DYNAMIC-MECHANICAL BEHAVIOR OF BANANA FIBER REINFORCED EPOXY MATRIX[1]

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Abstract

Dynamic-mechanical evaluations have not yet been conducted in banana aligned fiber reinforced polymeric composites. In this work, the temperature dependence of the dynamic-mechanical parameters in epoxy matrix composites reinforced with up to 30% in volume of continuous and aligned Banana fibers was investigated by DMA tests. The investigated parameters were the storage and the loss modulus as well as the delta tangent. The investigation was conducted in the temperature interval from 20°C to 180°C using a DMA equipment operating in flexural mode. The results showed that the incorporation of banana fibers tends to increase the viscoelastic stiffness of the matrix. Sensible modifications in the glass transition temperature and the damping capacity of the structure were found with the amount of fiber in the composite. The molecular mobility of the epoxy matrix is affected by its interaction with the banana fibers.

Key words: Banana fiber; Epoxy composite; DMA test; Glass transition.

COMPORTAMENTO DINÂMICO-MECÂNICA DAS FIBRAS DE BANANA EM COMPÓSITO REFORÇADO COM MATRIZ EPÓXI

Resumo

Avaliações Dinâmico-mecânicas em fibra alinhadas de banana em compósitos poliméricos ainda não foram conduzidas. Neste trabalho, a dependência da temperatura para os parâmetros dinâmico-mecânicas em compósitos epoxídicos reforçados com até 30% em volume, de fibras de banana contínuas e alinhadas serão investigados por meio de ensaios de DMA. Os parâmetros estudados serão o módulo de conservação e o módulo de perdas, bem como a tangente de delta. A investigação será conduzida no intervalo de temperatura de 20°C a 180°C usando um equipamento de exploração DMA no modo de flexão. Os resultados devem mostrar que a incorporação de fibras de banana tende a aumentar a rigidez viscoelástica da matriz. Modificações sensíveis na temperatura de transição vítrea e a capacidade de amortecimento da estrutura serão analisados com as diferentes quantidades de fibra no compósito. A mobilidade molecular da matriz epóxi é afetada por sua interação com as fibras da bananeira.

Palavras-chave: Fibras de banana; Compósito com epóxi; Ensaio DMA; Transição vítrea.

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1 INTRODUCTION

Natural lignocellulosic fibers such as cotton, flax, jute, ramie and banana have since long time, been used to fabricate textiles. However, the development of synthetic fibers in the 20th century brought new options for the textile industry with advantages against the natural fibers. In particular, the banana fiber was widely affected by synthetics, like the nylon and rayon fibers, in the fabrication of ropes and carpets. In fact, the use of banana fiber for these purpose has strongly declines, which contribute to decrease crops and caused uncertainties for those living on its applications. Since the banana fiber possess relatively higher mechanical strength, 700 MPa to 800 MPa, and stiffness, 27 GPa to 32 GPa,(1) a possible alternative of application might be its use as polymer composite reinforcement.

The incorporation of banana fibers into polymer matrices of composites was investigated(2-4) and found to present significant properties. These properties are directly related to the microstructure as well as physical and chemical characteristics of any lignocellulosic fibers.(5-7)

Among these characteristics stand the low cost and lightness. Furthermore, contrary to the glass fibers,(8) the lignocellulosic fibers are relatively smooth and procedure less wear to processing equipments. The environmental question is another point in favor of the natural fibers that are renewable, recyclable, biodegradable and neutral with respect to CO_2 emission, considered the main responsible for today´s global warming.(9,10)

In terms of the mechanical properties of polymer composites incorporated with banana fibers, it was reported an effective reinforcement for amounts up to 30% in volume of these fibers obtained in bend tests conducted at deformation speeds of 10^{-5} m/s.(11) This test procedure can be considered as a quasi-static deformation. By contrast, the dynamic mechanical response, by means of DNA test, of banana fibers reinforced epoxy composites has not yet been investigated. Other lignocellulosic fibers reinforced polymer composites have evidenced sensible changes in both the storage modulus, E´, and the loss modulus, E´´, as well as a reduction in amplitude and position of tangent delta , tan δ , with fiber incorporation.(12-15) Therefore, the present work evaluated the DMA behavior of epoxy matrix composites reinforced with up to 30% in volume of continuous and aligned banana fibers. This evaluation was carried out through the determination of the temperature dependence of E´, E´´ and tan δ.

2 EXPERIMENTAL PROCEDURE

Fibers extracted from the pseudostem of a banana tree were supplied by a local producer in the city of Campos dos Goytacazes, state of Rio de Janeiro, southeast of Brazil. The as-received lot containing 5 kg of fibers was cleaned with water and dried and at 60°C for 24 hours. Figure 1 illustrates banana trees (Figure 1a), and a cut pseudo stem (Figure 1b). Figure 2 shows longitudinal stalks (Figure 2a) sectioned from the pseudostem and banana fibers (Figure 2b) separated from the stalks.

Figure 1. (a) Banana trees; and (b) a cut pseudostem.

Rectangular specimens with dimension of 50 mm x 13 mm x 5 mm (Figure 3), were used for the dynamic-mechanical, DMA, test. The fabrication of the specimens was performed according to the following steps. Initially the banana fibers were lay down inside silicone molds with the nominal dimensions. Different volume fractions of 0%, 10%, 20%, 30% of continuous and aligned fibers were used for each specimen. A still fluid dyglycidil ether of the bisphenol-A (DGEBA) epoxy resin, already mixed in stoichiometric proportion, phr = 13, with triethylene tetra amine (TETA) as hardener, was poured into the molds to fabricate the composites. These composites specimens were cured for 24 hours at room temperature.

Figure 2. (a) Longitudinal stalks sectioned from the pseudostem; and (b) banana fibers separated from the stalks.

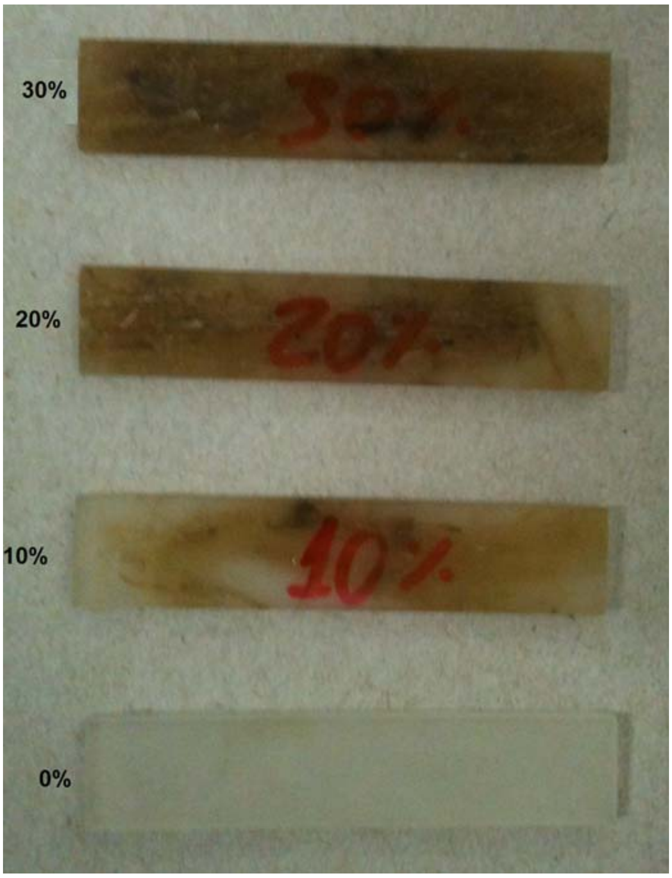

Figure 3. DMA epoxy composite specimens, incorporation with different volume fraction of banana fibers.

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°C to 200°C. In other to complete the curing of the epoxy matrix, two runs were performed for each specimen.

3 RESULTS AND DISCUSSION

Figure 4 shows the DMA curves for the first run of a neat DGEBA/TETA epoxy (0% banana fiber) specimen. These curves served as comparative reference for the corresponding DMA curves after the second run under the same conditions of a 3°C/min heating rate up to 200°C.

Figure 5 presents the respective neat DGEBA/TETA epoxy (0% banana fiber) for the second run, using the same specimen of the first run (Figure 4). A comparison between the two set of DMA curves, first run in Figure 4 and second run in Figure 5, indicates a significant increase in the temperature associated with the peaks in the loss modulus, E” and tan δ. These peaks are usually attributed to the upper limit of the glass transition temperature, T_g.(16,17)

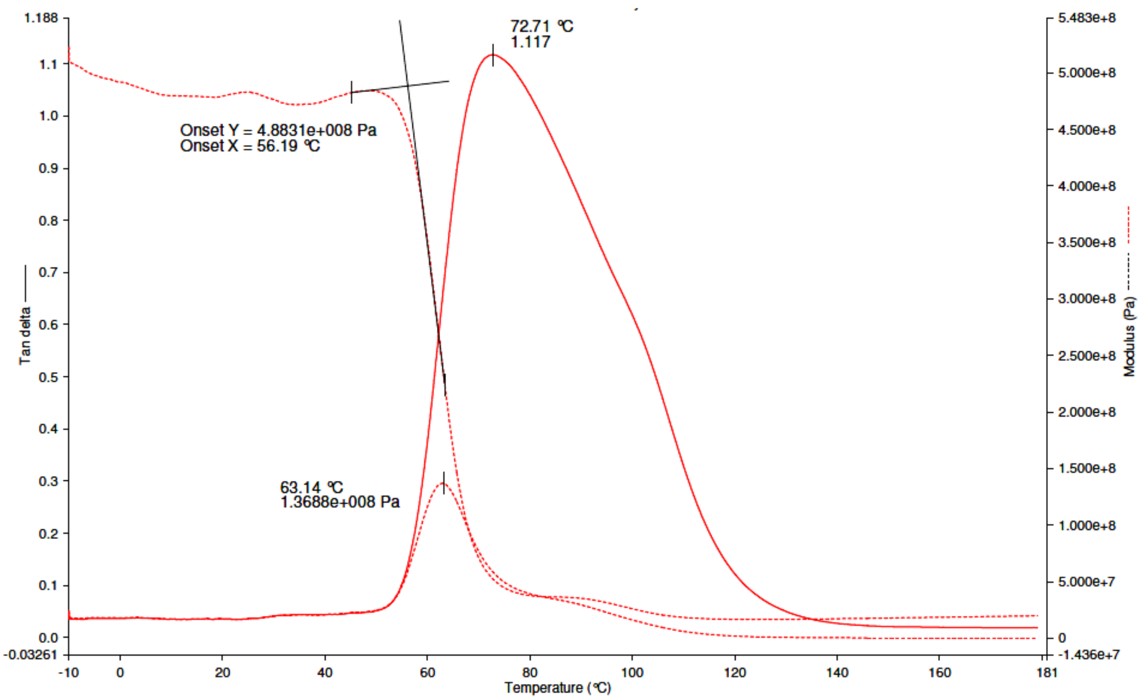

Figure 4. DMA curves for the first run of neat DGEBA/TETA epoxy.

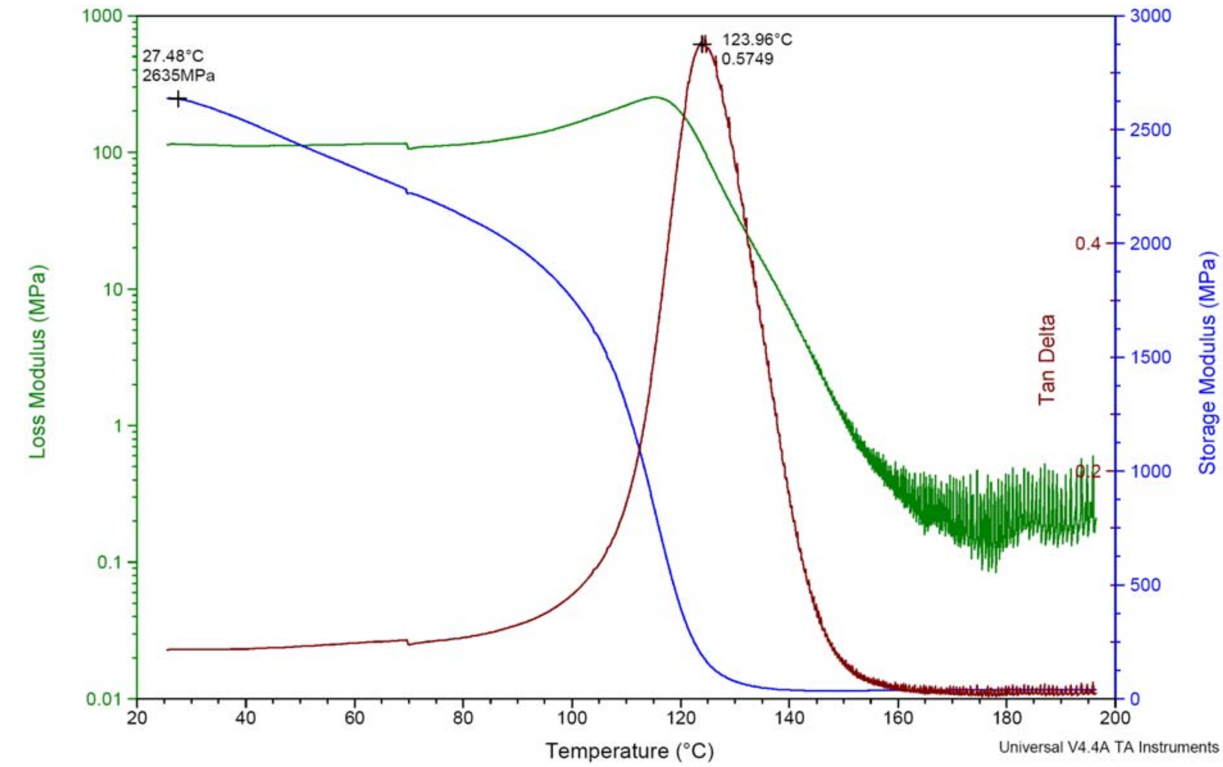

Figure 5. DMA curves for the second run of neat DGEBA/TETA epoxy.

Other relevant aspects in comparing the curves of Figures 4 and 5 are the changes occurring in the storage modulus, E’, after the second run. The value of E’ is related to the viscoelastic stiffness of the material and its sudden drop characterizes the lower limit for T_g. It can be seen that the re-heating promoted by the second run not only increased the lower T_g but also the level of E’. The reason for this behavior can be explained by the epoxy curing process. As the temperature is increased in the first run (Figure 4), the TETA hardener continues to react with the epoxy rings, which promotes further reticulations that retard the amorphous transformation and increase the matrix stiffness.

The effect of banana fiber incorporation into the epoxy matrix can be evaluated by means of the composites' DMA curves. Figures 6 to 8 show the second run curves for the 10 vol%, 20 vol% and 30 vol% of banana fiber composites, respectively. Corresponding curves of the first run are not presented due to space limitation for the present work.

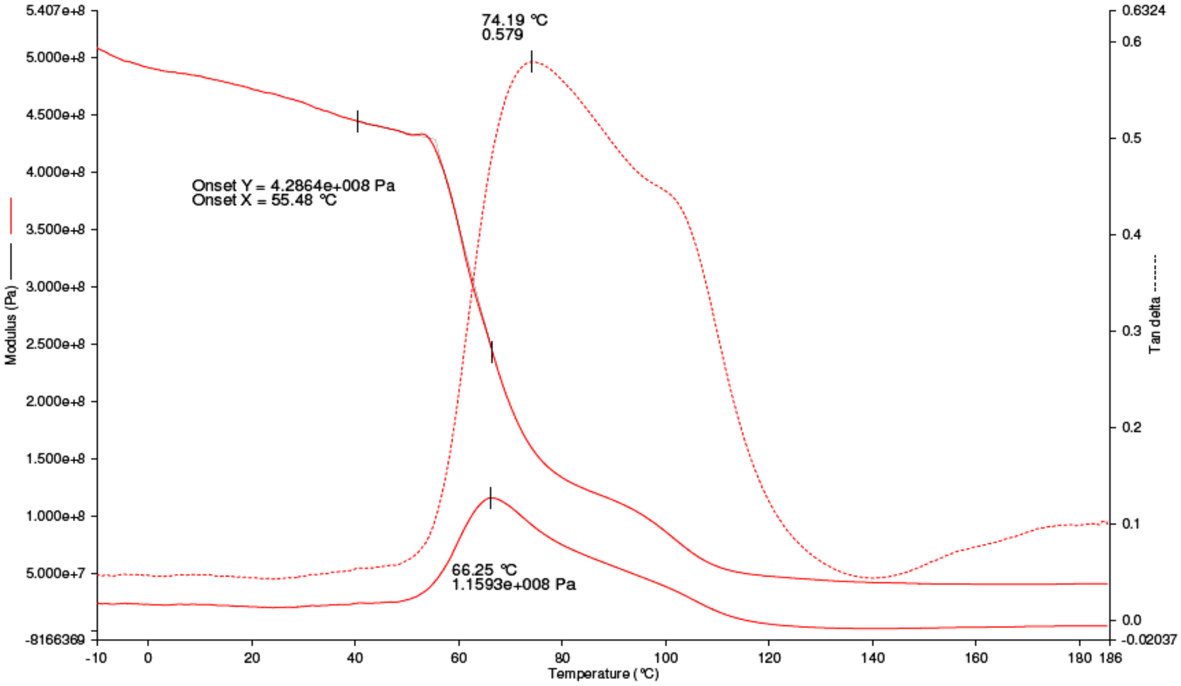

Figure 6. DMA curves for the second run of epoxy composites incorporated with 10 vol% of banana fibers.

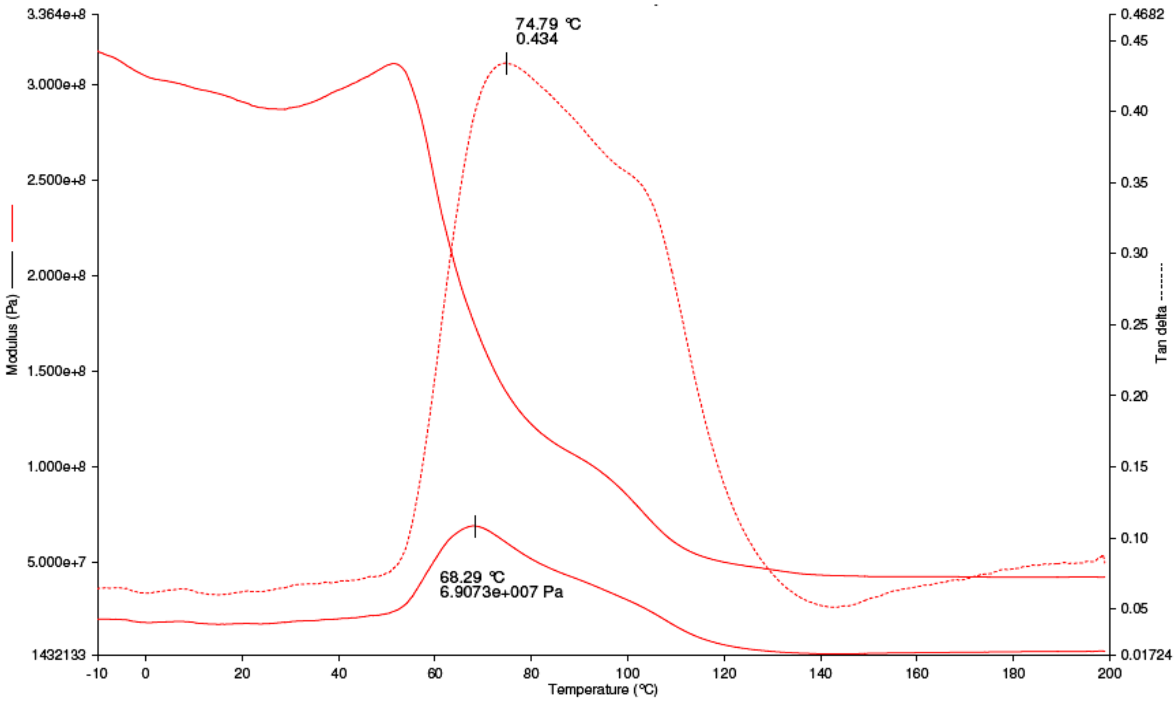

Figure 7. DMA curves for the second run of epoxy composites incorporated with 20 vol% of banana fibers.

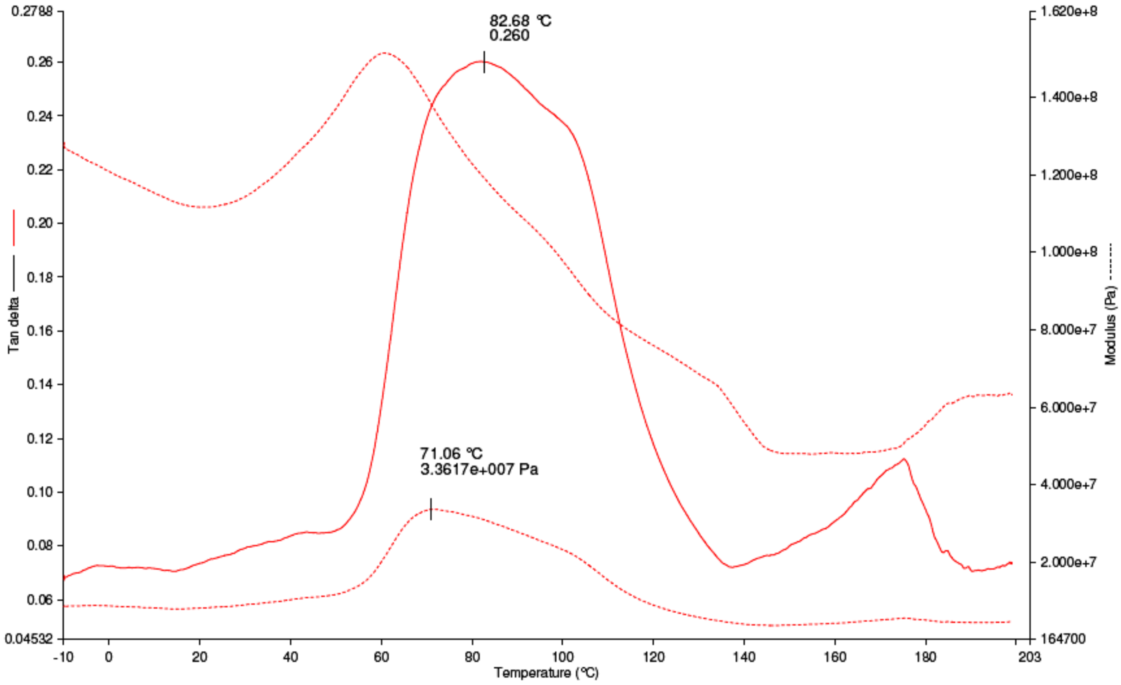

Figure 8. DMA curves for the second run of epoxy composites incorporated with 30 vol% of banana fibers.

Table 1 presents the values of main parameters obtained from the DMA curves in Figures 4 to 8 in addition to those parameters from composites' first run DMA curves, not shown in the present work. In this table, it is worth noticing that, after the second run consolidating the curing of the DGEBA/TETA epoxy matrix, all composites display a lower E' onset as compared to that, 125°C, for the epoxy (Figure 5).

Table 1. DMA parameters of the neat DGEBA/TETA epoxy and related composites with up to 30 vol% of banana fibers

Sample	Onset temperature for the sharp drop in E' (^{o}C)	Value of E' at the onset (MPa)	Peak temperature in E" (°C)	Peak temperature in tan δ (°C)	Value of tan δ at the peak
Neat epoxy (first run)	56	488	63	73	1.11
Neat epoxy (second run)	125	1850	115	124	0.57
Epoxy – 10% fiber (first run)	60	320	69	73	0.62
Epoxy – 10% fiber (second run)	55	427	66	74	0.58
Epoxy – 20% fiber (first run)	53	250	67	74	0.41
Epoxy – 20% fiber (second run)	53	315	68	75	0.43
Epoxy - 30% fiber (first run)	64	138	77	104	0.28
Epoxy - 30% fiber (second run)	60	151	71	83	0.26

In principle, this implies that the banana fiber incorporation results in a reduction of the lower limit of the T_g for the DGEBA/TETA epoxy matrix. Furthermore, the level of

E’ in the composites’ first stage is significantly below that of the neat epoxy. Since E’ is directly related to the material’s capacity to support mechanical loads with recoverable viscoleastic deformation,(18-20) comparatively lower E’ indicates that the banana fiber composites are less stiff than the neat epoxy.

Another relevant result obtained from Figures 4 to 8, together with those seen in Table 1, is the displacement to lower temperatures of the composites’ tan δ peaks with respect to that of the neat epoxy. Since the tan δ peak corresponds to the upper limit of the epoxy matrix T_g, the incorporation of banana 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. Similar results were reported by Nair, Thomas e Groeninckx(19-20) 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 this work present case could be the influence of banana fibers in disrupting the epoxy 3D structure at lower temperature. In other words, the banana fiber contributes to prematurely uncrystallize the epoxy network. 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 are displaced to lower values with banana fiber incorporation. As a general remark, it is suggested that the banana fiber sensibly affects the DMA parameters of DGEBA/TETA epoxy composites by changing the structure and mobility of the epoxy matrix macromolecular chains.

4 CONCLUSIONS

- A preliminary analysis of the dynamic-mechanical parameters of stoichiometric DGEBA/TETA epoxy matrix incorporated with continuous and aligned banana 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 banana 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 banana 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 low visoleastic interaction between the banana fibers and the epoxy macromolecules.

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