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Journal of Materials Research and Technology
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Original Article

Tensile strength of polyester composites reinforced with PALF[☆]



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ARTICLE INFO

Article history:

Received 15 June 2017

Accepted 28 August 2017

Available online 28 September 2017

Keywords:

Pineapple leaf fiber

PALF

Polyester resin

Composites

Tensile properties

ABSTRACT

Since its beginning, our new century is the witness of sustainable actions associated with energy saving and environmental protection. A typical case is the substitution of natural materials for synthetic ones. In particular, lignocellulosic fibers (LCFs) obtained from plants are replacing glass fiber as reinforcement of polymer composites in engineering applications, including automobile parts. Among the promising LCFs, those from the pineapple leaf fibers (PALF) have a potential for composite reinforcement. Therefore, this work investigates the tensile properties of polymer matrix composites incorporated with up to 30 vol% of PALF. The results show a significant increase in tensile strength and elastic modulus with the amount of fiber. Increase in total deformation is observed above 10 vol% of PALF incorporation. Scanning electron microscopy analysis revealed a mechanism of crack arrest by the long fibers that are well embedded in the matrix.

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1. Introduction

Fibers reinforced composites are versatile engineering materials that associate strong fibers with lighter and low cost matrix in order to attain superior performance [1–3]. Since mid-last

century, synthetic fiber composites, such as fiberglass, have been extensively used in most engineering sectors. However, our new century disclosed the potential advantages of lignocellulosic fibers (LCFs), obtained from plants, as reinforcing phase in polymer composites. Wambua et al. [4] suggested that LCF composites could replace fiberglass owing not only

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

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<https://doi.org/10.1016/j.jmrt.2017.08.006>

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Fig. 1 – Assembly of PALF.

to environmental and economical benefits but also technical advantages. Indeed, polymer composites reinforced with LCFs are found to be environmentally friendly, cheaper and tougher than common synthetic fiber composites [5]. An exponentially growing number of works has, since past decade, been dedicated to LCFs and related polymer composites as established in several review articles [6–14].

The fiber extracted from the leaves of the *Ananas comosus* plant, from which the common pineapple fruit is obtained, is known by its acronym PALF. The fiber components, 83% cellulose and 12% lignin as well as properties such as density, 1.44 g/cm³, Young's modulus, 82 GPa, tensile strength, 180 MPa and strain at break 3.2% [15] indicate a potential for composite reinforcement. In fact, 30 vol% PALF composites have been recently investigated and found to present improved performance in terms of impact resistance [16,17] and tensile properties in epoxy matrix [18]. It is also worth mentioning that Arib et al. [19] reported tensile properties of 16.2 vol% PALF incorporated polypropylene (PP) matrix composites, without improvement in comparison to neat PP.

These facts motivated the present work to investigate the tensile properties of polyester matrix composites incorporated with up to 30 vol% of PALF.

2. Experimental procedure

The basic materials used was the PALF, shown in Fig. 1, supplied by Desigan Natural Fibers, Brazil, and the orthophthalic polyester resin hardened with methyl-ethyl ketone as catalyst.

Fibers were randomly selected to serve as reinforcement to the polyester matrix. These fibers, with diameters varying from 0.09 to 0.30 mm, were laid down inside silicone dog

bone-shaped dies with distinct volume fractions up to 30 vol%. The fibers were continuously aligned along the 35 mm length of the mold, parallel to the tensile axis. The still fluid polyester resin was poured onto the fibers. The composite specimens were cured at room temperature for 24 h. For each volume fraction of fibers, more than 10 specimens were fabricated. Each specimen was tested at 25 ± 2 °C in a model 5582 Instron machine at a strain rate of 3×10^{-3} s⁻¹. Samples cut from the fracture tip of representative specimens were coated with gold prior to observation by scanning electron microscopy (SEM) using a model SSX-550 Shimadzu microscope operating at 15 kV.

3. Results and discussion

Typical load versus elongation curves for each fiber volume fraction investigated are shown in Fig. 2. These curves were directly recorded from the Instron machine data acquisition system. The values of tensile strength, elastic modulus and total tensile strain were calculated and listed in Table 1.

From Fig. 2 it is possible to observe that there is an initial curvature on graphs, a consequence of sample adjustment at the machine grips of tensile test in the beginning of the elastic regime. According to Fig. 2, the abrupt end of the linear stage characterizes elastic deformation and indicates the specimens rupture without plastic deformation. This reveals that both plain polyester resin and polyester composites are relatively brittle materials.

Fig. 3 presents specimens after corresponding tensile tests. The first specimen, made of plain polyester, without any reinforcement, shows transversal fracture, corroborating the mentioned fragile behavior of matrix. The other composite specimens also exhibit a tendency to transversal fracture, but with some deviations and fiber participations. This indicates that, before the rupture, the fibers were slightly pulled out from the matrix due to low adhesion. However, owing to the brittle behavior of fibers, they also ruptured. The deviations demonstrate that the fibers act as barriers to the crack propagation, demanding higher loads before rupture.

Based on the results of Table 1, Fig. 4 presents the composites tensile properties variation with the volume fraction of PALF. In this figure, one should note that the incorporation of PALF increases the tensile strength by working as an effective reinforcement material. As aforementioned, this increase can be attributed to the fact that fibers act as obstacles to crack propagation. It is also possible to observe that the presence of fibers significantly increases the elastic modulus. It is also possible to verify that the incorporation of PALF increases the maximum elongation, and consequently the total strain of the composites. This can be associated with the behavior of fibers,

Table 1 – Tensile properties for polyester composites reinforced by PALF.

Fiber content (%)	Tensile strength (MPa)	Elastic modulus (GPa)	Total deformation (%)
0	27.72 ± 7.22	0.31 ± 0.12	3.33 ± 1.80
10	36.22 ± 7.13	1.32 ± 0.32	2.90 ± 0.69
20	75.61 ± 11.02	1.72 ± 0.24	4.19 ± 0.73
30	103.25 ± 13.31	1.99 ± 0.28	5.14 ± 0.73

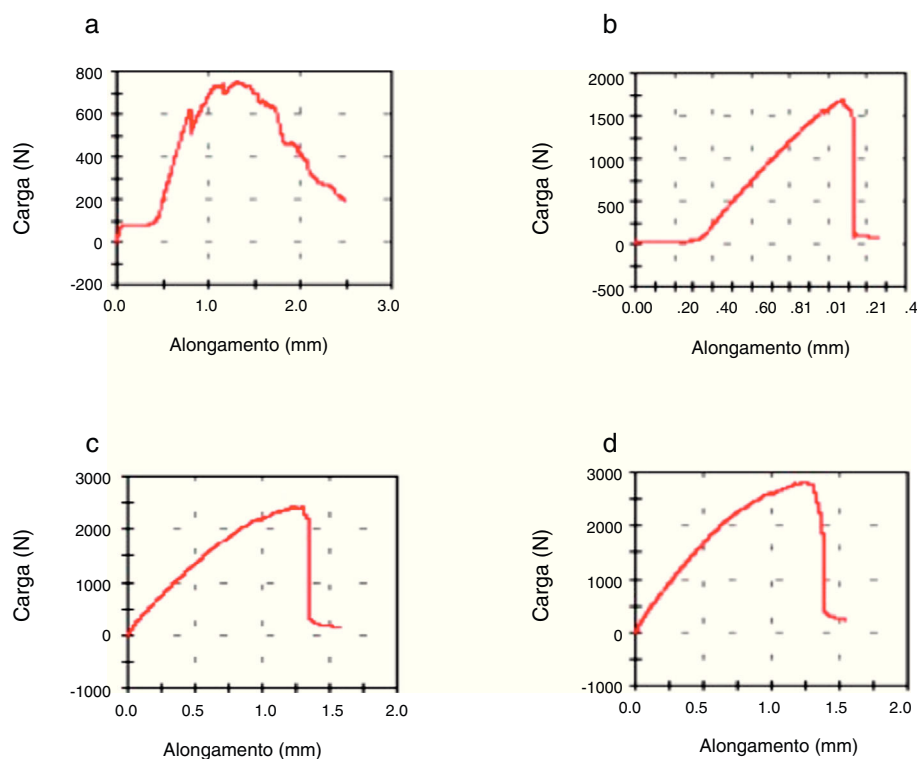


Fig. 2 – Typical tensile test curves, load vs. elongation: (a) 0%, (b) 10%, (c) 20% and (d) 30% in volume fraction of PALF.

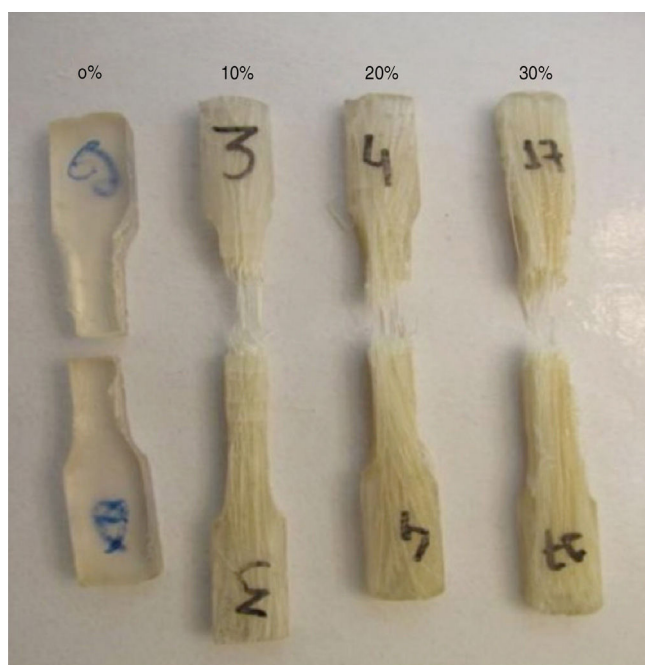


Fig. 3 – Specimen with plain polyester and composites reinforced with 10, 20 and 30 vol% of PALF.

which are able to elongate as much as the polyester matrix. Therefore, their incorporation tends to increase the elongation capacity of the composite.

Fig. 5 displays typical SEM fractographs for 30 vol% PALF reinforced composites. With lower magnification, Fig. 5(a), the

Table 2 – Tensile properties for polymer composites incorporated with PALF.

Polymer composite	Tensile strength (MPa)	Elastic modulus (GPa)	Reference
30 vol% PALF/epoxy	119.84	1.83	[18]
16.2 vol% PALF/PP	32	0.67	[19]
Plain PP	35	1.7	[9]

fracture surface displays evidence of broken fibers sticking out of the polyester matrix, however, most fibers are still well embedded in the matrix.

Additionally, a few holes in the surface of Fig. 5(a) could also indicate a low fiber/matrix interfacial resistance, as indeed happens in lignocellulosic fibers reinforcing polyester matrices [16–18]. In this respect, Fig. 5(b) with higher magnification shows a crack alongside a fiber beginning to detach from the polyester matrix. Therefore, although PALF could improve the strength of polyester composites, the weak adhesion between the fiber and the composite matrix is still a limitation to further increase in the mechanical strength and stiffness.

As a final remark, the results in Table 1 clearly indicate that additions of PALF contributes to a significant increase in both strength and stiffness of polyester composites. This also occurs with epoxy matrix composites as presented in Table 2. However, PP matrix composites are not much affected PALF incorporation [19]. In fact, in this table a reduction in strength and stiffness occurred for 16.2 vol% PALF addition into PP.

A possible reason for the contradictory behavior in Tables 1 and 2 could eventually be a different interaction between thermoset matrices (polyester/epoxy) and

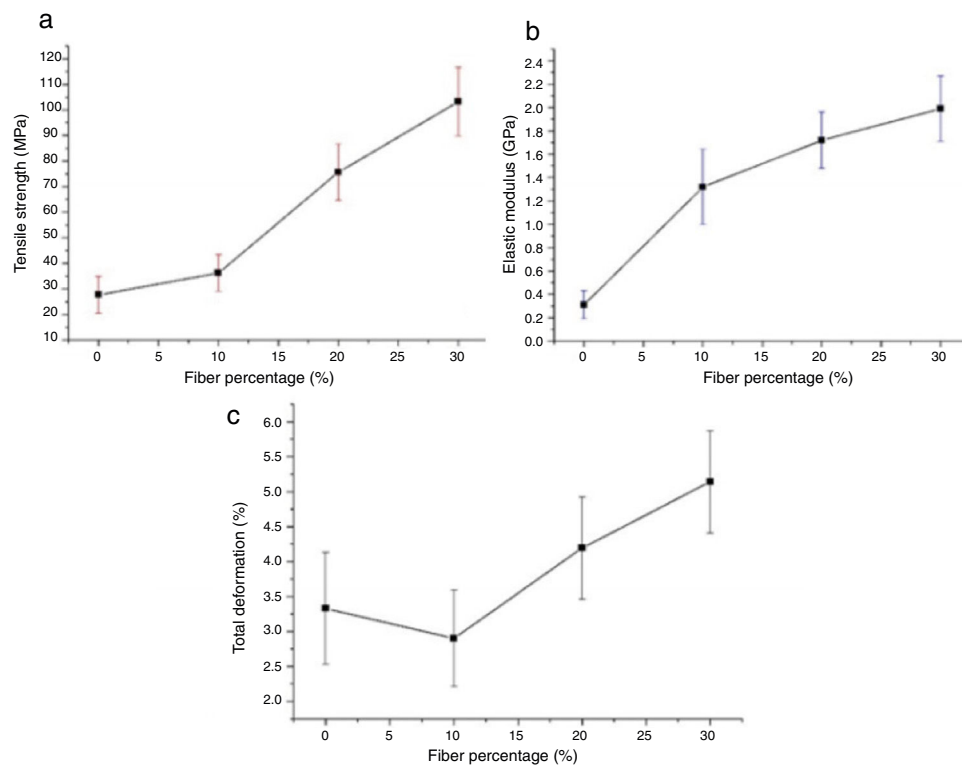


Fig. 4 – Variation of the (a) tensile strength, (b) elastic modulus and (c) total deformation, with volume fractions of PALF reinforcing polyester matrix composites.

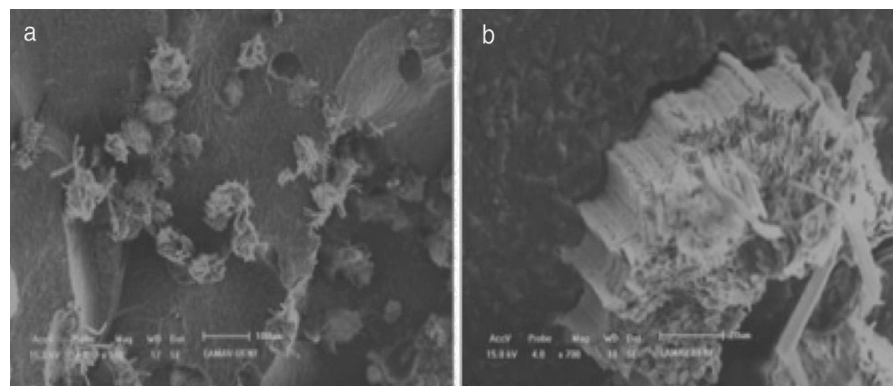


Fig. 5 – Microstructure of a composite with 30 vol% of fibers: (a) 100× and (b) 700×.

thermoplastic (polypropylene) with PALF. This deserves further investigation.

4. Conclusions

- Selected pineapple leaf fibers (PALF) significantly improve the strength of polyester matrix composites. This improvement corresponds basically to a linear increase up to 30 vol% of fiber incorporation and surpasses the flexural results with similar composites.
- The elastic modulus of the polyester composites is also increased with the volume fraction of PALF.

- SEM analysis indicates that PALF acts as an effective reinforcement for the brittle polyester matrix despite the weak fiber/matrix interface. In fact, the same fibers are well adhered to the polyester matrix but evidence of fiber pullout from the matrix indicates a relatively low interfacial shear stress. This is an important limitation for further composite improvement.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors would like to thank the support to this investigation by the Brazilian agencies: CNPq, CAPES, FAPERJ and TECNORTE/FENORTE.

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