IMPACT TESTS IN POLYESTER MATRIX COMPOSITES REINFORCED WITH CONTINUOUS CURAUA FIBER

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ABSTRACT

The objective of this work was to investigate the toughness behavior of polyester matrix composites reinforced with up to 30% in volume of long, continuous and aligned curaua fibers by means of Charpy impact tests. The addition of curaua fibers results in a visible improvement in the energy absorption ability of the composites. Macroscopic observation of the post-impacted specimens and the SEM fracture analysis showed that longitudinal rupture through the curaua fiber interface with the polyester matrix is the main mechanism for the higher toughness attended by these composites.

Keywords: curaua fiber, polyester composites, Charpy impact test, rupture mechanism.

INTRODUCTION

Natural fibers are nowadays replacing the synthetic ones, particularly the common glass fiber, as reinforcement of polymeric composites in many engineering applications, such as, automobile interior components, cyclist helmets, housing panels and windmill fins (1-4). The lignocellulosic fibers obtained from vegetables offer social, economical, environmental and technical benefits (5-6), in particular a higher impact resistance. These fibers are naturally flexible, while the glass fiber have a brittle characteristic, in a situation of a crash event the flexible ones absorbs more energy than the brittle ones. This is the case of automobile parts such as the head-
rest and the interior front panel that should not have a brittle rupture during an accident. In fact, the parts should be sufficiently soft and flexible to absorb the impact energy without splitting into sharp pieces, to avoid injuring the passengers\(^6\).

**EXPERIMENTAL PROCEDURE**

The materials used in this work were curaua fibers, supplied by the Brazilian firm Amazon Paper that commercializes natural fibers cultivated in the Amazonian region, and an unsaturated orthophthalic polyester resin supplied by the Dow Chemical Co.

![Curaua plant and fibers](image)

**Figure 1.** Curaua plant (a) and fibers extracted from the leaves (b).

A statistical analysis of the fibers from the as-received bundle revealed that the diameters were dispersed in the interval from 0.04 to 0.3 mm, with an average of 0.10 mm. These equivalent diameters were measured at 5 positions along the fiber length with two measurements performed at the same position with a 90° rotation.

<table>
<thead>
<tr>
<th>Density (g/cm(^3))</th>
<th>Diameter (µm)</th>
<th>Cellulose (%)</th>
<th>Hemi-cellulose (%)</th>
<th>Lignin (%)</th>
<th>Micro-Fibril Angle (degree)</th>
<th>Tensile Strength (MPa)</th>
<th>Elastic Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.92</td>
<td>40-300</td>
<td>71-74</td>
<td>21</td>
<td>8-11</td>
<td>18.8</td>
<td>200-1400</td>
<td>30-80</td>
</tr>
</tbody>
</table>

The fibers were initially cleaned and dried at room temperature for 24 hours. The continuous and aligned fibers were placed inside a mold along the length in
amounts from 0 to 30% in volume. The still fluid polyester resin was poured onto these fibers. The polyester resin was prepared with a phr 13 proportion, i.e., thirteen parts of hardener per one hundred parts of resin. Plates of these composites were press-molded and allowed to cure at room temperature for 24 hours. Standard specimens with 63 x 12.7 x 10 mm were fabricated for Charpy impact testing, according to the ASTM D256 norm. These specimens were cut from the plate along the direction of alignment of the fibers.

Figure 2 illustrates the Charpy impact pendulum and the schematic specimen with standard dimensions. For each proportion of fibers, 10 specimens were tested to assure a statistical validation. The specimens were impact tested with a PANTEC hammer pendulum, shown in Figure 2.

The impact fracture surface of the specimens was analyzed by scanning electron microscopy, SEM, in a model SSX-500 Shimadzu microscope. Gold sputtered samples were observed with secondary electrons imaging at an accelerating voltage of 15 kV.

![Charpy equipment and schematic for the standard specimen.](image)

**RESULTS AND DISCUSSION**

Table 1 presents the results of Charpy impact tests of polyester matrix composites reinforced with different volume fractions of curaua fibers.
Table 1. Charpy impact energy for polyester composites reinforced with curaua fibers.

<table>
<thead>
<tr>
<th>Volume Fraction of Curaua Fiber (%)</th>
<th>Charpy Impact Energy (J/m)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>22.91 ± 9.77</td>
</tr>
<tr>
<td>10</td>
<td>92.57 ± 9.07</td>
</tr>
<tr>
<td>20</td>
<td>149.0 ± 29.5</td>
</tr>
<tr>
<td>30</td>
<td>335.71 ± 35.67</td>
</tr>
</tbody>
</table>

Based on the results shown in Table 1, the variation of the Charpy impact energy with the amount of curaua fiber in the polyester composite is shown in Fig. 2.

Figure 2. Charpy impact energy as a function of different volume fractions of curaua fiber.
In this figure it should be noticed that the curaua fiber incorporation into the matrix significantly improves the impact toughness of the composite. This improvement can be considered almost as an exponential increase with respect to the amount of curaua fibers. A close mathematical adjustment for the points in Fig. 2 gives

\[ E = -105 + 130 \exp(0.04V) \]  

(1)

The relatively high dispersion of values, given by the standard deviation associated with the higher fiber percentage points in Fig. 2, is a well known heterogeneous characteristic of the lignocellulosic fibers\(^{(5)}\). The values shown in this figure are consistent with results reported in the literature\(^{(9-10)}\). The reinforcement of a polymeric matrix with both synthetic\(^{(11-12)}\) and natural\(^{(13-15)}\) fibers increases the impact toughness of the composite.

In this work, using aligned curaua fibers, the impact toughness of 335.71 J/m for 30% long curaua fibers is significantly higher than the value reported\(^{(13)}\), 51 J/m, for curaua/polypropylene composites reinforced with 50% of short cut and randomly oriented lignocellulosic curaua fibers.

The greater impact resistance of the polyester in comparison with the polypropylene matrix could be one reason for the superior performance found in the present work. However, there are other important factors related to the impact fracture characteristic of polymeric reinforced with long and aligned natural fibers.

The relatively low interface strength between a hydrophilic natural fiber and a hydrophobic polymeric matrix contributes to an ineffective load transfer from the matrix to a longer fiber. This characteristic allow the system to absorb more energy because of the flexibility of the fiber that slide out of the matrix but do not breaks, what amplifies the energy needed to rupture the specimen\(^{(16)}\). The macroscopic aspects of the typical specimen ruptured by Charpy impact tests are shown in Fig. 3.

In this figure it should be noted that the incorporation of fiber results in a completely different rupture shape with respect to pure polyester (0% fiber) in which a totally transversal rupture occurs.
Figure 4. Typical ruptured specimens of polyester composites reinforced with curaua fibers by Charpy impact tests.

Even with 10% of fiber, the rupture is no longer completely transversal. This indicates that the cracks nucleated at the notch will initially propagate transversally through the matrix, as expected in a monolithic polymer. However, when the crack reaches a fiber, the rupture will proceed through the interface. As a consequence, after the Charpy hammer hit the specimen, some long fibers will be pulled out from the matrix but will not break, simply bend. In fact, for volume fractions of fiber above 10%, some specimens are not separated at all. For these amounts of fibers, part of the specimen was bent enough to allow the hammer to continue its trajectory carrying away the specimen without breaking it into pieces, which is expected in a Charpy test. The value of the impact toughness in this case cannot be compared with others in which the specimen is totally split apart. Anyway, the fact that a specimen is not completely separated in two parts underestimates the impact toughness. In other words, had all the fibers been broken, the adsorbed impact energy would be even higher.

Figure 5 presents details of the impact fracture surface of a polyester composite specimen with 30% of curaua fiber. This fractograph shows an effective adhesion between the fibers and the polyester matrix, where cracks preferentially propagate. Some of the fibers were pulled out from the matrix and others were broken during the impact. By contrast, the part of the specimen, in which the rupture occurred longitudinally through the fiber/matrix interface, reveals that most of the fracture area is associated with the fiber surface. This behavior corroborates the
rupture mechanism of cracks that propagate preferentially in between the curaua fiber surface and the polymeric matrix due to the low interfacial strength\(^{16}\). The greater fracture area, Fig. 5, associated with the aligned curaua fibers acting as reinforcement for the composite, justify the higher absorbed impact energy, Fig. 2, with increasing amount of curaua fibers.

![Figure 5. Impact Charpy fracture surface of a polyester composite reinforced with 30% curaua fibers: (a) 30 X and (b) 500 X](image)

**CONCLUSIONS**

- Composites with aligned curaua fibers reinforcing a polyester matrix display a significant increase in the toughness, measured by the Charpy impact test, as a function of the amount of the fiber.

- Most of this increase in toughness is apparently due to the low curaua fiber/polyester matrix interfacial shear stress. This results in a higher absorbed energy as a consequence of a longitudinal propagation of the cracks throughout the interface, which generates larger rupture areas, as compared to a transversal fracture.

- Amounts of curaua fibers above 10% are associated with incomplete rupture of the specimen owing to the bend flexibility, i.e., flexural compliance, of the curaua fibers.

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REFERENCES
