Methodology for Tensile Tests on Vegetable Fibers

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Abstract

The use of composites reinforced with natural fibers had a significant increase in recent years due to the advantages of using vegetable fibers as reinforcement. Vegetable fibers have important properties such as low density, biodegradability, thermal and mechanical properties appropriate disposal facility in and renewability. Moreover, the heterogeneity of the geometry and composition of these fibers requires a more rigorous characterization. In this article, we report a methodology for testing fibers, with samples preparation, calculation and analysis of data related to the cross section and fiber diameter and stress-strain curves. It investigated the behavior of the fiber when subjected to different humidity conditions (dry, *In natura* and moist). The diameters were calculated assuming a constant cross section, the results of these tests were discussed and compared between sisal and banana fibers. The fibers of *Agave sisalana perr*. and *Musa spp.* cv Prata showed the same behavior of the treatments humidity, the higher the moisture content of the fibers to lower the mechanical stress, the fibers of *Agave sisalana perr.* were more resistant than the fibers of *Musa spp.*cv Prata.

Keywords: Vegetable Fibres, *Agave sisalana perr*., *Musa spp.* cv Prata, Stress.

1. Introdução

In countries with strong agricultural economic, such as Brazil, the use of natural fibers as raw material source for the reinforced polymers industry, is an important way of expanding the possibilities of exploring its natural raw material source with added value [1, 2].

Composite materials of natural fibers have received great attention and interest in the scientific community and industry due to their high mechanical performance and low specific weight, in addition being easily molded into shapes with wide versatility.

In Brazil, the production of composites in 2011 was estimated at 208,000 tonnes, of which 45% were intended for construction, the billing from the production of composites was approximately $ 1,400 billion and projections are for a 12% increase in revenues for the sector in 2012, *i.e.* more than $ 1.4 billion in revenue [3].

Because it is a natural material, the mechanical properties of natural fibers vary considerably with soil characteristics and climate conditions of the environment where the plants grows. The age of the plant where the fibers are extracted also influences the mechanical properties, where older wood fibers tend to exhibit higher strength than those extracted from young plants [4]. Therefore, the properties of the fibers should be determined whenever possible, thereby avoiding using literature data that cannot be effectively applied to the material.

The fibers of Musa spp. (banana) stand out for being easily cultivated in tropical regions, adapting very well, therefore, the climate of Bahia.

The pseudostem of the plant, after production of the fruit, may proliferate fungi with treatment unwieldy, due to moisture incident plantations. Thus, the use of banana pseudostem is an interesting alternative supplementary income for rural labor, and could be a viable alternative for making crafts and reinforcement of thermoplastic resins [5, 6].

Studies with other vegetable fibers such as *Agave sisalana perr*. (sisal) indicate their potential as reinforcement in polymer matrix composites, due to their thermal stability. Bahia is the state that has the largest production pole and sisal industry in the world, which is the town of Conceição do Coité. Moreover, according to Embrapa, regarding to the fibers extracted and benefited, only 4% of the harvested leaves are converted into salable product. The remaining 96% are discarded or used as fertilizer without treatment, making this an interesting alternative fiber reinforcement [7, 8]. It was decided, therefore, a comparison between the mechanical behavior of the sisal fibers with the fibers of *Musa spp.* cv Prata.

In view of the wide variety of vegetable fibers with potential for reinforcing composites used in the production of components for building construction, it becomes essential to characterize these materials to better apply them. The tests should be precise, have repeatability of results and are both simple and easy to perform as possible. There are standard methods for characterizing geometric and stress tests on fibers, but using equipment and features of the textile units [9, 10, 11] and is therefore little usual in laboratories of construction materials.

This paper seeks to obtain a testing methodology in vegetable fibers. For it will analyze the mechanical behavior of sisal and banana fibers, through humidification treatments. The fibers were characterized by mechanical testing of stress strength.

2. Materials and Methods

The work follows the guidelines of ASTM D3822, however, this standard defines parameters for testing the synthetic fibers, and therefore, some guidelines were adapted for the testing of natural fibers.

The fiber length was set to 60 mm, in order that the glue points stay farther from the base length range of the assay.

The average area of each fiber was determined indirectly from the real density of sisal fibers (1.591 g/cm3) [12] obtained as the average of 5 lectures of helium pycnometry. In the case of *Musa spp. cv* Prata, we adopted the density of 1.2524 g/cm ³ [13], also obtained by helium gas pycnometry. The fibers were measured and individually weighed on an analytical balance, and Eq.1 relates the fibers cross-sectional area regardless of the form and voids (A_m), mass (m), length (L) and real specific mass (ρ_r).

$$A_m = \frac{m}{\rho_r \times L}. \quad (1)$$

Thomas emphasizes the difficulty in determining the cross-sectional area (CSA) of the breaking point of the fiber because along of its structure there are variations in the diameter, therefore is spoken here in "average section" [14]. This leads to a lack of standardization in the determination of these values, which has hampered the understanding of the mechanical properties of the fibers. Moreover, it is emphasized the occurrence of non-circular sections and structural defects.

As the work consists in the mechanical characterization of natural fibers considering moisture as a variable, it was decided initially by a separation of the fibers to be tested in groups corresponding to each of the three moisture conditions defined: dry, *in natura*, and moist.

The group of fibers dried in oven (called "dry") had, firstly, its mass measured and then taken to the oven at 80 ºC for 24 hours. Once dry, the fibers had again recorded their masses. This second mass was used to calculate the fibers cross-sectional area. With these two mass values, it was calculated the moisture content, defined by Eq. 2 [14].

$$w = \frac{m_2 - m_1}{m_1} \times 100. \quad (2)$$

where m_2 is the mass in nature and m_1 the mass of the dry fibers.

Finally, the specimens were fixed in a paper pattern of 25x60 mm, using instant adhesive (cyanoacrylate ester), assembled according to the model:

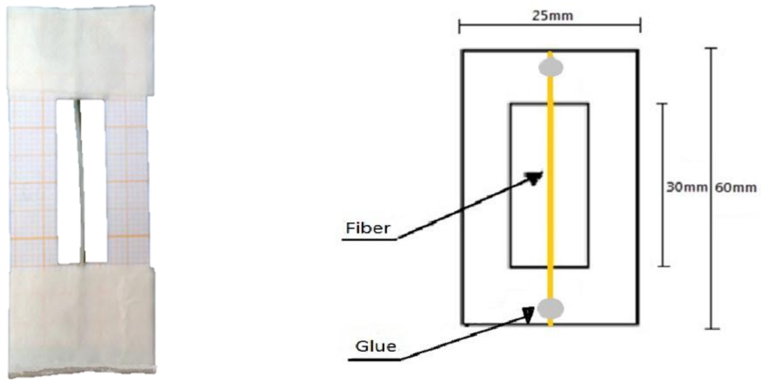

Fig. 1 – Type specimen (left) and scaling of the specimen (right).

The edges of the mold are covered with masking tape in order to decrease the occurrence of concentrated stresses in the region of the grips of the test apparatus. It is oriented that, once assembled the samples, the tests are conducted only after 24 hours, to ensure effective adhesion between adhesive/fiber.

Of the withdrawal of the fibers of oven until their weighing and mounting of specimens, the fibers, for being very hygroscopic material nature, already acquire moisture from the atmosphere, therefore it is recommended that transportation is always done in a desiccator, and after mounted, the samples back to the oven to be dried again for 24 hours at 80 ºC.

Finally, the fibers were tested in universal testing machine (EMIC, DL2000) with displacement speed of 3 $mm.min^{-1}$, 500N load cell and the distance between the grips of 30 mm.

The group tested in ambient humidity (called "*in natura*") was weighed, then the specimens were mounted according to the model shown in Fig.1, and tested the same way.

The group tested after immersed in water (called "moist") was first dried in an oven at 80 ºC for 24 hours. The fibers had, then, recorded their masses. Then, they were immersed in distilled water for 15 minutes and re-weighed. This second mass was used to calculate the fibers cross-sectional area. With these two values of mass, the relative humidity was calculated by Eq. 2, from which it was possible to analyze the rate of water absorption of the fibers at defined time.

To assemble the test samples, it is recommended that the fibers are air dried for approximately 30 minutes, so that the water does not adversely affect the adhesion of the glue with the mold. Once mounted, the samples are dried again in oven at 80 ºC for 24 hours, again soaked for 15 minutes, and then immediately tested.

Using data obtained by tensile tests, were plotted stress-strain graphs to observe the behavior of the curves of each fiber. From these graphs it is possible to extract a property of fundamental importance to this study, the Young's Modulus, which is an indication of the stiffness of the fiber. Generally the vegetable fibers present a mechanical behavior stress - strain with two distinct regions: the region of elastic deformation (linear region) and discrete plastic deformation to brittle fracture [15].

The selection criterion chosen to define a value more representative of the Young's Modulus was select the straighter region of the curve, excluding the 20% initial (corresponding to the stretch of grip accommodation of the device) and the final 20% (corresponding to the region of proportional limit) and calculate the angular coefficient of this line, which represents the Young's modulus.

In the statistical analysis, data were submitted to analysis of variance procedure of the program SAEG (UFV, Viçosa, MG) in a completely randomized model with different repetitions. At medias of the treatments, because they are qualitative, was applied Scott & Knott Grouping Test [16, 17, 18].

3. Results and Discussion

Characterization of fibers

The study of the mechanical properties of the fibers was performed by calculating the tensile strength (Failure stress) and Young's modulus. Table 1 and Table 2 refer to the results of the mechanical behavior of the fibers of *Musa spp*. cv Prata and *Agave sisalana perr*. with different moisture contents. In spite of fibers are very heterogeneous due to the cultivation and treatment received, could be observed that sisal fibers have a lower dispersion compared to its data banana fiber. The sisal fibers and *Musa spp.* cv Prata have a similar behavior with increasing water content, because there was a decrease in the values of tensile strength in both cases.

Table 1 – Mean values and standard deviations (SD) of physical and mechanical properties of the sisal fibers.

	Area (mm²)			Failure stress (MPa)			Young's modulus (GPa)		
	Dry	*In natura*	Moist	Dry	*In natura*	Moist	Dry	*In natura*	Moist
Mean	0.027	0.02	0.032	625.8	461.9	203.6	12.2	10.55	3.05
SD	0.004	0.006	0.01	177.6	100.2	77.6	3.2	3.9	1.41
CV (%)	14.3	29.8	30.9	28.4	21.7	38.1	26.6	36.9	46.3

Table 2 - Mean values and standard deviations (SD) of physical and mechanical properties of the *Musa spp*. cv Prata fibers.

	Area (mm²)			Failure stress (MPa)			Young's modulus (GPa)		
	Dry	*In natura*	Moist	Dry	*In natura*	Moist	Dry	*In natura*	Moist
Mean	0.011	0.015	0.037	555.4	376.73	130.89	18	14.41	5.06
SD	0.004	0.004	0.016	346.9	174.01	64.12	8.43	3.7	1.67
CV (%)	38.94	29.53	42.35	62.46	46.19	48.99	46.84	25.65	33.1

Table 3 shows the mean squares, waste and CV analysis of variance involving the Treatments (TRAT) and Cultures (CULT) and its interaction TRAT x CULT for the two variables (Failure stress and Young's modulus). It is noted that the factors TRAT and CULT are significantly different for the two variables used according to the Test F, that is, the treatments have different behaviors independent of culture imaged. The interaction of these factors, CULT X TRAT was not significant for the variables TNS and MOD, therefore there is an increase in mechanical properties with decreasing humidity in both cultures.

The mean squares of waste reflected in the estimates of the coefficients of variation (CV) are considered average for all variables TNS and MOD.

Table 3 - Mean squares of treatments and interaction CULT X TRAT for the variables Failure stress - TNS and Young's modulus - MOD, 2012.

Mean Square	Analysis of cross effect	
	TNS (MPa)	MOD(GPa)
Culture - CULT	159606*	402317.7*
Treatments - TRAT	1662729*	1298855*
Interaction CULT X TRAT	605.1871 ns	32041.96 ns
Wastes	24792.33	14554.55
CV (%)	42.96	39.51

* $p \leq 0.01$

ns - não significativo

Table 4 it can be seen that in respect to varying Failure stress the treatments were divided in three distinct groups for both sisal and for *Musa spp*. cv Prata, in this case the treatment which showed the best results was Dry, when analyzing the other variable, Young's modulus, the results showed that treatment Dry and *In natura* belong to the same group, namely the treatments did not have significant difference, in this way we choose to treat simplest in this case *In natura*.

Table 4 - Estimation treatment means within each test and the means analysis of the variables Failure stress (MPa), and Young's modulus (GPa), 2012.

Treatments	Failure stress (MPa)			Young's modulus (GPa)		
	Sisal	*Musa spp.* cv Prata	Total	Sisal	*Musa spp.* cv Prata	Total
1. Dry	625.82 a*	555.40 a	600.00 a	12.15 a	18.00 a	14.30 a
2. *In natura*	461.91 b	376.73 b	421.34 b	10.75 a	14.41 a	12.44 a
3. Moist	203.61 c	130.89 c	164.09 c	3.05 b	5.06 b	4.14 b
Means	424.65	302.08	366	8.57	10.88	9.66

* Means with different letters do not belong to the same group according to the Knott & Scott test, at 5% probability.

The sisal fibers presented a humidity content of 10%, a value close to that obtained by Rodrigues 12.5% [19] and Ghavamiet et al. 13.3% [20], but distant obtained by Pinto 16.79%, already the capacity of water absorption was 109%, higher than that found by Pinto of 82.7% for a 30 minute immersion [21]. These differences in moisture and absorption capacity can be justified by the high variability presented by the vegetable fibers. The fibers of *Musa spp.* cv Prata, have a moisture content ambient of 21.2% and water absorption capacity of 273%, i.e. the fiber *Musa spp.* cv Prata has more hygroscopic behavior, which may explain his poor performance in the tensile tests relative to sisal.

Through the data obtained by tensile tests were plotted graphs of the stress-strain (Fig. 2) to observe the behavior of the curves of each fiber. The selected graphs correspond to the mean voltage of the best treatment (dry). It can be seen that both fibers have similar performances in curves, i.e., both have predominantly elastic behavior, however, the sisal fiber has, on average, higher values of tensile strength and strain specific.

According to Thomas, lignin is hydrophobic and responsible for the rigidity of vegetable fibers [14]. As can be seen in Fig. 2, the banana fiber has a higher modulus of elasticity (stiffness) than sisal fiber, which is in agreement with the lignin determined for banana of 9.46% [13] and sisal, 7.6% [22].

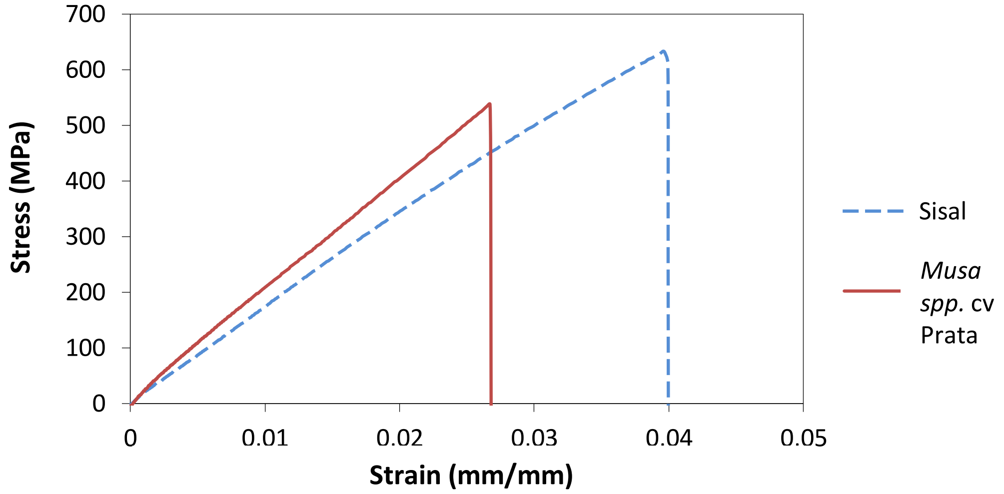

Fig. 2 – Stress - strain curve of sisal and banana fiber.

4. Conclusions

The tensile behavior of fibers are influenced by the different moisture contents through the tests performed, it can be concluded that the fibers of *Agave sisalana perr*. and *Musa spp*. Prata cv, has similar behaviors, despite sisal fibers are more resistant. It was observed that the lower the moisture content in the fiber, the more resistant it becomes, so the best treatment was the Dry, the wet fibers obtained inferior results. The next step of this work will be the interaction of fibers with the resin, it will be observed if the resin will have more interaction with the dry fiber or with *in natura* fiber. Through this work it was possible to create a testing methodology for natural fibers; the results were very significant; the results obtained will be compared with other fibers (*Ananas erectipholius* and *Musa spp.* cv Nanica), that will be submitted to the same tests and treatments.

Acknowledgments

APAEB for supplying sisal fibers; Group Energy and Materials Science and Separation Processes Thermodynamics (GECIM) for providing the fibers of *Musa spp*. cv Prata and FAPESB and CNPq for financial support.

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