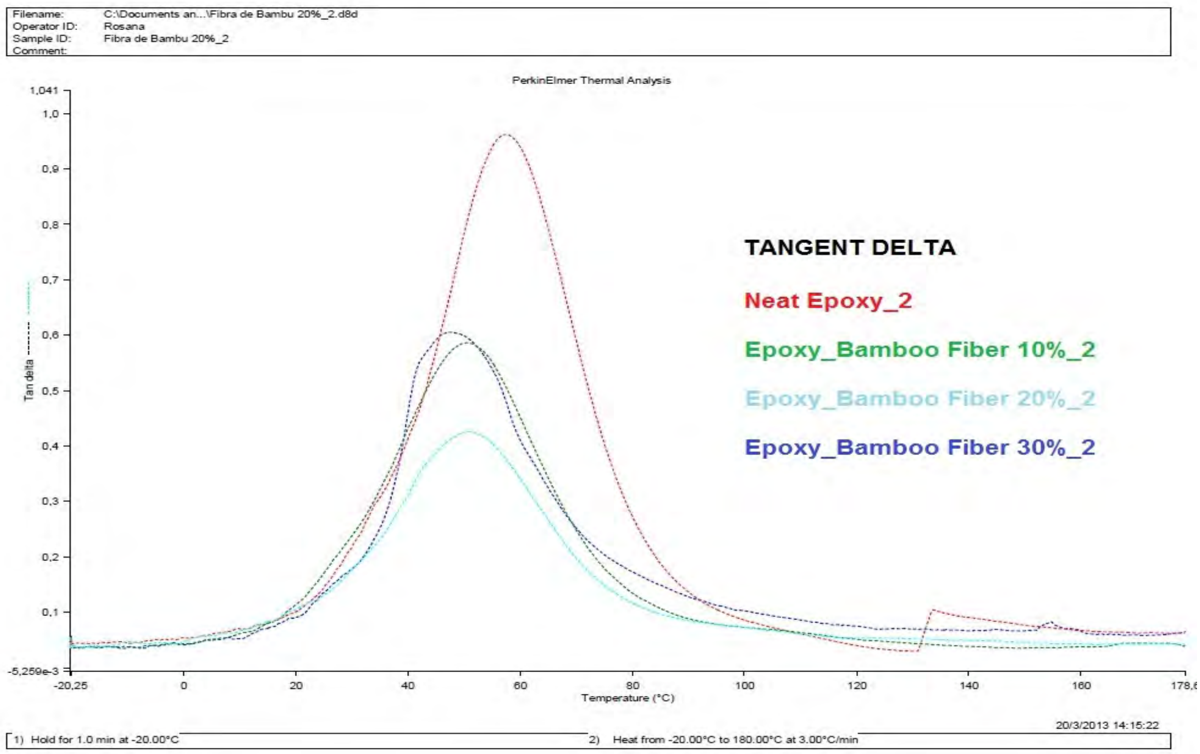

Figure 4. Tangent Delta Curves for 0% to 30% in Volume Fraction of Bamboo Fibers.

The interpretation of the DMA graphs in Figure 4 implies that the bamboo fiber incorporation results in a reduction of the lower limit of the T_g for the epoxy matrix. Another relevant result obtained from Figure 4, is the displacement to lower temperatures of the composites tan δ peaks with respect to that of the neat epoxy, with a difference about 10°C . Since the tan δ peak corresponds to the upper limit of

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the epoxy matrix T_g, the incorporation of bamboo fibers up to 30 vol% results in a low fiber/matrix interaction due to the difficult in developing effective molecular bonds. This should prematurely disrupt the crystallinity of the epoxy matrix.
Furthermore, the level of E' in the composites' first stage is significantly below that of the neat epoxy, even for composites with 20% and 30% of natural fibers, for the second run, where it is possible to see first a increase in the elastic modulus and after a decrease, as expected. Since E' is directly related to the material's capacity to support mechanical loads with recoverable viscoleastic deformation,[13] comparatively lower E' indicates that the bamboo fiber composites are less stiff than the neat epoxy. Similar results were reported by Nair, Thomas and Groeninckx[13] in short cut sisal fibers reinforced polystyrene matrix composites. These authors attributed the reduction in the neat polymeric matrix tan δ peak to the presence of residual solvent in their composites. However, another possible explanation in the present case could be the influence of bamboo fibers is disrupting the epoxy structure at lower temperature, i.e, the bamboo fiber contributes to prematurely uncrystallize the epoxy chains. The same rationale could be extended to the temperature of the loss of modulus, E", peaks, corresponding to the damping capacity of the composite structure, that is displaced to lower values with bamboo fiber incorporation. As a general remark, it is suggested that the bamboo fiber sensibly affects the DMA parameters of epoxy composites because of the disruption that it causes on the epoxy macromolecular structure.
It's important to mention that the different behavior of the storage modulus and tangent delta for the composite with 20% of fibers can be related to possible pores in the internal structure of the composite.

4 CONCLUSIONS

A preliminary analysis of the dynamic-mechanical parameters of epoxy matrix incorporated with continuous and aligned bamboo fibers showed a significant effect of samples second run, as compared to the first heating run.
After the second DMA run up to 200°C, not only the neat epoxy but also the bamboo fiber composites suffered considerable increase in both the lower and upper limits of the glass transition temperature. This is apparently related to the curing process, which was not completed until the second run.
The introduction of bamboo fibers in the epoxy matrix also affects the T_g and causes sensible reduction in both the viscoelastic stiffness and the damping capacity of the composites as compared to the epoxy matrix. It is suggested that a possible reason would be the weak visoleastic interaction between the bamboo fibers and the epoxyr macromolecules.

Acknowledgements

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REFERENCES

1 Chen, X.; Guo Q.; Mi Y. Bamboo fiber reinforced polypropylene composites: a study of the mechanical properties. J. Appl. Polym. Sci. v. 69, p 1891-1899, 1998.

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2 Shibata S.; Yong C.; Fukumoto I. Flexural modulus of the unidirectional and random composites made from biodegradable resin and bamboo and kenaf fibres. Composites Part A, v. 39, p 640-646, 2008.
3 Shin F. G.; Xian X. J.; Zhena W. P.; Yipp M. W. Analysis of the mechanical properties and microstructure of bamboo epoxy composites. J. Mater. Sci., v.24, p. 3483-3490, 1989.
4 Jain S.; Kumar R.; Jindal U. C. Mechanical behavior of bamboo and bamboo composites., J. Mater. Sci., v.27, p. 4598-4604 1992.
5 Jain S.; Kumar R.; Jindal U.C. Development and fracture mechanism of the bamboo/polyester resin composite. J. Mater. Sci. Lett., v.12, p. 558-560, 1993.
6 Seema J.; Kumar R. Processing of bamboo fiber reinforced plastics composites, Mater. Manufact. & Proc., v.9, p. 813-828, 1994.
7 Thwe M. M.; Liao K. Effects of environmental aging on the mechanical properties of bamboo glass fiber reinforced polymer matrix hybrid composites. Composites Part A, v.33, p. 43-52, 2002.
8 Okubo K.; Fujii T.; Yamamoto Y. Development of bamboo based polymer composites and their mechanical properties. Composites Part A, v.35, p. 377-383, 2004.
9 Okubo K.; Fujii T.; Yamashita N. Improvement of interfacial adhesion in bamboo polymer composite enhanced with micro-fibrillated cellulose. JSME Int. J. A. Solid M., v.48, p. 199-204, 2005.
10 Lee S. H.; Siqun W. Biodegradable polymer/bamboo fiber biocomposite with bio-based coupling agent. Composites Part A, v.37, p. 80-91, 2006.
11 Huang X.; Netravali A. Biodegradable green composites made using bamboo micro/nano-fibrils and chemically modified soy protein resin. Composites Sci. & Tech., v. 69, p. 1009-1015, 2009.
12 Costa L.L.; Monteiro S.N.; Loiola R.L. Mechanical behavior of polyester composites reinforced with continuous bamboo fibers. In: Proceedings of the Characterization of Minerals, Metals & Materials - TMS Conference 2010 , Seattle, 2010, Anais: Seattle, TMS Conference 2010, 2010, p. 1-6.
13 Nair K.C.M.; Thomas, S.; Groeninckx, G.. Thermal and dynamic mechanical analysis of polystyrene composites reinforced with short sisal fibres. Compos. Sci. Technol., v. 61, p. 2519-2529, 2001.