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WOOD RESIDUE OF JATOBÁ *(Hymenaea courbaril)* AND SHORT FIBER OF MALVA IN COMPOSITES

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ABSTRACT

Theoretical reference: The composites are formed by combining two or more materials, enabling improvements in properties and a variety of applications. These materials are highlighted by presenting low cost and enabling environmentally friendly alternatives.

Method: Quantitative study, In this work, composites of polyester matrix reinforced by mauve fibers, jatoba wood residues and hybrid mauve/residue system, were analyzed mechanically and microstructurally. The fabrication of the composites began with the cut of the mauve fibers in the lengths of 5, 10 and 15 mm. In the manufacture of the specimens, terephthalic polyester resin was used with incorporation of fibers and residue. The specimens were produced in silicone molds, for the tensile strength tests and scanning electron microscopy (SEM) analysis.

Results and conclusion: From the results obtained in the tensile test, it is observed that the resistance of the composites with mauve fibers of 15 mm (25,09 MPa) and hybrids in the proportions of 75% fiber/25% residue (26,06 MPa). In the microstructural characterization, the composites analyzed presented factors that contributed to the improvement and reduction of performance in the results of tensile strength.

Implications of the research: It presents important and overwhelming results on composite materials with wood waste and mallow fibers, providing an alternative for inserting waste and fibers into materials with good properties and low cost.

Originality/value: The compounds stand out for their simple and viable manufacturing method, in addition to superior results in relation to proven properties. Given the need to search for new materials with good properties and with minimal impacts on the environment.

Keywords: Composite, Hybrids, Fiber, Properties.

RESÍDUO DE MADEIRA DE JATOBÁ *(Hymenaea courbaril)* E FIBRAS CURTAS DE MALVA EM COMPÓSITOS

RESUMO

Referencial teórico: Os compósitos são formados pela combinação de dois ou mais materiais, possibilitando melhorias em propriedades e uma diversidade de aplicações. Esses materiais ganham destaque por apresentarem baixo custo e permitir alternativas ambientalmente favoráveis.

Método: Estudo quantitativo, os compósitos de matriz poliéster reforçados por fibras de malva, resíduos de madeira de jatobá e sistema híbrido de malva/resíduo, foram analisados mecânica e microestruturalmente. A fabricação dos compósitos teve início com o corte das fibras de malva nos comprimentos de 5, 10 e 15 mm. Na fabricação dos corpos de prova utilizou-se a resina poliéster tereftálica com incorporação de fibras e do resíduo.

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Os corpos de prova foram produzidos em moldes de silicone, para os ensaios de resistência à tração e análise por microscopia eletrônica de varredura (MEV).

Resultados e conclusão: A partir dos resultados obtidos no ensaio de tração, observa-se que a resistência dos compósitos com fibras de malva de 15 mm (25,09 MPa) e híbridos nas proporções de 75% fibra/25% resíduo (26,06 MPa). Na caracterização microestrutural, os compósitos analisados apresentaram fatores que contribuíram para a melhoria e redução do desempenho nos resultados de resistência à tração.

Implicações da pesquisa: Apresenta resultados importantes e satisfatórios sobre os materiais compósitos com resíduos de madeira e fibras de malva, disponibilizando uma alternativa de inserções dos resíduos e das fibras em materiais com boas propriedades e baixo custo.

Originalidade/valor: Os compósitos se destacam pelo método simples e viável de fabricação, além dos resultados satisfatórios em relação às propriedades analisadas. Visto que diante das necessidades da busca por novos materiais com boas propriedades e com mínimo de impactos ao meio ambiente.

Palavras-chave: Compósito, Híbridos, Fibra, Propriedades.

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1 INTRODUCTION

Analyzing the current scenario regarding environmental issues, there is a notorious concern about the large production of solid waste, which is considered to be the biggest aggressor of the environment. Despite recent technological advances, most industrial waste continues to be disposed of irregularly, with negative consequences not only for the environment, but also for public health. As a result, there is a need for research into the reuse of this waste as a way of reducing environmental impacts (Tera, 2021).

In the midst of technological advances in the automotive industry, there is a need to obtain specific material properties in order to meet certain demands, especially mechanical ones, aimed at the numerous vehicle components, whether internal or external. In this sense, the area of composite materials is analyzed as promising to meet this demand, promoting the union of materials, often chemically distinct, so that specific properties can be acquired (Rodrigues, 2012; Branco, 2016 and da Costa, 2012).

Given this scenario, the manufacture of composite materials with a polymeric matrix has emerged as an alternative source for using this waste. Composites are a mixture of different materials with more satisfactory properties than individual materials. In addition, composite materials have a continuous phase, which can consist of a ceramic, metallic or polymeric material, and a dispersed phase, in which the waste can be used as reinforcement (Callister Jr., 2021).

The composition of these materials offers advantages, especially from the point of view of mechanical behavior, such as increased rigidity and mechanical resistance, better fatigue responses under cyclic loads, reduced weight while maintaining the level of resistance, etc. (Shigley, 2005). According to Rodrigues (2008), the material's binder is called the matrix, which has the function of enveloping the components,

i.e. it makes up the shape of the material. The components inserted into the matrix generally act as reinforcing or filling substances, and the properties of the composites depend on the nature and properties of the reinforcement (Martins, 2010).

In the study of composite materials, the matrix phase is of great importance. As well as

acting as external protection for the reinforcement phase against chemical agents, it is also responsible for transmitting stresses from external forces to the reinforcement and promoting ductility in the material. When it comes to natural fiber composites, the polymer matrix is widespread, but other matrices, such as ceramics, have also been of great importance in current research in the field of engineering, such as the manufacture of sisal fiber reinforced material with a cementitious ceramic matrix (Teixeira, 2022 and Fujiyama, 2013).

Among the materials used as reinforcements in composites, the mallow plant, scientifically known as *Urena lobata L.*, has liberian fibers found between the cambium layer that surrounds the central woody pith of the stem and the outer layer of the bark, with a significant degree of resistance, which guarantees it a place in the commercial sector (Costa et al., 2012).

Wood is a composite of lignin and cellulose of natural origin, and the generation of waste is linked to the type of raw material used and the degree of utilization (HILILIG, et al., 2004). In this context, the large amount of waste generated has always been a cause for concern, especially sandpaper dust and sawdust, which have a low density and require more space for storage (Yamaji and Bonduelle, 2004).

Wood waste comes from bark, stumps and sawdust to the final product. The process of industrializing wood generates waste, which needs to be properly treated. On the other hand, improper disposal can cause significant environmental damage, including carbon dioxide emissions from open burning and river contamination from irregular dumping. To minimize these problems, sustainable alternatives can be made possible, such as the production of composite materials with this waste (Silva et al., 2017).

This work consists of reusing jatoba wood waste by incorporating it into polymer composites reinforced with mallow fibers.

2 OBJECTIVES

The purpose of this work was to evaluate the influence of incorporating mallow fibers and jatoba wood waste, individually and in combination (hybrids), into a polymer matrix, in order to assess the mechanical characteristics through tensile testing and microstructural characterization through scanning electron microscopy (SEM).

The specific objectives of the research were**:**

1. Analyze the influence of the type of reinforcement and fiber length on the mechanical properties of the composites;
2. Evaluate the mechanical performance of mallow fiber composites (5, 10 and 15 mm), composites with jatoba wood residue and the mallow/residue hybrid using a length of 15 mm;
3. Analyze the microstructure of the fractured surface of the composite specimens.

3 METHODOLOGY

3.1 Fabrication of Tensile Test Specimens

The mallow fibers were cut manually using scissors and millimeter paper in 5, 10 and 15 mm sizes and the jatobá wood waste, obtained from a local carpentry shop, was weighed and heated at 50 ºC for 20 minutes to remove the moisture.

The masses of the polyester resin and the catalyst were determined using an analytical balance, showing 61.5 g and 0.15 g, respectively.

Silicone molds were used to make the specimens according to the dimensions required by the ASTM D 638M standard, as shown in Figure 1. The silicone mold was chosen because

it maintains the mechanical consistency of the specimen and facilitates the process of demolding the composite.



Figure 1 - Silicone mold used to make the composites.
Source: Prepared by the authors (2023)

The fiber mass fractions to be used to manufacture the test specimens were taken from the work by Luz (2013). The jatoba wood residue was measured by filling a silicone mold to the limit of its volumetric capacity, followed by determining the mass on an analytical balance. The procedure was carried out five (5) times and, once the values were obtained, the composite compositions were defined, as shown in Table 1, where "CF" refers to fiber composites in different lengths, "CR" refers to composites with jatoba wood residue and "CH" refers to hybrid fiber/residue composites in percentage of mass.

Table 1 - Compositions used in the research.

Composition	Resin (g)	Fiber (g)	Waste (g)	Amount
CF05	15,37	0,74	-	5
CF10	15,37	0,67	-	5
CF15	15,37	0,61	-	5
CR	15,37	-	1,53	5
CH75/25	15,37	0,46	0,40	5
CH50/50	15,37	0,30	0,80	5
CH25/75	15,37	0,15	1,21	5

Source: Prepared by the authors (2023)

Production of the specimens began with weighing the resin and inserting the catalyst using a graduated pipette, followed by homogenizing the mixture for a period equivalent to 30 seconds, after which the mallow fiber reinforcement and jatoba wood waste were added, when necessary and according to the compositions determined in Table 1, mixing them for a further 4 minutes and 30 seconds, at which point the mixture was transferred to the molds.

After seven days of curing, the process by which the specimens solidify, they were removed from the mold for sanding and finishing. Once the sanding process was complete, the specimens were marked according to the specifications of ASTM D 638M, so that they could be taken to the mechanical test. Figure 2 shows (a) filling the mixture, (b) the composites before sanding, (c) after sanding and (d) the marked composites.

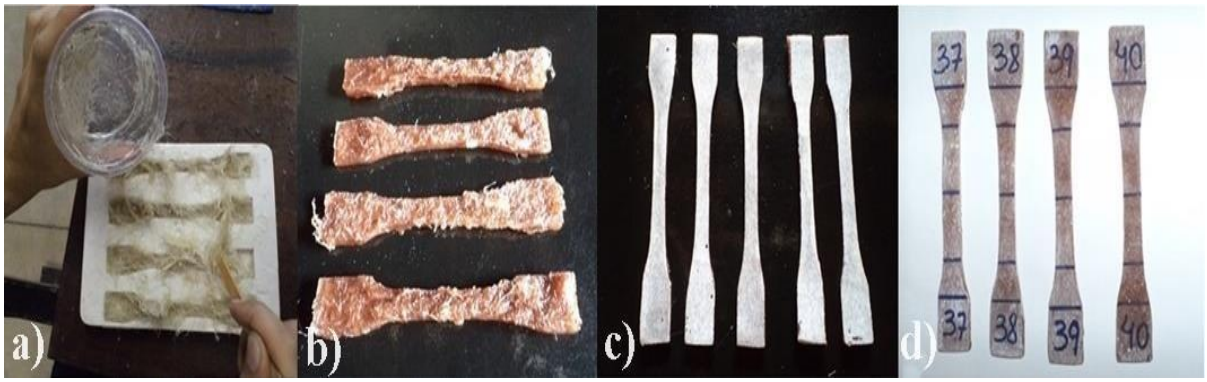

Figure 2 - a) Filling the mixture; b) Composites before sanding; c) Composites after sanding and d) Composites marked for tensile tests.
Source: Prepared by the authors (2023)

3.2 Mechanical Characterization of Composites

The mechanical characterization was carried out at the Mechanical Testing Laboratory of the Federal University of Pará - UFPA, using a tensile test in accordance with the specifications of the ASTM D 638M standard. A KRATOS model MKCA - KE machine was used for the test, where the specimen was positioned to apply a load of 5 kN in its center, at a test speed of 5 mm/min. Five repetitions were carried out for each composition.

3.3 Microstructural Characterization of the Composites

Microstructural characterization was carried out using scanning electron microscopy (SEM). Fracture surface analysis was carried out to help identify factors that could cause mechanical failure in the composites.

4 RESULTS AND DISCUSSIONS

4.1 Specimens

After the curing process, the specimen was sanded to conform to the test specifications, where the specimen had to be 3.2 mm thick.

In order to reach the specified value, sandpaper ranging in grain size from 80 to 120 µm was used.

4.2 Mechanical characterization

The mechanical characterization of the specimens consisted of tensile strength tests in accordance with the standard specifications. Table 2 shows the results of the tensile strength tests carried out on composites with jatoba wood waste and with mallow fiber in their respective lengths of 5, 10 and 15 mm.

Table 2 - Results of tensile strength tests carried out on mallow fiber and jatoba wood composites.

Composition	Tensile Strength (MPa) (Standard Deviation)	Maximum force (N) (Standard Deviation)	Linear elongation (mm) (Standard Deviation)
CR	20,67 (± 0,85)	661,67 (± 27,15)	4,70 (± 0,50)
CF05	23,41 (± 2,64)	749,08 (± 84,69)	4,93 (± 0,15)
CF10	23,51 (± 1,93)	752,43 (± 62,06)	4,80 (± 0,19)
CF15	25,09 (± 2,03)	803,10 (± 161,28)	4,92 (± 0,44)

Source: Prepared by the authors (2023)

The results shown in Table 2 show that the incorporation of particulate wood waste resulted in a composite with the lowest tensile strength when compared to fiber-reinforced composites, and the lowest linear elongation (on average), which may indicate an increase in the material's stiffness. Also according to Table 2, there is a tendency to improve tensile strength with increasing fiber length, where composites reinforced by 15 mm fibers obtained mechanical performance on average superior to the others, a fact that can be associated with the lower number of tips in the longer fibers when compared to the shorter ones, thus reducing the possibility of crack nucleation in the composite, acting positively on the mechanical properties (Costa, 2012).

There was also an improvement in the alignment effect of the fibers on the length of the specimens as the length increased. Figure 3 illustrates the Force x Displacement performance for 5, 10 and 15 mm mallow-reinforced composites and composites with added wood waste.

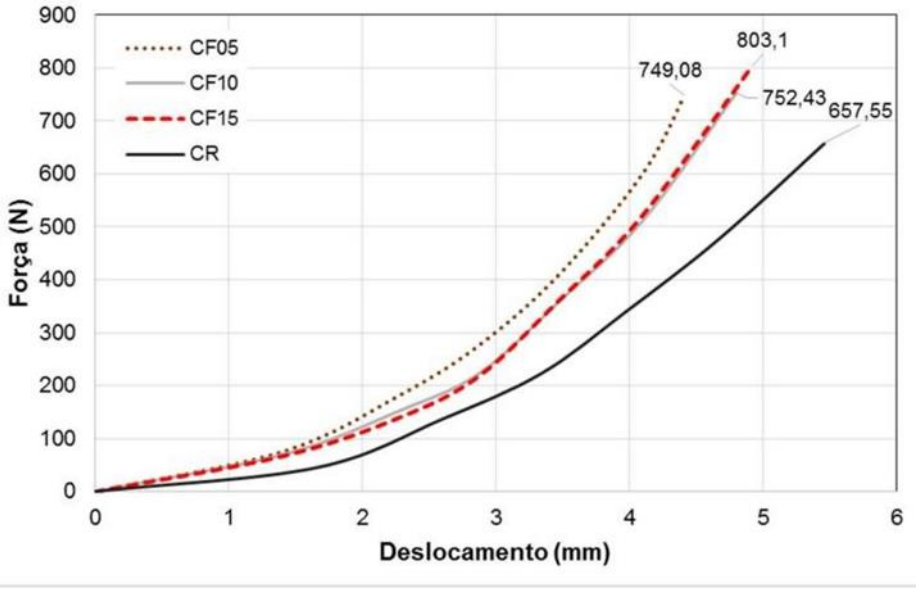

Figure 3 - Force x Displacement of composites reinforced with 5, 10 and 15 mm mauve.
Source: Prepared by the authors (2023)

According to Figure 3, which illustrates the performance of the force by displacement for a sample representing the average of the composites reinforced with 5, 10 and 15 mm mallow and wood waste, it can be seen that as the length of the fibers increased there was a greater tolerance to the force before the specimen broke, similarly, the jatoba waste reinforcement did not have a considerable influence on the tensile strength of the composites.

The combined incorporation of waste and fiber was carried out with 15 mm fibers (best mechanical performance) varying in composition from 0 to 100% of the dispersed phase incorporated into the composites, with the remainder comprising the particulate. It can be seen that the most significant strength results occurred when the proportions of fibers were higher than those of jatoba waste, as shown in Table 3.

Table 3 - Tensile test results for pure and hybrid composites.

Composition	Tensile Strength (MPa) (Standard Deviation)	Maximum force (N) (Standard Deviation)	Linear elongation (mm) (Standard Deviation)
CR	20,67 (± 0,85)	661,67 (± 27,15)	4,70 (± 0,50)
CH25/75	21,23 (± 1,77)	679,61 (± 56,86)	4,72 (± 0,19)
CH50/50	21,49 (± 2,64)	687,62 (± 148,65)	4,59 (± 0,30)
CH75/25	26,06 (± 1,91)	833,90 (± 29,40)	5,12 (± 0,12)
CF	25,09 (± 2,03)	803,10 (± 161,28)	4,92 (± 0,44)

Source: Prepared by the authors (2023)

Thus, it can be seen that the incorporation of the residue did not show property gains, however, in the CH75/25 composition, the incorporation of 25% particulate did not have a negative impact, being the fraction with the highest performance, which, in an initial analysis, justifies the incorporation of this residue in hybrid composites, obtaining a result similar to that presented by the fiber composite with the highest performance, and promoting an alternative for the reuse of wood residue.

4.3 Microstructural characterization

Microstructural analysis was carried out using scanning electron microscopy (SEM) on the fractured surfaces after the tensile test, in order to more accurately identify the failure mechanisms in the composites. Figure 4 illustrates the fractured surface of the composite reinforced with jatoba residue.

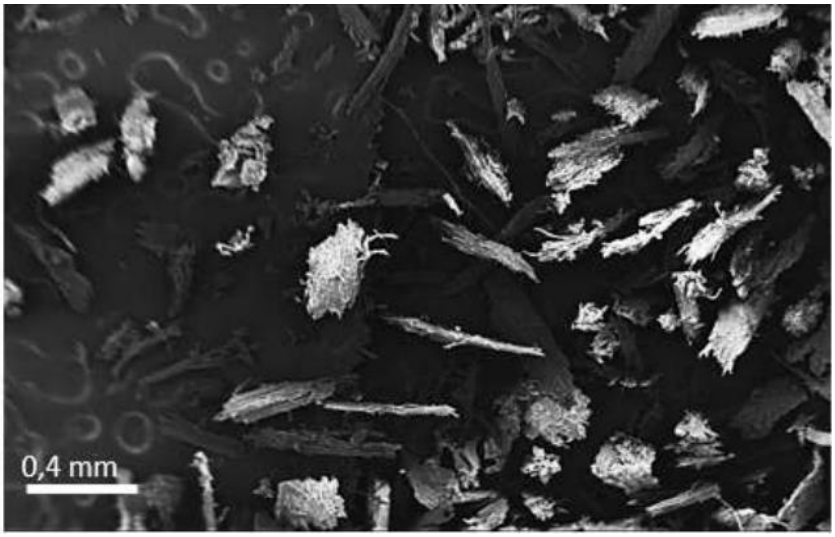

Figure 4 - Fractured surface of the composite with jatoba residue reinforcement.
Source: Prepared by the authors (2023)

Figure 4 shows that the wood waste is not evenly distributed and varies in shape and particle size, resulting in instability in its action as an effective reinforcement, which corroborates the mechanical result presented. According to Rodolfo Jr. (2005), the smaller the particle size of a filler, the greater its reinforcing capacity in a polymer matrix. Figure 5 illustrates the fractured surfaces of the mallow fiber composites:

(a) 5 mm composites (b) 10 mm composites and (c) 15 mm composites.

Figure 5(a) shows the presence of fibers detached from the polymer matrix.

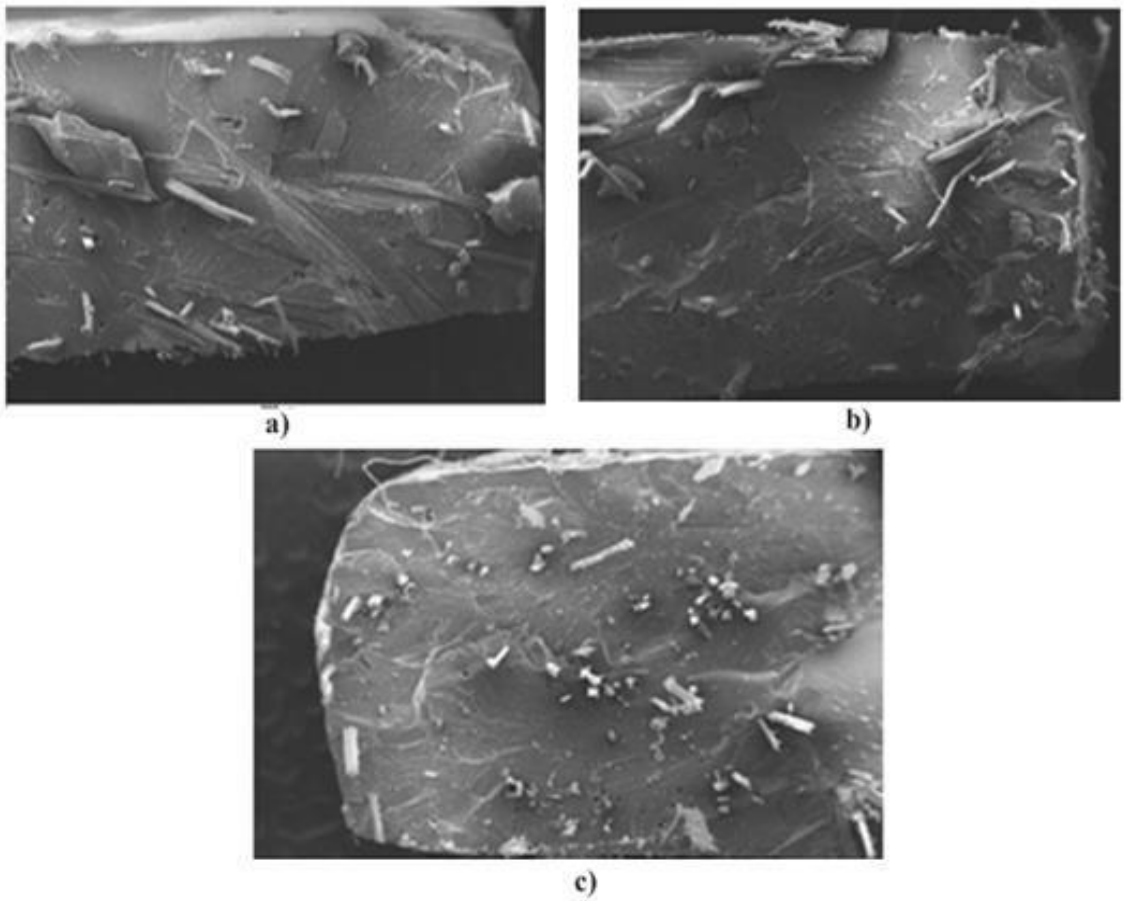

Figure 5 - Fractured surfaces of mallow fiber composites: a) CF05; b) CF10 and c) CF15.
Source: Prepared by the authors (2023)

It was also observed that the fibers arranged transversely are in the direction of the load to which the force was applied. It is clear that the positioning of the fiber can be detrimental to the tensile strength of the composite. Figure 5(b) shows a similarity with the 5 mm mallow fiber composites, where the fibers are displaced from the matrix and arranged transversely to the loading direction. It was diagnosed that in both composites the fibers were not well arranged and accommodated in the polymer matrix. Thus, it is inferred that during the curing process there was no unidirectional accommodation of the fibers, which may have suffered wear and tear due to the sanding action, causing stress concentrators or crack initiators, depreciating the tensile strength of the composites. Figure 5(c), on the other hand, shows a predominance of breakage rather than detachment, as well as the absence of transverse fibers, providing greater potential for mechanical resistance, as shown by the mechanical results.

Figure 6 illustrates the fractured surfaces of the 15 mm hybrid composites in the 75% fiber/25% wood residue ratio - CH75/25.

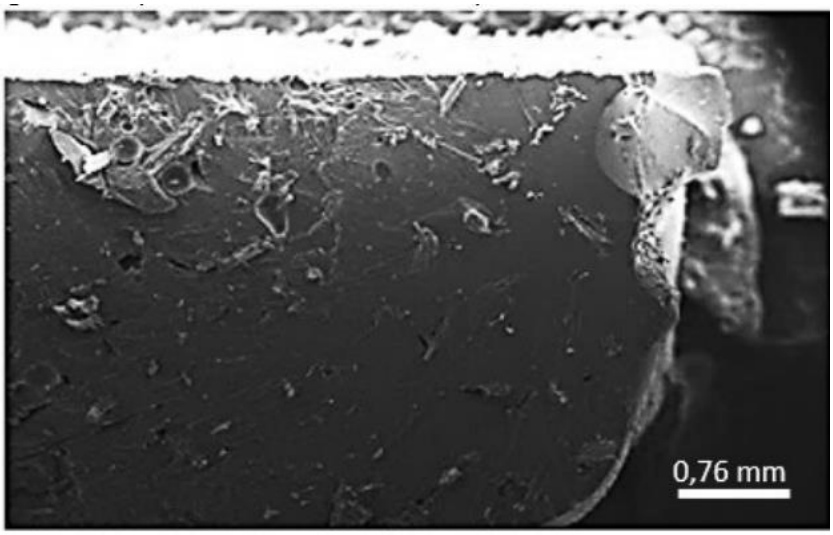

Figure 6 - Fractured surfaces of the hybrid composites: 15 mm - 75/25.
Source: Prepared by the authors (2023)

Figure 6 shows total fiber breakage and the presence of small voids formed by air bubbles, as well as the absence of fibers transverse to the stress. The composites analyzed showed factors that contributed to improving and reducing their performance.

5 FINAL CONSIDERATIONS

Analyzing the data cited in the paper, it was noted that the composites had satisfactory aspects, with few voids in their surfaces and good rigidity and appearance. The results obtained in the tensile strength test of the composites showed that fiber length had an influence on the mechanical property of tensile strength. It was also evident that the tensile strength performance of the composites with 15 mm mallow fiber at 25.09 MPa and the hybrid with 15 mm length fibers and 75/25 ratio at 26.06 MPa were more satisfactory than the composites reinforced only with jatoba wood waste.

In addition, the composites analyzed showed factors or failure mechanisms that contributed to improving or reducing the mechanical performance of the composites. In the higher-strength composites, fiber breakage predominated. In the lower-strength composites, craters and voids predominated.

Although the research did not find a significant effect that justifies the individual application of wood waste, it does prove to be an alternative for reusing this waste. Its application, together with natural fibers, showed performance equivalent to that presented by the fibers alone, providing a material with good properties and which, from an environmental and economic point of view, is promising.

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