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STUDY ON THE FLEXURAL-SHEAR STRENGTH OF HYBRID COMPOSITES REINFORCED SISAL/CANA-BRAVA

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Abstract. *The study of interlaminar shear in flexion of hybrid composites of sisal (*Agave sisalana*) and cana-brava (*Gynierium sagittatum*) were performed experimentally through the short beam test. The objective was to study the incorporation of finely chopped cana-brava fibers as an intermediary element to ensure greater interfacial mechanical coupling between sisal mats and polyester matrix, thus increasing stiffness and shear strength. The results have shown good mechanical properties for hybrid composites in compared to sisal mats, expressed by the increasing on 12% of short beam resistance. The combination of sisal and cana represent technical and environmental relevant parameters on composite materials, since they are natural resources with greater potential of exploitation and reutilization, especially in the most vulnerable regions in the state of Bahia.*

Keywords: *hybrid composites, flexural-shear strength, sisal mats, cana-brava.*

1. INTRODUCTION

The use of natural fibers as reinforcement in polymer composites has become a new concepts of eco-friendly materials, face to their renewability, non-abrasiveness, high specific strength, light weight in structural components and energy saving processing (GOPINATH *et al.*, 2014; JAUHARI *et al.*, 2015; JAWAID *et al.*, 2011)

Sisal (*Agave sisalana*) and cana-Brava (*Gynierium sagittatum*) are lignocellulosic fibers with high potential of exploitation in northeast of Brazil. Sisal is a plant adaptable to climatic characteristics of Semiarid and plays an important role on the socioeconomic development of regions with low Human Development Index (HDI) in Bahia, in which is considered the green gold and the drive force of local workers (CERCHIARO, 2010). Among other natural fibers, sisal has good quality for commercial applications, while simultaneously, detain one of the higher mechanical properties, especially the Young Modulus (ARAÚJO *et al.*, 2009). Cana-brava fibers are native from America and have great availability in almost all state of Brazil. In Ilha de Maré - Bahia, for example, a project for social knowledge technology transfer with cana-brava is encouraging producers on the development of acoustic panel however, a still lack of infrastructure, mechanical tests and scale production logistic has been hampering their industrial applications.

Hybrid composites reinforced natural fibers has emerging on industries with the new perspective business, in which the philosophy is to combine low cost renewable products with good specific properties (high stress to weight ratio) to be used on non-structural applications, mainly automotive and civil industry (SANJAY *et al.*, 2015). A hybrid composites can be a solution of balance the cost and performance, achieving superior properties and materials for specific designs (THWE and LIAO, 2003). A study with kapok/glass, sisal/glass and sisal/kapok fiber reinforced polymer composites, have showed an increase in shear strength with the increase of fiber content, especially with kapok/glass (REDDY, 2009). The mechanical strength of hybrid composites is superior to non-hybrid, due to the increase of the stiffness and generally improve the interfacial interlocking fiber/matrix. However, those performance depends on several factors, such as reinforcement concentration, ratio, content, and fillers added to polymers, as well a good compatibility between matrix and reinforcement (OLIVEIRA *et al.*, 2011, GOPINATH *et al.*, 2014, REDDY, 2009). Gopinath *et al* (2014) argues that interlaminar shear strength depends primarily on the combination of properties

of the matrix and interfacial fiber/matrix resistance. Others works with curauá and sisal fibers showed that an increasing on the thickness has lead poor wettability and more voids content inside composite, which has influenced the shear strength (SILVA *et al.*, 2009). Voids inside composites act as stress concentrators, reducing the interlaminar strength (REZENDE and ALMEIDA, 2001). Moreover, the length of sisal and curauá on polymer composites has showed no significant influence on the short beam tests, unlike fiber content, showing an increase on shear strength until maximal of 30% of fiber volume fraction (SILVA *et al.*, 2009). Botelho and Rezende (2002) explain that interlaminar shear property is an important parameter in structural projects, and they are considered a difficult task due to the anisotropic nature of the composites. Thus, a valid result must have a shear failure or exhibit a plastic deformation with evidence of delamination.

Therefore, the aim of this work is to study the mechanical properties of hybrid and non-hybrid composites, especially the interlaminar shear strength behavior, with adding finely chopped cana-brava to act as an intermediary element among mats layers, seeking a better interlocking fiber-fiber and fiber-matrix.

2. MATERIALS AND METHODS

2.1 Materials

The materials used was sisal mats donated from Hamilton Ltd. and cana-brava fibers obtained from Ilha de Maré – Salvador/BA. The resin was unsaturated polyester orthophthalic ($\rho=1.10 \text{ g/cm}^3$) and commercially purchased. Some important physical and mechanical properties of the fibers are detailed below.

Table 1. Fibers Properties.

Fibers Properties	Sisal fibers	Reference	Cana-Brava fibers	Reference
Tensile Strength	347-700	Melo 2017	91-264	Melo (2017)
Tensile Modulus (MPa)	1899,00	Carvalho (2005)	1936,96	Melo (2017)
Density (g/cm^3)	1,591	Carvalho (2005)	0,959	Melo (2017)

2.2 Methods

2.2.1 Composite fabrication

Compounding process was carried out by using hot compression molding with 5 tons (0,78 MPa) pressure, 90 °C of temperature and time established at 90 minutes. Two sisal mats were used and cana-brava sieved as an intermediate coat with a mass ratio of cana-brava/sisal mats of 0.5. Two composites panels have been produced with dimensions (32 x 20 x 0,4 cm). The first composite panel was made consisting of 100% of sisal (w/w) and the second panel was a hybrid composed by 68% / 32% of sisal/cana-brava. The cana-brava particulate homogeneous distribution between mats layers was an important element, since a better anchorage of fibers can enhance the resistance of interlaminar shear. The Figure 1 show the surface of samples and Figure 2 an illustrative drawing of cana-brava fibers are disperse into the panel structure.



(A)



(B)

Figure 1. (a) Sisal mats composite, (b) Hybrid composite.

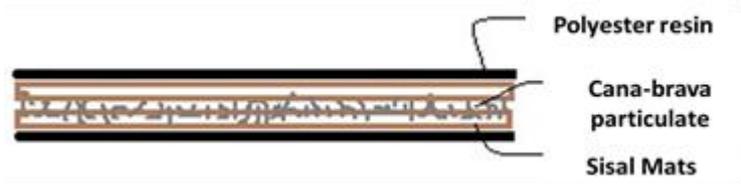


Figure 2. Illustrative of the hybrid composite transversal section.

2.2.2 Mechanical tests

Identical Short beam Test (ASTM D2344M) specimens were produced with a recommended geometry, length (h) 6mm, thickness and width 2mm. The specimen geometry are showed in the Figure 3. Ten identical specimens of each type of composite are used. In the Figure 4, we observe the configuration of how the test was performed in a universal testing machine EMIC 250KN with speed for shear of 1mm / min.

The short beam resistance (F^{sbs}) was calculated using equation (1), where P is the maximum load (N) recorded, b and h are the width and thickness of the specimen (mm).

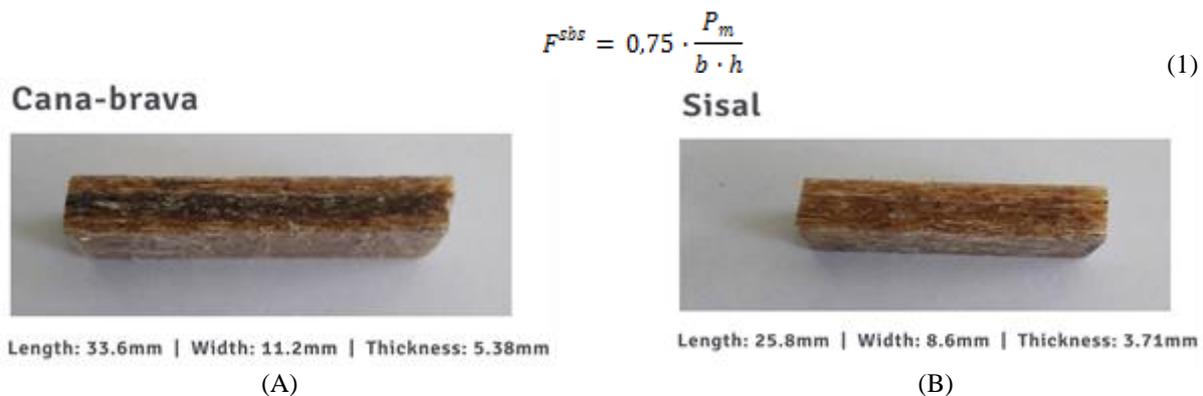


Figure 3. (a) CH specimen geometry. (b) CM specimen geometry.

3. RESULTS AND DISCUSSION

3.1. Short beam Test

The Figure 4 and 5 show the photo of the short beam shear test based on ASTM D2344 and the graphic of Force (N) versus Deflection (mm) of both composites: sisal mats composite - CM and hybrid composite with sisal mats and cana-brava - CH. The curves were adjusted from raw data with greater emphasis on the lowest flexural strength, highest flexural strength and one sample as reference. All samples were performed to measure the interlaminar shear resistance of the CM and CH), mainly the improvement on properties of hybrid composites. From the graphic, is possible to see that the maximal deflection of CH was approx. 1,5 mm, on the contrary of CM that showed 2,5 mm of deflection, which means less rigid capacity. In addition, it must be highlight a well-defined CH graph with three major's stages/behavior of flexural mechanical strength. The first one referring to the elastic zone between 0,5 and 1 mm of deflection, afterwards a yield stress around 600 N and a plastic zone with the ultimate stress and materials fracture. Mechanical properties can be explained by the improvement of stress transfer after cana-brava fiber particulate incorporation between sisal mats layers, which could have enhanced fiber anchorage, acting as cross-stitching and reducing mobility of fibers and reduce voids into composites.

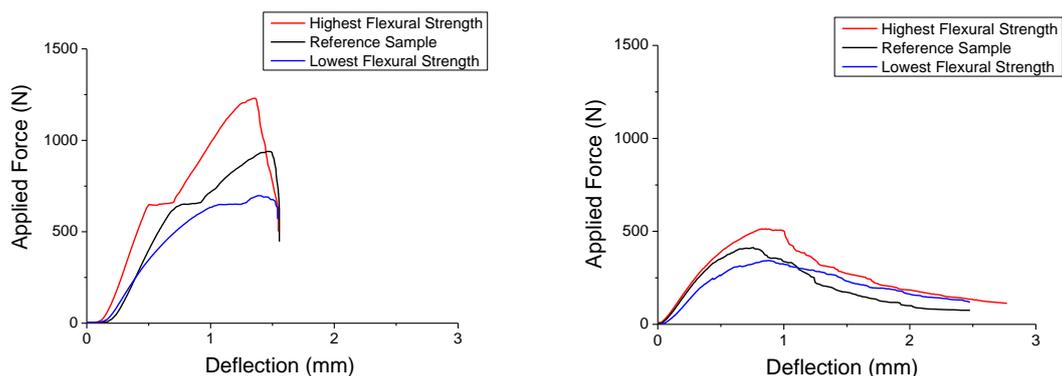


Figure 4. (a) Short beam test for sisal composites. (b) Short beam test hybrid composites

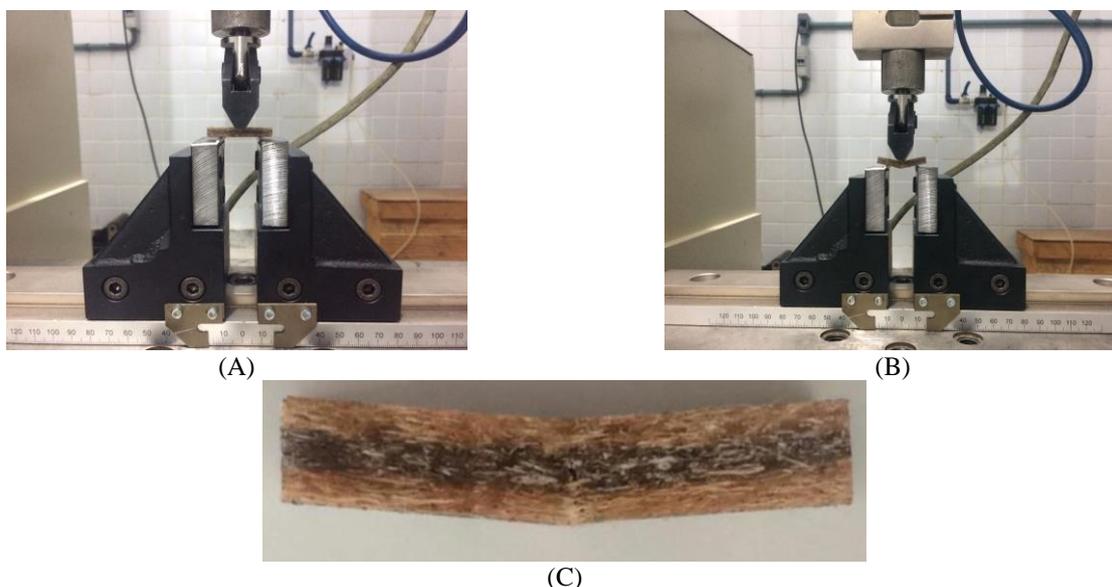


Figure 5. (a) Initial Short beam test (b) Final Short beam test (c) Deformed specimen.

The Student's T test was applied to evaluate differences between CH and CM composites. The Table 2 are composed by statistical results with the mean, standard deviation, hypothesis testing and p-values.

Table 2. Statistical result of composites short beam strength.

Properties	Hybrid Composites	Mats Composites	Test "t"	Prob. (bi-caudal)
Flexural Force (N) ⁽¹⁾	843,72 ± 156,85	421,35 ± 66,06	7,09	0,00
Maximum Deflection (mm) ⁽¹⁾	2,38 ± 0,43	2,96 ± 0,01	4,05	0,00
Short beam Strength (MPa) ⁽¹⁾	9,83 ± 1,02	8,73 ± 0,95	-2,24	0,03

(1) Measured at 25 °C. p ≤ 0,05 – non-significant.

From the Table 2 is possible to see that CH showed an increase of almost 12% in the short beam resistance compared to CM. This can be initial explained by the small diameter of cana-brava compared to sisal, which could have filled voids spaces inside mats, giving a better stress transfer through in the interfacial zone. The statistical results showed for both properties (flexural force and short beam strength) non-significant p-values ($p \leq 0,05$), which can be conclude that null hypothesis of similar results was neglected, therefore they were considered all different. This reinforces the importance of the incorporation of cana-brava fibers on increasing flexural mechanical performance of hybrid composites.

3.1.2 Analysis of SEM

The Figure 6 show fracture analysis on the CM by Scanning Electron Microscopy (SEM). A fiber debonding was found to be at interfacial zone as can be seen at Figure 6 (A) (D) for both composites CM and CH. This is supported by

non-chemical compatibility, leading to lower interfacial strength (anchorage) between natural fiber and polymer matrix. In other hand, the Figure 6(B) shows a cohesive fracture occurring with more intensity at the matrix for the composite CM.

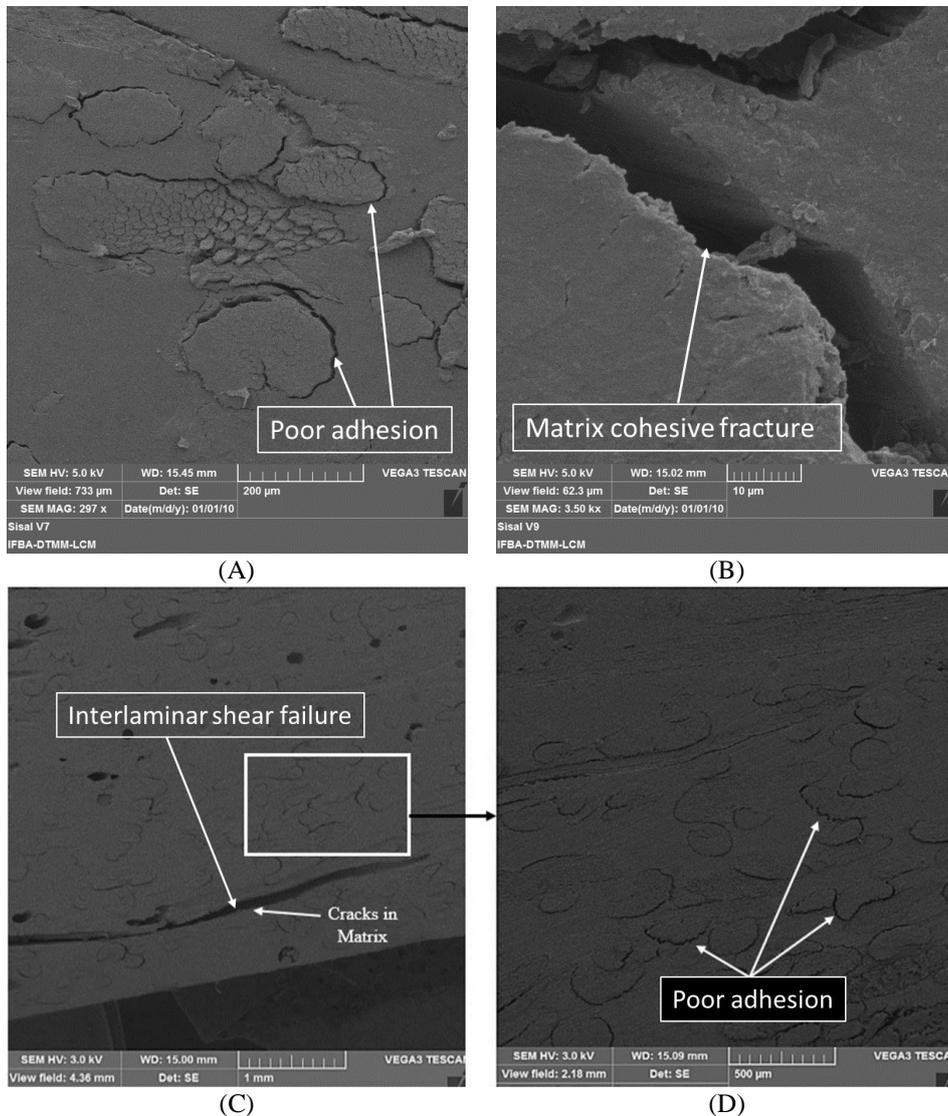


Figure 6: (A) and (B): Sisal Composites, (C) and (D): Hybrid Composite.

Based on Figure 6(C) is possible to note a shear failure mode, due to the homogeneous and transversal crack propagation at the polyester matrix. Adding cana-brava as an intermediate element has shown better stiffness on hybrid composite and a failure behavior consistent with shear mode. According to Resende and Botelho (2002) composites usually fail by bending, the authors support that a valid shear test need to have a vertical/horizontal crack inside composites. This is important to establish requirements for develop new materials and desirable properties to satisfy structural elements.

4. CONCLUSIONS

From the discussion of the results above, it can be concluded that 32% (w/w) of cana-brava as reinforcement in sisal mats composites showed slightly better short beam strength than just sisal mats composites in the same conditions. Also, hybrid composite showed shear mode failure after short beam test and SEM images observation, which can be a satisfactory result for the reproducibility of the tests and material. This result is an indicative that, since cana-brava fibers have been treated as waste in many regions of Bahia state, they have showed good properties to be applied as intermediate element on composite shear strength. Finally, there are few studies with cana-brava and this work aims to potentialize the use of this renewable material to increase the aggregate their value to be use as reinforcement in polymeric composites.

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6. REFERENCES

- ARAÚJO, S. S. *et al.* Propriedades mecânicas de compósitos PP/Sisal processados por extrusão. *10º Congresso Brasileiro de Polímeros*, p. 9, 2009.
- ASTM D2344 – 16. Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates, 2016.
- BOTELHO, E. C.; REZENDE, M. C. Caracterização Mecânica de Compósitos de Poliamida/Fibra de Carbono Via Ensaio de Cisalhamento Interlaminar e de Mecânica da Fratura. *Polímeros*, v. 12, n. 3, p. 153–163, 2002.
- CARVALHO, R. F. Compósitos de fibras de sisal para uso em reforço de estruturas de madeira. Brasil: Tese apresentada à Área Interunidades em Ciência e Engenharia de Materiais da Universidade de São Paulo para obtenção do título de Doutor em Ciência e Engenharia de Materiais, 2005.
- CERCHIARO, J. R. Comportamento mecânico de compósitos com poliéster e tecidos de sisal por moldagem manual. Dissertação de Mestrado.—[s.l.] *Programa de Pós graduação em Engenharia Ambiental Urbana. Universidade Federal da Bahia.*, 2010.
- GOPINATH, A.; SENTHIL KUMAR, M.; ELAYAPERUMAL, A. Experimental investigations on mechanical properties of jute fiber reinforced composites with polyester and epoxy resin matrices. *Procedia Engineering*, v. 97, p. 2052–2063, 2014.
- JAUHARI, N.; MISHRA, R.; THAKUR, H. Natural Fibre Reinforced Composite Laminates – A Review. *Materials Today: Proceedings*, v. 2, n. 4–5, p. 2868–2877, 2015.
- JAWAID, M.; ABDUL KHALIL, H. P. S. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydrate Polymers*, v. 86, n. 1, p. 1–18, 2011.
- MELO, F. L. B. Caracterização da fibra de cana-brava (*Gynerium safittatum*) e sua viabilidade como reforço na preparação de compósitos com ABS. Dissertação de Mestrado. Programa de Pós-graduação em Engenharia Química. Universidade Federal da Bahia, 2017.
- OLIVEIRA, F. H. *et al.* Influência do teor de fibras na resistência ao cisalhamento interlaminar em compósitos unidirecionais de curauá ou vidro. *11º Congresso Brasileiro de Polímeros*, Campos do Jordão, SP, 2011.
- REDDY, G. V. Flexural, Compressive, and Interlaminar Shear Strength Properties of Kapok/Glass Composites. *Journal of Reinforced Plastics and Composites*, v. 28, n. 14, 2009.
- SANJAY, M. R.; ARPITHA, G. R.; YOGESHA, B. Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review. *Materials Today: Proceedings*, v. 2, n. 4–5, p. 2959–2967, 2015.
- THWE, M. M.; LIAO, K. Durability of bamboo-glass fiber reinforced polymer matrix hybrid composites. *Composites Science and Technology*, v. 63, n. 3–4, p. 375–387, 2003.

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