

THERMAL AND MECHANICAL PROPERTIES ANALYSES OF SISAL FIBER COMPOSITES

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Abstract. *Natural fibers are becoming of ever-greater interest to the engineering community primarily because of their low cost and biodegradability. The purpose of this work is to study some thermal and mechanical properties of polyester matrix composites containing sisal fibers. Samples of various fiber mass fractions are tested to investigate the effect of fiber content on the composite properties. In addition, samples containing both untreated and alkali treated fibers are manufactured and tested to study the effect of fiber treatment on some mechanical and thermal properties of the composite material. Based on the experimental results, mechanical and thermal properties dependence on fiber treatment and fiber content is discussed.*

Keywords: *Composites, Sisal, Natural fibers.*

1. Introduction

The use of biodegradable fibers in composite materials has been a topic of great interest in recent years (Alvarez *et al.*, 2003; Cosenza *et al.*, 2001; Iannace *et al.*, 1999; Dufresne and Vignon, 1998). Composite materials can be tailored to offer a unique combination of material capabilities and therefore can offer design solutions not achieved with more traditional materials. Due to these characteristics, composites are also an appealing option as a substitute of more conventional materials. Natural lignocellulosic fibers are becoming prospective materials for many polymer composites largely due to the ever growing environmental awareness and increased environmental restrictions. Compared to conventional synthetic fibers, they offer the advantage of low cost, low density and, most important, environmental advantages, since they come from renewable resources and are biodegradable.

Brazil is the world's largest producer of sisal fiber (Silva and Beltrão, 1999). However, the sisal fiber has been traditionally used to make ropes, rugs and handcraft products. Due to the low value of these products, the sisal fiber has been of low economical importance to that country. Thus, the use of sisal fiber in more valued applications will provide a better application to this natural resource and contribute to the economical and social development of the producing regions. Thermal and mechanical analyses of sisal fibers have shown their great potential to engineering applications, including operating temperatures up to 200°C (Martin *et al.*, 1997; Mukherjee and Satyanarayana, 1984). Sisal fiber reinforced composite materials are potential candidates as substitute of traditional materials in various application areas including the automotive and construction industries, where it can be used as roofing materials, panels, and water tanks.

Sisal fibers are typically 0.6-1.2 m long with a diameter on the range of 100-300 μm (Kalaprasad *et al.*, 2000; Joseph *et al.*, 1996). Large variations in chemical composition and properties of these fibers are possible depending upon the fiber source and age, and also the measurement technique. Joseph *et al.* (1996) has reported that sisal fibers contain 85–88% of cellulose. The density of sisal fibers is between 1.37 g/cm^3 and 1.44 g/cm^3 , as reported in the literature (Alvarez *et al.*, 2003; Kalaprasad *et al.*, 2000). Regarding the mechanical properties, the tensile strength of sisal fibers may be on the order of 300 to 700 MPa, Young's modulus on the order of 9 to 20 MPa, and strain at break of 4 to 14%, depending upon fiber treatment (Alvarez *et al.*, 2003; Kalaprasad *et al.*, 2000; Joseph *et al.*, 1996).

New applications for natural fiber composites must not only be cost-effective but also bring technical advantages. Thus, understanding the properties of these composites is critical to the evaluation of their suitability for the proposed applications. Physical and mechanical properties of fiber composites are dependent upon constituent materials, fiber content and orientation, and fiber/matrix interface. When natural fibers are combined with hydrophobic polymeric matrices, the hydrophilic nature of the fibers may result in a poor interface, due to poor fiber wetting. In order to improve fiber wetting, alkaline treatment has been one of the most used chemical treatments of natural fibers (Alvarez *et al.*, 2003).

In the present investigation, some mechanical and thermal properties of a sisal/polyester composite material are experimentally measured, for various fiber mass fractions. Samples containing both untreated and alkali treated fibers are manufactured and tested to study the effect of fiber treatment on mechanical and thermal properties of the composite

material. Alkaline solutions, in two different concentrations, were used to investigate the effect on the composite material properties. Based on the experimental results, mechanical and thermal properties dependence on fiber treatment and fiber content is discussed.

2. Experimental

2.1. Materials and Test Specimens

Sisal fibers were obtained from local sources in Brazil. The fibers were treated with sodium hydroxide in concentrations of 5% and 10%, to remove part of the lignin. It is known that lignin worsens the fiber/matrix interface when a hydrophobic polymeric matrix is used.

Initially, the sisal fibers were chopped into lengths ranging from 5mm to 40mm. Then, approximately 200g of fibers were placed in 4L of NaOH solution with the selected concentration (5% or 10%) in a ball mill container. The container was set to rotate during 24 h. No balls were added since the goal was simply to maintain all fibers wet by a uniform solution of NaOH. After the conclusion of the time set, the fibers were washed thoroughly under running water to remove the excess of NaOH. Then, the pre-washed fibers were washed again with distilled water. Finally, the fibers were placed on a clean aluminum plate and naturally dried under the sun light.

All specimens were fabricated using unsaturated polyester (orthophthalic) resin, prepared with 1% (w/w) MEKP initiator. Specimens were manufactured using fiber mass contents of 0%, 7% and 9%. For each fiber mass fraction, fibers treated with different alkaline solutions (5% and 10% NaOH) were used.

The composite plates were produced using a glass tool as shown in Fig. 1. Prior to fabrication, mold release wax was applied to the glass tool surface to avoid part/tool sticking and to ensure proper release. Then, a small portion of the polymer was poured in the mold. Next, fibers were added, in random orientation, with careful control to obtain a uniform distribution throughout the mold area. The random fiber orientation is intended to produce a quasi-isotropic material. After that, another thin layer of polymer was added, followed by another layer of fibers, until the desired plate thickness was obtained. After the mold was closed, to improve consolidation and to remove porosities and air bubbles from the manufactured plate, an external pressure was applied on the top portion using a load of about approximately 700N.

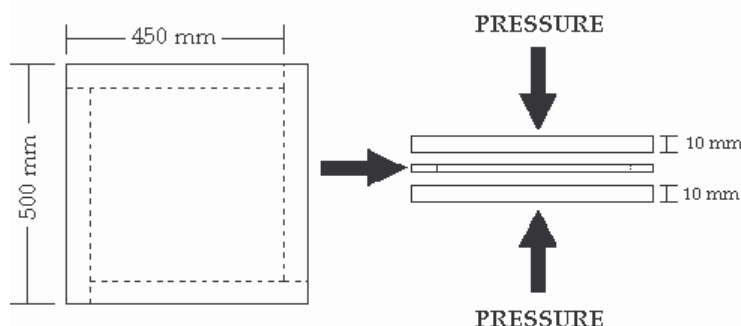


Figure 1. Glass tool for processing laminates.

The specimens for the determination of the mechanical properties were produced from a plate with nominal thickness of 2mm. Before cure was complete, the plate was removed from the tool and cut into rectangular strips, using a metal blade. Then, five test specimens were fabricated from each plate. After the cutting procedure, the specimens' edges were sanded flat to the final nominal dimensions of 25 x 175 x 2 mm (Fig. 2), as recommended by ASTM: D 3039/D 3039M – 00. No end tabs were used, as they are not required by the standard test method and proved not necessary for the material tested. Acceptable failure mode and location were obtained in almost all specimens tested.

The specimens for the determination of the thermal properties were produced with dimensions of 120 x 120 x 18mm, using the same glass tool (Fig. 3). In this case, only one sample was produced for each fiber mass fraction and fiber treatment, since measurements could be conducted in various points of the same specimen.

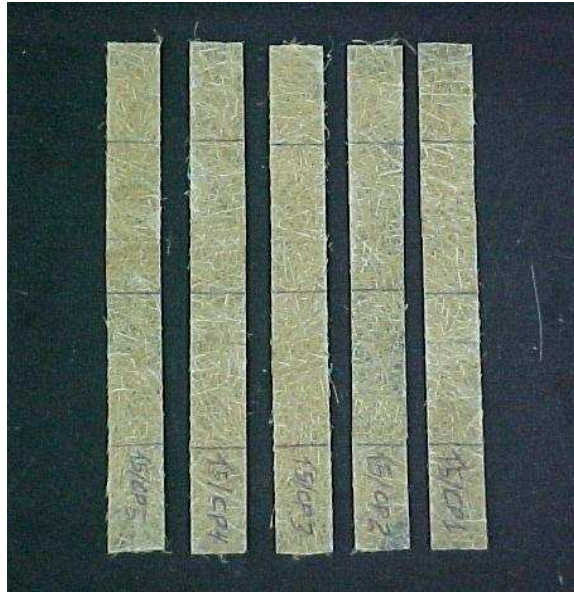


Figure 2. Tensile test specimens.



Figure 3. Thermal conductivity test specimens.

2.2. Mechanical Properties – Testing Procedure

The tensile tests were carried out in a Shimadzu Autograph 100kN universal testing machine (Fig. 4). All tests were conducted under a displacement-controlled mode with cross-head speed of 2mm/min. An extensometer was used for the strain measurements during the elastic region (Fig. 5). During the tests, after the load reached 300N, the test was paused and the extensometer was removed to avoid any damage to the extensometer in the case of specimen failure. All mechanical tests were conducted for the determination of the modulus of elasticity, tensile strength and maximum strain, at approximately 25°C, representing room temperature. The strain measured by the extensometer was used only to calculate the elastic modulus.



Figure 4. Shimadzu Autograph Universal Testing Machine.



Figure 5. Specimen with extensometer mounted.

2.3. Thermal Properties – Testing Procedure

The coefficients of thermal conductivity (κ) were measured using a QUICK LINETM – 30 – Thermal Properties Analyzer, of the ANTER CORPORATION, with a sensor API 210411 – S/N 0711001, which has a manufacturer specified conductivity range of 0.03 to 0.3 W/m.K and temperature range of -15 to 50°C , (Fig. 6). All thermal conductivity measurements were performed according to the recommendations of ASTM C-177-76.



Figure 6 – Thermal Conductivity Tests.

3. Results and Discussion

3.1. Mechanical Properties

The measured mechanical properties are presented in Tab. 1.

Table 1. Tensile properties of sisal/polyester composites.

Composite Properties	0% fiber	7% fiber untreated	9% fiber untreated	7% fiber NaOH 5%	9% fiber NaOH 5%	7% fiber NaOH 10%	9% fiber NaOH 10%
Tensile Strength (MPa)							
Average	37.02	18.13	13.55	18.93	18.82	18.18	21.68
Standard Deviation	4.03	0.67	1.10	1.41	3.39	1.35	1.56
Elastic Modulus (GPa)							
Average	3.42	2.38	2.04	3.47	4.21	4.45	3.89
Standard Deviation	0.08	0.13	0.08	0.09	0.39	0.14	0.21
Maximum Strain (%)							
Average	2.58	2.04	1.99	1.42	1.43	1.27	1.33
Standard Deviation	0.24	0.19	0.15	0.11	0.12	0.13	0.11

Comparing the tensile strength of all specimens, it can be seen that the material strength decreases when sisal fibers are added. For specimens with fiber content (wt %) of 7%, there was no significant change in tensile strength between composites with untreated fibers and those with fibers treated with NaOH in concentrations of 5% and 10%. Comparing to the polyester resin, there was a decrease of approximately 50% in tensile strength for all specimens with fiber mass fraction of 7%, regardless the fiber treatment.

For specimens with 9% of sisal fibers, although there was also a decrease in tensile strength compared to the pure resin, there seems to be an improvement with fiber treatment. Comparing to the pure resin, there was a decrease in tensile strength of 63% to the composites with untreated fibers, 50% to specimens with fibers treated with NaOH - 5% and 41% to specimens with fibers treated with NaOH - 10%. Therefore, for specimens with 9% (w/w) of fibers, the results indicate an improvement in tensile strength due to alkaline fiber treatment.

Regarding the effect of fiber treatment, the overall results of tensile strength measurements are somewhat conflicting. While specimens with fiber content of 9% (wt) show some improvement in tensile strength with fiber treatment, specimens with 7% of sisal fibers did not show any increase in strength due to fiber treatment. However, the results show a clear indication of strength reduction when sisal fibers are added.

The results of the modulus of elasticity measurements indicate that the untreated sisal fibers decrease the modulus of the material in 30% and 40% corresponding to fiber mass fractions of 7% and 9%, respectively. To fibers treated with NaOH - 5%, the modulus of elasticity was about the same as in the pure resin when 7% (w/w) of fibers are used, while there was an increase in modulus for 9% of fibers (23%). To fibers treated with NaOH - 10%, the modulus of elasticity increased in 30% to 7% of fiber mass fraction and in 14% to 9% of fiber content. Thus, although it can be concluded that the use of alkali treated sisal fiber may produce a composite with higher modulus than the matrix alone, the results are not conclusive about the effect of the concentration of NaOH on this mechanical property.

Regarding the maximum strain to fracture, it was observed that the sisal fibers added to the polyester resin decrease material ductility. Comparing to the pure resin, the maximum strain decreased in 20% to composites containing untreated fibers, 45% to specimens with fibers treated with NaOH - 5% and 50% to specimens with fibers treated with NaOH - 10%. There was no significant change in ductility as related to the fiber mass fraction, for the two fiber mass fractions studied.

In summary, it can be concluded that the presence of alkaline treated sisal fibers restricts the strain of the polymeric matrix, thus producing a slightly higher elastic modulus when compared to the matrix alone. Alkaline fiber treatment produces more efficient interfacial bond leading to a more efficient load transfer from the matrix to the fiber through the fiber/matrix interface. The poor fiber/matrix interface, especially in the case of untreated fibers, is responsible for a decrease in tensile strength, if compared to the pure matrix. The decrease in ductility observed may also contribute to a reduction in tensile strength. In addition, since vacuum was not applied during processing, the presence of the fibers makes the removal of air bubbles difficult, decreasing the strength. Nevertheless, it is important to mention that only randomly distributed fibers were evaluated in this work. The best mechanical performance can be achieved when fibers are oriented according to the applied load.

3.2. Thermal Properties

The results obtained for the thermal properties of the sisal/polyester composites are shown in Tab. 2.

Table 2. Thermal conductivity of sisal/polyester composites.

Composite Property	0% fiber	7% fiber untreated	9% fiber untreated	7% fiber NaOH 5%	9% fiber NaOH 5%	7% fiber NaOH 10%	9% fiber NaOH 10%
Thermal Conductivity (W/m.K)							
Average	0.205	0.209	0.210	0.225	0.220	0.224	0.228
Standard Deviation	0.001	0.007	0.003	0.005	0.004	0.003	0.009

No significant change in thermal conductivity was observed between specimens with 7% and 9% of fibers, related to fiber content. In the case of specimens with untreated fibers, the thermal conductivity was about the same of the pure resin, regardless the fiber content. Thus, the thermal conductivity of the sisal fiber composite perpendicular to the fiber direction is mainly dominated by the conductivity of the polymeric matrix and the sisal fiber has only a minor effect. However, the measured thermal properties show a slight increase in thermal conductivity (about 10%) when alkaline treated sisal fibers are added to the polyester matrix. There was not any significant change in thermal conductivity of the composites as related to the concentration of NaOH for the fiber treatment, between the two alkali treatments used (5% and 10%).

A small increase in thermal conductivity was previously observed in other investigations conducted by different authors and using sisal fibers (Alsina *et al.*, 2005; Kalaprasad *et al.*, 2000). Considering the low thermal conductivity of the sisal fibers, a decrease in thermal conductivity of the composite should be expected. However, the phenomenon observed may be related to a modification of the resin in the vicinity of the fibers, which is affected by the presence of the fibers, forming an interphase region. The presence of the sisal fibers may have induced matrix changes in the regions surrounding them such as changes in cross-link densities. This matrix modification may result in changes in mechanical and physical properties. Nonetheless, a thorough investigation must be conducted to verify this assumption before any conclusive statements can be made.

4. Conclusions

This research has focused on the study of thermal and mechanical properties of sisal fiber/polyester composites. The goal was to study mechanical and thermal properties of polyester matrix composite materials with randomly oriented sisal fibers, as related to fiber content and fiber treatment. Specimens were manufactured with fiber mass fractions of 0%, 7% and 9%. Further, two different alkaline treatments for the sisal fibers - NaOH in concentrations of 5% and 10% - were investigated and the effect on mechanical and thermal properties was assessed.

It was demonstrated that randomly distributed sisal fibers does affect negatively some mechanical properties of polyester composites, such as tensile strength and strain at rupture. However, although untreated sisal fibers decrease the modulus of the composite, there can be an improvement in modulus when alkaline treated fibers are used. Alkaline treatment of the sisal fibers in concentrations of 5% and 10% produce basically the same improvement in those mechanical properties.

Regardless to the fiber content, the measured thermal conductivity of all specimens was very similar to the pure resin, indicating that the thermal conductivity of sisal fiber composites perpendicular to the fiber direction is mainly dominated by the conductivity of the polymeric matrix. However, as in the case of the elastic modulus, the measurements show a slight increase in thermal conductivity (about 10%) when alkaline treated sisal fibers are added to the polyester matrix, suggesting the formation of an interphase in the vicinity of the fibers. Similarly to the mechanical properties, there was no difference in thermal conductivity between composites of alkali treated fibers in concentrations of 5% and 10%.

In summary, alkali treatment of sisal fibers in concentration of 5% produced basically the same benefits in thermal and mechanical properties of the fiber treatment in concentration of 10%. Although the presence of randomly distributed sisal fibers in composite materials may decrease the mechanical properties, the use of these fibers can be justified to reduce the material cost, in applications where mechanical properties are not the main design requirement. Regarding the potential of sisal fiber composites as a thermal insulator, the results presented show that the sisal fibers may even produce a slight increase in thermal conductivity when compared to the polyester matrix alone.

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7. Responsibility notice

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