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MECHANICAL CHARACTERISATION OF HYBRID NATURAL FIBERS COMPOSITES

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Abstract. *The incorporation of natural fibre reinforced composites (NFRC) in all aspects of industrial and life in general, have increased and with it the need for stronger, renewable and more energetically efficient composites. The objective of this paper is to investigate the effects of hybrid sisal, rami and jute reinforced fibre composites and their effectiveness in substituting non-hybrid composites in structural components. Tensile tests as detailed by the ASTM D638 with hybrid composite specimens constituted of jute-sisal, jute-rami and sisal-rami were performed. The specimens were manufactured by layering the fiber mats, maintaining a 60/40% volume of jute and each other type of fibre. The results were compared with non-hybrid reinforced composites and it was found that the hybrid composites presented better mechanical properties than non-hybrid composites. With the data obtained it is possible to implement more ecologically minded materials in a variety of different areas of the industry. The hybridization and fibre patterns are key factors in expanding the use and effectiveness of NFRC.*

Keywords: *Natural hybrid composites, Jute, Sisal, Mechanical Proprieties*

1. INTRODUCTION

With the industries desire to implement more eco-friendly materials in their production matrices the studies in natural fibre reinforced composites (NFRC) are steadily growing as they provide a less dense, less toxic and cheaper alternative to their synthetic counterparts. Also, one must consider the social impact in the communities that can produce these fibres, since obtaining natural fibers do not depend on heavy machinery or complex chemical procedures, and the fact that they are much simpler to recycle or dispose of (Swolfs *et al.*, 2014; Júnior *et al.*, 2012;). The main drawbacks are also related to their natural origin, high humidity absorption, lower mechanical properties when compared to grass fibre reinforced polymers (GFRPs), shorter life-cycle due to the rotting or degradation of the fibres (Júnior *et al.*, 2012; Ornaghi Jr. *et al.*, 2011). To solve these deficiencies recent studies have focused on improving their mechanical properties so that the NFRC can have a wider range of uses other than secondary structural applications. The most promising is the use of two or more different types of natural fibre, known as hybridization (Rafiquzzaman *et al.*, 2016; Zah *et al.*, 2007).

The main objective of this work is to investigate three different hybrid natural fibre composite materials made by woven cloths of sisal with jute, jute with ramie and ramie with sisal. The results will be compared with non-hybrid reinforced composites manufactured in the same way to investigate the effectiveness of hybrid NRFC.

1.1 Natural composites

Natural composites are composites reinforced by materials that are made from natural sources. The type of natural material can be subdivided by its origin, being: animal, mineral and cellulose/lignocellulose.

The cellulose based fibers present several advantages over the other natural fibers, since they do not present the toxicity levels found in minerals and are easier to manipulate, harvest and store then animal fibres.

When compared with synthetic reinforcements the natural fibers present a lower energy to produce and to recycle. Table 1 presents the energy to produce some fibers (Jauharia *et al.*, 2015; John and Thomas, 2008).

Table 1. Energy for production of fibers (Modified from Jauharia *et al.,* 2015).

Fibre	Sisal	Glass	Carbon
Energy (MJ/t)	2488	31700	355000

Natural fibers are a good alternative to synthetic fibers, especially when compared to glass fiber. They present lower density, are renewable, less expensive, low production and manipulation hazard, less abrasive and exiled less toxic fumes when burned. These advantages make them perfect for use in the automotive and sports industries, giving lighter, cheaper and environmentally friendly products (Jauharia *et al.*, 2015; Pickering *et al.*, 2016).

Although these materials are exceptional they are not without limitation. They present lower overall resistances, less interaction with most commercial resins, mechanical properties vary according to environmental changes and high moister absorption.

1.2 Hybrid composites

As stated by (Bouguessir *et al.,* 2016; Jawaid *et al.,* 2011; Pickering *et al.*, 2016; Swolfs *et al.,* 2014), hybrid composites are material reinforced with two or more different types of reinforcements within the same matrix and/or two different matrixes with the same type of reinforcement. The objective of this type of composites is to reduce the limitations and disadvantages of one type of fiber or resin while, at the same time, improving on its advantages, resulting in a balanced composite with the desired mechanical properties. In this work two natural fibers where united, having one of them, the jute, as a base upon which the other fibres were weaved unidirectionally in hopes of raising the overall properties of the resulting NFRC, in all cases the same epoxy resin was used.

2. MATERIALS AND METHODS

Jute, sisal and ramie fibers woven mats were selected for this study (supplied by Sisalsul, São Paulo - Brazil), and as a base for comparison a bi-directional non-hybrid jute fabric (provided by Sisalsul, São Paulo - Brazil) was used. AR260 / AH260 bi-component epoxy resin (supplied by Barracuda Advanced Composites, Rio de Janeiro, Brazil) was used.

For the fabrication of the composites a simple rectangular mold was used and the specimens were cut at the dimensions specified by ASTM 638.

All polymeric composites, either reinforced with natural fiber or synthetic, were prepared using the Hand Lay-up technique with the help of a mold and a hydraulic press. The hybrid composites were made up from two layers of woven mats of 60% jute and 40% of other fibres. In order to manage the desired proportions of fibre and matrix all finished woven fabrics were weighted and cataloged. The AR260/AH260 epoxy resin was mixed in the correct proportions in accordance to the datasheet provided by the supplier. The pre-cut woven mats of hybrid fibres and/or non-hybrid fabric were placed on the mold and the already mixed AR260/AH260 was poured on the layers using a spatula. The composites were cured using a hydraulic press at 80 °C for 6 hours and left to cool down in a controlled environment at room temperature.

The tests were performed in an Instron 5966 machine with a load cell of 10kN, with the speed test of 5mm/min for tensile tests. At least 5 samples were tested for each case. Load displacement curves were recorded and an extensometer of 25 mm length was used to record the displacement.

2.1 Specimens manufacture

The materials used were fibers commonly found in Brazil, them being: jute, sisal and ramie. A pain weave jute fabric is used as a means of comparison.

The jute has a plain wave configuration with 0° and 90° orientation, as seen in Fig. 1, and was chosen due to its availability and price. In order to guarantee a minimum of impurities and other elements that may affect the adhesion process, the fibres were washed with distilled water and dried in an oven at 100 °C for 2 hours.

Figure 1. Jute fabric.

The sisal and ramie used were in twine form. These fibers where woven unidirectionally in the jute fabric with a twill design (John and Thomas, 2008), as can be seen in Fig. 2.

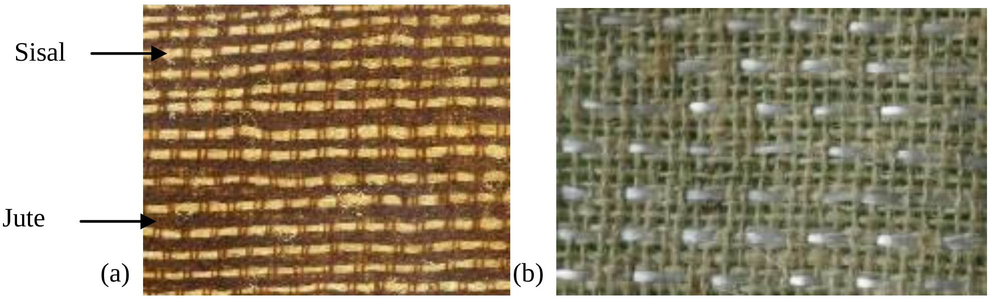

Figure 2. (a) Jute/Sisal hybrid composite; (b) Jute/Fiberglass fabric.

Figure 3 represents the chosen design. The twill configuration, according to (John and Thomas, 2008) presents better energy distribution by reducing crimp and providing higher mechanical properties. This method provides an intayarn type of composite, which is not commonly found in the literature, being the interlaminated configuration much more common.

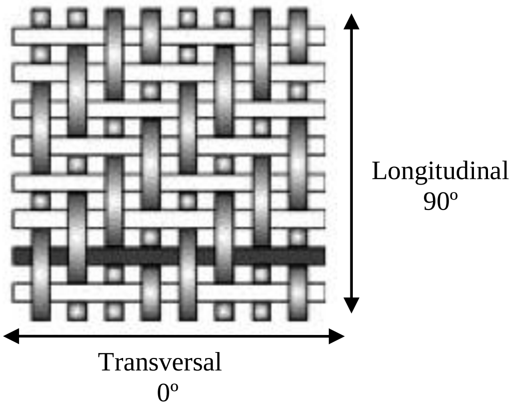

Figure 3. Twill design.

Ramie presents better mechanical characteristics then most fibers, Tab. 2. The sisal was chosen because presents good mechanical characteristics and Brazil is the largest exporter of this type of fibre.

Table 2. Mechanical properties of fibres used (Modified from Gurunathan *et al.*, 2015).

Fibre	Tensile strength (MPa)	Young`s modulus (GPa)	Density (g cm^{-3})	Price (kg^{-1}) (USD)
Jute	187–773	20–55	1.23	~$0.926
Sisal	507–855	9–22	1.2	~$0.65
Ramie	400–938	61.4–128	1.44	~$2
E-glass	2000–3500	70–73	2.5	~$2

All fibers were supplied by Sisalsul, São Paulo – Brazil. The resin used was a bi-component epoxy resin provided by Barracuda Advanced Composites, Rio de Janeiro, Brazil. The mixture used was 100 parts of resin for 26 parts of hardener, and the proper proportions of resin to reinforcement were used (i.e. 30% of reinforcement in the final product).

2.2 Tests and samples

As to proceed with the tensile tests the ASTM 638 was used. In Fig. 4 and Fig. 5 it is possible to see the dimensions used. The samples were cut from the laminated plates, each having 2mm of thickness.

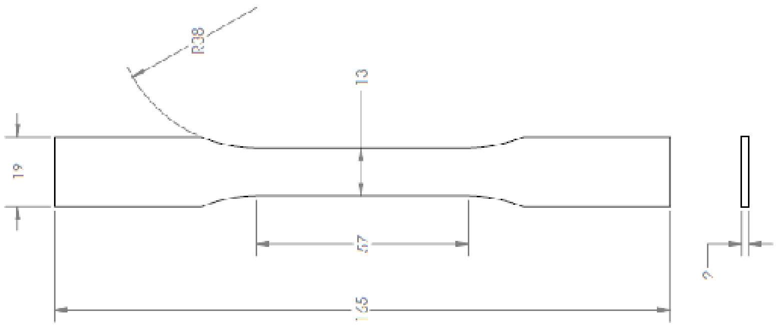

Figure 4. ASTM 638 sample dimensions.

Figure 5. Jute composite sample.

The samples were tested using an Instron 5966 machine with a load cell of 10kN, in conjunction with a 25mm extensometer. The velocity of the test was 5mm/min.

In order to better understand the fracture characteristics of these materials a scanning electron microscopy (SEM) analyses was performed on the fractured surface of the tensile properties.

3. RESOULTS AND DISCUTION

In accordance to the ASTM 638 only specimens that broke in the specified area were considered, as seen in Fig.6. In Fig. 7 it is possible to see all the fractured specimens used in the 100% jute composite (all specimens were valid).

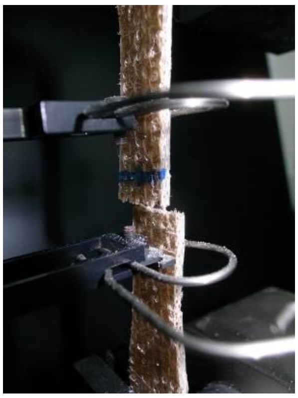

Figure 6. Jute specimen after tensile tests.

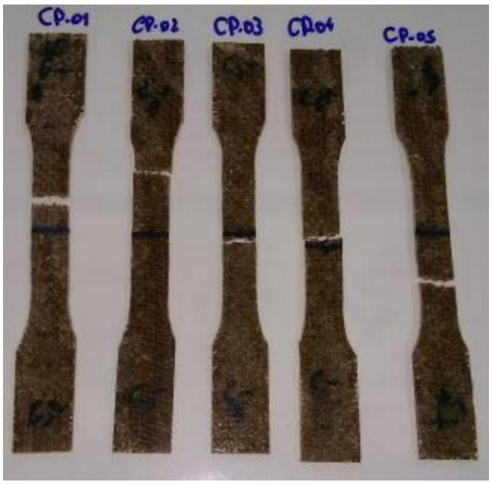

Figure 7. Fractured jute specimens.

Table 2 presents the results obtained via tensile tests and Fig. 8 presents the average longitudinal tensile strength. It is possible to see that the hybrid composites presented better mechanical properties then the simple jute composite. The specimens where tested in both 0 and 90 degrees, being the longitudinal direction (90°) the one containing the second type of fibre (Sisal and ramie) and the transversal (0º) did not receive any type of other reinforcement fibers.

Table 2. Properties of the composites studied (MPa).

	Type of composite	**Load (N)**	**Tensile strength (MPa)**	**Elongation (%)**	**Young's modulus (GPa)**	**Density (g/cm³)**
	Resin	745±212.72	28±8.18	10	3.9±0.13	1.15
Longitudinal	Jute	1122±97.35	39.1±1.16	25	4.2±0.19	1.15
	Jute + Sisal	3039.78±251.93	75.99±6.3	12	9.7±0.78	1.3
	Jute + Ramie	2558.7±219.67	49.2±4.22	25	5.7±4.5	1.2
Transversal	Jute	1432±169.82	51.7±3.45	20	4.6±0.22	1.15
	Jute + Sisal	-	-	-	-	-
	Jute + Ramie	1015±91	35±4.1	15	0.9±1.05	1.2

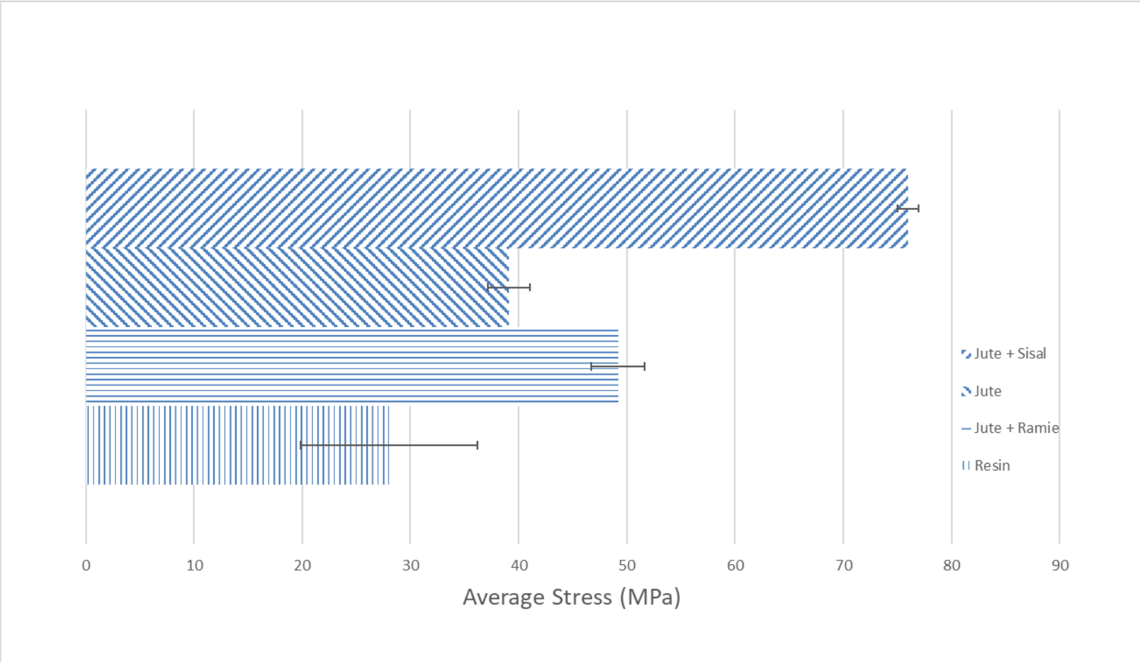

Figure 8. Average strength (MPa).

With a small increase in density, and subsequently weight, there was a gain of near double in strength (48%), when comparing the simple twin layer jute composite with the other, also twin layered, jute/sisal composite. The Young's modulus also presents a great increase (57%). The ramie influences the jute/ramie fabric in a positive manner, but not as much as the sisal. This might occur due to a worse interaction of the ramie + jute than the sisal + jute. It was shown in the literature (Swolfs *et al.*, 2014) that the interaction between hybrid composites is not linear in relation to their part in the composite. Therefore, it is possible that a rise in the percentage of ramie in the jute fabric might result in a nonlinear increase in properties.

In order to investigate the fracture mechanics of the composites studied SEM images were taken from the fractured tensile specimens. Figure 9 shows the jute/ramie composite fracture area and it is possible to see where the debonding occurred. The fragmented and lighter colored fibers are the jute, the darker areas are the matrix and the less fragmented fibers are the rami.

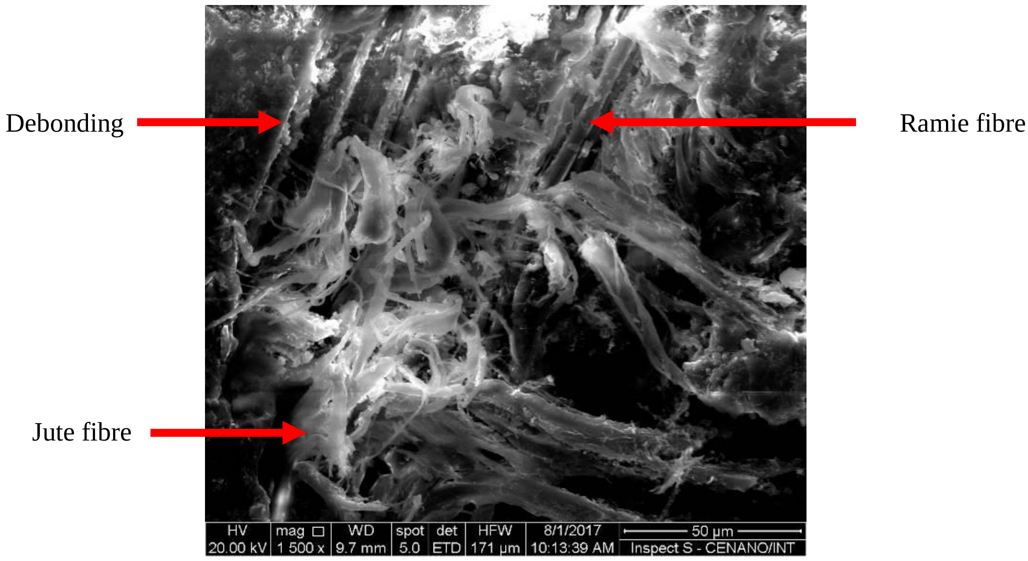

Figure 9. SEM image of the jute/rami specimens.

The debonding is expected as these types of fibers often present a weaker interaction with epoxy matrixes then other synthetic fibers. The main fracture mechanism was matrix cracking; debonding and an uneven fibre rupture along the width of the sample, as seen in Fig. 6 and Fig. 7. No necking or deformation was observed in the specimen's width, as expected. There are no apparent voids or air bubbles that can be seen, ruling out failure due to defects in manufacturing.

4. CONCLUSION

The present work studied and obtained the mechanical properties of simple jute NFRC and compared it to more complex intrayarn hybrid NFRC. Intrayarn hybrid NFRC's shows great potential as a means to improve the mechanical properties of simpler NFRC's with little alteration to its overall dimensions. Interactions between fibers have shown an increase in strength with very little change in density proving that these composites may, with more research and study, be applied in structural application in the near future. The best result was found for the jute/sisal composite, having 48% more tensile strength and an increase of 57% of the Young's modulus compared to the other tested fibres. It has also been shown that the interactions between fibres in a hybrid fabric will greatly affect the end properties of the composite.

5. ACKNOWLEDGEMENTS

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