J MATER RES TECHNOL. 2017;xxx(xx):xxx–xxx

Available online at www.sciencedirect.com
jmr&t Journal of Materials Research and Technology
www.jmrt.com.br

Original Article

Toughness of polyester matrix composites reinforced with sugarcane bagasse fibers evaluated by Charpy impact tests☆

Verônica Scarpini Candido [a], Alisson Clay Rios da Silva [a], Noan Tonini Simonassi [b], Fernanda Santos da Luz [b], Sergio Neves Monteiro [b,]*

[a] *Federal University of Pará – UFPA, Campus Ananindeua, Materials Engineering Faculty, BR 316, Km 7, N° 590, Ananindeua, PA, Brazil*
[b] *Military Institute of Engineering – IME, Praça General Tibúrcio 80, Urca, 22290-270 Rio de Janeiro, RJ, Brazil*

ARTICLE INFO

Article history:
Received 26 May 2017
Accepted 13 June 2017
Available online xxx

Keywords:
Sugarcane bagasse fiber
Polyester composites
Charpy test
Impact toughness

ABSTRACT

The fibers extracted from the sugarcane bagasse have been investigated as possible reinforcement for polymer matrix composites. The use of these composites in engineering applications, associated with conditions such as ballistic armor, requires information on the impact toughness. In the present work, Charpy tests were performed in ASTM standard specimens of polyester matrix composites, reinforced with 10, 20 and 30 vol% of continuous and aligned sugarcane bagasse fibers, in order to evaluate the impact energy. Within the standard deviation, the composite absorbed impact energy increased with the volume fraction of sugarcane bagasse fiber. This toughness performance was found by scanning electron microscopy to be associated with the fiber/matrix delamination.

1. Introduction

In the past decade, a marked interest in natural lignocellulosic fibers obtained from plants as engineering materials has motivated their use as reinforcement of polymer composites [1–6]. The diversity of natural lignocellulosic fiber, which exists worldwide, has raised interest on their properties aiming at replacing strong synthetic fibers such as glass, carbon, nylon and aramid in engineering applications [7–9]. This is of special interest in the case of applying several natural fibers extracted from plants as reinforcement of polymer composites [1,2]. Nowadays these composites are already being used in the automobile industry [2,10,11]. Economical, societal, technical and environmental advantages favor the increase number of research works [5] on natural fiber composites. In particular, the possibility of substituting natural fiber composites for conventional materials made of synthetic fibers, such as Kevlar^{TM}, in personal ballistic armor has recently been

☆ Paper was a contribution part of the 3rd Pan American Materials Congress, February 26th to March 2nd, 2017.

* *Corresponding author.*
E-mail: snevesmonteiro@gmail.com (S.N. Monteiro).

http://dx.doi.org/10.1016/j.jmrt.2017.06.001

investigated [12–16]. It was found that mechanisms other than the fiber strength [17] benefit a natural fiber over a synthetic like the aramid in Kevlar™. In principle, in multilayered armor systems, composites might not be reinforced with stronger fibers to equally perform as compared to Kevlar™.

Based on these findings, it was decided to investigate the impact resistance of a composite reinforced with sugarcane bagasse fiber, which is considered a by-product or even a residue of the sugar/ethanol industry [18]. Several works have been dedicated to polymer composites incorporated with sugarcane bagasse both in raw state [19–24] or its extracted fibers (bagasse fiber for short) [25–32]. The tensile strength of these bagasse fibers was found to vary from 26 to 174 MPa [33]. It is also worth mentioning that bagasse fiber composites are already industrially applied in automobile components in Brazil [34]. In spite of all these works on bagasse fiber composites, their impact properties have not yet been fully investigated. Therefore, the objective of the present work was to evaluate the notch toughness of polyester matrix composites reinforced with bagasse fibers by means of Charpy impact tests.

2. Materials and methods

The bagasse fibers used in this work were collected in commercial places that extract the sugarcane juice by roll-pressing the stalks and dispose the bagasse as residue. The as-collected bagasse was cleaned in running water to remove any remaining sugar. This cleaning procedure was followed by drying in a store at 60 °C for 24 h. Fibers were then manually extracted from the bagasse and selected for a minimum length of 10 cm. Polyester orthophthalic unsaturated resin was hardened with 5 wt% of methyl-ethyl-ketone catalyst, both produced by Dow Chemical and supplied by Resinpoxy, Brazil.

Notched impact specimens were molded according to the Charpy configuration as per the ASTM standard [35]. For the molding procedure, aligned bagasse fibers were lay down at the bottom of a 150 mm × 120 mm × 10 mm steel mold in amounts of 10, 20 and 30 vol%. Still fluid polyester resin mixed with catalyst was poured onto the fibers and the mold was closed. A pressure of about 3 MPa was applied to the lid of the mold for 24 h at room temperature (RT). A second curing stage of 2 h at 100 °C followed by cutting the composite plate and machining the 2.54 mm notch with an angle of 45°, finished the specimen preparation. Control specimens of plain polyester (0 vol% fiber) were also fabricated in a similar way as the composites.

Charpy tests were performed at RT according to ASTM standards [35] in a model X-50 Pantec instrumented impact pendulum. After test the broken specimens were macroscopically analyzed and the ruptured surface observed by scanning electron microscopy (SEM) in a model Quanta FEG-250, FEI microscope operating at 20 kV.

3. Results and discussion

Fig. 1 shows the Charpy impact energy, associated with the notch toughness, of polyester matrix composites incorporated with different volume fraction of bagasse fibers. In this figure, one should notice that the Charpy impact energy, within the standard deviation, continuously increases with the amount of fibers. A mathematical adjustment to the average values of impact energy revealed a linear relationship between the impact energy, E_i, and the volume fraction if fibers, V_f, with a precision of $R^2 = 0.91$.

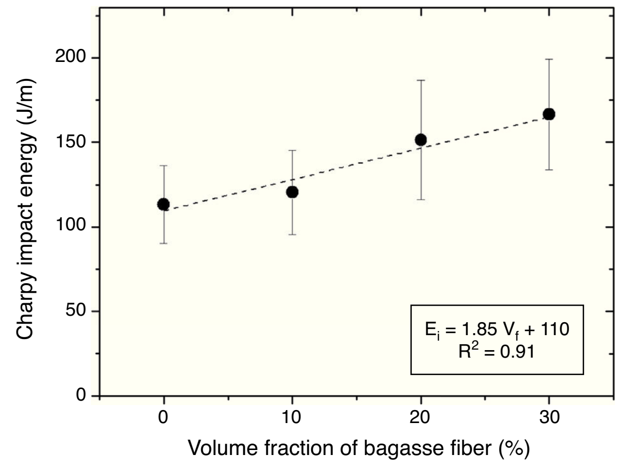

Fig. 1 – Variation of the Charpy impact energy of polyester composites as a function of volume fraction of reinforcing bagasse fibers.

$$E_i = 1.85V_f + 110 \quad (1)$$

In principle, Eq. (1) indicates that higher volume fractions of aligned bagasse fibers would correspond to increasing composite toughness. In other words, despite a relatively weaker strength, the bagasse fiber is able to improve the absorbed impact energy of a polymer composite.

The results in Fig. 1 are, to the best of our knowledge, the first showing the evolution of the impact resistance of a polymer composite with incorporation of bagasse fiber. Tita et al. [36] reported on the impact resistance of phenolic

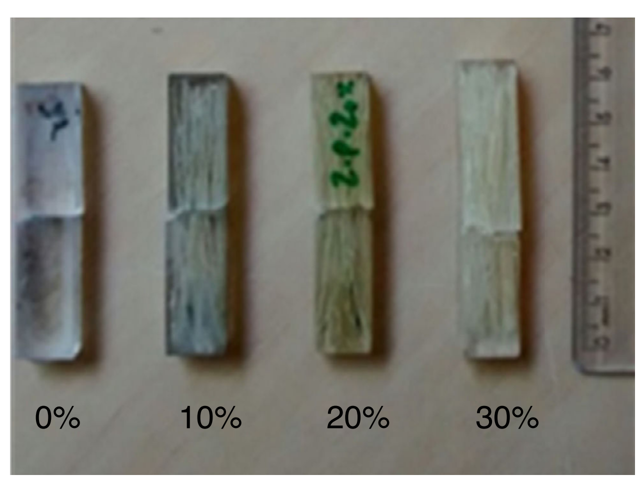

Fig. 2 – Macroscopic aspect of impact-tested polyester composites Charpy specimens with different volume fractions of aligned bagasse fibers.

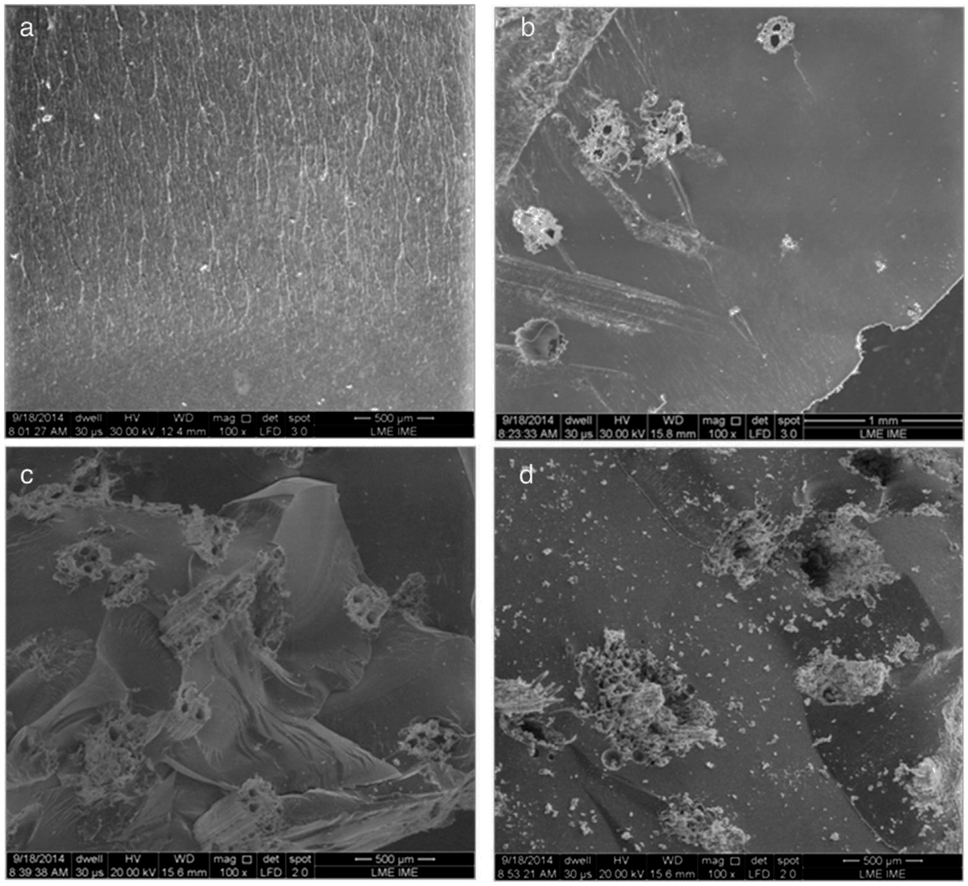

Fig. 3 – SEM fractographs of Charpy impact tested: (a) plain polyester, (b) 10 vol%, (c) 20 vol% and (d) 30 vol% sugarcane bagasse fiber reinforced polyester composites.

matrix composites incorporated with 70 vol% of bagasse fibers. In their work only pure phenolic and 70 vol% bagasse fiber-incorporated composites were presented. Thus, it was not possible to have an evolution of the impact resistance. Moreover, much lower values for the impact energy, below 25 J/m, were found by Tita et al. [36].

As for the macroscopic fracture, Fig. 2, all specimens were split in two parts after the Charpy hammer impact. The specimen rupture occurred at the notch as required by the standard [35].

Fig. 3 shows SEM micrographs of the fracture surface of polyester specimens incorporated with different volume fraction of bagasse fibers. All specimens displayed typical brittle fracture, which is a characteristic of the polyester matrix. Indeed, specimen of plain polyester, without bagasse fiber in Fig. 3(a), revealed brittle fracture with river pattern associated with crack propagation. The incorporation of 10 vol% of bagasse fiber, Fig. 3(b), is not enough to interfere with the main crack propagation in the brittle polyester matrix. By contrast, incorporation of 20 vol%, Fig. 3(c), and 30 vol%, Fig. 3(d), displayed evidence of crack arrest by the bagasse fiber, which causes irregular ruptured surfaces of the polyester matrix near the fibers. Moreover, the relatively low adherence of bagasse fiber to the polyester matrix is responsible for fiber pullout and secondary crack propagation at the fiber/matrix interface. As a consequence, a relatively higher fracture area is created and contributes to increase the impact energy [37] as shown in Fig. 1.

4. Conclusions

- The incorporation of sugarcane bagasse fiber in volume fractions of 10, 20 and 30% into a polyester matrix composites continuously increases the notch toughness of Charpy impact tested composites.
- The impact energy increase followed a linear relationship and indicates that higher toughness might be attained with increasing volume fraction.
- The macroscopic aspect of the impact ruptured specimens was brittle and typical of a polyester fracture.
- The incorporation of bagasse fiber interfered with crack propagation in the polyester matrix and promotes fiber pull-out and secondary crack propagation along the fiber/matrix interface.
- The relatively low interface resistance causes an increase in surface fracture that justifies the increasing impact energy with volume fraction of bagasse fiber.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors of the present work wish to thank the Brazilian supporting agencies CAPES, CNPq and FAPERJ.

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