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Hybridization effect on the mechanical and dynamic mechanical properties of curaua composites

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ABSTRACT

This study aims to evaluate the performance of curaua/glass hybrid composites focusing on mechanical and dynamic mechanical analysis (DMA). Composites with distinct glass/curaua fiber loading ratios were studied. Flexural strength and modulus, impact strength and Barcol hardness increased for higher glass fiber content. The same was found for storage and loss modulus. The activation energy of the relaxation process in the glass transition region showed a maximum for the all-glass composite, corroborating with the results of concentration of elastic chains (υ_e). Cole–Cole plots were obtained and found to follow the same trend regardless of the glass content, whereas peak height and peak width at half-height were maximum for the all-glass composite.

1. Introduction

The Brazilian vegetal fiber called curaua is receiving special attention nowadays. Its use is growing steadily due to its unique characteristics [1]. Curaua fiber is already considered the third most important Brazilian fiber, after sisal and jute, being among the strongest lignocellulosic fibers. Indeed, its tensile strength has already been reported as 5–9 times higher than that of sisal or jute [2].

Perhaps the most promising ongoing investigation related to the use of cellulosic fibers regards their use as reinforcement in composite materials [3]. However, their application is limited by generally poor mechanical properties, high moisture absorption and highly polar surface. These limitations (among other consequences) lead to very low interfacial compatibility and inter-fiber aggregation by hydrogen bonding when compared to synthetic fibers [4,5]. Considerable research work has been devoted to ways of minimizing these drawbacks [6,7], and the simultaneous use of synthetic and vegetable fibers, i.e. producing hybrid composites, is between the most promising strategies to broaden the range of applications [8,9].

The commercial use of hybrid composites with the tailoring of the material properties by varying the relative amount of reinforcements is still in its early stages, but it is already known that if the fibers are adequately combined, the resulting materials may be used in a variety of fields [2]. Hybridization with glass fiber, for instance, is an unquestionable way of incrementing the overall mechanical properties of natural fiber composites in order to enable new applications.

Many factors dictate the final performance of hybrid composites such as the nature of the matrix, length and relative composition of the reinforcements, fiber–matrix interface, fiber entanglement degree, among others [10–13]. The behavior of hybrid composites may sometimes be estimated as a simple weighted sum of the characteristics of the individual components, and the combination strives to yield a more favorable balance between advantages and disadvantages inherent in each material [14].

To evaluate the composite performance, conventional mechanical properties are widely used. Nevertheless, dynamic mechanical properties, obtained over a wide range of temperature or frequencies, may be quite useful in understanding the composite structure [15,16]. Dynamic mechanical analysis (DMA) is, for instance, a sensitive technique to study the fiber/matrix interface characteristics [17], and the results may corroborate those from mechanical testing [18,19].

There are some studies in the literature devoted to the dynamic mechanical analysis of composites containing natural fibers [14,15,17]. de Paiva et al. [14] studied the dynamic mechan-

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ical behavior of unmodified and surface modified sisal fibers for phenolic and lignophenolic matrix composites. The authors reported an improvement in the fiber/matrix interfacial adhesion when mercerized and esterified fibers were used comparatively to ionized air-treated fibers. A stronger fiber/matrix interaction was noticed when the lignophenolic matrix was used, shifting the glass transition temperature to higher values in comparison with the phenolic matrix.

However, there are just a few studies focusing on the dynamic mechanical analysis of hybrid composites containing natural fibers [6,10]. For instance, Idicula et al. [19] studied randomly oriented banana/sisal fiber reinforced polyester composites and observed that the dynamic properties modified according to the total volume fraction of fiber and the relative volume fraction of the two fibers. On this context, this work aims to evaluate the hybridization effect on curaua/glass composites (22% overall fiber volume fraction) focusing on their dynamic mechanical properties.

2. Experimental

2.1. Materials

Commercial unsaturated isophthalic polyester resin Arazyn AZ 12.0 (supplied by AraAshland) was used as the composite matrix. Commercial grade benzoyl (BPO) peroxide (from Akzo Nobel) was used as initiator. Raw curaua fiber was obtained from a native producer in the Para state of Brazil.

2.2. Methods

Composites were prepared using the hot compression molding technique. The curaua fiber was chopped to the desired length (50 mm), washed in distilled water for 1 h and dried in an oven with air circulation (105 °C, 50 min). The fibers were manually dispersed and randomly arranged in a pre-mold of the required rectangular shape to produce a mat. The mat was then dried in an oven at 105 °C for 30 min just prior to molding.

The mat was placed in the mold and hot compressed under the following conditions: 3 ton and 95 °C, for 70 min. The polyester resin (100 ml) used was previously mixed with 1 wt.% of BPO peroxide (curing agent). In all composites, the overall fiber volume fraction was kept constant (22%). The hybrid composites were named based on the curaua/glass fiber volume ratio, as 100/0, 75/25, 50/50, 25/75 and 0/100. The corresponding curaua/glass fiber weight fraction ratio was: 100/0, 62/38, 36/64, 16/84, 0/100, respectively.

Flexural tests were carried out according to ASTM D790. Ten specimens (120 mm × 12.7 mm × 3 mm) were tested in each case and the average values are reported. Impact testing was carried out using a CEAST impact machine and the impact strength was estimated according to ASTM D256, with 5.5 J hammer. Twelve specimens (60 mm × 12.7 mm × 3 mm) were tested in each case and the average values are reported. Density of the specimens was determined according to ASTM D792 using distilled water.

The viscoelastic properties of the composites were investigated using an Anton Paar Physica MCR 101 analyzer in torsion mode (strain amplitude: 0.08%) and with rectangular specimens (50 mm × 10 mm × 3 mm). Tests were performed at variable frequencies (1, 3, 10 or 30 Hz) and the specimens were heated from room temperature to 180 °C at a heating rate of 3 °C min^{-1}.

3. Results and discussion

3.1. Mechanical properties

The flexural strength and modulus (Table 1) of the composites showed an increase with the incorporation of glass. This is expected due to the better adhesion of the synthetic fiber to the polyester resin in comparison with the curaua fiber. Consequently, there is a higher degree of stress transfer to the former fibers upon loading [5]. In flexural testing, various mechanisms such as tension, compression and shearing take place simultaneously. For higher glass fiber content, flexural strength increased due to the increased resistance to shearing [13], yielding c.a. 100% increase in this property for the all-glass composite.

Table 1
Flexural properties of the curaua/glass composites.

Sample (curaua/glass)	Flexural strength (MPa)	Flexural modulus (MPa)	Elongation at break (%)
100/0	97 ± 6.0	5119 ± 233	2.9 ± 0.2
75/25	102 ± 16.7	6376 ± 683	2.3 ± 0.4
50/50	148 ± 19.2	8037 ± 490	2.6 ± 0.3
25/75	175 ± 15.6	8723 ± 578	2.8 ± 0.2
0/100	194 ± 25.1	9221 ± 1244	3.2 ± 0.3

On the other hand, the variation in elongation at break did not show a clear trend. In a hybrid composite, failure is directly related to the strain at break of the individual reinforcing fibers [13] and the strain at break of the glass fiber (2.5%) is low compared to the curaua fiber (4.5%) [20]. However, the glass fibers are able to take most of the load when present in sufficient amount in the composite, avoiding premature fracture of the hybrids. When the glass fibers fail, high stress is transferred to the weaker curaua fibers and this leads to curaua failure and, ultimately, composite failure. For the 50/50 composites, 10.34% reduction was found upon glass incorporation.

The Barcol hardness and impact strength results are shown in Table 2. Upon glass incorporation, hardness increased around 75% for the 0/100 composite due to the higher hardness of the ceramic glass fiber. Impact strength also increased with the incorporation of the synthetic fiber since it enables better adhesion to the polyester resin than the vegetable fiber. Consequently, there is more energy dissipation at the fiber/matrix interface via fiber pull-out following an impact event [5]. Incorporation of glass (50% in weight) led to an increase of 335% in impact strength.

3.2. Dynamic mechanical characteristics

3.2.1. Storage and loss moduli

As shown in Fig. 1, storage modulus of the composites was considerably higher than that of the neat polyester resin. Besides, the storage modulus of all composites decreased with temperature, being higher for the composites with more glass fibers. It can also be noted that even a small content of glass fiber shows a pronounced effect on the storage modulus of the hybrid composites in the glassy and the elastomeric regions.

Modulus in the glassy state is primarily determined by the strength of the intermolecular forces and the way the polymer chains are packed [18]. This explains the high values obtained by the glass fiber composites that show a stronger bond to the polymeric chains though the interface. The decrease in modulus with temperature is due to the microbrownian movement of the polymer chains as the polymer approached the glass transition. Microbrownian

Table 2
Barcol hardness and impact strength of the curaua/glass composites.

Sample (curaua/glass)	Barcol hardness	Impact strength (kJ/m^2)
100/0	32 ± 3.3	20 ± 3.0
75/25	39 ± 2.7	64 ± 8.9
50/50	39 ± 3.3	87 ± 12.1
25/75	48 ± 3.1	97 ± 8.0
0/100	56 ± 2.9	107 ± 9.1