SUSTAINABLE COMPOSITES REINFORCED WITH SISAL FIBRE

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Abstract. *This work investigated the mechanical properties of polymeric composites reinforced with sisal fibre. Tensile and flexural tests were carried out in the phases respectively: fibre of sisal and epoxy resin. The experimental results were used in the micromechanics analysis in order to estimate the modulus of elasticity and the flexural strength of the composites. The samples were manufactured by a manual lamination process and flexural tests were performed. A comparison between the experimental results and the micromechanics analysis was conducted. The mean of flexural strength and modulus of elasticity of the composites were: 71,96 MPa and 2,76 GPa, respectively. The micromechanics analysis allowed to verify the mechanical behaviour of the developed composites based on the characterization of the individual phases. The experimental results were close to the estimated results obtained through the micromechanics analysis, identifying a quasi-perfect condition of the interface. The incorporation of 10 wt-% of sisal fibres in the epoxy resin provided an increase of 38% in the flexural strength and 28% in the modulus of elasticity, showing a significant enhancement of the final mechanical properties.*

Keywords: *Composite materials, fibres of sisal, epoxy resin, micromechanics analysis, and mechanical properties*

1. INTRODUCTION

The addition of lignocelluloses materials as a reinforcement in polymeric composites has been the focus of many researches due to their low cost and low specific weight (Rozman *et al.,* 1998); and also the requirements of the legislative authorities in order to avoid synthetic fibres making the consumers aware of the necessity of preserving the environment and natural sources (Silva, 2003).

Natural fibres are cheaper than synthetic fibres and can be substituted in many applications where cost is the most important factor besides the strength. Natural fibres such as jute, sisal, coconut, banana and pineapple have been extensively used as reinforcement in polymeric matrixes (Ghavami et al., 1999; Mohanty *et al*., 2002; Wambua *et al.*, 2003; Saheb and Jog, 1999). The use of sisal is particularly interesting due to the high impact, tensile and flexural strengths they exhibit when compared to others natural fibres.

In thermoset composites the fibres are commonly combined with resins of polyester, phenolic and epoxy. This type of polymer develops reactive groups that provide a strong interface condition. Several works have been carried out on thermorigid polymeric matrices in order to investigate the effects of the volume fraction of fibres and the type of chemical treatment on the mechanical properties of the composites (Kaddami *et al*., 2006; Oksmana *et al*., 2003).

Roe et al. Apud Saheb and Jog (1999) have studied the behaviour of mechanical properties of polyester/jute composites as a function of the fibre volume fraction. An increase of the modulus of elasticity and the tensile strength up to 60% of fibres has been observed, decreasing with higher fibre fractions due to the absence of resin spread along the fibres.

Jain et al. Apud Saheb and Jog (1999), have investigated the properties of epoxy composites reinforced with fibres of bamboo and leaf of banana tree with a volumetric fraction varying up to 85% of fibres. The banana fibres provided larger tensile and flexural strengths over the bamboo fibre composites.

The mechanical properties of natural composites depend on many parameters, such as fibre volume fraction, length of fibres, interface condition, fibre orientation and mainly the capacity of stress transference between the fibre and the matrix. Most studies on natural composites involve the analysis of the mechanical properties of the fibre, the effect of different chemical treatments in the fibre and the addition of monomers (Gomes *et al*., 2007). The micromechanics analysis is commonly used to estimate the effective properties of the composites through the characterization of the individual phases (Stellbrink, 1996).

This work focus on the development of polymeric composites manufactured with epoxy resin and fibre of sisal. The mechanical properties such as modulus of elasticity and flexural strength were investigated. A micromechanics analysis was carried out in order to verify the performance of the material through the comparison between the effective and the experimental properties.

2. MATERIALS AND METHODS

The composite investigated in this work consists of a two-phase material: the first one is known as the matrix phase (epoxy resin), being continuous and involving the other phase, namely as dispersive phase (fibres of sisal). The unidirectional continuous-fibre composite is a laminate made up of fibres distributed in the same direction.

2.1 Matrix phase: epoxy resin

The thermoset matrix used in this work was the epoxy resin constituted of two parts, Araldite LY 1564 and HY 954, both manufactured by Huntsman Company Ltda. A ratio of 90 parts in weight of the resin (LY 1564) for 10 parts in weight of the hardener (HY 964) was adopted.

Flexural tests were carried out in the matrix phase in order to obtain the mechanical properties, flexural strength and modulus of elasticity, which are used for the micromechanics analysis of the composites. The flexural test procedure followed the recommendations of ASTM-D 5023 (1991). Five samples of each experimental condition were tested using EMIC-DL2000 testing machine.

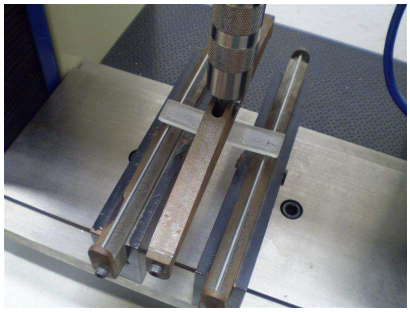

Figure 1. Flexural test in the epoxy resin.

2.2 Dispersive phase: sisal fibre

The sisal fibre was characterized through the tensile mechanical test. Five samples were tested using EMIC-DL2000 testing machine. The specimen is a single fibre of sisal fixed by a resin moulded in its extremities (Figure 2). The apparent density of the fibres was determined through the Archimedes principle, following the recommendations of British Standard 10545 (1997).

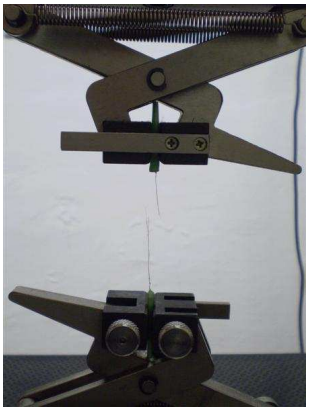

Figure 2. Tensile test for the fibre of sisal, failure.

2.3 Manufacturing process

The hand lay up process was adopted to manufacture the laminates of unidirectional fibres of sisal. A wooden plate was used to distribute the fibres and form a ply of sisal (Figure 3). Three millimetres were set as the distance between the parallel fibres.

Figure 3. Sisal ply manufacturing process.

The laminate of sisal/epoxy was cured during seven days, after that the samples were cut using a precision saw to obtain prismatic specimens (2mm x 10mm x 70mm) for the flexural test(Figure 4).

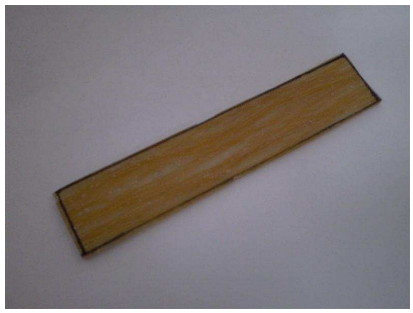

Figure 4. Prismatic sample for flexural test.

3. EXPERIMENTAL RESULTS

3.1 Matrix phase: epoxy resin

The flexural test results for the epoxy resin are presented in Table 1. A flexural strength of 52,17MPa and a modulus of elasticity of 2,15GPa were obtained. The mechanical behaviour of the epoxy matrix is shown in Figure 11 in order to be compared to the composite behaviour.

Table 1. Mechanical properties of the epoxy matrix obtained through the flexural test.

N=5	Flexural strength (MPa)	Modulus of elasticity (GPa)
Mean	52,17	2,15
Standard Deviation	± 0,923	± 0,072

3.2 Dispersive phase: fibre of sisal

Due to the large variability of the transversal section of the natural fibre, the diameter was set considering the average of five measurements using a digital vernier at different points of the fibre. Table 2 shows the tensile test results for the sisal fibre, exhibiting a tensile strength of 462MPa and a modulus of elasticity of 8,02GPa. The apparent density of the fibre was 1,36g/cm3.

Table 2. Tensile test results for the fibre of sisal.

N=5	Diameter (mm)	Tensile strength (MPa)	Modulus of elasticity (GPa)
Mean	0,234	462	8,02
Standard Deviation	±0,014	±23,05	±1,457
Apparent density: 1,36g/cm³			

The mechanical behaviour of the sisal fibre during the tensile test is shown in the stress-strain plot of Figure 5. Two types of failure were consistently observed during the tests, namely “normal behaviour” and “early failure behaviour”. Although the most of the samples has presented a normal behaviour, it is important to emphasize the presence of early failure of some fibres. The normal behaviour exhibited uniformity until the tensile stress of 250MPa. From this point the fibre suffered a large strain with intense variability of stress, indicating a partial failure of the fibre. When the specific deformation reaches a value of approximately 0,075 mm/mm, the sisal fibre stabilizes exhibiting a significant recovery of strength up to 460MPa. On the other hand, the early failure can be justified by the irregular transversal section of the fibre, causing large concentration of stress.

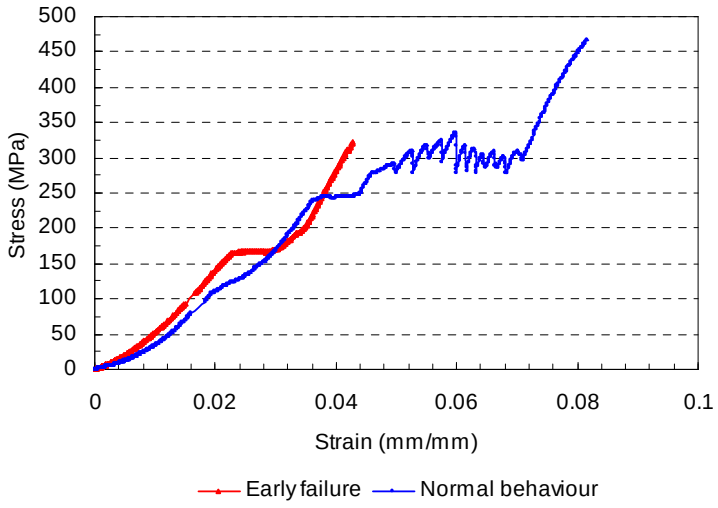

Figure 5.Tensile test of the fibre of sisal, normal behaviour and early failure.

3.3 Composite: epoxy/sisal

The flexural test of the composites was carried out following the recommendations of British Standard 2562 (1997). A test set consisted of 5 prismatic test specimens. The flexural strength data varied from 62,76MPa to 81,41MPa and the modulus of elasticity data varied from 2,59GPa and 2,93GPa (Table 3).

Table 3. Flexural test results of the composite epoxy/fibre of sisal.

N=5	Flexural strength (MPa)	Modulus of elasticity (GPa)
CP 1	62,76	2,59
CP 2	69,39	2,93
CP 3	81,41	2,92
CP 4	73,66	2,71
CP 5	72,57	2,65
Mean	71,96	2,76

The flexural mechanical behaviour of the natural composite is presented in the plot of Figure 6. The stress-strain curve showed a small variation when the stress is near 27 MPa. This variation can be explained due to the initial failure on the bottom surface of the composite where the tensile stress is extreme; moreover, this region is composed of a fine resin layer and the absence of fibres, resulting in a critical area, more susceptible of imperfections.

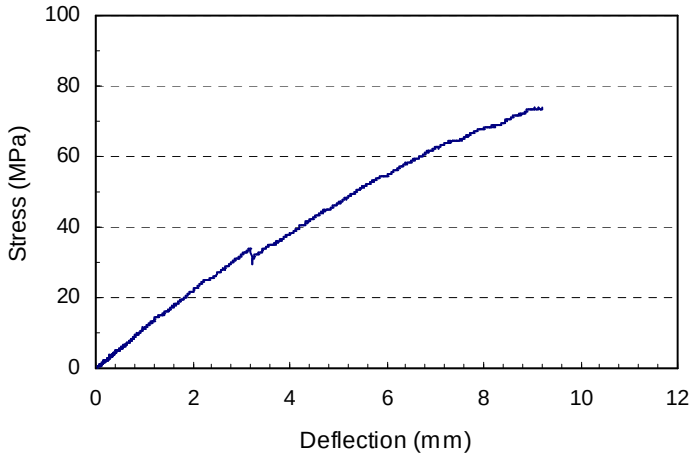

Figure 6. Flexural test of the composite epoxy/fibre of sisal.

After the occurrence of this superficial failure the load was transferred to the fibres which act as the stiffener phase until the failure of the material. It is important to say that the fibres situated on the upper surface of the composite remain unbroken where the compressive loads are submitted (Figure 7).

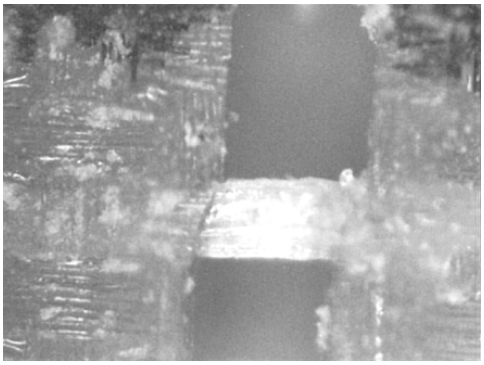

Figure 7. Optical microscope image, matrix failure.

The strong adhesion between the matrix and the dispersive phases contributed to the enhancement of the mechanical properties avoiding the delamination process and the early failure of the laminated composite. The plot of Figure 8 shows the behaviour of the composite and the polymeric matrix phase during the flexural test, showing that the fibre of sisal exhibits a significant importance on the mechanical strength and the modulus of elasticity of the composites.

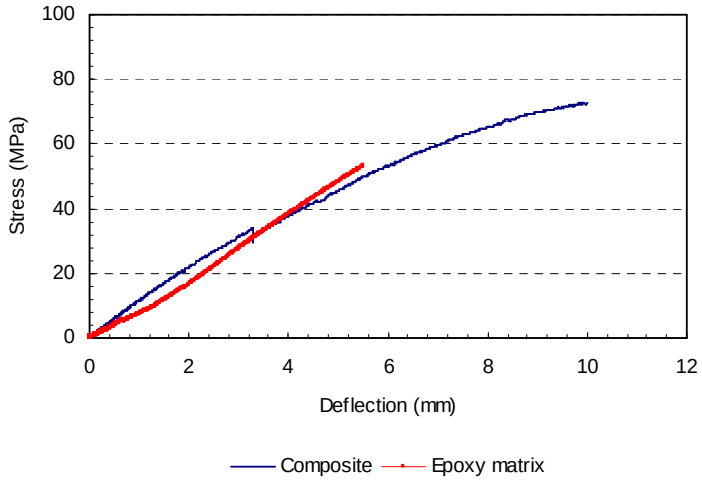

Figure 8. Flexural testing, comparative plot between the composite and the epoxy matrix.

It is concluded that the addition of 10% (in weight) of fibres in the epoxy resin provided a percent increase of 38% on the flexural strength and 28% on the modulus of elasticity data, representing a significant enhancement on the final mechanical properties.

Based on the properties of the phases individually, a micromechanics analysis was carried out. The effective flexural strength and modulus of elasticity were determined through the rule of mixture (Eq. (1)), presenting the following values: 93,15 MPa and 2,74 GPa, respectively. These results were calculated for the composite made of 10% of fibres and 90% of matrix (Figure 9) in order to compare with the experimental data.

$$C^{*}=V_f C_f + V_m C_m \tag{1}$$

Where:

C^{*}= effective mechanical properties

V_f, V_m = volume fraction of fibre and matrix.

C_f, C_m = experimental properties of the phases: fibre and matrix.

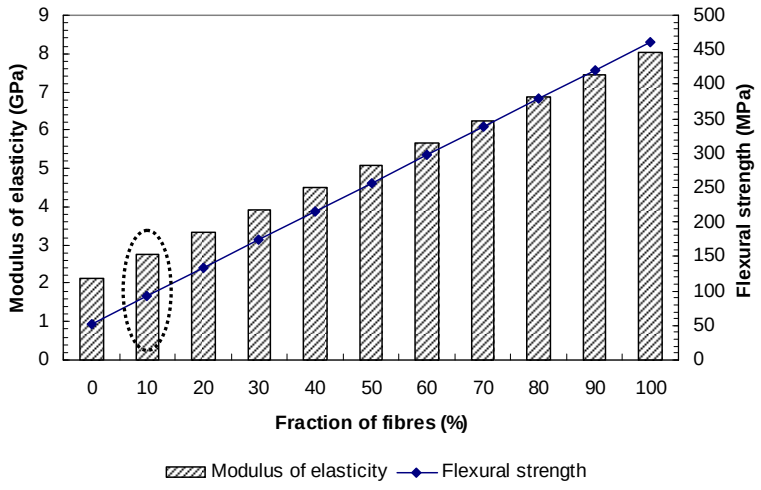

Figure 9. Micromechanics analysis, estimation of modulus of elasticity and flexural strength properties.

The mean of flexural strength of the composites obtained by the mechanical test was 71,96 MPa, which means a decrease of 30% compared to the estimated data from the micromechanics analysis. This difference can be explained by the presence of an early failure of fibres in the composite due to the concentration of stress proceeding from irregularities of the transversal section of the fibre. The properties of the individual phases of the composite used in the micromechanics analysis were obtained from the tensile test of the fibres and the flexural test of the epoxy resin. The effective (2,76GPa) and the experimental (2,74GPa) modulus of elasticity results were similar indicating a strong interface condition.

4. CONCLUSION

The mechanical behaviour of the investigated composites is affected directly by the properties of the sisal fibre, exhibiting an increase of 38% on the mechanical strength and 28% on the modulus of elasticity in comparison with the values found for the pure matrix phase. The mean of the flexural strength and the modulus of elasticity of the composites were respectively: 71,96 MPa and 2,76 GPa. The micromechanics analysis allowed to verify the behaviour and the mechanical performance of the composite based on the characterization of the properties of the phases individually. The experimental results were similar to the effective properties found by the micromechanics analysis, indicating a quasi-perfect interface condition and, thus, confirming the properties and the final performance of the developed composites.

5. ACKNOWLEDGEMENTS

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