v. 3, n. 40, 2023

Journal of
Engineering
Research

CHARPY IMPACT TEST OF POLYESTER MATRIX COMPOSITES REINFORCED WITH SHORT MALLOW AND PIASSAVA NATURAL FIBERS

Douglas Santos Silva
Military Institute of Engineering - IME, Materials Science Program, Rio de Janeiro, Brazil

Raí Felipe Pereira Junio
Military Institute of Engineering - IME, Materials Science Program, Rio de Janeiro, Brazil

Lucas de Mendonça Neuba
Military Institute of Engineering - IME, Materials Science Program, Rio de Janeiro, Brazil

Noan Tonini Simonassi
State University of Northern Rio de Janeiro - UENF, Materials Science Program, Campos dos Goytacazes, Brazil

María Teresa Gómez del Río
Rey Juan Carlos University, Durability and Mechanical Integrity of Structural Materials Group (DIMME), School of Experimental Sciences and Technology, Madrid, Spain

Sergio Neves Monteiro
Military Institute of Engineering - IME, Materials Science Program, Rio de Janeiro, Brazil

Abstract: In the contemporary world, natural lignocellulosic fibers (NLFs) reinforced polymer composite materials are of great interest owing to their eco-friendly nature, lightweight, life-cycle superiority, biodegradability, low cost, and improved mechanical properties. Based on this, the present study aims to determine the impact resistance of polyester matrix composites reinforced with mallow and piassava 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 ± 3.26 kJ/m^2 for the unreinforced polyester to 78.59 ± 1.58 and 78.44 ± 1.44 kJ/m^2 for the mallow and piassava 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 composite material.
Keywords: Mallow and piassava natural fibers, polyester resin, Charpy impact test, composite materials.

INTRODUCTION

Sustainable development is an internationally widely recognized concept, even though there is a lack of consensus on the means and methods of its development [1]. The concept emphasizes the need to consider both the current and future generations when making decisions. Eco-materials have been defined as a set of materials that should help reduce the environmental impact of human activities, and many researchers are working within this framework to develop eco-friendly materials that can play a leading role in promoting sustainable development [2,3].

Composite materials, due to their advantageous mechanical characteristics and light weight, are continually evolving towards products that are the most efficient and least expensive possible. They are increasingly used in various industries, such as the automotive, aeronautics, marine, and sporting goods sectors, among others [4,5]. In particular, the use of plant fibers as reinforcement of composite materials is expanding in various sectors of activity, like the automotive industry, where textiles have been used for years to reinforce the plastics applied in cars, as they offer excellent insulation and are based on sustainable cellulose [6,7].

Synthetic-reinforced composite materials, such as aramid, carbon, and glass fibers, have numerous applications in various fields, including automobile, construction, and aeronautics [8]. Among these materials, glass fibers are the most popular due to their unique mechanical properties and low production cost. However, using synthetic fibers might be harmful to human health and the environment, causing issues such as skin allergies and lung cancer [9].

As a solution to these issues, environmentally friendly materials such as natural fibers are gaining popularity in the composites industry [10,11]. Natural fibers can come from various sources, including plants (such as linen, hemp, jute, and cotton), animals (like wool and silk), and minerals (such as asbestos) [12]. However, some types of natural fibers have been banned in many countries due to health concerns, such as cancer caused by asbestos [13,14].

Despite these concerns, natural lignocellulosic fibers (NLFs) are still widely used in the composites industry, with a variety of types available, including bast (such as flax, jute, ramie, hemp, and kenaf), seed (like cotton, coir, and kapok), leaf (such as pineapple, abaca, and sisal), grass and reed (like corn, rice, and wheat), kernel (such as hemp, jute, and kenaf), and even roots and wood [12,15].

In view of this, the present work evaluates the Charpy impact resistance of polyester matrix composites reinforced with discontinuous and randomly oriented mallow and piassava 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. [16], 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 mallow (*Urena lobata*) and piassava (*Attalea funifera Mart*) and commercially obtained in the city of Belem, state of Para, Brazil. Initially, both mallow and piassava 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.

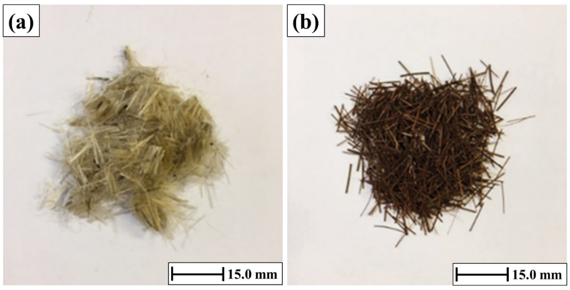

Figure 1: Fibers cut to a length of 15 mm. (a) mallow, (b) piassava.

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 and 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.

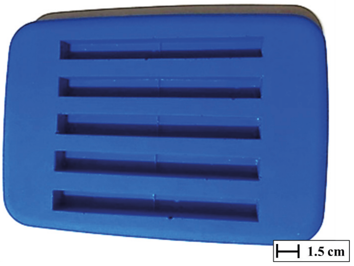

Figure 2: Impact silicone mold for molding specimens.

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 (%)
Mallow	15	3.82
Piassava	15	14.82

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 [17] with dimensions shown schematically in Figure 3.

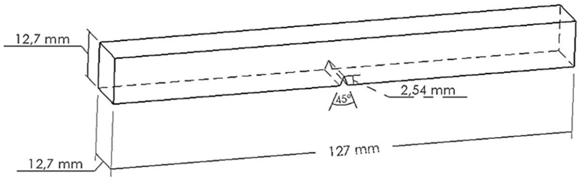

Figure 3: Dimensions of specimens for impact tests.

The tests were conducted 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.

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

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).

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

Where:

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

θ - is the scale parameter that indicates the characteristic value of what 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 (SEM), model SSX-550 operating at a voltage of 10 kV for the secondary electron beam.

RESULTS AND DISCUSSION

CHARPY IMPACT TEST RESULTS

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.

Sample	β	θ	R^2	E_{abs} (kJ/m^2)	Standard deviation	Refe-rences
Polyester	-	-	-	31.50	3.26	[18]
Mallow	62.87	79.30	0.875	78.59	1.58	PW*
Piassava	69.33	79.08	0.972	78.44	1.44	PW*

Table 2: Absorbed energy values of composites.

*PW – Present Work.

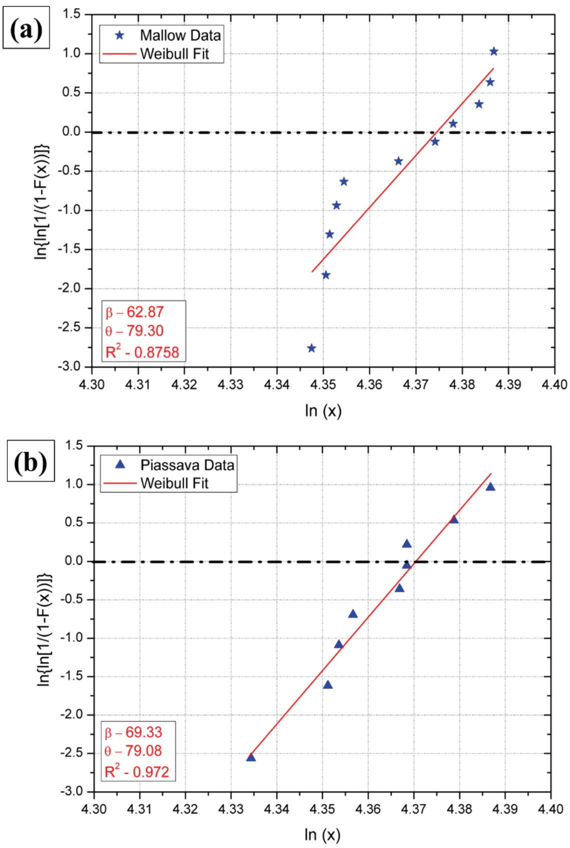

Figure 4: Weibull parameters referring to the Charpy impact test. (a) mallow, (b) piassava.

In Table 2, it can be seen that the incorporation of mallow and piassava fibers into the polyester matrix significantly improves the impact resistance of the composite. The relatively low interface strength between a hydrophilic natural fiber and a hydrophobic polymer matrix contributes to ineffective load transfer from the matrix to the fiber. This characteristic allows the system to absorb more energy due to the flexibility of the fiber that slides out of the matrix, but does not break, which amplifies the energy needed to break the specimen [19].

It was also possible to observe that the incorporation of mallow and piassava 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 mallow (78.59 kJ/m^2) and piassava (78.44 kJ/m^2) fiber composites there was an increase of more than two times in Charpy impact energy absorption. The reinforcement of a polymeric matrix with synthetic [20,21] and natural [19,22] fibers increases the impact resistance of the composite.

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

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3173402323114

by SEM of the fracture surface of one of the mallow composite specimens subjected to the Charpy impact test.

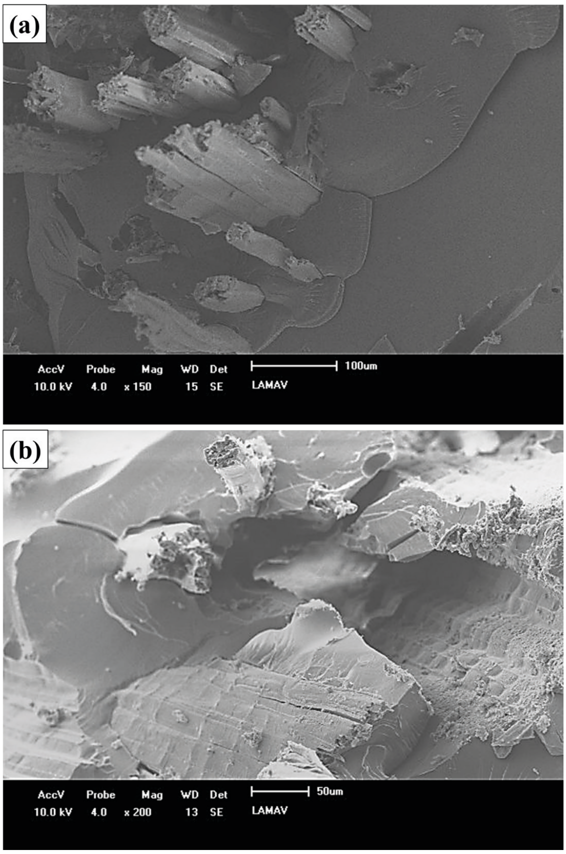

Figure 5: Micrographs of the fracture surfaces of polymer composite samples reinforced with randomly oriented mallow fibers with a length of 15 mm: (a) 150x magnification, (b) 200x magnification.

It is possible to observe in Figure 5(a) and 5(b) a "folding" of the mallow fibers. It is also possible to observe the propagation of cracks that propagate with a "river mark" pattern and, at the matrix-reinforcement interface. It is also possible to notice the cracks propagating at the interface, which consists of the fracture mechanism between the mallow fiber and the polyester matrix associated with weak resistance at the interface, resulting in an increase in impact energy.

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

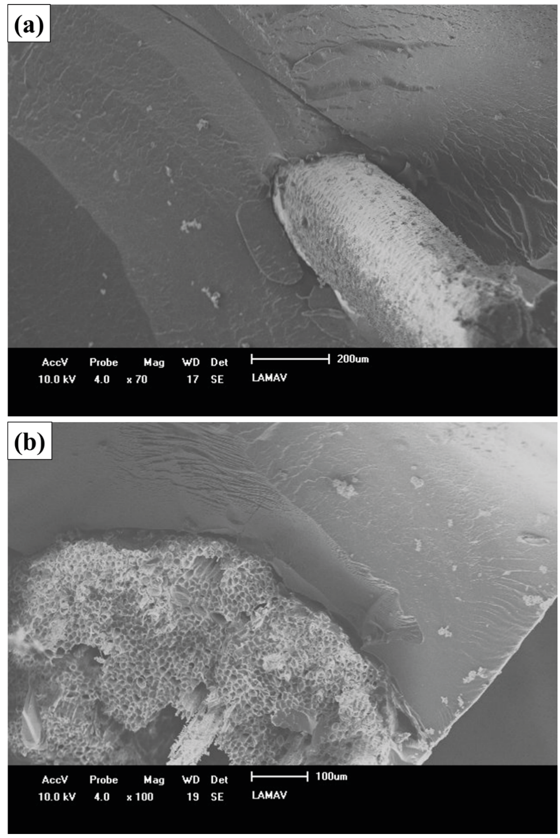

Figure 6: Micrographs of the fracture surfaces of polymer composite samples reinforced with randomly oriented piassava fibers with a length of 15 mm: (a) 70x magnification, (b) 100x magnification.

Figure 6(a) and 6(b) shows the debonding of the fiber and "river marks", which is an aspect of the polyester brittle fracture. Debondings from the weak fiber/matrix interface lead to microcracks that allow rupture to begin at relatively low stresses. In addition, piassava fibers also serve as a block to the propagation of cracks. These conditions combine to promote the composites great capacity to resist impact through an increase in absorbed energy and thus contribute to the high tenacity recorded in the composites.

CONCLUSIONS

Composites made up of discontinuous and randomly oriented natural fibers of mallow and piassava reinforcing polyester matrix, cured at room temperature, show a significant increase in notch toughness, measured in Charpy impact tests, in relation to pure unreinforced polyester resin.

Part of this increase in toughness is due to the low interfacial tension between the mallow/piassava fibers and the polyester resin. This leads to greater energy absorbed in the impact owing to the propagation of cracks at the fiber/matrix interface, generating a greater rupture area in relation to a transverse fracture that occurs in the matrix, and then breaking the fibers.

ACKNOWLEDGEMENTS

The authors thank the support to this investigation by the Brazilian agencies: CNPq, CAPES and FAPERJ. This study was financed in part by the Coordination of Superior Level Staff Improvement – Brasil (CAPES) – Number code: 88882.445152/2019-01.

REFERENCES

[1] S. Duffy, M. Verges, **It matters a hole lot: perceptual affordances of waste containers influence recycling compliance**, Environ. Behav. 41 (5) (2009) 741–749.

[2] J. Youngquist, **Literature Review on Use of Nonwood Plant Fibers for Building Materials and Panels**, E. B.E., S. R.C., C. P., and S. S, US Government Printing Office, 1994.

[3] M. Habibi, S. Selmi, L. Laperriere, H. Mahi, S. Kelouwani, **Damage analysis of low-velocity impact of non-woven flax epoxy composites**, J. Nat. Fibers 17 (11) (2020) 1545–1554.

[4] A.S.B.F. Yousif, **In state of art: mechanical and tribological behaviour of polymeric composites based on natural fibres**, Mater. Des. 48 (2013) 14–24.

[5] M. Habibi, S. Selmi, L. Laperriere, H. Mahi, S. Kelouwani, **Post-impact compression behavior of natural flax fiber composites**, J. Nat. Fibers 17 (11) (2020) 1683–1691.

[6] E. Sassoni, S. Manzi, A. Motori, M. Montecchi, M. Canti, **Novel sustainable hemp-based composites for application in the building industry: physical, thermal and mechanical characterization**, Energy Build. 77 (2014) 219–226.

[7] C. Baley, AM, **Fibres naturelles de renfort pour materiaux composites** ». Techniques de l'Ingenieur, 5 130, 2005, pp. 1–12.

[8] F. Biomaterials, in: S. Fare, G. Candiani (Eds.), Engineering. Maria-Cristina Tanzi, 2019.

[9] P.N. K Petersen, G. Bertelsen, M. Lawther, **Potential of biobased materials for food packaging**, Trends Food Sci. Technol. 10 (1999) 52–68.

[10] Tahir et al. **Review of bast fiber retting**, Bioresources 6 (4) (2011) 5260–5281 5273.

[11] A. May-Pat, A. Valadez-Gonz´alez, P.J. Herrera-Franco, **Effect of fiber surface treatments on the essential work of fracture of HDPE-continuous henequen fiberreinforced composites**, Polym. Test. 32 (6) (2013) 1114–1122.

[12] J.E.G. V, D.L. Harri¨ette, **Consultation sur les fibres naturelles**, 2004.

[13] J.P. J, J.P.C. Karine, C.M. Gomina, L. Bizet, J. Breard, **Morphologie and Mechanical Behavior of a Natural Composite: the Flax Fiber** », 2007.

[14] A. Ticoalu, T. Aravinthan, F. Cardona, **A Review of Current Development in Natural Fiber Composites for Structural and Infrastructure Applications**, SREC 10, Toowoomba, Australia, 2010, pp. 113–117.

[15] O. Faruk, A.K. Bledzki, S.H.-P. Fink, **Biocomposites reinforced with natural fibers: 2000–2010**, Prog. Polym. Sci. 37 (11) (2012) 1552–1596.

[16] Rodrigues, J.; Souza, J.A.; Fujiyama, R. **Polymeric composites reinforced with natural fibers from Amazon manufactured by infusion**. Matéria 2015, 20, 946–960.

[17] American Society for Testing and Materials. D6110-18: **Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics**; American Society for Testing and Materials: West Conshohocken, PA, USA, 2018.

[18] Silva, D. S.; Ribeiro, M. M.; Rodrigues, J. da S.; Corrêa, A. de C.; Costa, D. C. L.; Costa, H. A. de O.; Silva, F. J. A. R. da.; Santos, A. J. G. dos.; Silva, M. H. P. da.; Fujiyama, R. T. **Properties of flexural and impact of matrix composites polyester reinforced with short lignocellulosic fibers**. Research, Society and Development, [S. l.], v. 11, n. 3, p. e32511326612, 2022.

[19] S.N. Monteiro, R.C.M.P. Aquino, F.P.D. Lopes, E.A. Carvalho and J.R.M. d'Almeida, **Charpy impact notch toughness of piassava fibers reinforced polyester matrix composites** (in Portuguese), Rev. Mater., 11(3) (2006) 204-210.

[20] P.V. Joseph, K. Joseph, S. Thomas, **Short sisal fiber reinforced polypropylene composites: the role of interface modification on ultimate properties**. Compos. Interf., 92(2) (2002) 171-205.

[21] S.N. Monteiro, W.P. Inacio, F.P.D. Lopes, L.L. Costa, L.F.L. Santos Jr., **Characterization of the critical length of sisal fibers for polyester composite reinforcement**, Proceedings of Characterization of Minerals, Metals & Materials – TMS Conference, (San Francisco, USA, March, 2009) 1-8.

[22] S.Y. Fu, B. Lauke, E. Mäder, X. Hu and C.Y. Yue, **Fracture resistance of short-glassfiber-reinforced and short-carbon-fiber-reinforced poly-propylene under charpy impact load and dependence on processing**, J. Mater. Process. Technol., 89/90 (1999), 501-507.