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CHARPY TOUGHNESS BEHAVIOR OF CONTINUOUS AND ALIGNED JUTE FIBERS REINFORCED EPOXY MATRIX COMPOSITES[1]

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Abstract

Natural fibers obtained from cellulose-based plants are being used as reinforcement of polymer composite owing to both environmental and technical advantages. Jute fibers have in the past decades being investigated as possible reinforcement of polymer composites. One important technical characteristic of most lignocellulosic fibers is the bend flexibility, which allows them to resist impact forces. This work investigated the toughness behavior of epoxy matrix composites reinforced with up to 30% in volume continuous and aligned jute fibers by means of Charpy impact tests. Up to 30 wt% has been found that, as jute fibers is incorporated in the epoxy matrix, there is a significant increase in energy absorbed by the composite, measured in the Charpy impact. This result indicates higher toughness brought about by the jute fiber, the epoxy matrix composites investigated. Macroscopic observation of the post-impact specimens and SEM fracture analysis showed that longitudinal rupture through the jute fiber interface with the epoxy matrix is the main mechanism for the remarkable toughness of these composites.

Keywords: Jute fibers; Epoxy composites; Charpy test; Fracture analysis.

TENACIDADE AO IMPACTO CHARPY DE COMPÓSITOS DE MATRIZ EPÓXI REFORÇADOS COM FIBRASCONTÍNUAS E ALINHADAS DE JUTA

Resumo

Fibras naturais, obtidas a partir de plantas à base de celulose são utilizadas como reforço de compósitos poliméricos devido às vantagens tanto ambientais quanto técnicas. Nas últimas décadas as fibras de juta tem sido investigada como possível reforço de compósitos poliméricos. Uma característica técnica importante da maior parte das fibras lignocelulósicas é a flexibilidade de curvatura, o que lhes permite resistir a forças de impacto. Este trabalho investigou a tenacidade ao impacto de compósitos de matriz epóxi reforçados com fibras contínuas e alinhadas de juá com até 30 % em volume, por meio de ensaios de impacto Charpy. Com até 30% em peso, verificou-se que a medida que as fibras de juta são incorporadas na matriz epóxi, há um aumento significativo na energia absorvida pelo compósito, medida no impacto Charpy. Este resultado indica uma maior tenacidade provocada pela fibra de juta, nos compósitos de matriz epóxi investigados. A observação macroscópica das amostras após o impacto e análise microscópica da fratura mostrou que a ruptura longitudinal através da interface da fibra de juta com a matriz de resina epóxi é o principal mecanismo para a resistência notável destes compósitos.

Palavras-chave: Fibras de juta; Compósitos de epóxi; Ensaio Charpy; Analise da fratura.

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1 INTRODUCTION

Since mid last century, polymeric composite materials have been replacing several conventional materials.(1) More recently, however, synthetic composites are losing their importance due to environmental and energy issues. Investigations are under way to find alternative solutions.

The interest of this research is to develop composites with epoxy resin matrix reinforced with continuous and aligned jute fibers, for applications in various industries, including construction and automotive industry. Conflicts related to the use of non-renewable forms of energy are increasing the interest to enter the market to replace natural materials, synthetic materials have a higher power consumption in its manufacture.(2-5)

Therefore, applications of natural lignocellulosic fibers obtained from cellulose-based plants are receiving increased attention as an alternative to replace more environmentally correct non-recyclable materials, energy intensive and glass fiber composites.(6,7)

In particular the impact resistance of a naturally flexible lignocellulosic fiber is a technical advantage over the brittle glass fiber in a situation of a crash event. 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 soft and able to absorb the impact energy without splitting in sharp pieces, to avoid injuring the passengers.(2)

However, in order to have a composite rigid enough to compete with conventional products such as sheets of wood, only a limited percentage of jute fiber can be incorporated in the polymer matrix (8-10). This means that the final cost of the composite would more depending on its processing and polymer resin used as matrix.

In view of these considerations, it is valid to invest in materials reinforced with jute fibers, they can provide good toughness and endurance. The objective of this study was to investigate the impact resistance of specimens of epoxy matrix reinforcement with different amounts of continuous and aligned jute fibers.

2 MATERIALS AND METHODS

The jute fibers used in this work were supplied as a 5kg lot by the Brazilian firm Sisalsul. Figure 1 illustrated a bundle from the as-received lot of jute fibers as well as isolated fibers extracted from the bundle.

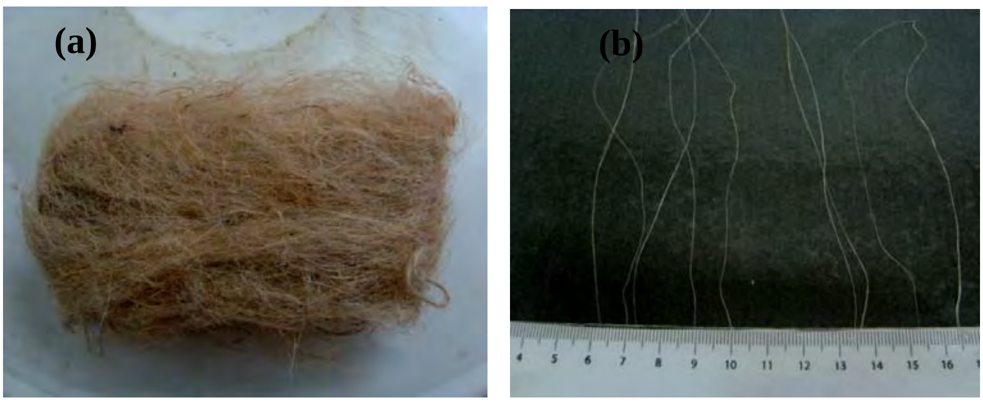

Figure 1. A bundle of as-received (a) and individually separated jute fibers (b)

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As the composite matrix, a type diglycidyl ether of the bisphenol A (DGEBA) epoxy resin hardened with 13 parts per hundred of triethylene tetramine (TETA) in stoichiometric proportions was used. The as received fibers were water cleaned and dried in a stove at 60°C for 24 hours. Composite with 0, 10, 20 and 30 vol % of continuous and aligned ramie fibers were fabricated.

Composites with 0, 10, 20 and 30 vol % of jute fibers were aligned and manufactured by continuous accommodation of the fibers in rectangular mold of 152 x 122 x 10 mm and embedded with the epoxy matrix into the mold until the fraction of weight desired, obtaining plates that were cut as test specimens.

Plates of each composite were then cut, according to the direction of alignment of the fibers into bars measuring 120 x 12 x 10 mm which were the basis for making specimens of Charpy impact test in accordance with ASTM D256, according to the scheme in the Figure 1 (b).

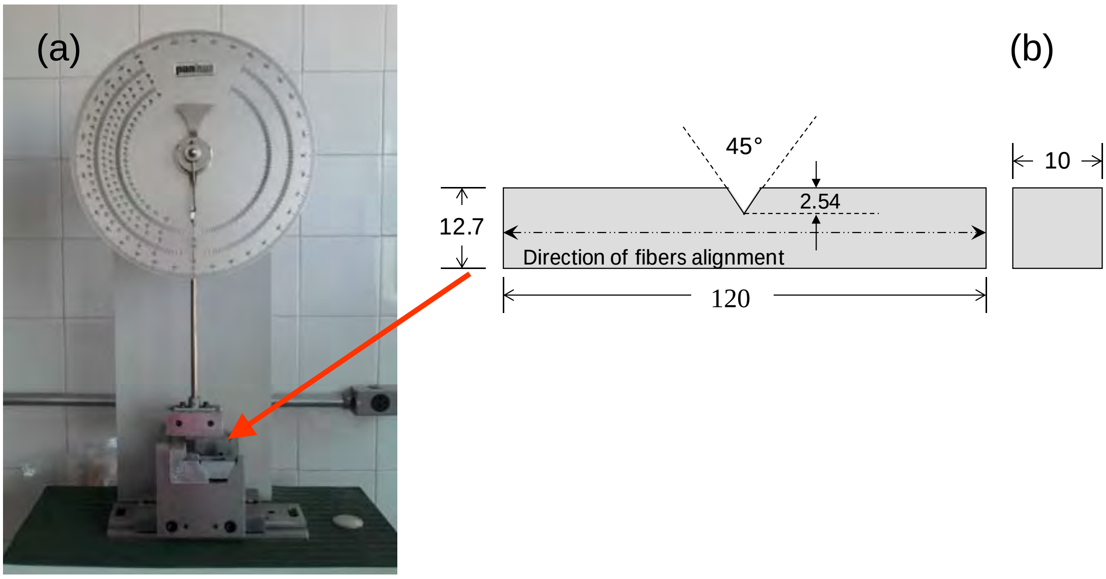

Figure 2. Charpy equipment and standard specimen schematic.

The notch was prepared with a depth of 2.54 mm and angle of 45° required by the standard (Figure 2b), we used a manual carver style brand CEAST Notchvas. The specimens were tested in an instrumented pendulum Pantec (Figure 2a), in Charpy configuration.

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

3 RESULTS AND DISCUSSION

The results of Charpy impact tests of the epoxy matrix composites reinforced with different volume fractions ramie fibers are shown in Table 1.

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Table 1. Charpy impact energy for epoxy composites reinforced with jute fibers

Volume fraction of jute fibers (%)	Charpy Impact Energy (J/m)
0%	12,43 ± 0,98
10%	45,00 ± 6,38
20%	101,80 ± 34,65
30%	211,71 ± 23,90

Based on the results shown in Table 1, the variation of the Charpy impact energy with the amount of jute fiber in the epoxy composite is shown in Figure 3.

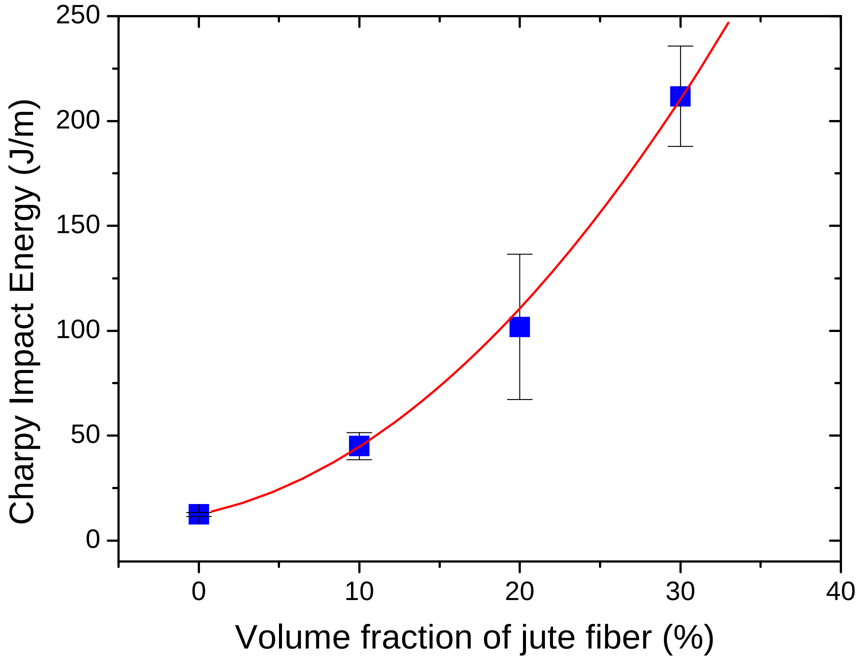

Figure 3. Charpy impact energy as a function of the amount of jute fiber.

This figure also shows the marked increase in Charpy impact energy with the volume fraction of jute fibers. It is also important to note that the points relating to composites have error bars, relative to the standard deviation, relatively large. This is due to the heterogeneous nature of natural fibers, which results in substantial dispersion properties of composites reinforced by them.

Even considering the error bars, it is possible to interpret the increase of impact energy, i.e., toughness of the composites in Figure 2, to vary exponentially with the volume fraction of ramie fibers. A line passing through the median demonstrates this exponential growth. The mathematical interpretation for this growth corresponds preliminarily equation:

$$E_e = 13 \exp 0.10 F \quad (1)$$

Where E_e is the energy absorbed by the epoxy matrix composite Charpy impact on J / F me the volume fraction of ramie fibers in percentage.

Another important aspect to be discussed is the characteristic macroscopic rupture of the specimens after the test. Figure 4 illustrates a typical characteristic of rupture of the specimens of epoxy composites with different volume fractions of jute

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fibers. In this figure is shown that the test piece with 30% jute fibers, i.e, one with greater tenacity was not separated into two parts after impact.

This indicates that the crack nucleated at the notch, spreads across the fragile early epoxy matrix. Up to 20% jute fibers proceeds to crack the matrix to complete rupture. However with 30% jute, the crack is blocked by the fibers and becomes rupture occurs along the interface fiber / matrix. The specimen then bends around the head of the hammer, but does not separate due to the flexibility of the fibers are not broken. Because not occur total rupture (Figure 4), for the specimen with 30% fiber underestimate the toughness of the composite. If all fibers were broken, causing the specimen to separate into two parts the energy absorbed would be even greater.

The reason for having a crack nucleated at the notch, changing its trajectory to reach the jute fibers and to propagate through the interface with the matrix is due to the low interfacial resistance.

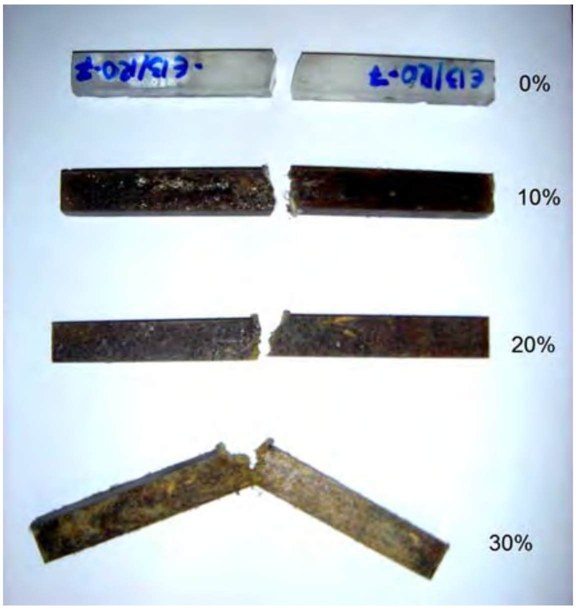

Figure 4. Typical ruptured specimens by Charpy impact tests.

The SEM analysis of the Charpy impact fracture permitted to have a better comprehension of the mechanism responsible for the higher toughness of epoxy composites reinforced with long and aligned jute fibers. Figure 5 shows the aspect of the fracture surface of a pure epoxy (0% fiber) specimen. With lower magnification, the lighter layer in the left side of the fractograph (Figure 5a), corresponds to the specimen notch, revealing the machining parallel marks. The smoother and gray layer on the right side corresponds to the transversal fracture surface. The fracture in Figure 5 suggests that a single crack was responsible for the rupture with the roughness in Figure 5b, being associated with voids and imperfections during the processing.

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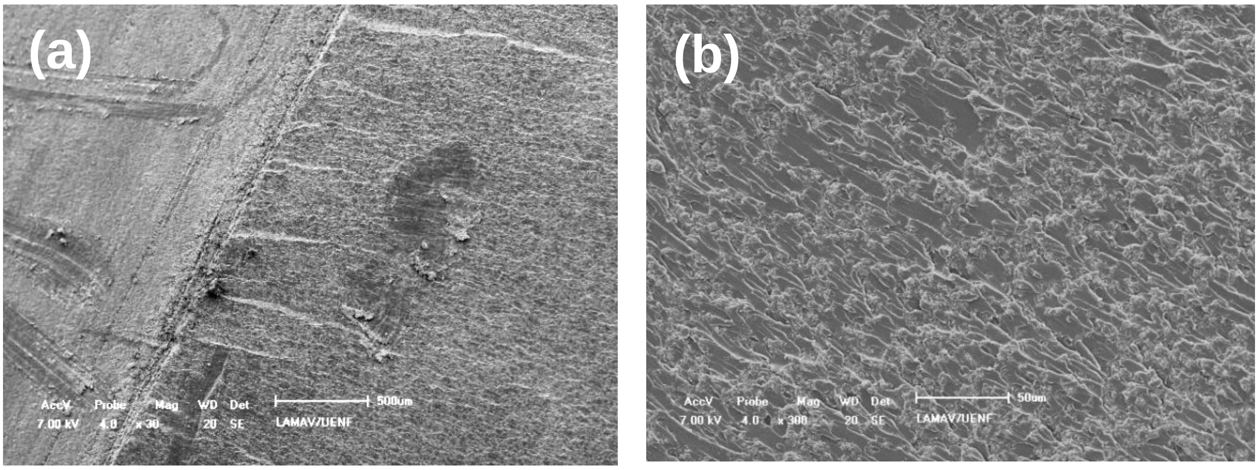

Figure 5. Charpy impact fracture surface of pure epoxy specimen (0% fiber): (a) general view; (b) detail of the epoxy transversal fracture.

Figure 6 presents details of the impact fracture surface of an epoxy composite specimen with 30% of jute fiber. This fractograph shows an effective adhesion between the fibers and the epoxy 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 preferentially occurred longitudinally through the fiber/matrix interface reveal 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 jute fiber surface and the epoxy matrix due to the low interfacial strength. The greater fracture area (Figure 6), associated with the aligned jute fibers acting as reinforcement for the composite, justify the higher absorbed impact energy (Figure 3), with increasing amount of jute fibers.

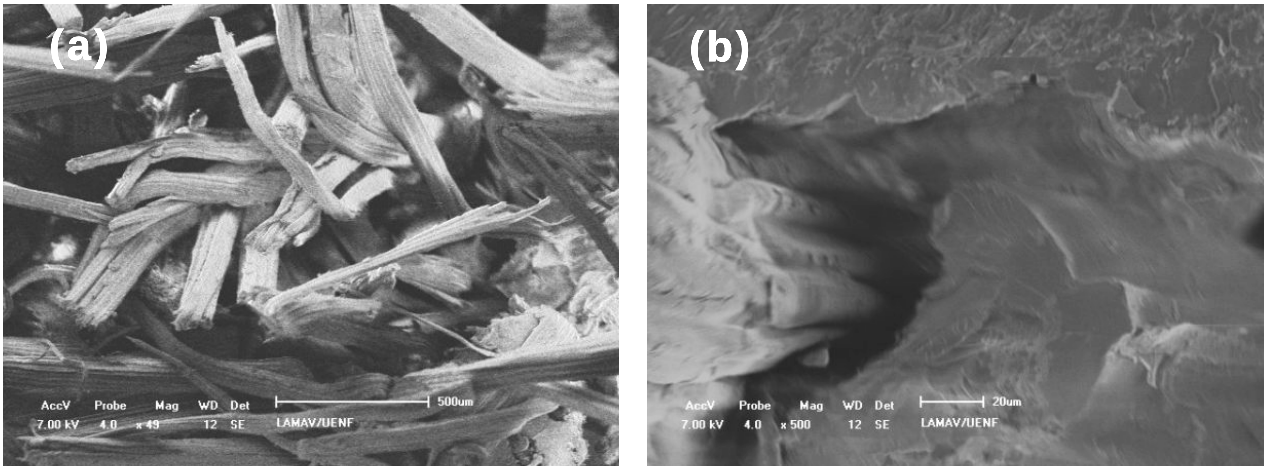

Figure 6. Impact Charpy fracture surface of a epoxy composite reinforced with 30% jute fibers: (a) 30 X and (b) 500 X

4 CONCLUSIONS

- Composites with aligned jute fibers reinforcing a epoxy matrix display a significant increase in the toughness, measured by the Charpy impact test, as a function of

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the amount of the fiber. The values of the absorbed energy are the highest thus far obtained for lignocellulosic fiber composites.

- Most of this increase in toughness is apparently due to the low jute fiber/epoxy 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 jute fibers above 10% are associated with incomplete rupture of the specimen owing to the bend flexibility, i.e., flexural compliance, of the jute fibers.

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