TENSILE BEHAVIOR OF POLYESTER COMPOSITES REINFORCED WITH STRONGER BURITI PETIOLE FIBERS

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Abstract

The current interest for natural fibers as an environmentally correct composite reinforcement has motivated the investigation of new possibilities. For instance, the fibers extracted from the petiole of the buriti palm tree were recently found to have adequate mechanical properties to reinforce polymer composites. Therefore, the present work evaluates the tensile properties of polyester composites incorporated with thinner buriti petiole fibers for improved mechanical performance. Composites with up to 40% in volume of buriti petiole fibers embedded in orthophtalic polyester matrix were post-cured and then ruptured in tension. Fracture surfaces were analyzed by scanning electron microscopy. A marked increase in the tensile strength was found with the amount of buriti fibers. The fracture analysis revealed aspects of the bonding condition at the fiber/matrix interface, which could be associated with the composite performance.

Introduction

In recent years the world has been involved with environmental issues related to the continuous use of non-renewable fossil fuels mainly petroleum and coal. Global warming associated with CO_2 emission and long term pollution caused by plastic wastes are among the most serious issues [1]. Proposed solutions involve not only mitigation and reduction but also changes to alternative forms of energy, like solar, wind and biofuels, as well as the use of natural, renewable and recyclable materials. In this respect, the use of natural fibers is a successful example being investigated and industrially applied since the past decade [2-5]. In particular, the lignocellulosic fibers obtained from plants are increasingly being considered as reinforcement of composites for engineering applications, especially in automobile components [6-8]. Some of these composites are totally biodegradable, both in terms of the reinforcing natural fiber and the polymeric matrix [3,9,10]. Most natural fiber composites, however, are fabricated with traditional non-degradable polymer matrix but still presenting a recycling advantage over the common glass fiber reinforced polymer composites (fiberglass). In fact, any natural fiber polymer composite, after being discarded as a waste, can be burnt in a thermoelectric plant to generate power. This is not possible with fiberglass. [11].

The advantages and drawbacks of lignocellulosic fibers for polymer composite reinforcement have been extensively discussed [2-4,12,13] and, it is beyond the scope of this work to review them. One point, however, is worth mentioning. Hundreds of lignocellulosic fibers can be found around the world, mainly in tropical and temperate regions. The most commonly known fibers such as cotton, flax, sisal, jute, hemp, and coir are cultivated. Others such as sugar cane bagasse, piassava, sponge gourde and buriti are obtained as waste or simply extracted from naturally occurring plants [5]. Among these fibers, those extracted from the buriti palm tree (*Flexuosa mauritia*) are the less known and only recently were investigated as possible composite reinforcement [14-19]. In the buriti palm tree two distinct fibers could be extracted, one from the leaf and the other from the petiole. The petiole fibers were found to be much stronger, with tensile strength reaching 350 MPa [19]. Actually an inverse hyperbolic correlation exists between the tensile strength and the equivalent diameter. This correlation was also obtained for other lignocellulosic fibers [20] and appears to be associated with a more uniform rupture of the thinner fibers with less structure defects.

By selecting stronger buriti petiole fibers with smaller diameter, in principle, it would be possible to fabricate composites with improved properties. Therefore, the objective of the present work was to evaluate the tensile properties of polyester composites reinforced with thinner buriti petiole fibers in an attempt to obtain superior mechanical properties.

Experimental Procedure

Buriti fibers, which is also known as miriti fibers, cut from the petiole part of the palm tree, Fig. 1, were supplied by Dr. Nubia S. S. Santos from her private property in the state of Pará, north of Brazil. For composite matrix, a commercial unsaturated orthophtalic polyester resin added with 0.5% of methyl-ethyl-ketone hardener was used.

Figure 1. Buriti petioles and their fibers used in this investigation.

A statistical evaluation of the equivalent diameter, measured in a model 6 C Nikon profile projector, was carried out in one hundred randomly selected as-cut buriti petiole fibers. For every fiber, the equivalent diameter was considered as the mean value of ten measurements at five points, with 90 rotation at each point, along the fiber length. In this way, the equivalent diameter corresponds to the average between the smaller and the larger cross section dimensions. Figure 2 shows the histogram of the equivalent diameter distribution for the as-cut lot of the buriti petiole fiber.

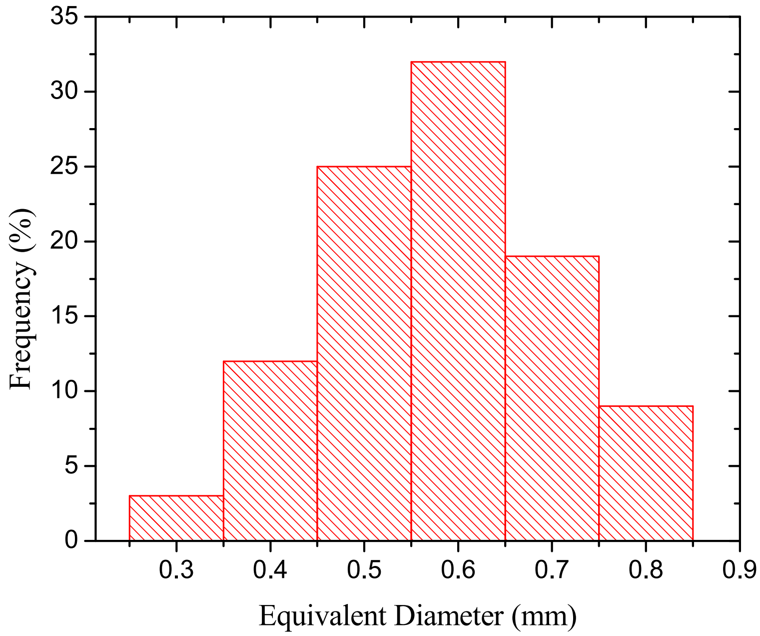

Figure 2. Statistical distribution of the equivalent diameter for the buriti petiole fibers.

The distribution in Fig. 2 reveals that the diameter varies from 0.25 to 0.85 mm with an average of 0.58 mm. This diameter dispersion is characteristic of all lignocellulosic fibers [11-13] and justifies the six equally spaced arbitrary intervals of 0.1mm proposed for the histogram.

For composite preparation, only the thinner fibers from the as-cut lot, with diameter in the interval from 0.35 to 0.45 mm, Fig. 2, were considered. As shown previously [19], this diameter interval corresponded to the strongest fibers with ultimate tensile stress ranging from 150 to 350 MPa. The fibers were initially dried at 60°C for 24 hours. Tensile specimens were fabricated by laying down the fibers, in a continuous arrangement inside a dog-bone shaped silicone mold with 5.8x4.5 mm of reduced gage dimensions. Separated amounts of fibers up to 40% in volume were aligned along the 35 mm total specimen length, corresponding to its tensile axis. Still fluid polyester resin was poured onto the fibers inside the mold and allowed to cure at room temperature for 24 hours. Following suit, the composite specimen was post-cured at 60°C for 4 hours. Each specimen was then tensile tested at 25±2°C in a model 5582 Instron machine at a strain rate of $3x10^{-3}$ s^{-1}.

After testing, some representative composite specimens had their fracture observed by scanning electron microscopy (SEM). Fracture samples were first attached by conducting carbon tape to a metallic support and then gold sputtered before being analyzed in a model SSX-550 Shimadzu SEM microscope operating with secondary electrons accelerated at a maximum voltage of 15kV.

Results and Discussion

Figure 3 shows representative load *vs.* elongation curves for the polyester composites reinforced with different volume fraction of thinner buriti petiole fibers. These curves were recorded directly from the data acquisition program of the Instron machine. The first linear elastic part of the curves was followed by some curvature and then a sudden drop, indicating limited plastic strain before an almost brittle rupture.

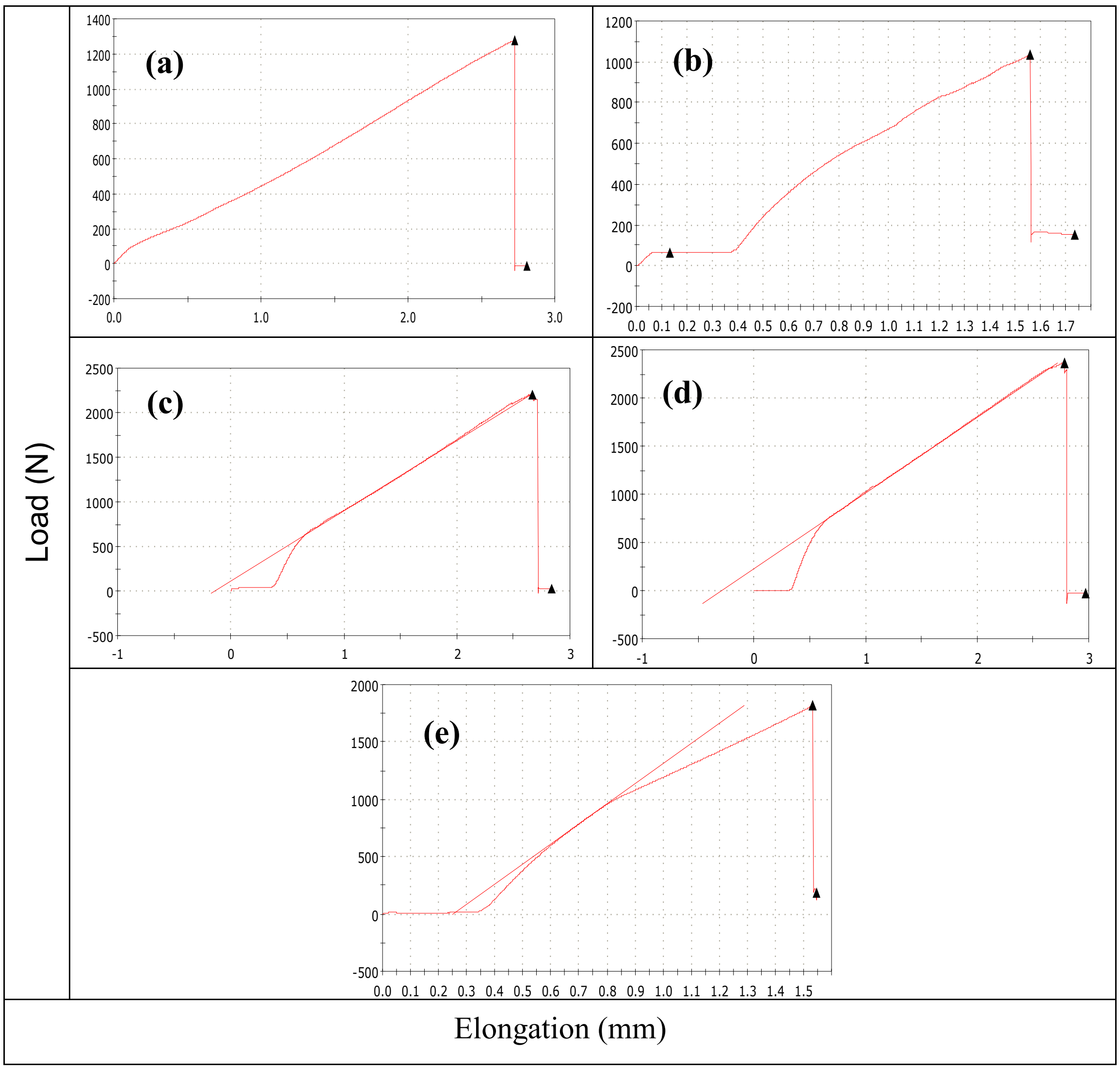

Figure 3. Tensile load *vs.* elongation curves for polyester composites reinforced with: (a) 0%, (b) 10%, (c) 20%, (d) 30%, and (e) 40% of volume fraction of thinner buriti petiole fibers.

Figure 4 shows the macro aspect of the ruptured specimens representative of each volume fraction of thinner buriti petiole fiber reinforced polyester composites. In this figure it should be noted that the fracture tips are progressively non-uniform with increasing amount of fibers in the composite. In particular, loosen fibers can be observed in association with longitudinal rupture due to crack propagation at the fiber/matrix interface. This fracture mechanism will be further discussed.

0% 10% 20% 30% 40%

Figure 4. Representative tensile-ruptured specimens corresponding to the different volume fraction of thinner buriti petiole fiber in the polyester composites.

Based on the results from curves such as the ones in Fig 3, the tensile strength (ultimate stress at the maximum load), the elastic modulus and the total tensile strain were calculated. The average values of these mechanical properties are listed in Table 1 for the different volume fraction of thinner buriti petiole fibers reinforced polyester composites.

Tabela 1. Tensile properties of thinner buriti petiole fiber rein forced polyester composites.

Volume Fraction of Thinner Buriti Petiole Fiber (%)	*Tensile Strength (MPa)*	*Elastic Modulus (GPa)*	*Total Tensile Strain (%)*
0	50.90 ± 2.99	0.59 ± 0.09	11.0 ± 1.1
10	53.71 ± 8.79	0.95 ± 0.16	4.8 ± 2.3
20	72.24 ± 9.48	0.84 ± 0.17	9.4 ± 3.7
30	96.97 ± 11.27	0.96 ± 0.17	6.7 ± 3.7
40	100.15 ± 10.72	1.66 ± 0.27	5.4 ± 0.5

The average values of the tensile strength and elastic modulus listed in Table 1 for the polyester composites are plotted in Fig 5 as a function of the volume fraction of thinner buriti petiole fibers. In this figure it is important to notice that the introduction of thinner buriti petiole fibers increases both the strength and stiffness of the polyester matrix. In fact, values of strength above 100 MPa were found for 40% of fiber volume fraction, while the elastic modulus that characterizes the stiffness of the composite reached a value above 1.6 GPa. This indicates that the thinner buriti petiole fiber acts as an effective reinforcing phase for polyester composites.

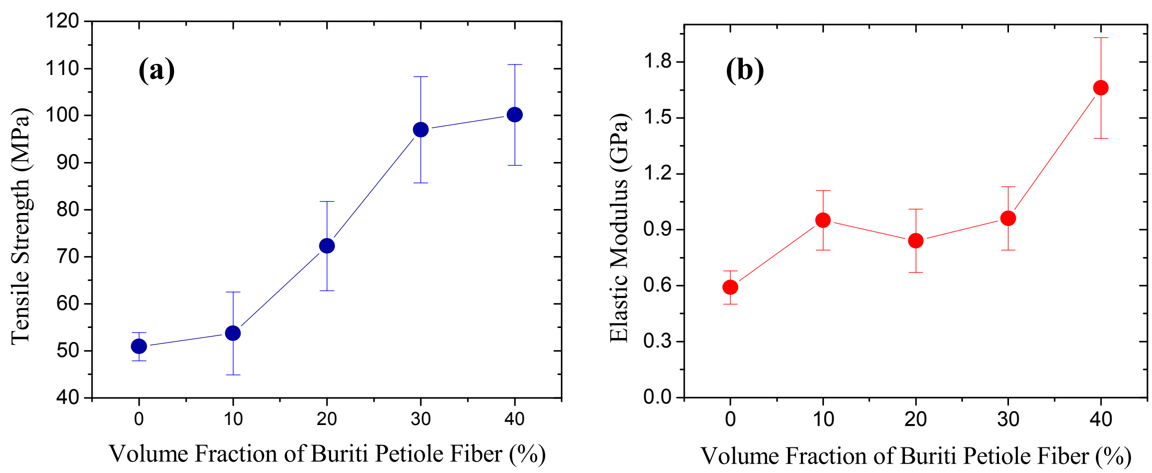

Figure 5. Variation of the tensile strength (a) and the elastic modulus (b) with buriti petiole fiber reinforced polyester composites.

The fracture analysis of the tensile-ruptured composites specimens was performed by both macro (visual) and microscopic (SEM) observations. The macroscopic aspect of ruptured tips of a specimen with 40% of volume fraction of thinner buriti petiole fibers is shown in Fig. 6. An important aspect to note is the non-uniform fracture. In general, fracture occurred by transversal crack propagation through the brittle polyester matrix.

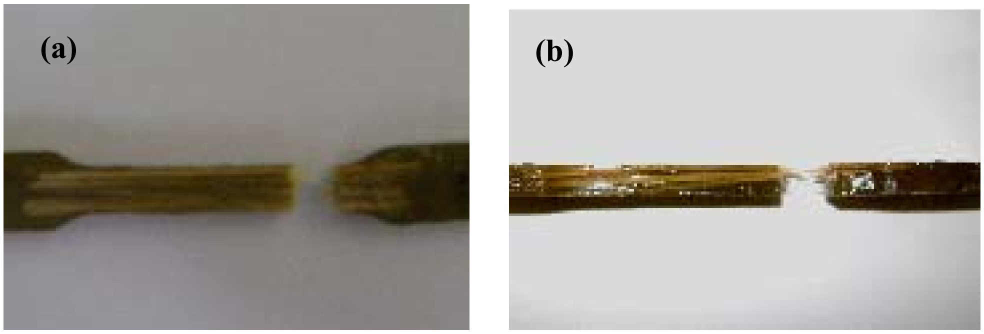

Figure 6. Macroscopic aspect of the ruptured tip of a polyester composite specimen reinforced with 40% of thinner buriti petiole fibers. (a) front view; (b) side view.

Although the general fracture is transversal to the specimen axis, some details at the tip display evidences of longitudinal rupture associated with an apparent decohesion of fibers from the matrix. This mechanism is further discussed together with the microscopic observations.

Figure 7 shows typical SEM fractographs of a tensile-ruptured specimen of pure polyester (0% fiber). With low magnification, Fig. 7(a), one could note the uniform and flat aspect of the fracture surface characteristic of a brittle material. With higher magnification, Fig. 7(b), the marks in the surface are evidences of a single crack propagation though defects such as voids and flaws in the polyester structure.

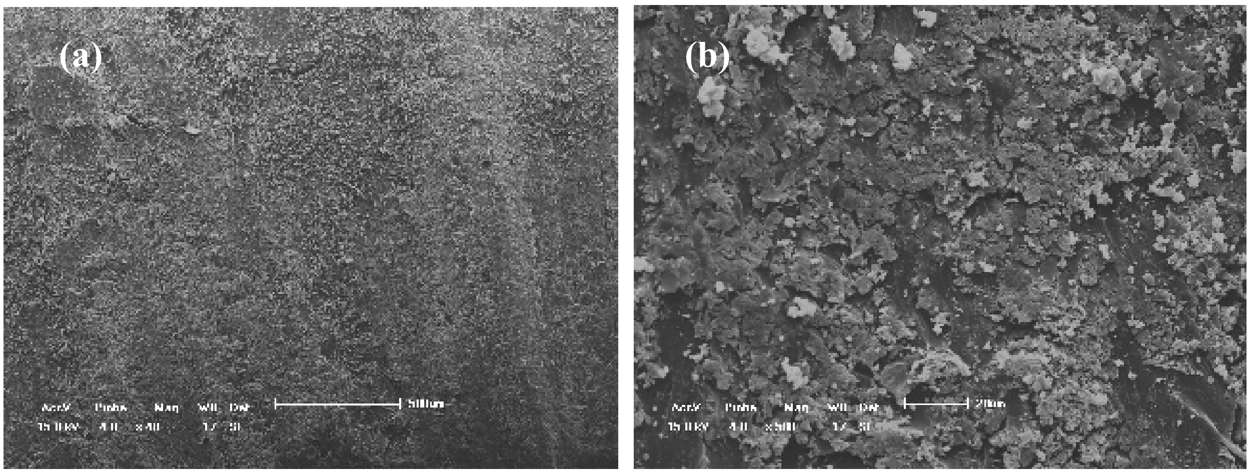

Figure 7. SEM fractographs of a pure polyester sample with different magnifications: (a) 40x, and (b) 500x.

Figure 8 shows with different magnifications typical SEM fractographs of a polyester composite reinforced with 30% volume of thinner buriti petiole fibers. With low magnification, Fig 8 (a), fibers are shown sticking out of the matrix. Actually, some fibers are completely separated from the matrix, indicating decohesion along the fiber surface. This is an evidence of longitudinal cracks propagating in between the fiber and the polyester matrix. With higher magnification, Fig 8 (b), it is observed a fiber that was fractured near the transversal crack that propagated through the brittle matrix. The separation at the fiber/matrix interface also indicates that longitudinal cracks were nucleated at this interface.

The reason for this behavior is apparently a consequence of the weak fiber/matrix interface resistance. It is well known [2,5,11] that one of the drawbacks of a lignocellulosic fiber is the fact that, due to its hydrophilic nature, water is absorbed onto the surface. Thus, a weak bonding is expected to form between the surface of the buriti fiber and the hydrophobic polyester matrix. This weak bonding might be responsible for the fiber decohesion from the matrix causing the longitudinal rupture shown in Fig 6 and 8(b).

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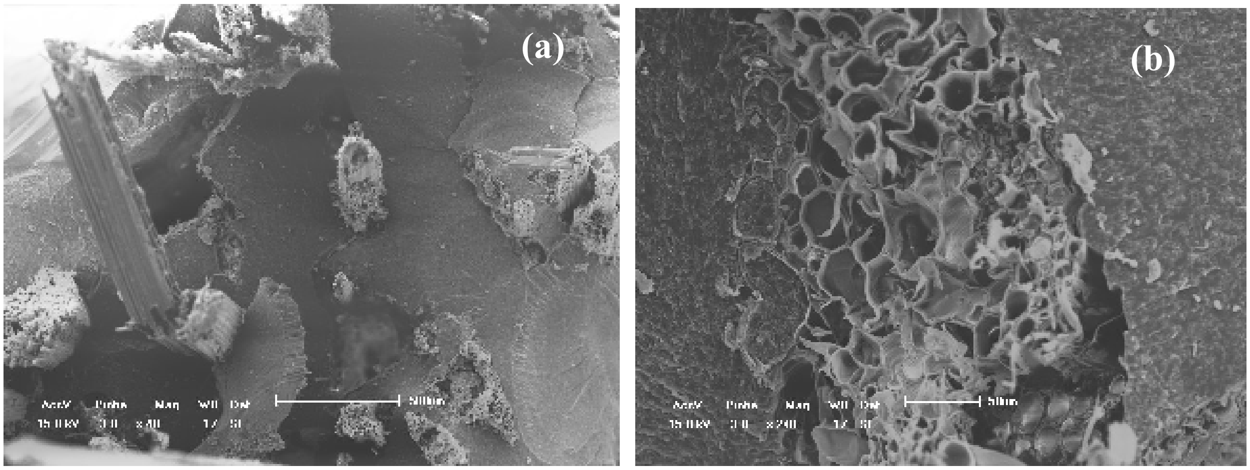

Figure 8. SEM fractographs of a 30% thinner buriti petiole fiber reinforce composite with different magnification: (a) 40x, and (b) 240x.

Finally, it is worth mentioned that thinner buriti petiole fibers are effective reinforcement for polyester matrix composites. However, the weak fiber/matrix bonding is a limitation to further improvement of the composite strength and stiffness.

Conclusions

- Thinner buriti fibers that were manually cut from the petiole part of the palm tree are strong enough to reinforce the polyester matrix of tensile- tested composites. In fact, polyester composites reinforced with continuous and aligned thinner buriti petiole fibers significantly improve their tensile strength and elastic modulus.
- This effective reinforcement can be attributed to the stronger thinner buriti petiole fiber with smaller diameter acting as a barrier to crack propagation though the brittle matrix.
- The weak fiber/matrix interface allows longitudinal cracks to proceed along the interface as a continuation of the transversal cracks initially propagating through the matrix. This causes separation of the fiber from the matrix and represents the main mechanism of composite rupture

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