

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, Ananindeua, PA, Brazil

^b Military Institute of Engineering (IME), Rio de Janeiro, RJ, Brazil

ARTICLE INFO

Article history:

Received 26 May 2017

Accepted 13 June 2017

Available online 5 July 2017

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.

© 2017 Brazilian Metallurgical, Materials and Mining Association. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

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 KevlarTM, 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>

2238-7854/© 2017 Brazilian Metallurgical, Materials and Mining Association. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

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

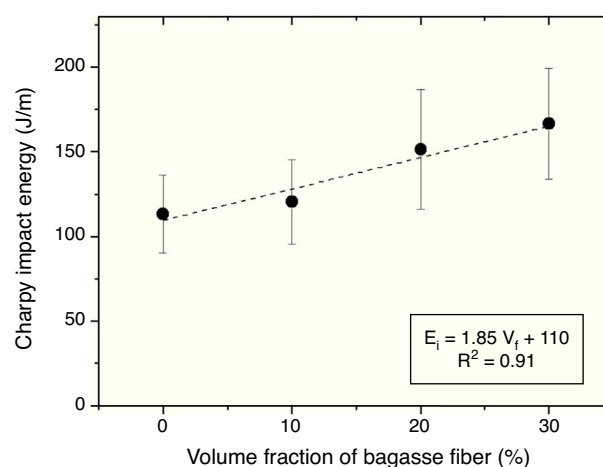


Fig. 1 – Variation of the Charpy impact energy of polyester composites as a function of volume fraction of reinforcing bagasse fibers.

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 of fibers, V_f , with a precision of $R^2 = 0.91$.

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

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

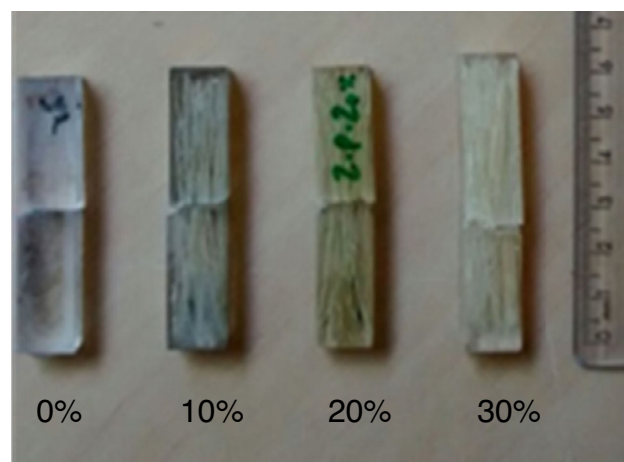


Fig. 2 – Macroscopic aspect of impact-tested polyester composites Charpy specimens with different volume fractions of aligned bagasse fibers.

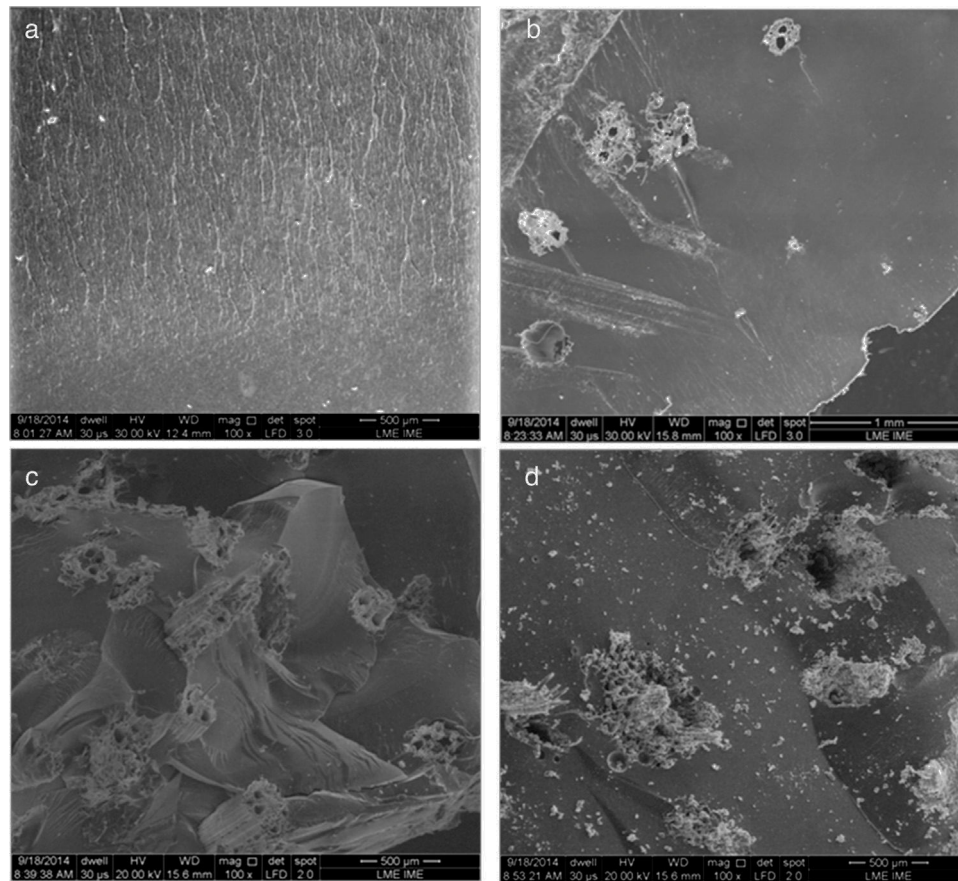


Fig. 3 – SEM fractographs of Charpy impact tested: (a) plain polyester, (b) 10 vol%, (c) 20 vol% and (d) 30 vol% sugarcane bagasse fiber reinforced polyester composites.

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 pullout 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.

REFERENCES

- [1] Monteiro SN, Lopes FPD, Barbosa AP, Bevitori AB, da Silva ILA, da Costa LL. Natural lignocellulosic fibers as engineering materials – an overview. *Metall Mater Trans A* 2011;42:2963–74.
- [2] Kalia S, Kaith BS, Kaur I, editors. *Cellulose fibers: bio and nano-polymer composites*. New York, USA: Springer; 2011.
- [3] Faruk O, Bledzki AK, Fink HP, Sain M. Biocomposites reinforced with natural fibers: 2000–2010. *Prog Polym Sci* 2012;37:1552–96.
- [4] Thakur VK, Thakur MK. Processing and characterization of natural cellulose fibers/thermoset polymer composites. *Carbohydr Polym* 2014;109:102–17.
- [5] Güven O, Monteiro SN, Moura EAB, Drelich JW. Re-emerging field of lignocellulosic fiber – polymer composites and ionizing radiation technology in their formulation. *Polym Rev* 2016;56:702–36.
- [6] Pickering KL, Efendy MGA, Le TM. A review of recent developments in natural fibre composites and their mechanical performance. *Composites A* 2016;83:98–112.
- [7] Wambua P, Ivens J, Verpoest I. Natural fibres: can they replace glass in fibre reinforced plastics. *Compos Sci Technol* 2003;63:1259–64.
- [8] Satyanarayana KG, Guilmaraes JL, Wypych F. Studies on lignocellulosic fibers of Brazil. Part I: source, production, morphology, properties and applications. *Composites A* 2007;38:1694–709.
- [9] Monteiro SN, Lopes FPD, Ferreira AS, Nascimento DCO. Natural fiber polymer matrix composites: cheaper, tougher and environmentally friendly. *JOM* 2009;61:17–22.
- [10] Holbery J, Houston D. Natural-fiber-reinforced polymer composites applications in automotive. *JOM* 2006;58:80–6.
- [11] Mercedes-Benz. www.mercedes-benz.com.br; 2016 [cited 15.11.16].
- [12] da Cruz RB, Lima EP Jr, Monteiro SN, Louro LHL. Giant bamboo fiber reinforced epoxy composite in multilayered ballistic armor. *Mater Res* 2015;18:70–5.
- [13] Monteiro SN, Louro LHL, Trindade W, Elias CN, Ferreira CL, Lima ES, et al. Natural curaua fiber-reinforced composites in multilayered ballistic armor. *Metall Mater Trans A* 2015;46:4567–77.
- [14] Rohen LA, Margem FM, Monteiro SN, Vieira CMF, Araujo BM, Lima ES. Ballistic efficiency of an individual epoxy composite reinforced with sisal fibers in multilayered armor. *Mater Res* 2015;18:55–62.
- [15] da Luz FS, Lima EP Jr, Louro LHL, Monteiro SN. Ballistic test of multilayered armor with intermediate epoxy composite reinforced with jute fabric. *Mater Res* 2015;18:170–7.
- [16] Monteiro SN, Braga FO, Lima EP Jr, Louro LHL, da Silva LC, Drelich JW. Promising curaua fiber-reinforced polyester composite. *Polym Eng Sci* 2016, <http://dx.doi.org/10.1002/pen.24471>.
- [17] Monteiro SN, Lima EP Jr, Louro LHL, da Silva LC, Drelich JW. Unlocking function of aramid fibers in multilayered ballistic armor. *Metall Mater Trans A* 2015;46:37–40.
- [18] Kiatkittipong W, Wongsuchoto P, Pavasant P. Life cycle assessment of bagasse waste management options. *Waste Manag* 2009;29:1628–33.
- [19] Monteiro SN, Rodriguez RJS, Souza MV, d'Almeida JRM. Sugarcane bagasse waste as reinforcement in low cost composites. *Adv Perform Mater* 1998;5:183–91.
- [20] Stael GC, Tavares MIB. Solid-state carbon-13 NMR study of material composites based on sugarcane bagasse and thermoplastics polymers. *J Appl Polym Sci* 2001;81:2150–4.
- [21] Mothé CG, Araujo CR, Oliveira MA, Yoshida MI. Thermal decomposition kinetics of polyurethane – composites with bagasse of sugarcane. *J Therm Anal Calorim* 2002;67:305–12.
- [22] Brugnago RJ, Guimaraes JL, Wypych F, Ramos LP. The effect of steam explosion on the production of sugarcane bagasse/polyester composites. *Composites A* 2011;42:364–70.
- [23] Riyajan S, Intharit I. Characterization of modified bagasse and investigation properties 16 of its novel composite. *J Elastom Plast* 2011;43:513–28.
- [24] Huang Z, Wang N, Zhang Y, Hu H, Luo Y. Effect of mechanical activation pretreatment on the properties of sugarcane bagasse/poly(vinyl chloride) composites. *Composites A* 2012;43:114–20.
- [25] Lu JZ, Wu Q, Negulescu II, Chen Y. The influences of fiber feature and polymer melt index on mechanical properties of sugarcane fiber/polymer composites. *J Appl Polym Sci* 2006;102:5607–19.
- [26] Vilay V, Mariatti M, Mattaib R, Todo M. Effect of fiber surface treatment and fiber loading on the properties of bagasse-fiber reinforced unsaturated polyester composites. *Compos Sci Technol* 2008;68:631–8.
- [27] Luz SM, Caldeira-Pires A, Ferrão PMC. Environmental benefits of substituting talc by sugarcane bagasse fibers as reinforcement in polypropylene composites: ecodesign and LCA as strategy for automotive components. *Resour Conserv Recycl* 2010;54:1135–44.
- [28] Cerqueira EF, Baptista CARP, Mulinari DR. Mechanical behavior of polypropylene reinforced sugarcane bagasse fiber composites. *Eng Proc* 2011;10:2046–51.
- [29] Verma D, Gope PC, Maheshwari MK, Sharma RK. Bagasse fiber composites – a review. *J Mater Environ Sci* 2012;3:1079–92.
- [30] Moubarik A, Grimi N, Boussetta N. Structural and thermal characterization of Moroccan sugarcane bagasse cellulose fibers and their applications as a reinforcing agent in low density polyethylene. *Composites B* 2013;52:233–8.
- [31] Martins ALBS, Gouvea RA, Oliveira MP, Candido VS, Monteiro SN. Characterization of epoxy matrix composites incorporated with sugarcane bagasse fibers. *Mater Sci Forum* 2014;775–776:102–6.
- [32] de Paula PG, Rodriguez RJS, Duarte LPR, Candido VS, Monteiro SN. Formulation and characterization of polypropylene composites with alkali treated bagasse fiber. *Mater Sci Forum* 2014;775–776:319–24.
- [33] Candido VS, Oliveira MP, Gouvea RA, Martins ALBS, Monteiro SN. Weibull analysis to characterize the diameter dependence of tensile strength in sugarcane bagasse fibers. *Mater Sci Forum* 2014;775–776:80–5.
- [34] Fiat Uno Ecology, <http://g1.globo.com/carros/noticia/2010/06/fiat-divulga-detalhes-doprototipo-uno-ecology.html>; 2017 [in Portuguese, cited May 2017].

- [35] American Society for Testing Materials ASTM D6110, Pennsylvania, USA Standard Test Methods for Determining the Charpy Impact Resistance of Notched Specimens of Plastics; 1997.
- [36] Tita SPS, de Paiva JMF, Frollini E. Impact strength and other properties of lignocellulosic composites: phenolic thermoset matrices reinforced with sugarcane bagasse fibers. *Polím Ciênc Tecnol* 2002;12:228-39 [in Portuguese].
- [37] Yue CY, Looi HC, Quek MY. Assessment of fibre-matrix adhesion and interfacial properties using the pull-out test. *Int J Adhes Adhes* 1995;15:73-80.