Izod Impact Tests in Polyester Matrix Composites Reinforced with Fique Fabric

Artur C. Pereira, Sergio N. Monteiro, Foluke S. Assis and Henry A. Colorado

Abstract The fique fibers are studied worldwide as an alternative of synthetic fibers in composites. This study evaluated the impact resistance of this type of composite. Specimens were made with up to 30% in volume of fique fabric in an Izod normalized mold. The fique fabric was embedded with polyester resin and cured at room temperature for 24 h. The specimens were tested in Izod impact pendulum and the fracture surfaces were examined by scanning electron microscopy (SEM). The impact resistance of composites increased linearly with the relative amount of fique fabric reinforcing the composite. This performance was associated with the difficulty of rupture imposed by the fique fabric as well as the type of cracks resulting from the interaction jute fiber/polyester matrix that corroborate the energy absorption at the impact test.

Keywords Fique fabric · Composite · Polyester matrix · Izod impact tests

Introduction

Natural fibers, especially those lignocellulosic obtained from plants, offer economical environmental and technical advantages in comparison to synthetic fibers for application as the reinforcement of polymeric composites [1–3]. Some of these lignocellulosic fibers like jute, sisal, cotton, flax, hemp, coconut and sawdust are, since long time, being added to polymers to enhance the properties [4]. This historical fact dates back to the first industrial polymer, the Bakelite, which was more than one hundred years ago incorporated with sawdust to improve its impact resistance and reduce cost [5]. For the industry, low cost is certainly an important

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incentive associated with the use of lignocellulosic fibers that usually have a commercial price around five times lower than that of glass fiber, the cheapest among the synthetic fibers.

Environmental issues are, additionally gaining attention owing to worldwide problems related to climate changes and pollution. This is nowadays a major advantage for the natural fibers that are renewable, biodegradable and recyclable. By contrast to glass fiber composites that cannot be recovered, natural fiber composites can be completely burnt to produce energy [6]. Moreover, lignocellulosic fibers are neutral with respect to CO_2 emission, the main responsible for global warming [7].

Technical advantages are also associated with the use of lignocellulosic fibers in polymeric composites. According to Zah et al. [5], the application of natural fiber composites is rapidly increasing in the automobile industry with annual growth rates above 20%. Both interior and exterior components are already on the market and a major reason is the technical advantage of a higher impact resistance. This is of great importance in case of a crash event and applies equally for an automobile head rest or a cyclist helmet.

Earlier works [8, 9] on impact resistance of polymeric composites were conducted with different short-cut randomly oriented lignocellulosic fiber reinforcement. In these works, Izod impact tests with notched and fixed specimens resulted in absorbed energy values lower than 60 J/m for all fibers investigated as polypropylene composite reinforcement. Recent works on the impact resistance of thermoset polymer composites reinforced with long and aligned lignocellulosic fibers [10–15], revealed a much higher value for the impact energy. In particular, a polyester composite reinforced with 40% of fique fabric reached 170 J/m [11], which is more than three times the maximum obtained by any short-cut and randomly oriented lignocellulosic fiber composites [9]. This remarkable result served as motivation for a work to confirm it with a different impact method, the Charpy test.

According to the ASTM D 256 norm, there are significant differences between both tests, Charpy and Izod [15] that could lead to distinct results. These differences are shown in Fig. 1.

This figure reveals that the Charpy specimen, with a minimum length of 124 mm, is free-standing on the support during the impact, Fig. 1a, with a hammer, which strikes exactly at the opposite side of the notch. By contrast, the Izod specimen has a maximum length of 63 mm and is fixed to the support during the impact, Fig. 1b, which strikes at a point 22 mm away from the notch. In practice, the Izod test simulates better the actual situation of a component fixed into a system, which is hit at a point away from a stress raiser like a grove or a flange.

Base on these considerations, the objective of the present work was to assess the impact resistance, by means of Izod tests, of polymeric composites reinforced with different amounts of fique fabric.

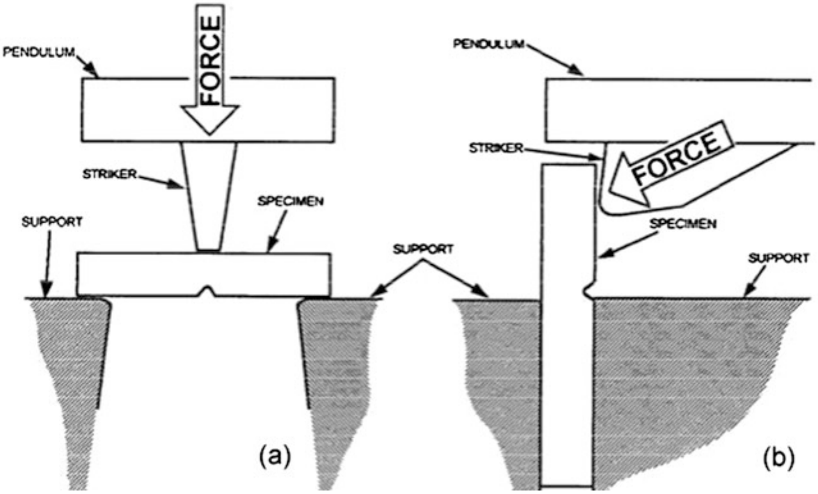

Fig. 1 The Charpy **a** and the Izod **b** impact test methods

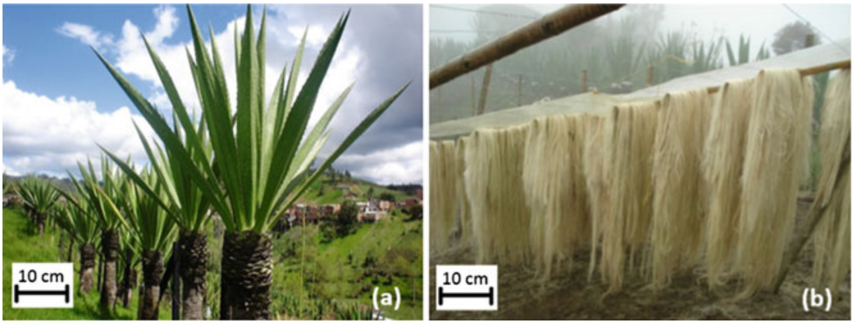

Fig. 2 Fique plant **a** and its fibers **b**

Experimental Procedure

The fique fabric was obtained from the Colombia. The typical aspect of a fique plantation and a bundle of soft fibers are shown in Fig. 2.

From the as-received lot of fique, one hundred fibers were separated for a statistic dimensional analysis. The distribution of diameter is presented in Fig. 3. This figure reveals that dimensions of the fique fabric as any other lignocellulosic fiber [1–3], are heterogeneous with a significant dispersion in values. This is considered a condition for long fiber in terms of composite reinforcement and assures an effective strengthening of the matrix [17].

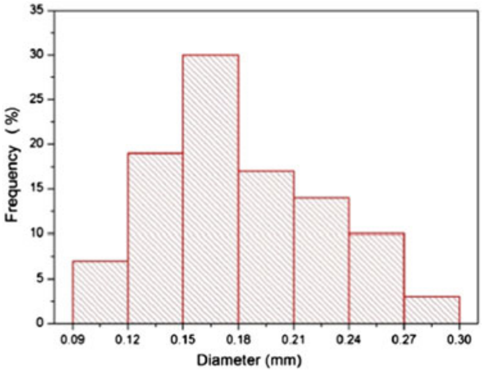

Fig. 3 Histogram of the statistical distribution of diameter of fique fabric

After cleaning and room temperature (RT) drying, aligned fique fabric were mixed in amounts of 0, 10, 20, and 30% in volume with a commercial orthophthalic polyester resin added with 0.5% methyl-ethyl-ketone hardener. Plates of these composites were press molded and allowed to cure at RT for 24 h. Standard notched specimens, 63 × 12.7 × 10 mm for Izod impact testing, according to the ASTM D256 norm, were cut from the plate along the direction of alignment of the fibers. The notch with 2.54 mm in depth, angle of 45° and a tip curvature radius of 0.25 was machined according to DIN 847 norm. For each condition, 10 specimens were tested to assure a statistical validation. The specimens were impact tested with a EMIC hammer pendulum.

The impact fracture surface of the specimens was analyzed by scanning electron microscopy, SEM in a model JSM-6460 LV Jeol microscope. Gold sputtered SEM samples were observed with secondary electrons imaging at 15 kV.

Results and Discussion

The variation of the Izod impact energy with the amount of fique fabric in the polyester composite is shown in Fig. 4.

In this figure it should be noticed that the fique fabric incorporation into the polyester matrix significantly improves the impact toughness of the composite. Within the standard deviation, this improvement can be considered as an exponential function with respect to the amount of fique fabric up to 30%. The relatively high dispersion of values, given by the error bars associated with the higher fiber percentage points in Fig. 4 is a well known non-uniform characteristic of the lignocellulosic fibers [2]. The values shown in this figure are consistent with results reported in the literature. The reinforcement of a polymeric matrix with both synthetic [18] and natural [8, 10] fibers increases the impact toughness of the composite. Table 1 compares values of impact toughness of polymeric composites with different natural fibers.

Fig. 4 Izod impact energy as a function of the amount of fique fabric

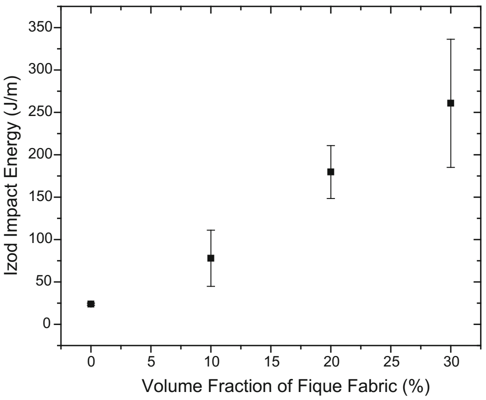

Table 1 Impact toughness of polymeric composites reinforced with natural fibers

Composite	Amount of fiber (%)	Fiber condition in the composite	Izod impact toughness (J/m)	Reference
Jute/polypropylene	50	Short-cut randomly oriented	39	[8]
Sisal/polypropylene	50	Short-cut randomly oriented	51	[8]
Flax/polypropylene	50	Short-cut randomly oriented	38	[8]
Wood/polypropylene	50	Short-cut randomly oriented	28	[8]
Fique/polypropylene	50	Short-cut randomly oriented	54	[8]
Coir/polypropylene	50	Short-cut randomly oriented	46	[8]
Coir/polyester	40	Long and aligned	121	[19]
Fique/polyester	30	Long and aligned	260	This work

In this work, using long and aligned fique fabric, the impact toughness is significantly higher than the values reported for polypropylene composites reinforced with 50% of short cut and randomly oriented lignocellulosic fibers. The greater impact resistance of the polyester in comparison with the polypropylene matrix could be one reason for the superior performance of the present result. 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 results in relatively greater fracture surface and higher impact energy needed for the rupture [20]. Another factor is the flexural compliance of a long fiber during the impact test, which will be further discussed.

The incorporation of long and aligned fique fabric results in a marked change with respect to pure polyester (0% fiber) in which a totally transversal rupture occurs. 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 polyester matrix, as expected in a monolithic polymer. However, when the crack front reaches a fiber, the rupture will proceed through the interface. As a consequence, after the Izod hammer hit the specimen, some long fibers will be pulled out from the matrix but, owing to their compliance, will not break but simply bend. In fact, for amounts of fiber above 10%, the specimens are not separated at all. For these amounts of long fique fabric, part of the specimen was bent enough to allow the hammer to continue its trajectory without carrying away the top part of the specimen, as expected in a Izod 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 higher.

The SEM analysis of the Izod impact fracture permitted to have a better comprehension of the mechanism responsible for the higher toughness of polyester composites reinforced with long fique fabric. Figure 5 shows the aspect of the fracture surface of a pure polyester (0% fiber) specimen. With lower magnification, the upper darker layer in the fractograph, Fig. 5a, corresponds to the specimen notch, revealing the machining horizontal marks. The smoother and light gray layer underneath corresponds to the transversal fracture surface. The fracture in Fig. 5 suggests that a single crack was responsible for the rupture with the roughness in Fig. 5b, being associated with voids and imperfections during the processing.

Figure 6 presents details of the impact fracture surface of a polyester composite specimen with 30% of fique fabric. 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 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 fique fabric surface and the polyester matrix due to the

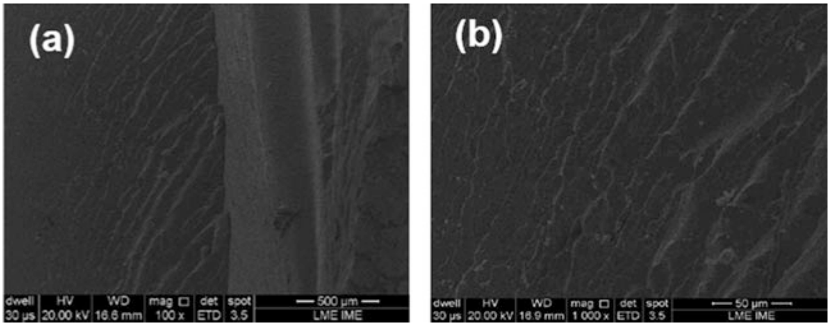

Fig. 5 Izod impact fracture surface of pure polyester specimen (0% fiber): **a** general view; **b** detail of the polyester transversal fracture

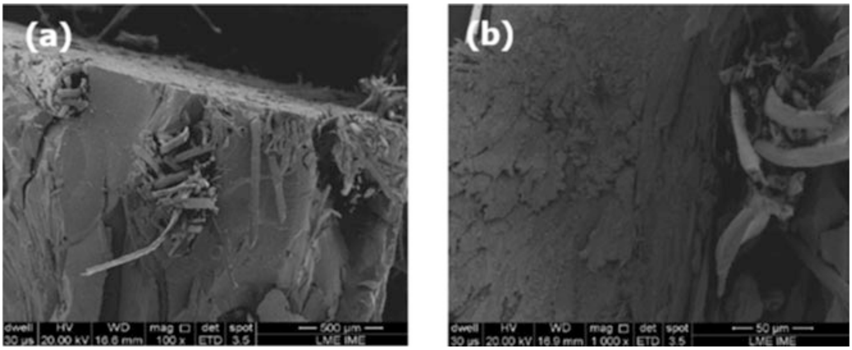

Fig. 6 Impact fracture surface of a polyester composite reinforced with 30% fique fabric: **a** 30× and **b** 500×

low interfacial strength [20]. The greater fracture area, Fig. 6, associate with the long and aligned fibers acting as reinforcement for the composite, justify the higher absorbed impact energy, Fig. 4, with increasing amount of fique fabric.

Conclusions

Composites of aligned fique fabric reinforcing a polyester matrix display a significant increase in the toughness, measures by the Izod impact test, as a function of the amount of the fiber.

Most of this increase in toughness is apparently due to the low 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 fique fabric above 10% are associated with incomplete rupture of the specimen owing to the bend flexibility, i.e., flexural compliance, of the fique fabric.

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