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# Tensile Behavior of lignocellulosic reinforced polyester composites: Part III coir fiber

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## ABSTRACT

The fiber extracted from the husk of a coconut fruit, known as coir fiber, has been extensively investigated as a second phase incorporation into polymer composites. The moderate strength of the coir fiber usually does not represent reinforcement to relatively strong thermoset matrices such as polyester, epoxy and phenolic. However, a selection of thinner coir fibers and a post cure treatment of the composite could improve its mechanical performance. Therefore, this work investigated the tensile properties of post-cured polyester matrix composites incorporated with the thinnest coir fiber. Tensile specimens with up to 40% in volume of long and aligned coir fibers were tested and their fracture analyzed by scanning electron microscopy. A relatively improvement was found in the tensile properties for the amount of 40% of coir fiber. These results were compared with similar composites that were bend-tested. The fracture analysis showed a comparatively better fiber/matrix adhesion.

**Keywords**: Coir fibers, polyester composites, tensile properties, fracture analysis.

## 1 INTRODUCTION

The fiber extracted from the husk of a coconut fruit, commonly known as a coir fiber, has been traditionally used in tropical regions of Asia, Africa and South America in a variety of simple item such as rugs, couch and mattress stuffing as well as gardening pots. According to Satyanarayana *et al*. [1], since these items with relatively low aggregated value can utilize only small quantity of coir fibers, there are many researches and developing efforts to find new uses with high aggregated value such as a composite reinforcement. However investigations carried out so far [2-5] have shown that coir fiber are not an effective reinforcement for polymer matrix composites. The water adsorbed into the lignocellulosic surface of the hydrophilic coir fiber apparently prevents an efficient adhesion to the hydrophobic polymer matrix, which also happens in other natural fiber composites [6-7]. As a consequence the incorporation of coir fiber tends to decrease the mechanical strength of polyester composites for any volume fraction of fiber [4]. In principle, there are ways to reverse this negative condition. For instance, a strong alkali treatment of coir fiber [8] improves the adhesion to the polyester matrix and thus increases the composites strength by approximately 50% for a volume fraction of 30% of coir fiber.

Another possibility of effective reinforcement to a polymer matrix could be obtained through the selection of thinner coir fiber. In fact, in a recent work [9] improved polymer matrix composites were fabricated with the thinnest fibers of sisal, ramie and curaua. It was found that the level of flexural strengths of these composites was more than 30% of the corresponding values obtained for identical composites with non-selected, average diameters, fibers. The mechanism suggested for higher strength composites reinforced with thinner fibers was a relatively more uniform rupture of these fibers, which statistically has a greater probability of having less structure defects [9].

Based on the above consideration, the present work evaluated the tensile properties of post-cured polyester composites incorporated with the thinnest coir fiber available in a supplied lot.

## 2 EXPERIMENTAL PROCEDURE

A lot of 5 kg of coir fiber, extracted from the husk (mesocarp) of dried green coconut was supplied by the Brazilian firm “Coco Verde Reciclado”. The characteristic of the fiber obtained from this lot has been

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described elsewhere [8]. A statistical analysis of measurements by profile projector of 115 separated coir fibers, was performed for the as-received lot. The corresponding histograms of this analysis are presented in Fig. 1. This statistical distribution of fiber diameter has shown a range of values extending up to 0.6 mm, with an average of 0.28 mm. In the present work, it was decided to consider the thinnest coir fiber selection, which corresponds to the interval up to 0.1 mm in diameter shown in Fig. 2.

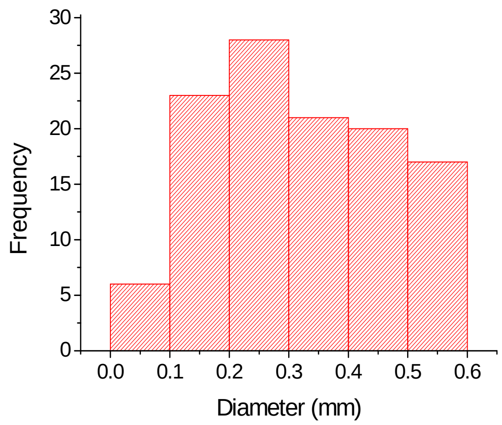


**Figure 1:** Statistical distribution of diameter of the lot of coir fibers by profile projector.

Composite with up to 40% in volume of the thinnest selected coir fiber were fabricated by setting them in a rectangular dog-bone shaped silicone mold with 5.8 x 4.5mm of reduced gage and then pouring still fluid orthophtalic polyester resin just mixed with methyl-ethyl-ketone, as hardener. The coir fibers were aligned along the 35 mm total specimens length, which corresponded to the tensile axis. The composites specimens were allowed an initial cure to occur at 25°C for 24 hour. A post cure was then conducted at 60°C for 4 hour. Seven composites specimens were produced for a given fiber volume fraction. Each specimen was tested at a 25 ± 2°C in a model 5582 Instron machine at a strain rate of 3 x$10^{-3}$ $s^{-1}$.

The fracture tip of representative specimens was cut into 1 x 1 mm samples. After attaching to the metallic support with carbon tape, these samples were gold sputtered to be analyzed by scanning electron microscopy (SEM) in a model SSX-550 Shimadzu microscope operating with secondary electrons accelerated at 15 kV.

## 3 RESULTS AND DISCUSSIONS

Representative load *vs*. elongation curves, directly recorded from the Instron machine, are shown in Figure 2. In this figure one should note that all curves present an initial stage of adjustment of the specimen to the grip, up to 400 N, until the linear elastic stage is reached. At the end of the elastic region, a sudden drop indicates that rupture occurred abruptly without much plastic extension. This characterizes the coir fiber reinforced polyester composites as predominantly brittle materials.

The macro aspects of ruptured tensile specimens representatives of each different volume fraction of coir fiber reinforcing polyester composites are presented in Figure 3. In this figure it can be observed that up to 10% coir fiber, the fracture tip is uniform with a characteristic rupture transversal to the tensile axis. Above 10%, fracture tips show individual coir fibers that have been separated from the polyester matrix. This apparently indicates a debonding process associated with the weak fiber/matrix interface.

From the results of load *vs*. elongation like the ones shown in Figure 2, the tensile properties were calculated. Thus, Table 1 depicts the values of the tensile strength (ultimate stress), elastic modulus and total tensile strain for the coir fiber reinforced polyester composites. In this table one can see that the incorporation of coir fiber, as previously reported [4], does not improve the tensile strength, except for a slight increase in the 40% coir fiber composites.

However, the elastic modulus, which represents the composite stiffness, is significantly increased for the 40% coir fiber composites. The total tensile strain has a minimum for the 30% coir fiber, which is compatible with the minimum in the tensile strength.

The results of tensile strength and elastic modulus in Table 1 are plotted in Figure 4 as a function of the volume fraction of coir fiber. In this figure it is important to notice that the incorporation of coir fiber decreases both the strength and the stiffness up to 30%. For the 40% of coir fiber composites, there is a tendency of increasing both, the strength, Figure 4(a), and the stiffness, Figure 4(b), to values above those obtained for the polyester matrix.

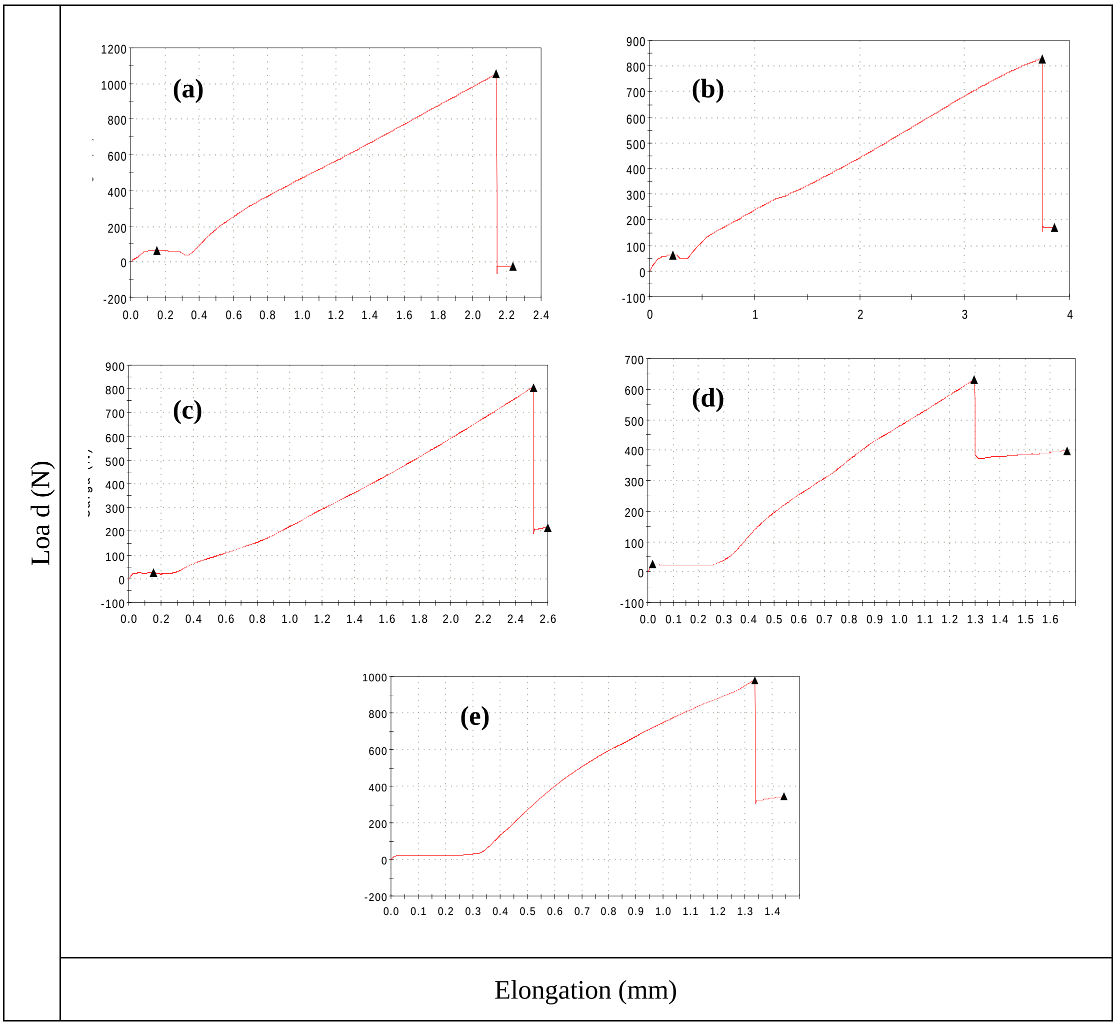


**Figure 2:** Load vs. Elongation tensile curves for polyester composites reinforced with: (a) 0%, (b) 10%, (c) 20%, (d) 30%, (e) 40% of volume fraction of coir fibers.


**Figure 3:** Representative tensile ruptured specimens for each volume fraction of coir fiber in polyester composites.

**Table 1:** Tensile properties of coir fiber reinforced polyester composites.

| Volume Fraction of Coir Fiber (%) | Tensile Strength (MPa) | Elastic Modulus (GPa) | Total Tensile Strain (%) |
|---|---|---|---|
| 0 | 27.91 ± 1.12 | 0.57 ± 0.10 | 5.7 |
| 10 | 30.91 ± 4.45 | 0.55 ± 0.16 | 5.8 |
| 20 | 25.92 ± 4.65 | 0.52 ± 0.09 | 4.7 |
| 30 | 21.50 ± 2.72 | 0.53 ± 0.11 | 3.3 |
| 40 | 29.39 ± 0.77 | 1.06 ± 0.40 | 5.3 |

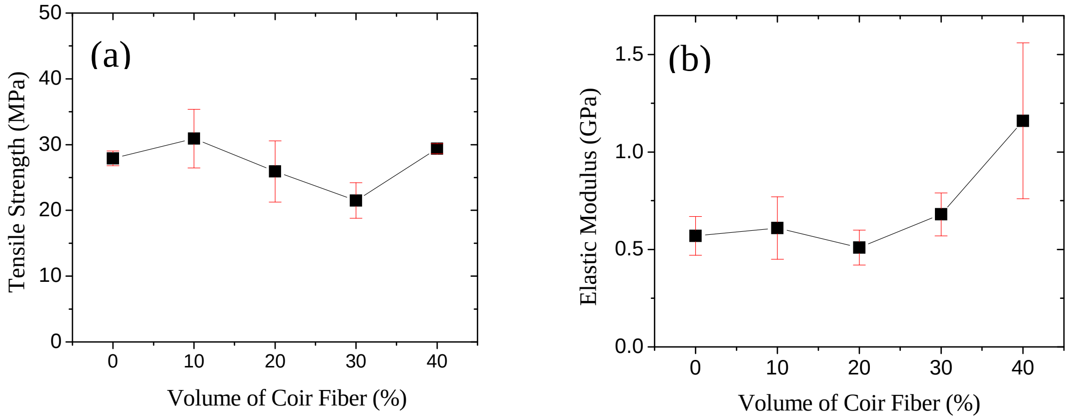


**Figure 4:** Variation of tensile strength (a) and the elastic modulus (b) with the volume fraction of coir fiber reinforcing polyester composites.

Figure 5 shows the macro aspect of the fracture tip of 40% coir fiber composite specimen. In this figure the separation of the coir fiber from the matrix at the fracture tips can clearly be seen. In fact, the 40% of coir fiber composite in Fig 5 displays a great participation of loose fibers that were the last resisting force after the polyester matrix collapse. As a consequence, composites with 40% of coir fiber, Fig. 4 (b), present the highest strength and stiffness.

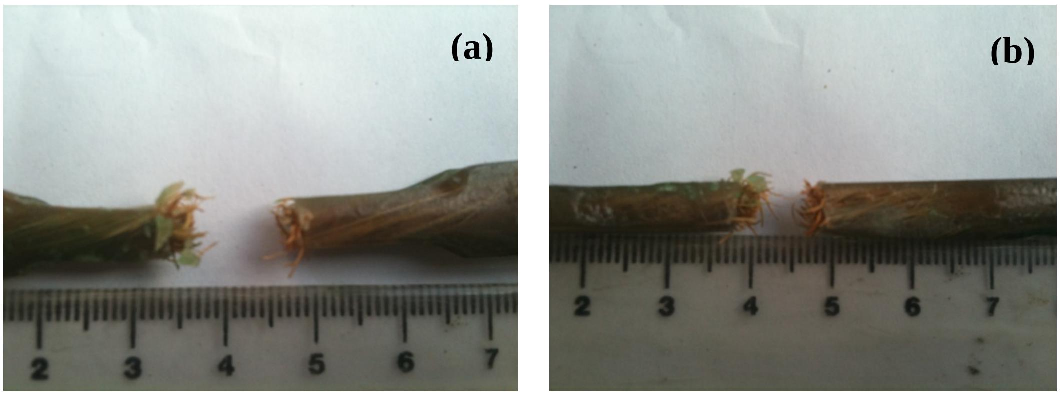


**Figure 5:** Fracture tip of a 40% coir fiber polyester composites specimen (a) front view and (b) side view.

The microscopic aspects of the fracture surface of tensile tested coir fiber composites revealed possible mechanisms associated with the mechanical properties. Typical SEM fractographs for the pure polyester (0% coir fiber) are shown in Figure 6. In this figure it can be observed, with lower magnification, Figure 6(a), the flat aspect of the fracture surface with marks of crack propagation, characteristic of a brittle material. With higher magnification, Figure 6 (b), the details of the surface marks are apparently associated with a single crack propagation through defects such as voids and flaws in the polyester matrix.

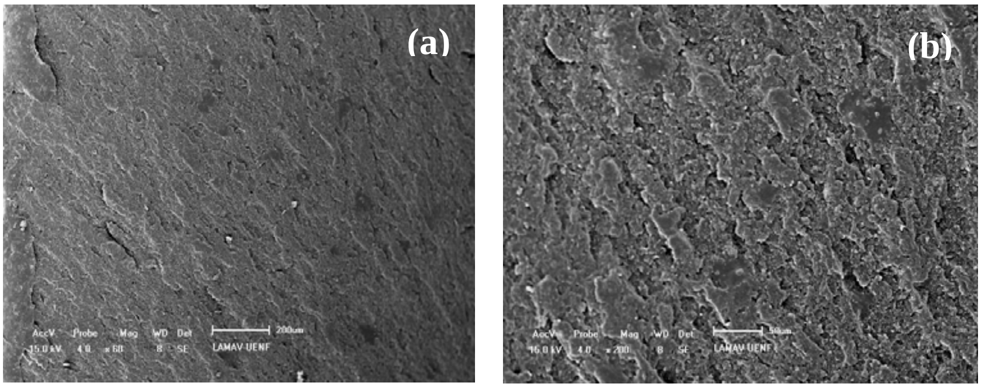


**Figure 6:** SEM fractographs of pure polyester specimen with different magnifications: (a) 60x and (b) 200x.

The typical SEM fractographs with different magnifications of polyester composites reinforced with 40% in volume of coir fiber are shown in Figure 7. In this figure it can be seen with lower magnification, Figure 7 (a), that coir fibers have been detached from the polyester matrix and show evidence of individual tensile rupture. This indicates decohesion of the fibers due to a low interface resistance with the matrix [3], which causes longitudinal cracks to propagate between the coir fiber and the polyester matrix. Additionally, Figure 7(a) also shows that transversal cracks propagating through the brittle polyester matrix are hindered by the coir fibers sticking out of the matrix. With higher magnification, Figure 7(b), it is observed evidence of the decohesion of fiber from the matrix as well as the obstacle posed by the fibers to the propagation of cracks through the brittle polyester matrix.

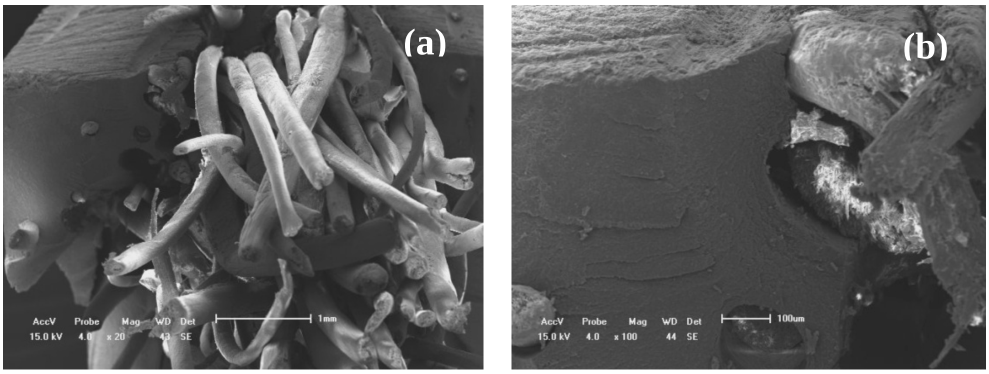


**Figure 7:** SEM fractographs of a 40% in volume of coir fiber reinforced composite with different magnifications: (a) 20x and (b) 100x.

Finally, it should be mentioned that the amount of coir fibers in the 40% composites is, by itself, enough to resist the tensile loading and, therefore, improve both strength and stiffness of the composite, if compared to the pure polyester matrix. This is a better performance than that previously obtained by means of bend tests [4].

## 4 CONCLUSIONS

Continuous coir fibers incorporated into polyester matrix composites do not improve the tensile strength and the stiffness, except for a slight increase as well as a significant increase in the elastic modulus for the 40% of volume fraction.

The difficult in reinforcement during tensile tests of the composites can be attributed to the easy decohesion of the coir fiber from the polyester matrix. This is a consequence of the weak interface between the coir fiber and the polyester matrix, which allows cracks to be nucleated and propagate along the fibers/matrix interface.

This mechanism promotes premature failure and reduces the composite strength and stiffness up to 30% of coir fiber. For the 40% composites, the amount of coir fibers acts as an effective barrier to crack propagation and improves both the tensile performance of the composites.

## 5 ACKNOWLEDGEMENTS

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