MECHANICAL BEHAVIOR OF EPOXY REINFORCED WITH JUTE FIBER APPLIED TO CERAMIC TILES FOR A VENTILATED FAÇADE SYSTEM

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ABSTRACT

The ventilated façade is one of the solutions found by civil construction and architecture to increase the useful life of buildings. The materials used as coverings include ceramic tiles. Fiberglass meshes are adhered to the back of the ceramic tiles using epoxy resin. The purpose of using this composite conjoint is for safety reasons. Currently, several studies are focused on replacing synthetic fibers with natural fibers. Among the natural fibers, jute is the cheapest and most widely produced. The present work compares the mechanical performance between glass fiber and jute fiber. The following conjoint composites were produced: glazed porcelain tile, epoxy resin, glass fiber and jute fiber meshes. Jute fiber can present 88% lower tensile stress than glass fiber, although meeting the standard for the minimum requirement in the safety impact in the hard body test.

1. INTRODUCTION

The ventilated façade is one of the solutions found by civil construction and architecture to increase the useful life of buildings. This is due to energy efficiency and aesthetic characteristics [1]. The ventilated façade consists basically of ceramic tiles and an auxiliary substructure [2,3]. This system separates the ceramic tiles from the substructure. An air chamber is thus formed, cooling the building.

According to Campos [3], the advantages of the ventilated façade regarding the adhered façade are as follows: energy savings; reduction/elimination of moisture problems, efflorescence or infiltration of external envelopes; reduced deterioration and reduction in maintenance costs of the façade; satisfactory results in renovation work; improvement in thermal/acoustic comfort and reduction/elimination of the risk of ceramic tile detachment.

As covering components of the ventilated façade, ceramic, metallic, or polymeric materials can be used. When ceramic tiles are used, the façade component consists of an epoxy resin reinforced with a fiberglass mesh adhered to the back of the ceramic tile. This composite conjoint is used in ventilated façades to ensure consumer safety in the event of ceramic tile breakage. Therefore, the ceramic tile will not detach from the building façade. According to Richardson et al. [4], later chipping is an important concern to protect the public from debris that may occur due to fragmentation.

During the last decade, with increased environmental concern, there has been a growing interest in natural fibers. Polymeric composites of natural fibers have been increasingly used in industrial applications as substitutes for synthetic fiber composites. The environmental and economic advantages of weight reduction, higher specific strength, higher modulus of elasticity and reduced price are the main factors [5-20]. According to Bisaria et al. [21], among natural fibers, one of the major sources of lignocellulosic fibers is jute fiber. Jute fiber is obtained from the stem of the *Corchorus capsularis* plant, which comes from the Amazon region. This fiber was introduced in Brazil in the years 1950-1980. Jute fiber has moderate tensile and flexural strength when compared to other natural fibers. Jute fiber-reinforced polymer composites are suitable for primary structural applications, interior elements, and temporary outdoor applications. The insulation feature of jute becomes useful in automotive doors and roofs, engine separation panels and passenger compartments [21]. They are traditionally used in the manufacture of bags, curtains, yarns, textiles, and ropes, among others [22].

In recent years, ventilated façades have been built using ceramic tiles with large formats and reduced thicknesses. Among the properties of ceramic materials, impact resistance is one of the most critical characteristics to be considered to ensure suitability in such environments [23,24]. Therefore, in this work the replacement of glass fiber by natural jute fiber as reinforcement for ceramic tiles used in façades is studied. The mechanical performance of the structural composite was determined. The mechanical behavior of each individual component was studied, in addition to the performance of the conjoint composite against impact.

2. MATERIALS AND METHODS

a) Materials

The materials used in the preparation of the final systems included glazed porcelain tiles, epoxy resin, fiberglass mesh and jute fiber mesh. The jute fiber mesh was prepared so as to be compatible with the epoxy resin.

Glazed porcelain tiles of 0.59 m × 1.182 m × 0.012 m (width, length and thickness) were supplied by Mohawk Brazil. The epoxy resin was supplied by Shackerley (United Kingdom). The bicomponent epoxy resin was derived from bisphenol A and amines (DGEBA). The fiberglass was a bidirectional type E mesh, supplied by Gavazzi (Italy). The wire of the fiberglass mesh had dimensions of 4.0 mm × 4.5 mm × 3.0 mm. The natural fiber mesh was similar to that of the fiberglass (dimensions), but the thickness was 8.0 mm. The jute mesh was supplied by Companhia Têxtil Castanhal (Pará, Brazil). A plasticizer based on esters of acrylic acid and styrene, supplied by Claritex (Brazil), was used to make the jute fiber mesh compatible to the polymeric matrix. After treatment, the jute fiber became 66% heavier than the glass fiber. The plasticizer had a solids content of 50% and viscosity of 3.0-5.0 $kg \cdot m^{-1} \cdot s^{-1}$. The fibers used in this work are shown in Fig.01.

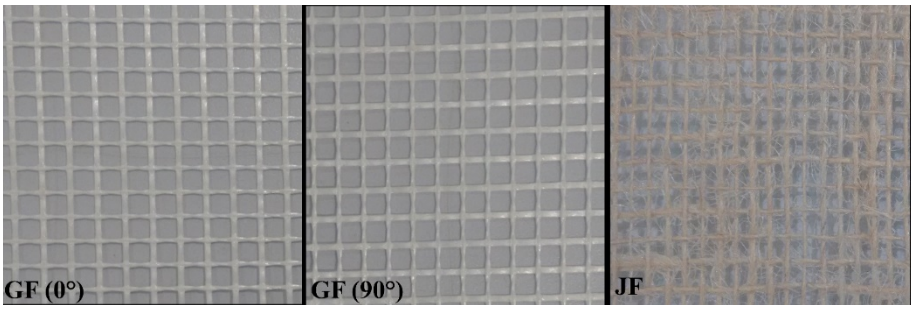

Figure 01. *Fiberglass meshes at 0° (GF (0°)) and 90° (GF (90°)) and jute fiber mesh (JF)*

b) Preparation of test specimens

To carry out the mechanical tests, three configurations were prepared: (1) ceramic tile + epoxy resin (Cer + E); (2) ceramic tile + epoxy resin + fiberglass (Cer + GFRE) and ceramic tile + epoxy resin + jute fiber (Cer + JFRE); and (3) epoxy resin + fibers (GFRE and JFRE).

For the first and second configurations, the procedure was as follows: The glazed porcelain tiles were cut into 0.30 m × 0.30 m samples using an industrial cutting machine. The meshes (fiberglass and jute) were cut according to the size of the ceramic tiles. The meshes were cut using a stylus. The plasticizer was applied to the natural jute fiber mesh with a brush in a layer of 0.280 $kg \cdot m^{-2}$. The mesh was dried at 25±1°C for 24 h. For both fibers (GF and JF), the epoxy resin was applied using a brush and a metal spatula. The mixture of the resin (82 wt.%) with the curing agent (18 wt.%) was made according to the supplier's instructions. The epoxy resin was applied on both meshes with a layer of approximately 0.50 $kg \cdot m^{-2}$. The composites were prepared applying both epoxy resin/(fiberglass or jute) meshes on the back of the tiles.

The curing was performed in a ventilated environment at 25±1°C for 72 h. After curing, the samples were cut to the required dimensions for each test following the specific standard. After cutting, the specimens were dried at 40 °C to constant weight.

For the third configuration, the hand lay-up method was used to obtain sheets with layers of 4 kg/m² and with the required thickness for the tests. After the sheets had been made, they were cut into the required dimensions.

3. TEST METHODS

The microstructures of the composites were evaluated using a scanning electron microscope (SEM) (Zeiss EVO-MA10).

A universal testing machine (EMIC DL10000, 1,000 kgf load cell) was used to determine the mechanical behavior of the samples. The tensile strength of the fibers was determined for threads with 0.025 m × 0.25 m (diameter × length) in the axial direction. Six threads were used for each fiber and epoxy resin was applied at the end of each sample to fix the samples in the clamps. Five samples of each fiber were tested at 2 mm/m. To test the tensile strength of the resin + fiber (GFRE and JFRE) samples, the dimensions of the test specimens were based on the standard test method for polymer matrix composites with dimensions of 0.025 m × 0.25 m × 0.0025 m. Five samples of each resin + fiber systems were tested at 2 mm/m. For the tensile strength test of the conjoint composites, samples with 0.012 m × 0.25 m × 0.012 m were used. The flexural strength test was based on the ISO 10545-4:2014 standard. Samples with 0.025 m × 0.25 m were used. Five samples of each configuration were tested at 1 mm/min speed.

The Charpy impact test was performed using a 75 J hammer. The height of the hammer was changed for an impact energy of 1 J. Due to the thickness of the samples (0.012 m) and to prevent the hammer from sticking on the sample, the gap of the hammer was changed (to 0.055 m). A notch of 0.010 m was made in the ceramic tile (using a cutting disc) to minimize the effect of the tile and to evaluate only the energy absorbed by the composite. The total thickness of the sample was 0.12 m.

The (Cer + GFRE and Cer + JFRE) configurations were subjected to the hard-body impact test. The procedure was based on the NBR 15.575-4:2013 Brazilian standard (Requirements for internal and external vertical sealing systems, SVVIE). The displacement and movements of the substructure were not analyzed. Failures, fissures, sinkings, transposition, delamination and collapse of the system were analyzed. Failure occurrences were more severe for the ventilated façade system than for the traditional system. Therefore, the minimum safety performance or the transposing of the sphere was not considered as a collapse of the system. The NBR 15.575-4:2013 standard establishes that the ceramic tile should not break after 10 impacts on the sample using two spheres (0.5 and 1.0 kg). The ceramic tiles are fixed vertically, as in a building façade, and the spheres hit the surface of the samples in a pendulum movement. The impact energies for façades under real use condition (3.75 J) and for safety (20 J) were analyzed. The dimension of the samples was 0.59 m × 1.182 m, corresponding to the industrial size of ceramic tiles for ventilated façades.

4. RESULTS AND DISCUSSIONS

a) Microstructural analysis

The microstructure of the GF and JF conjoint composites is shown in Fig.02. A thin layer of epoxy (400 µm) over fiberglass mesh is observed in Fig.2(A). The longitudinal section of the fiberglass shows the homogeneity of the yarns (Fig.(B)). The epoxy layer on the jute fiber conjoint composite (1,000 µm) is observed in Fig.2(C). The epoxy resin covers the fibers but does not completely fill in the weft. As the jute fibers are thick, the conjoint composite thickness was consequently larger. A void was formed in the set due to the irregularity of the natural fiber (Fig.2(C)). The longitudinal section of the jute fiber is shown in Fig.2(D). Although the jute fiber is natural, the yarns show homogeneous diameters. However, longer fibers show different thicknesses since the jute yarn is not continuous (as is fiberglass).

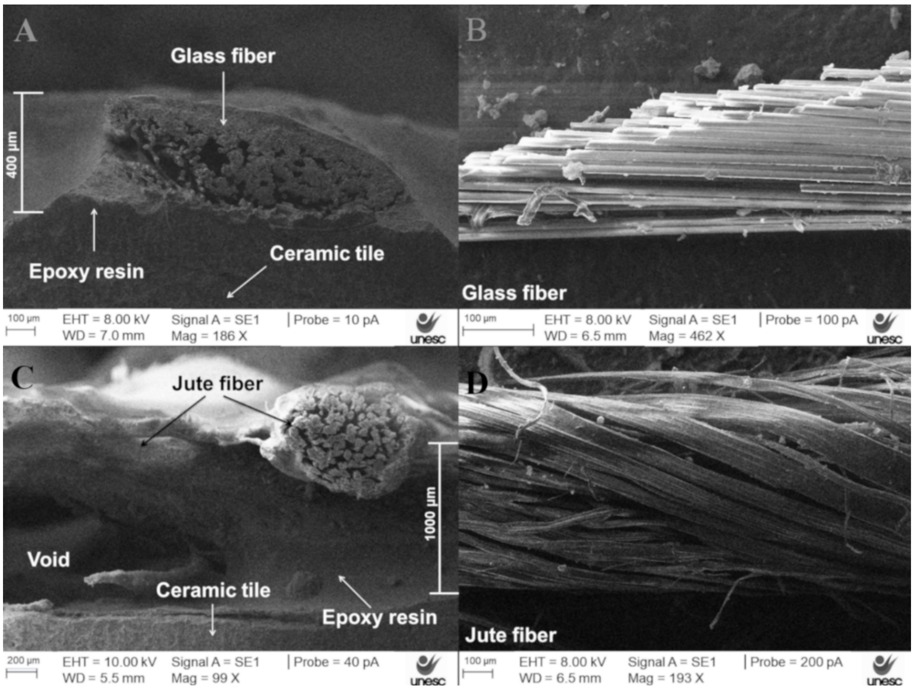

Figure 02. *Scanning electron microscopy images of the fiberglass and jute fiber conjoint composites: (A) cross-section of the fiberglass conjoint composite, (B) longitudinal section of the fiberglass, (C) cross-section of the jute fiber conjoint composite, and (D) longitudinal section of the jute fiber*

b) Fiber: Tensile strength

The tensile strength and the breaking load of the fiberglass and jute fiber meshes are shown in Fig.03. At 0° direction, the tensile strength of the fiberglass mesh is higher due to fiber interlocking of the warp (0° direction) with the weft (90° direction, see Fig.01). The tensile strength of jute fiber mesh was 88% lower than that of the fiberglass mesh at 0°. The breaking load of the jute fiber mesh was 75% lower than that of fiberglass mesh in the 90° direction.

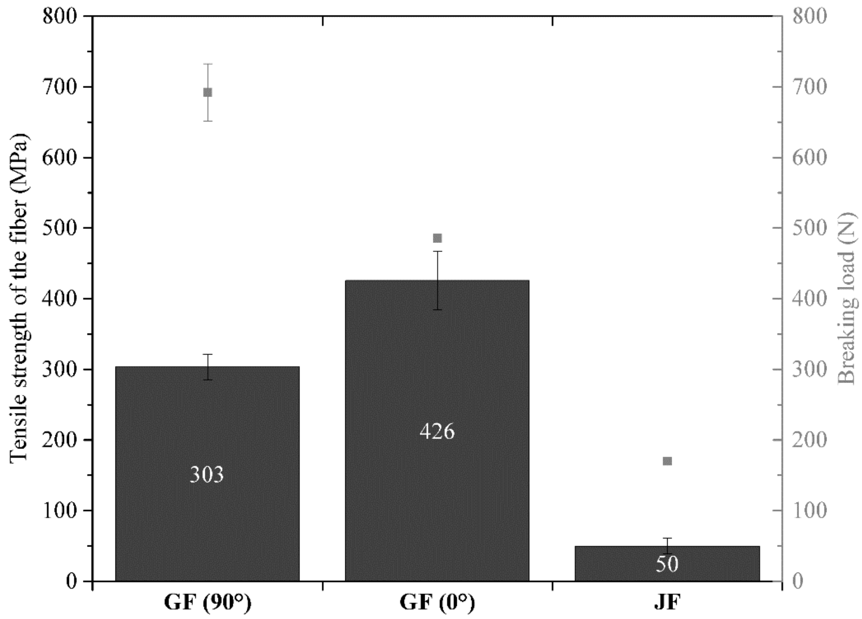

Figure 03. *Tensile strength (columns) and breaking load (dots) of the GF (0°), GF (90°) and JF fibers*

Although the jute fiber mesh exhibited lower breaking load than the fiberglass, the lower tensile strength was not expected. The breaking load × displacement of the fiber meshes is shown in Fig.04. The failure of the fiberglass mesh is steep, while that of the jute fiber is continuous. The failure of the jute fiber mesh takes place after great displacement in comparison to that of fiberglass, a positive feature for composites. Bensadoun et al. [25] and Ramesh et al. [22] stated that the defects caused by the growth and processing of natural fibers are heterogeneous along their length, weaking their strength, thus explaining this behavior.

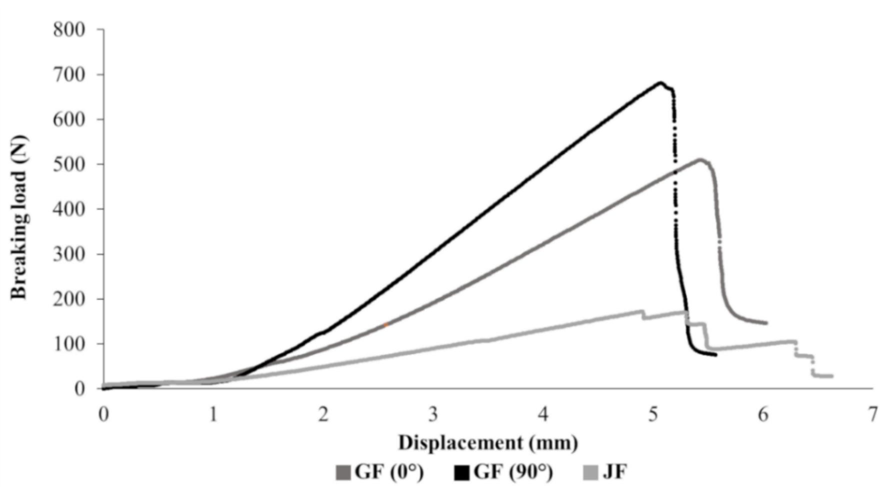

Figure 04. *Breaking load × displacement of the GF (0°), GF (90°) and JF fiber meshes*

c) Composite and conjoint composites: Tensile and flexural strength

The tensile strength of the epoxy resin was increased with the reinforcement of the fiber meshes (Fig.05), with an increase of 77% for the fiberglass at 90°. The epoxy reinforced with jute fiber had an increase of 35% in tensile strength. For all samples, the load transfer from the matrix to the fiber was due to a good fiber-matrix interface.

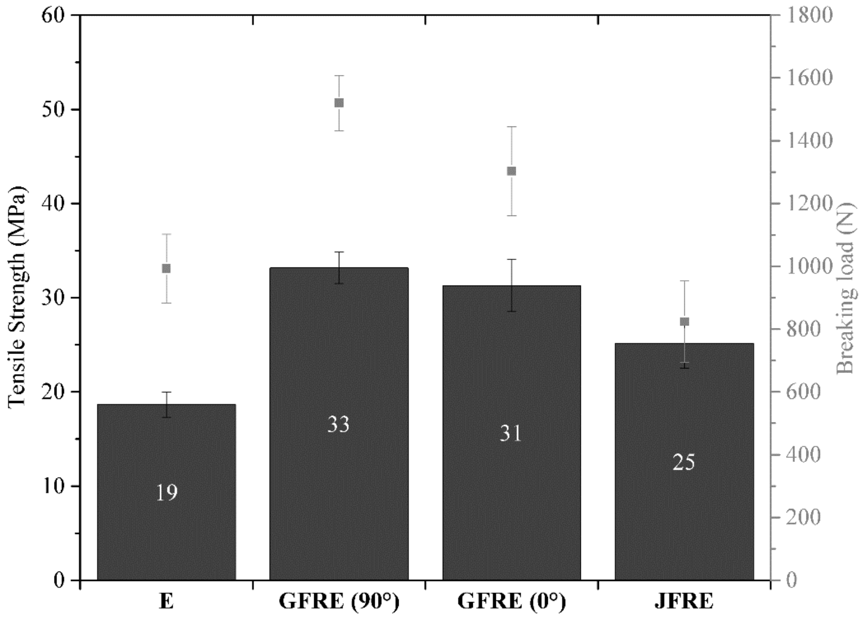

***Figure 05**. Tensile strength of the epoxy and GFRE (0°), GFR90°) and JFRE composites*

Regarding the breaking load of the composites, the largest load was found for the 90° fiberglass mesh, agreeing with the higher tensile strength. The lowest load was found for the jute fiber-reinforced epoxy (JFRE). As the thickness of the jute fiber is twice as large of that of the fiberglass, the thickness of the epoxy layer on the samples became smaller, resulting in a lower breaking load.

There was no increase in the tensile and flexural strength of the conjoint composites. In addition, there was no increase in tensile/flexural strength or breaking load even for the fiberglass-reinforced composite. Although the UNI 11018:2003 standard establishes the evaluation of ceramic tile flexural strength, the standard does not consider the effect of the fiber reinforcement. The effect of the fiber was not considered due to the thickness of the ceramic tile (12 mm), which was much larger than that of the fiberglass (0.30 mm), jute fiber (0.8 mm) and epoxy layer (~0.4 mm). However, when using low-thickness porcelain tiles (3 mm), the effect of the fiber must be considered.

d) Impact resistance of the composites

The absorbed energy of the composites, measured by the Charpy impact test, is shown in Fig.06. The ceramic tile and the epoxy resin absorbed a small amount of energy during the impact test due to the brittle nature of these materials. The fiberglass-reinforced epoxy (GFRE 90°) showed the highest energy absorption, followed by GFRE 0° and JFRE. The variability of the results for the fiberglass samples is due to delamination during the impact test. The absorbed energy is greater when there is delamination. When the fibers break, the energy absorption is lower.

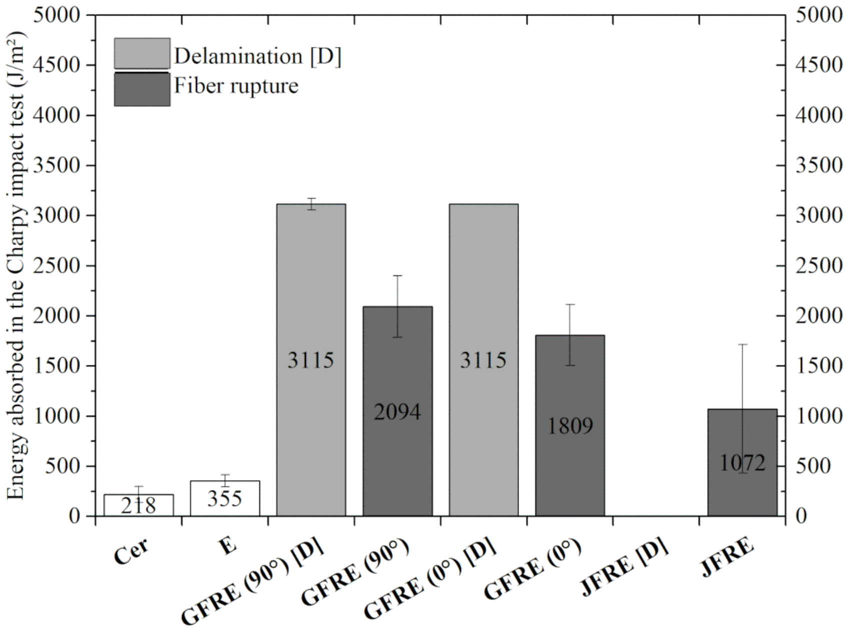

Figure 06. *Charpy impact test of the ceramic tile (Cer), epoxy resin (E) and GFRE (0°), GFRE (90°) and JFRE composites (notched)*

Bensadoun et al. [25] stated that composites with an epoxy matrix tend to fail when subjected to impact due to extensive delamination caused by their low resistance to interlaminar crack growth. Crack propagation was observed in the impact resistance test (Fig.07). The jute fiber samples were not delaminated but the fibers broke. The variability of the results is inherent to the natural characteristic of the fiber. The fracture of the conjoint composite in the Charpy test shows the interlaminar type II mode (Fig.07).

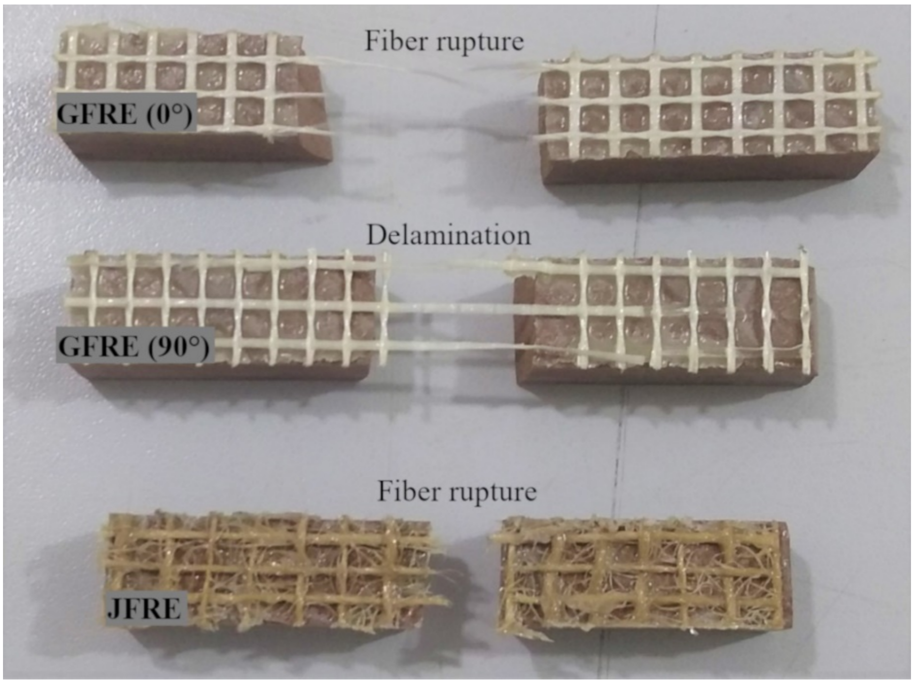

Figure 07. *Charpy impact test: fracture mode for the GFRE (0°), GFRE (90°) and JFRE composites (notched)*

Absorbed energy increases (Fig.06) when the breaking load of the fiber meshes increases (Fig.03). However, the breaking load of the jute fiber mesh is too small to justify the absorbed energy in the Charpy test. On the other hand, in addition to the higher breaking load than that of jute fiber mesh, the epoxy resin shows low absorbed energy under impact. The fiber-reinforced epoxy samples have the combined effect of both components, resin and fibers. The epoxy matrix enhances the breaking load of the composite, and the fibers increase the absorbed energy under impact.

e) Hard-body impact resistance

The hard-body impact test resembles the performance in real-life conditions. For an impact of 3.75 J (impact during use), a failure of the system (cracks, fissures or sinkings) was observed for all conditions, including the ceramic tile alone. Therefore, all configurations comply with the requirements of the standard.

The results for the 20 J impact test, after 10 impacts are shown in Fig.08. The ceramic tile alone (Cer) and the ceramic tile with epoxy resin (Cer+E) were transposed (perforated) by the sphere. This result is not acceptable with regard to the safety requirements of the standard. When fiber meshes were used, the systems showed cracks, fissures and sinkings but without the transposition of the sphere and, therefore, the systems did not collapse. Thus, both systems, Cer+GFRE and CER+JRFE composites, are adequate for use in façades, exhibiting the minimum performance for safety impact. The most frequent behavior in both cases was sinking without transposing.

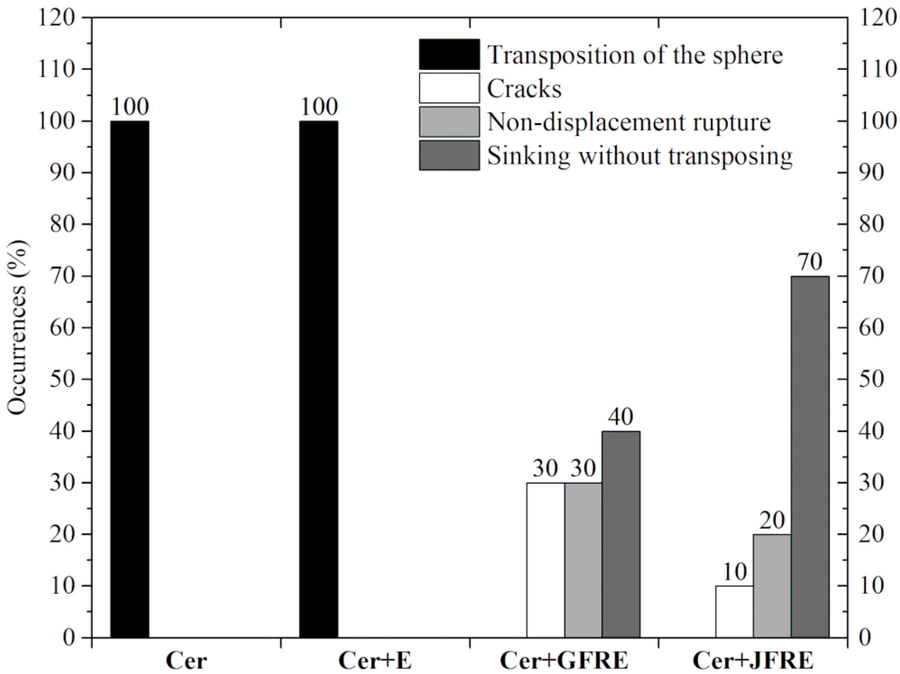

Figure 08. *Percentage of occurrences with the 20 J hard-body impact for the ceramic tile (Cer), epoxy resin (E) and Cer+GFRE and CER+JRFE composites*

Besides the similar results of jute mesh and fiberglass mesh for the occurrence of sinking without transposing, the energy absorption mechanisms after impact were different for both fiber meshes. Some jute fibers broke in the region of the sinkings (Fig.09).

Fiber breakage was also observed in the tensile strength test (Fig.04).

Despite the lower tensile strength of the jute fiber mesh, a similar elongation before breaking compared to that of the fiberglass mesh could explain the performance of the natural fiber. The sinking regions of both systems are shown in Fig.09. Some jute fibers were broken, while the fiberglass fibers were not, probably due to their higher tensile strength.

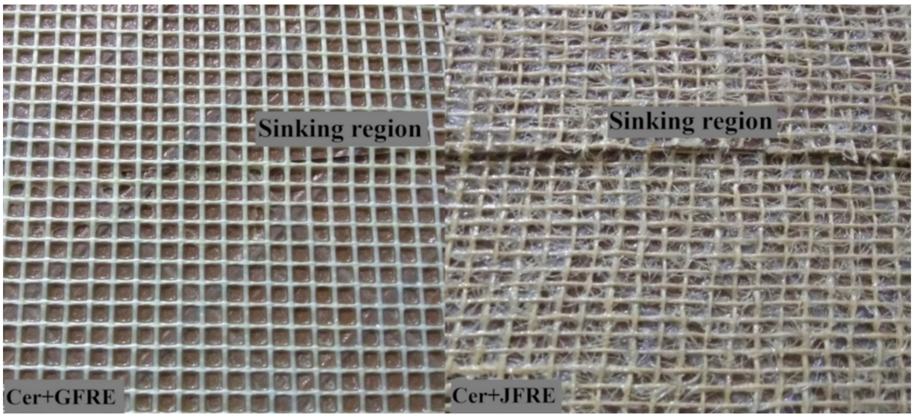

Figure 09. *Sinking region after the 20 J hard-body impact test: Jute fibers × fiberglass*

Comparing the Charpy test with the hard-body impact test, the non-reinforced samples showed a very low energy absorption (in the Charpy test), less than 360 J/m^2, while all reinforced samples showed at least 1100 J/m^2. Both fiber-reinforced systems, fiberglass and jute, met the safety requirements of the standard. The lower absorbed energy and breaking load for the jute fiber mesh could also explain the higher occurrence of sinking without transposing.

5. CONCLUSIONS

In this study, the mechanical performance of a jute fiber-reinforced composite was compared to that of a fiberglass-reinforced composite for ventilated façades. Although the jute fiber mesh shows 88% less tensile strength than the fiberglass mesh, the jute fiber breaks gradually, not exhibiting brittle behavior, an important feature for composites.

Despite the lower tensile strength and absorbed energy (Charpy impact test), the jute fiber composite shows adequate mechanical behavior. According to the hard-body impact test, both conjoint composites have adequate performance for real use conditions and safety. The jute fiber conjoint composite (Cer+JFRE) exhibited more sinking than the fiberglass without sphere transposition, probably due to the partial breaking of the fibers that is inherent to the origin and processing of the fibers.

Although the jute fibers present lower mechanical performance than the fiberglass mesh, the jute-reinforced epoxy meets the minimum requirement of the standard for ventilated façades regarding mechanical performance. The requirements for durability and fire exposure should be considered to ensure the final substitution of fiberglass by natural fibers.

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