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CHARPY IMPACT TEST IN POLYESTER MATRIX COMPOSITES REINFORCED WITH SHORT SISAL AND JUTE FIBERS

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Abstract: Natural lignocellulosic fibers (NLFs) are increasingly being studied and applied as substitutes for fibers of synthetic origin. The advantage is the fact that NLFs are renewable, biodegradable, have good specific mechanical properties and are cost-effective. Based on this, the present study aims to determine the impact resistance of polyester matrix composites reinforced with sisal and jute fibers through Charpy impact tests. The fibers were used as acquired, without surface treatment, under environmental conditions, and cut to a length of 15 mm. The specimens were manufactured by manual molding (hand lay-up) using silicone molds and without pressure. The impact tests were carried out on specimens reinforced with discontinuous and randomly oriented fibers, for mass fractions varying according to the volumetric capacity of the mold. The absorbed energy increased from 31.50 kJ/m^2 for the unreinforced polyester to 78.16 and 78.13 kJ/m^2 for the sisal and jute reinforced composites, respectively. To statistically validate the level of reliability and significance of the Charpy impact test results, Weibull analysis was performed. Furthermore, a fractographic analysis was carried out using scanning electron microscopy (SEM) to analyze in detail the fracture surfaces of the tested samples and understand the failure mechanisms of each material.

Keywords: Sisal and jute natural fibers, polyester resin, Charpy impact test, composite materials.

INTRODUCTION

The use of renewable and biodegradable materials has advanced notably in recent years. Among these, natural lignocellulosic fibers (NLFs) have stood out as a sustainable alternative to replace synthetic fibers in polymer composites [1-3]. The diversity of NLFs, which exist throughout the world, has sparked interest in their properties with the aim of replacing strong synthetic fibers such as glass, carbon, nylon and aramid in engineering applications [4–6].

The use of thermosetting resins, such as polyester and epoxy, is justified, in turn, through advantages such as low cost, thermal and dimensional stability, chemical resistance at high temperatures and the ease of molding large pieces, although their fracture resistance makes the use of reinforcement necessary [7].

In fact, the replacement of NLFs traditional synthetic ones has been gaining increasing attention since the last few decades, as indicated by review articles [8-10]. The automotive industry, in particular, already applies polymer composites with NLFs mainly in internal parts [11,12]. This is the case of composite parts such as headrests and front panels, which must be soft and capable of absorbing the impact energy, coming from with sharp parts, to avoid injuries to passengers [13].

The use of NLFs as reinforcement in polymeric matrices favors environmental and economic aspects and results in new materials with satisfactory mechanical properties, which allows different applications [14]. Cost-effectiveness, low density, high specific strength and modulus of elasticity [15], are some of the characteristics that favor its use in various industrial sectors. Examples of fibers used in the automobile industry on an industrial scale are coir, linen, jute, ramie, curaua and sisal fibers [16].

In view of this, the present work evaluates the Charpy impact resistance of polyester matrix composites reinforced with discontinuous and randomly oriented sisal and jute fibers, contributing to the search for new materials that are more sustainable alternatives, with economic viability and appropriate technology.

MATERIALS AND METHODS

MATERIALS

POLYESTER RESIN

The polymer matrix used was pre-accelerated orthophthalic, unsaturated polyester resin, crystal, produced by CENTER GLASS (Salvador, state of Bahia, Brazil).

The curing agent used was MEK peroxide in a proportion of 0.33% (v/v), following the procedure established by Rodrigues et al. [17], who tested different proportions (v/v) of MEK-P curing agents in unsaturated polyester resin, defining 0.33% as the proportion with the longest workability time with good mechanical properties.

NATURAL LIGNOCELLULOSIC FIBERS (NLFs)

The NLFs used were sisal (*Agave sisalana*) and jute (*Corchorus capsularis*) commercially obtained in the city of Belem, state of Para, Brazil. Initially, both sisal and jute fibers were used as acquired, in natural condition, without chemical treatment. They were cut to a length of 15 mm. The desired lengths were obtained by manual cutting (with scissors) from the fiber bundles, as illustrated in Figure 1.

(a)

(b)

Figure 1: Fibers cut to a length of 15 mm. (a) sisal, (b) jute.

EXPERIMENTAL PROCEDURES

MANUFACTURING OF SPECIMENS

The specimens were manufactured by manual molding using silicone molds without pressure, show in Figure 2. The process began by treating the mold surface by applying a release agent to remove the part after the curing process. The mass fraction of each type of reinforcement used in the manufacture of the specimens in this research was defined by the volumetric capacity of the mold to accommodate the reinforcement without pressure or compaction and in the absence of the matrix. For each type of reinforcement, with a fiber length of 15 mm, the impact molds were filled with the reinforcement up to the limit of their volumetric capacity, without pressure or mechanical vibration.

Then, each amount of reinforcement was properly weighed and the value of the mass obtained, converted into mass fraction, was established as the incorporation and workability reference for the manufacture of pressureless composites. From this reference value, the proportions to be used in the composites were prescribed.

Figure 2: Impact silicone mold for molding specimens.

Once the reference values for the mass fraction were determined, the test specimens were manufactured to evaluate the workability of the mixture in the liquid state, estimating its moldability and the wettability of the matrix over the reinforcements involved. From this procedure, the proportions of the fiber reinforcement composite were established with the mass fractions presented in Table 1.

Natural Fibers	Fiber Length (mm)	Mass Fraction (%)
Sisal	15	3,90
Jute	15	5,94

Table 1: Mass fractions of natural fibers used in the manufacture of impact specimens.

CHARPY IMPACT TEST

The notched Charpy impact tests in this work were carried out according to the procedures of ASTM D 6110-18 [18] with dimensions shown schematically in Figure 3.

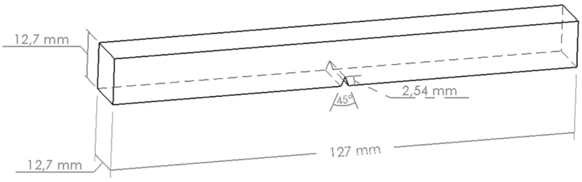

Figure 3: Dimensions of specimens for impact tests.

The tests were carried out on a PANTEC Pendulum XC-50 testing machine in Charpy configuration. Equation (1) was used to calculate the Charpy impact resistance on the manufactured specimens.

$$E_{abs} = \frac{W}{h \times b} \times 10^3 \qquad (1)$$

Where **W** is the energy absorbed when breaking the specimens in J, **h** is the thickness of the specimen in mm and **b** is the width of the specimen in mm.

STATISTICAL VALIDATION

To statistically validate the level of reliability and significance of the Charpy impact test results, Weibull analysis was performed using the corresponding computer program. The Weibull parameters β and θ in the frequency distribution function are related as shown in Equation (2).

$$f(x) = 1 - exp\left[-\left(\frac{x}{\theta}\right)^{\beta}\right] \qquad (2)$$

Where:

β – is the shape parameter, better known as the Weibull Modulus;

θ - is the scale parameter that indicates the characteristic value of what is being measured with a confidence of 63.8%. In the present work, θ represents the characteristic Charpy impact energy;

R^2 - is the adjustment parameter, as it indicates how well the points on the Weibull graph will be adjusted to its central line. The value of R^2 can vary from 0 to 1. The closer the parameter is to 1, the better adjusted the experimental points will be to the central line.

SCANNING ELECTRON MICROSCOPY (SEM)

After carrying out the mechanical tests, the fracture surfaces of the specimens were metallized and analyzed using a Shimadzu scanning electron microscope, model SSX-550 operating at a voltage of 10 kV for the secondary electron beam.

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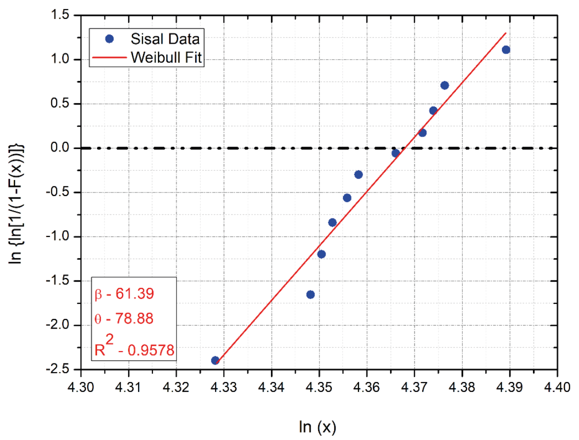
RESULTS AND DISCUSSION

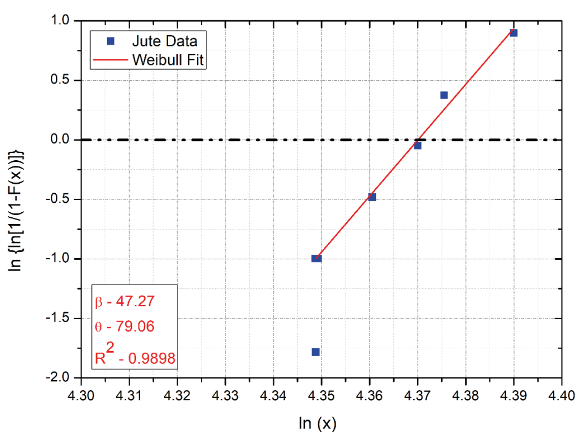
CHARPY IMPACT RESULTS

Some factors related to impact fracture in polymeric matrices reinforced by NLFs consist an the relatively low resistance at the interface. Indeeds a polymeric matrix has a hydrophobic nature while a reinforcing phase has a hydrophilic nature, as it is the case of a NLF, contributing to an inefficient transfer of loads from the matrix to the fibers.

The results obtained by the Charpy impact test as well as the Weibull parameters referring to the Charpy impact test can be seen in Table 2 and Figure 4.



(a)



(b)

Figure 4: Weibull parameters referring to the Charpy impact test. (a) sisal, (b) jute.

In Table 2, it can be seen that there was an improvement in the absorption of impact energy while sisal and jute fibers were inserted in the polyester matrix, the NLFs proved to be good reinforcement, favoring the absorption of impact energy, since the crack stops propagating freely through the matrix and starts to encounter "obstacles" which are the fibers, requiring greater energy to break or bypass this "barrier".

It was also possible to observe that the incorporation of sisal and jute fibers in the polyester matrix increased the impact resistance of the composite so that, when comparing the unreinforced polyester resin (31.50 kJ/m^2) with sisal (78.16 kJ/m^2) and jute (78.13 kJ/m^2) fiber composites there was an increase of more than two times in Charpy impact energy absorption.

In Figure 4(a) and 4(b), analyzing the Weibull modulus (β) which represents the degree of dispersion of the results obtained, the absorbed energy values obtained for the composites showed low dispersion of the results, associated with low standard deviation, consequently they presented a high value for the Weibull modulus. The higher the value of this parameter, the closer the characteristic Charpy impact energy value (θ) is to the average Charpy impact energy value.

SCANNING ELECTRON MICROSCOPY (SEM)

The SEM images of the fractured surfaces of the studied composites after the impact test are presented in Figures 5 and 6. They were used to analyze the interfacial characteristics and surface structure of the fractured specimens in relation to the observed mechanical impact behavior.

Figure 5 shows the micrograph obtained by SEM of the fracture surface of one of the sisal composite specimens subjected to the Charpy impact test.

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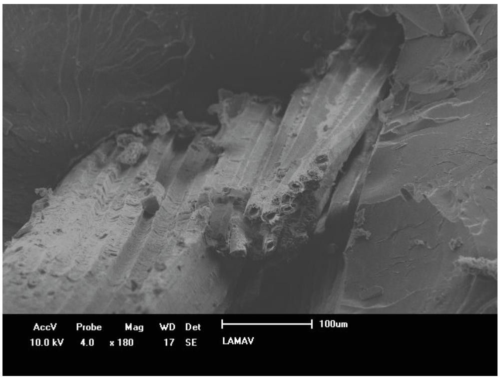
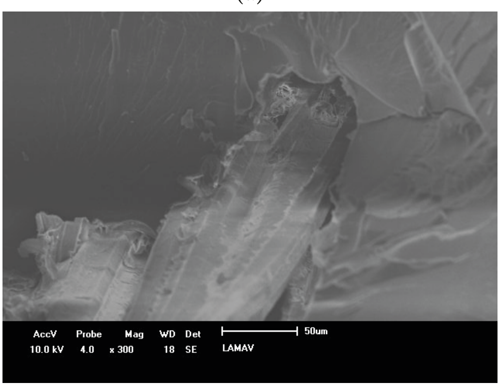
Sample	β	θ	R^2	E_{abs} (kJ/m^2)	Standard deviation	References
Polyester	-	-	-	31.50	3.26	[19]
Sisal	61.39	78.88	0.95	78.16	1.61	PW*
Jute	47.27	79.06	0.98	78.13	2.08	PW*

Table 2: Absorbed energy values of composites.

*PW – Present Work.

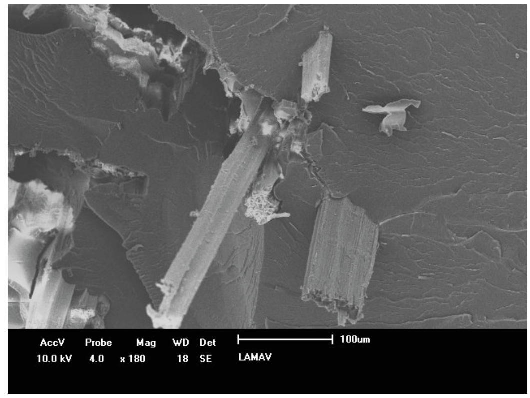


(a)

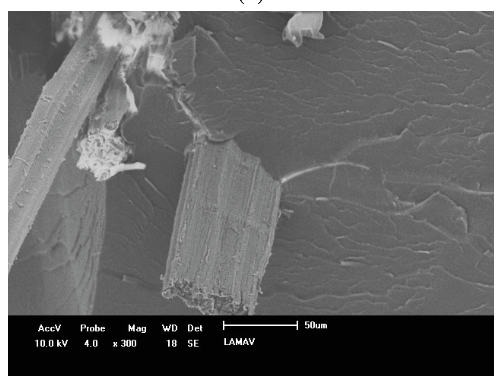


(b)

Figure 5: Micrographs of the fracture surfaces of polymer composite samples reinforced with randomly oriented sisal fibers with a length of 15 mm: (a) 180x magnification, (b) 300x magnification.



(a)



(b)

Figure 6: Micrographs of the fracture surfaces of polymer composite samples reinforced with randomly oriented jute fibers with a length of 15 mm: (a) 180x magnification, (b) 300x magnification.

It can be seen in Figure 5(a) and 5(b) that the sisal fiber acts as a barrier to crack propagation in the polyester matrix, contributing to the toughening of the composite. In addition, the composites showed “river marks”, which is an aspect of brittle fracture.

Figure 6 shows the micrograph obtained by SEM of the fracture surface of one of the jute composite specimens subjected to the Charpy impact test.

Figure 6(a) and 6(b) shows a crack propagating as a “river mark” pattern and also shows cracks propagating at the matrix-reinforcement interface, which consists of a fracture mechanism between the jute fiber and the polyester matrix associated with weak resistance at the interface, resulting in an increase in impact energy.

CONCLUSIONS

There is a significant increase in the energy absorbed in Charpy impact tests with the incorporation of sisal and jute fibers into a polyester matrix composite. The weak interface between the sisal and jute fibers and the polyester matrix contributes greatly to increasing the impact energy, altering the trajectory of the cracks in the composite and creating more surface areas.

Most of this increase in toughness is apparently due to the low interfacial shear stress of the natural fibers and the polyester matrix. This results in greater absorbed energy as a consequence of the longitudinal propagation of cracks along the interface, which generates larger rupture areas compared to a transverse fracture.

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