Article

Influence of the Quantity of Water Absorption in the Mechanical Properties of Jute Fiber and Glass Fiber Composites

Camilla Medeiros Dantas [1], Raimundo Carlos Silverio Freire Júnior [1], Jayna Kátia Dionisio dos Santos [2], Camilla Cruz da Silva [3], Elmo Thiago Lins Cöuras Ford [1]*

[1] Federal University of Rio Grande do Norte. Natal, RN – Brazil;
[2] Federal Institute of Science Education and Technology of Ceara, Jaguaribe, CE – Brazil;
[3] Federal Institute of Science and Technology of Bahia, Vitória da Conquista, BA – Brazil;

* Correspondence: elmocouras@hotmail.com; Tel.: +55-83-998521609

Abstract: The use of plant fibers as reinforcement in composites with the aim of totally or partially replacing synthetic fibers has received significant attention in the last years. However, one of the disadvantages of the use of these fibers in polymeric composites is associated to the fact that they are hydrophilic, resulting in poor adhesion with most matrices when in the presence of moisture. In addition, another problem encountered is the lower strength of this type of fiber and, as a solution to minimize these problems, the composite can be hybridized by adding layers of natural and synthetic fibers and the use of resin protection along the thickness of the composite. (Lateral protection) to reduce moisture absorption by the laminate. The objective of this work is to obtain composites formed by five layers of reinforcement and terephthalic polyester matrix, one of which is reinforced only with short glass fiber-E blanket, another reinforced only with jute fiber and a third hybrid containing the fibers. Two types of reinforcements with interlayer layers. Afterwards, the loss of mechanical properties was observed when these materials were immersed in distilled water, with and without lateral protection, until reaching saturation. We evaluated parameters such as the influence of configuration type and environmental conditions, such as the amount of water absorption. The obtained results show that the hybrid composite obtained a behavior close to the composite containing only fiberglass, and better than the one containing only jute fiber and that the absorption was smaller in the samples with side protection.

Keywords: Polymer composites, fiberglass, jute fiber, moisture absorption.

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1. Introduction

There is a worldwide trend towards sustainable alternatives to traditional materials in all sectors of the economy. In this context, there has been a greater demand for materials that met specific characteristics, that is, materials that are economically viable and at the same time meet the new technological and environmental requirements. Thus, there has been an increase in the use of composite materials with the aim of replacing traditional materials [1].

In addition to synthetic reinforcements (fiberglass and carbon) [2-4], natural fibers (rami, jute, sisal and curauá) can be used in the fabrication of composite materials. The latter still have the benefit of using a lower cost fiber and when discarded still have the advantage of being less aggressive to the environment [5].

Due to the poor mechanical performance of some plant fibers, their union with higher performance (synthetic) fibers can give rise to materials with greater probability of structural application. In hybrid composites two or more types of fibers are used as reinforcements in one or more types of resins. The main idea is to meet certain properties that only one type of fiber and matrix does not meet [6].

During the use of a composite, a common problem to be verified is the loss of its mechanical properties with the presence of moisture, being more aggravating in the natural fiber-based composites due to its hydrophilic nature [7-8]. In addition, plant fibers may be susceptible to fungal and bacterial attacks.

Thus, this work has the objective of verifying the loss in the mechanical properties of three laminated composites after being saturated in distilled water. One of them was reinforced only with E-glass fiber blanket (MV), another hybrid with E-glass fiber and jute fabric with interlayer layers (HJV) and a third containing only jute fiber fabric (TJ). In addition, it has been found that the use of a side shielding of the samples decreased moisture absorption and loss in mechanical properties.

2. Materials and methods

2.1. Manufacturing Process

For the manufacture of the laminates, Terephthalic polyester resin was used as matrix, with density of 1.30 g/cm³ and viscosity of 310 cP at 25 °C. The catalyst used for the resin curing system was Butanox. As reinforcement material, the E-glass short fiber blanket (5 cm long) was used, with a weight of 450 g/m², the fiber density at 2.54 g/cm³ and a bidirectional jute fabric at a weight of 306 g/m². The composites were manufactured by the manual laminating process, which consists of placing blankets and fiber fabrics on the surface of a mold, followed by the application of resin for impregnation.

Three plates of 1.5 m² each were obtained, in the form of laminar structures, all with 5 layers of reinforcement and polyester matrix. Where one of them contains five layers of E-Glass (MV) Short Fiber Blanket, the other contains five layers of Bi-Directional Jute Fibers (TJ) and the third is a hybrid of three layers of Short Glass Fiber Blanket -E and two layers of two-way jute fabric (HJV) (Figure 1).

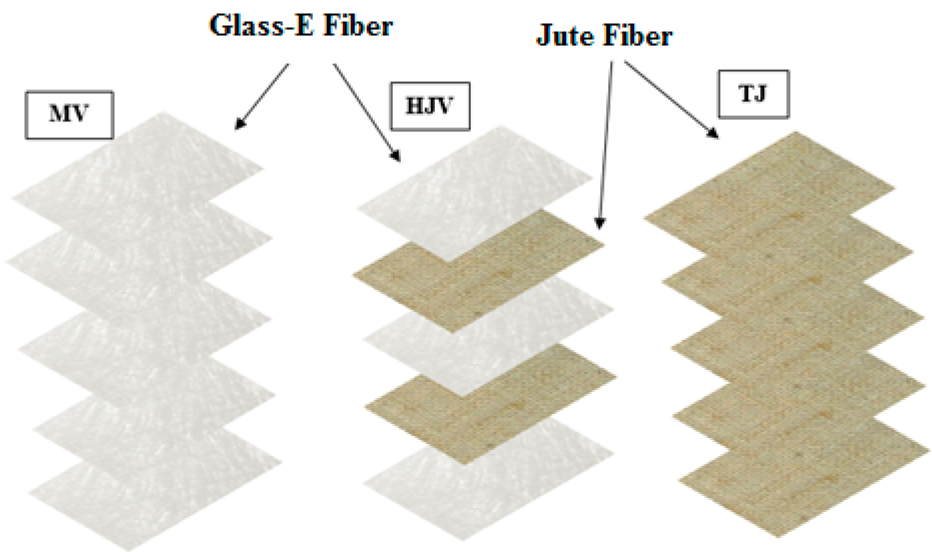

Figure 1. Configuration used in the construction of composite laminates MV, HJV and TJ.

It should be noted that, for the uniaxial tensile tests, the bidirectional tissues present with the directions of the fibers always parallel (0°) and perpendicular (90°) to the direction of application of the load. The thicknesses of the composites resulted in approximately 4 mm, 5 mm and 6 mm for the MV, HJV and TJ, respectively. For the mechanical tests, eight tests were carried out for each case and for the water absorption and density tests, five samples were used, totaling 186 tests.

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The idealization of these types of laminates is aimed at the application involving high moisture content, such as reservoirs, water and sewage pipes or even in the nautical industry.

2.2. Volumetric density and calcination

For the determination of the volumetric density of the composite, the standard ASTM D7929 was used. Calculations were performed according to Equation (1).

$$D = \frac{a}{(a+w+b)} . 0.9975 \quad (1)$$

In Equation 1, D is the density of the composite, (g/cm^3), a is the weight of the dry sample, (g), w is the weight of the yarn partially immersed in water, (g) and b is the weight of the yarn with samples immersed in water, (g).

The procedure for obtaining the percentages of fiber, resin and voids was through the calcination test. For this, the test proof bodies of volumetric density were used, where they were pyrolyzed to eliminate part of the resin, and then were placed in the murine-like oven at 750 °C for a period of 40 min. In this way, the volumetric fractions of fiber, resin and voids were obtained.

2.3. Uniaxial Traction Test

The ASTM D303910 was used to perform this test. For the determination of the mechanical properties of uniaxial traction, eight specimens of each composite were tested and, for each situation, dried and then saturated in distilled water with and without protection of the lateral edges. The test was performed at a speed of 1 mm/min and then the ultimate tensile strength, modulus of elasticity and rupture deformation were determined for the samples before and after immersion of the specimens in the distilled water.

2.4. Water Absortion Test

The water absorption tests were conducted in distilled water and based on ASTM D57011. For each laminate, five test specimens measuring 25 mm x 76 mm were used.

The test specimens were cut, measured and weighed before being immersed in water at ambient temperature. Since absorption is greater at the start of the process, the samples were weighed in the first 12 h and after 24 h measures were taken every week (168 hours).The material was considered saturated, that is, could not absorb more water, when absorption did not exceed the previous measure by 1 % or when the absorbed weight was less than 0.005 g between weighings.

It is important to underscore that the tensile and three-point bending tests were conducted in both dry and saturated samples for both laminates.

In addition, we analyzed the value of the diffusion coefficient (D) and coefficient of Fick, this parameter is the absorption rate, in this case the speed that the water is absorbed by the material, so that a material with high diffusivity coefficient will absorb large amounts of water quickly, something undesirable in most applications, while a material with a low value of diffusion coefficient takes a long time to absorb water even absorb large quantities at the end of the test. Equation 2 [12] then refers to the calculation of the Fick coefficient (mm^2/s).

$$D = \pi \left(\frac{h}{4M_m}\right)^2 \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2 \quad (2)$$

In the Equation 2, D is the coefficient of Fick, h is the mean thickness of sample (mm) mm and the maximum moisture absorbed t_2, t_1, M_2 and M_1 are time points (s) and humidity respectively obtained in the linear region (initial) humidity test.

From Fick obtaining the coefficient may be constructed to theoretical curve of water absorption (G), represented in Equation 3 [12]. Where t is the time in seconds, and D shows the diffusion coefficient.

$$G(t) = 1 - \exp\left[-7.3\left(\frac{Dt}{h^2}\right)^{0.75}\right] \quad (3)$$

3. Results and Discussion

3.1. Volumetric densities and volumetric percentages of Composites

The volumetric densities and fiber percentages of the composites MV, HJV and TJ are shown in Table 1. As expected, the volumetric density value of the glass fiber composite presented the highest value, while the composites with jute fiber presented lower values, due to the density of the jute being smaller than that of the glass fiber.

Table 1. Volumetric density of the three composites analyzed.

Configuration	Density (g/cm^3)	Fiber glass	Jute fiber
MV	1.51	24%	-
HJV	1.37	12%	15%
TJ	1.19	-	26%

In addition, it is noticed that the volumetric percentages of the fibers are similar to each other, this is important because it allows to make a comparison between the laminates considering only the fiber used.

3.2. Moisture absorption test

In order to analyze the moisture absorption in glass fiber blanket (MV) laminates, in fiberglass and jute blanket (HVJ) laminates and in jute fiber (TJ), moisture absorption tests were performed, which are shown in Figures 2 and 3, respectively. By these results we can see that all these materials presented an absorption that follows the law of Fick. This result was found with similar values by other authors [14-16].

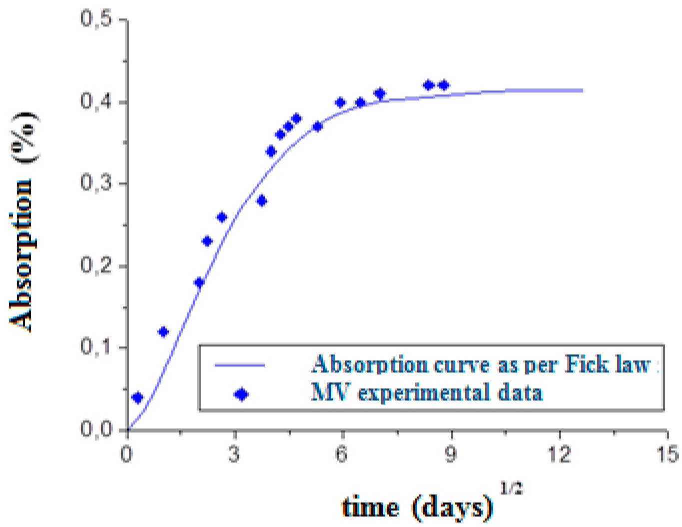

Figure 2. Percent absorption x immersion time - MV.

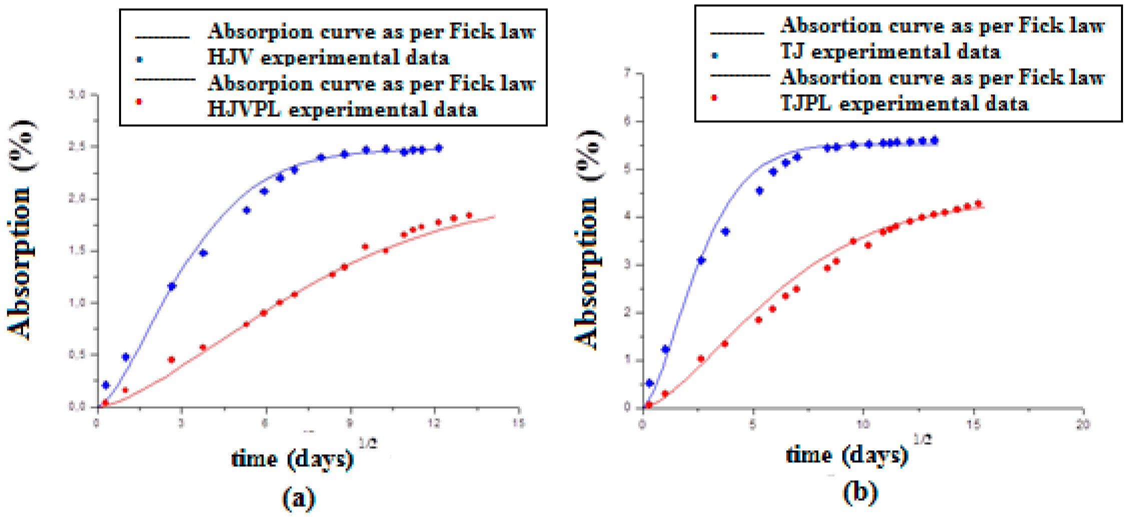

Figure 3. Percent absorption x immersion time. (a) HJV e HJV_{PL}. and (b) TJ and TJ_{PL}.

Moreover, in the laminates that have jute fiber, in some specimens, the sides were sealed in order to try to decrease the moisture absorption in their thickness, by protecting them laterally (HV_{PL} and TJ_{PL}). Figure 3 shows that the use of this technique decreased the water absorption.

With the results obtained by the absorption it was possible to obtain the main properties to the absorption of these materials, according to the data presented in Table 2. From these results it is verified that the fiberglass blanket laminate has the lowest maximum absorption value and that the protection Lateral lamellae significantly decreased the diffusivity in the laminates (with a decrease from $2.88.10^{-6}$ to $0.545.10^{-6}$ for TJ laminate).

Table 2. Results obtained in the Moisture Absorption Test.

Material	Maximum Absorption (%)	Saturation Time (Days	Coefficient of Diffusivity (mm²/s)
MV	0.41	49	$1.51.10^{-6}$
HJV	2.48	105	$1.24.10^{-6}$
HJV_{PL}	1.81	161	$0.267.10^{-6}$
TJ	5.53	105	$2.88.10^{-6}$
TJ_{PL}	4.36	203	$0.545.10^{-6}$

In addition, the lateral protection significantly increased the saturation time (from 105 to 161 days in the HJV material) and the maximum absorption value, and it is recommended for use in any application to reduce the moisture absorption along the time.

3.3. Uniaxial Traction Tests

In order to evaluate the influence of fiber type and moisture (with and without protection) after saturation, tensile tests were carried out on the materials studied here and their results are presented in table 3, where it was verified that there was a decrease in resistance of 39.33 MPa (percent difference of 40.4%) of the MV laminate for the HJV hybrid laminate, while that decrease was 31.62 MPa (54.5% difference percentage) of the HJV for the TJ for the dry state. These results were expected, since the mechanical properties of the jute fiber are inferior to those of the fiberglass.

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Table 3. Uniaxial Traction Properties of the MV, HJV and TJ Composites in the dry, wet saturated state and HJVPL and TJPL composites in the wet state with lateral protection

Mechanic Proprieties	Composite materials							
	MV		HJV			TJ		
	Dry	Saturated	Dry	Saturated	HJV_{PL}	Dry	Saturated	TJ_{PL}
Last tension (MPa)	97.33	95.05	58.00	55.30	56.89	26.38	19.39	23.43
Modulus of Elasticity (GPa)	2.74	2.31	1.67	1.52	1.66	1.20	0.97	1.02
Breaking Deformation (%)	3.14	3.86	3.13	3.28	2.39	2.16	1.92	1.88

In the wet state, the last resistance results are presented in Table 3, there was a decrease of 39.75 MPa (percentage difference of 41.82%) of the MV laminate for the HJV hybrid laminate, while that decrease was of 35.91 MPa (percentage difference of 64.94%) from the HJV to the TJ. They obtained similar decrease to those obtained in the dry state.

For the lateral protection composites, the final tensile stress values show a decrease of 33.46 MPa (58.8% percentage difference) of the HJVPL hybrid laminate for the TJPL laminate. However, when compared the laminate with lateral protection with the unprotected ones, it' is observed that the protection does not bring gain of performance.

With respect to the elastic modulus, in Table 3 it is verified that the jute fiber decreases the stiffness of the material. This can be confirmed by analyzing the behavior of the hybrid composite. The percentage difference recorded in the elastic modulus is 39.05% (decrease from 2.74 GPa to 1.67 GPa), when comparing MV and HJV, and 28.14% in relation to HJV and TJ (decrease from 1.67 GPa to 1.2 GPa). It is also found that the jute fiber decreases the stiffness of the material when they are wet.

In order to better visualize all the results, the bar graph shown in Figure 4 was designed for the resistance of the laminates with the respective dispersions. By this graph, it can be seen that, as already mentioned, the addition of jute fiber decreases the strength of the materials. Even though the resistance decreases in all cases, it decreases within the dispersion margin, except for the TJ, and the use of lateral protection improves the resistance of the TJ. This result demonstrates the importance of hybridization, which in addition to increasing the strength of the composite (relative to TJ), makes it less immune to moisture.

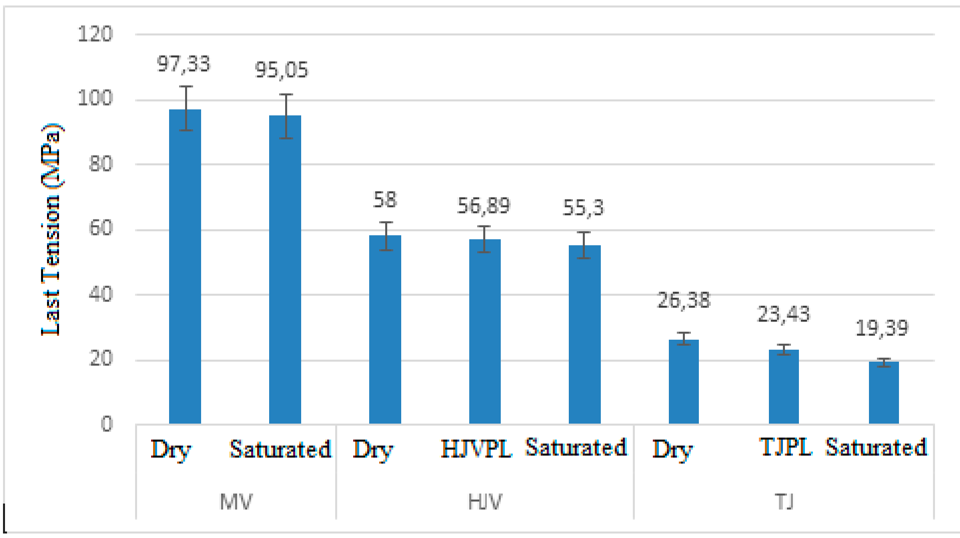

Figure 4. Comparison of the last tension of the laminates MV, HJV and TJ in the dry and saturated state and with lateral protection

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It is also important to note that side-shielded samples were tested in the saturated condition, and that this occurred in a much longer time (50% to 100% of the time) than samples without lateral protection, as shown in Table 2. And yet, they exhibited higher values of resistance. This demonstrates the importance of this procedure in situations of application in great humidity.

To analyze the effect of rigidity, the bar graph of Figure 5 was drawn with its respective dispersions. Here, as in the resistance, a decrease in stiffness with the addition of jute fiber and that the humidity has little influence in this factor, staying within the dispersion values, even for the TJ laminate.

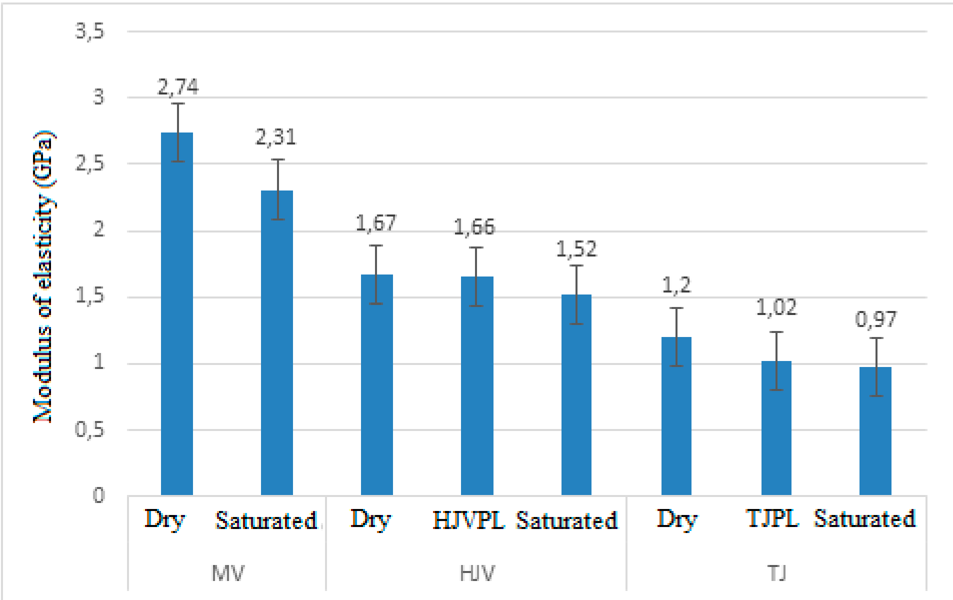

Figure 5. Comparative of the modulus of elasticity of laminates MV, HJV and TJ in the dry and saturated state and with lateral protection.

5. Conclusions

Based on the presented results, it can be concluded that:

- The insertion of jute fiber in the composite makes it lighter due to its low volumetric density.

- The use of lateral protection reduced the moisture absorption of all combinations of composites analyzed.

- The MV laminates and the HJV hydride composite had similar final tension behavior in the dry and saturated state. The TJ composite, however, had its resistance decreased in the saturated state compared to the dry state.

All the laminates had their modulus of elasticity reduced in the saturated state.

- The use of lateral protection did not represent significant gains in the analyzed materials, having a little efficiency only in the TJ laminate.

- The insertion of the jute fiber significantly decreased the strength and modulus of elasticity.

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