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*Original Paper*

# Mechanical Performance of Fiber Cement Composites Reinforced with Hybrid Jute and Cellulose and Rice Husk Ash

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***Abstract***

*The construction industry is always looking for materials that combine good technical performance, environmental sustainability and cost-effectiveness. This study analyzed the mechanical behavior of fiber cement composites reinforced with a combination of jute mesh and cellulose pulps. In addition, the effects of replacing 15% of the cement with rice husk ash (RHA) on the material properties were evaluated. Half of the samples were produced without RHA and the other half with RHA. Flexural tests were performed to calculate the Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Specific Energy (SE). The results showed that both the hybrid reinforcement and the presence of RHA led to a strain hardening behavior, which means a more ductile failure and greater capacity to absorb energy. Statistical analysis indicated a significant increase in MOR and E.E. for the samples with RHA, while the MOE did not change in a statistically relevant way. The combination of fibrous reinforcement with the pozzolanic action of RHA improves the strength and toughness of fiber cement. This work contributes to the literature by investigating this specific combination of materials, providing important data for the creation of more sustainable and resistant construction solutions.*

***Keywords***

*Fiber cement, Jute, Cellulose pulp, Rice husk ash, Mechanical properties*

## 1. Introduction

The construction industry, a vital sector for global development, is constantly seeking innovations in materials that balance technical performance, environmental sustainability and economy. Sustainable construction involves several areas such as energy efficiency, use of materials with low environmental impact, water management, air quality in the built environment and user comfort. In this scenario, the use of sustainable materials such as hybrid reinforced fiber cement emerges as an efficient way to reduce the environmental impact of construction and encourage the use of renewable resources (Ardanuy et al., 2015).

Fiber cement is a cementitious material widely used in construction, but it has a limitation: its low tensile strength. To improve this, reinforcements must be added. There are several types of fibers that can be used, both synthetic (man-made) and natural (of plant, mineral or animal origin). The choice of fiber depends largely on the production cost which is important in the manufacture of cement boards. Natural fibers such as jute and cellulose pulps are advantageous since in their processing they consume less energy and generate less waste than synthetic fibers. In addition, using industrial waste such as rice husk ash (RHA), which is rich in amorphous silica, helps to reduce landfill waste and reduce the need for virgin raw materials, as highlighted by Ullal et al. (2022).

In recent years, there has been growing interest in research on the mechanical performance of sustainable construction materials (Majumder et al., 2022, Pramreiter et al., 2024, Zheng et al., 2023). Several studies show that adding natural fibers, industrial waste or other alternative materials to cementitious composites (CC) can improve their mechanical properties such as compressive strength, tensile strength, modulus of elasticity and durability (Song et al., 2021; Ahmad et al., 2022, Khatri et al., 2024).

Ubayi et al. (2024) indicates that adding jute fiber (JF) to concrete improves its mechanical properties, although it may make workability somewhat more difficult, especially with higher fiber content or with long fibers. Furthermore, replacing part of the cement along with the addition of JF can increase the strength of concrete. The research highlights the importance of using natural fibers in CC, especially in developing countries. Jute, which is abundant in places such as India, Bangladesh, and Brazil, has high tensile strength, is inexpensive, and mixes well with the cement matrix (Chandra et al., 2021, Shahinur et al., 2022). The jute mesh also gives the composite more impact and crack resistance, in addition to increasing its energy absorption capacity (Ubayi et al., 2024).

Song et al. (2021) point out that adding FJ can positively impact the mechanical performance of composites, as long as the fibers are well distributed, which helps to improve the microstructure of the matrix. The authors consider that adding up to 5% of the fiber volume increases the strength and decreases the brittleness of CC, in addition to improving toughness and ductility. On the other hand, Ahmad et al. (2022) suggest that the limit for adding FJ to CC is 2%; above this, the mechanical properties may be impaired.

Khan et al. (2023) studied the effects of FJ on fresh and hardened CC, noting that the best results for reinforced concrete are obtained with 0.10% FJ by weight. Amounts greater than 0.10% do not bring benefits. The addition of 0.10% FJ resulted in maximum values of compressive strength (63 MPa), tensile strength (6.01 MPa) and flexural strength (5.22 MPa). In addition to fiber reinforcement, replacing part of the cement RHA also has a positive effect on the mechanical properties of the composite. RHA is a common agro-industrial waste in rice-producing areas and has a lot of amorphous silica, which gives it pozzolanic properties. This means that RHA reacts with the calcium hydroxide released when the cement hydrates, forming extra hydrated compounds that help increase the strength and durability of the material (Ullal et al., 2022). Shahinur et al. (2022) support the use of hybrid reinforcements in composites, highlighting that RHA, which is abundant in several countries, can replace artificial fibers and be used in biodegradable packaging, fashion, electronics, medicine, energy and, above all, in civil construction.

Several studies support the partial replacement of cement with RHA, the use of hybrid reinforcements and the application of natural fibers, especially cellulose pulp in different quantities. However, no research has been found in which the composite matrix was made of cement with RHAand, at the same time, the hybrid reinforcement was a combination of cellulose pulp and jute mesh. This combination of materials is very important for creating sustainable construction materials.

Thus, this article aims to contribute to the knowledge about the mechanical performance of fiber cement with hybrid reinforcement and with cement partially replaced by RHA, offering useful information for researchers, engineers, architects and other professionals in the construction industry. The jute mesh gives strength and toughness to the composite, while the cellulose pulps facilitate the work and reduce the density. Using these two materials contributes to reducing the use and dependence on synthetic or polymeric fibers, making fiber cement more sustainable and environmentally friendly.

## 2. Materials and Methods

### *2.1 Materials*

In this study, the materials were carefully selected and prepared to ensure the validity of the results. The cement chosen was Portland CPV-ARI, from Lafarge-Holcim, known for its high initial strength and for following Brazilian standards. RHA from Silcca Nobre, manufactured by Pilecco, was added as a pozzolanic material with a high amount of amorphous silica. The limestone filler ($CaCO_3$) was used as a mineral load. The water came from the Belo Horizonte supply system which ensured that there were no impurities that could hinder the hydration of the cement.

For reinforcement, natural jute fabric in the form of a mesh was used, purchased at retailers for crafts, decoration and packaging. Jute is composed of 72% cellulose, 8.1% lignin and 12.8% hemicelluloses, according to Fidelis (2014). The eucalyptus cellulose pulps used as reinforcement were supplied by Suzano Indústria de Papel e Celulose.

Table 1 shows the details of the fiber cement matrix components, while Table 2 presents the physical properties of the materials used.

**Table 1. Chemical Composition of the Constituents of the fiber Cement Matrix**

| Constituents | Cement CPV-ARI (%) | Limestone filler (%) | RHA (%) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| PF 1000ºC | 4,03 | - | - |
| C (LOI) | - | - | 2,67 |
| $CaCO_3$ | - | 92,82 | - |
| $SiO_2$ | 18,85 | 3,67 | 95,9 |
| $TiO_2$ | | - | 0,02 |
| $Al_2O_3$ | 4,67 | 2,48 | 0,26 |
| $Fe_2O_3$ | 3,07 | 0,36 | 0,03 |
| MnO | - | - | 0,31 |
| CaO | 64,82 | - | 0,43 |
| MgO | 0,70 | - | 0,36 |
| $Na_2O$ | - | - | 0 |
| $K_2O$ | 0,77 | 0,29 | 1,43 |
| $P_2O_5$ | - | - | 0,27 |
| R.I. | 0,60 | - | - |
| $SO_3$ | 2,90 | 0,18 | - |
| $CO_2$ | 2,97 | | |
| SrO | | 0,19 | - |
| CuO | | 0,01 | - |
| PF 500ºC | 0,67 | | |
| $C_3A$ | 7,11 | | |
| Sources: | Gomes 2019 | Jacóe 2015 | Manufacturer |

**Table 2. Physical Characteristics of the Constituents of the Cement Matrix**

| Characteristics | Cement CP-V | Limestone filler | RHA |
|---|---|---|---|
| Specific area (BET $m^2/g$) | - | 0,743 | 10,786 |
| Average dimension (μm) | 10,00 | 38,00 | 11,00 |
| Density ($g/cm^3$) | 3,10 | 2,752 | 2,44 |

*2.2 Production Process of the Plates*

The production of the plates followed several steps, with the preparation of two groups of samples: one with rice husk ash (CCCA) and the other without (SCCA). For the SCCA plates, cement, limestone filler, cellulose pulps and water were mixed in a digital mechanical stirrer for 7 minutes, ensuring a homogeneous mixture. For the CCCA plates, 15% of the cement and limestone filler were replaced by RHA, maintaining the other materials, as detailed in Table 3. The amount of pulp was 8% of the mass, considering the humidity of 69% at the time.

**Table 3. Sample Constituent Materials**

| Sample type | Cement (g) | Limestone filler (g) | RHA (g) 15% | Water (ml) | Cellulose pulp (g) 8% |
|---|---|---|---|---|---|
| SCCA | 115,00 | 115,00 | 0 | 900 | 31,10 |
| CCCA | 97,75 | 97,75 | 34,5 | 900 | 31,10 |

The mixture was placed in a 160x160 mm metal mold, which had a filter at the bottom to drain the water. The jute mesh measuring 170x170 mm was placed over one third of the mixture, and the remaining two thirds were added on top of the mesh. The mixture was compacted manually with a metal support to ensure that the consistency and thickness of the piece (approximately 8 mm) were uniform. Excess water was removed by a vacuum pump and stored in a cylinder. The molded pieces were then placed in the press for final removal of the water and cured for 7 days, covered with transparent plastic. The plates measured approximatedly 160x160x8 mm. Figure 1 shows how the fiber cement samples were molded, including the placement of the mixture in the mold, the jute mesh, and manual compaction.

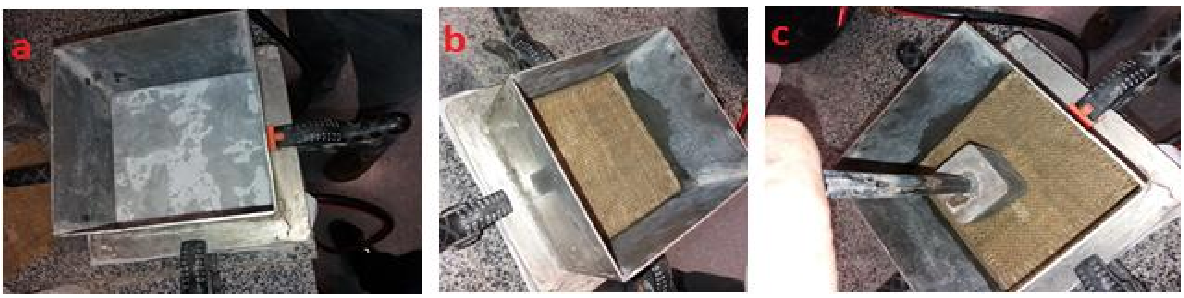



**Figure 1. Molding of Fiber Cement Samples. a) Insertion of the Mixture into the Mold, (b) Placement of the Jute Mesh, (c) Manual Compaction of the Mixture**

*2.3 Preparation of Test Specimens*

After making the plates, they were cut to form the test specimens (TS). Seven days after molding, each plate was divided into 3 parts, forming a PC measuring approximately 40x160x8mm, for a total of 30 units, 15 for each type of matrix (with and without RHA). Figure 2 shows the molded fiber cement samples, including the entire plate, a top view of the plates and the TS.

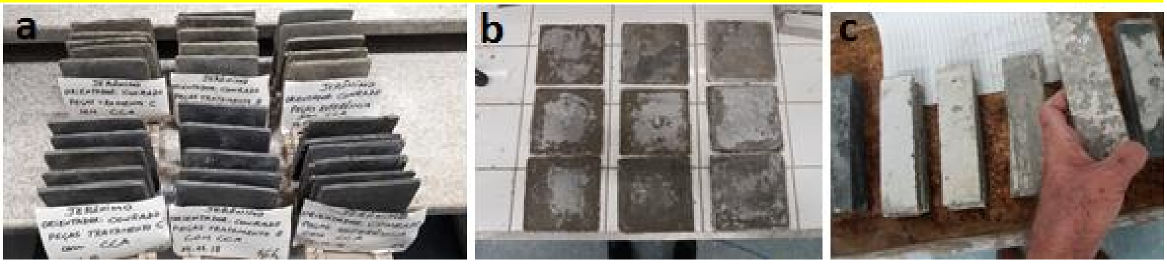



**Figure 2. Molded fiber Cement Samples. (a) Fiber Cement Plate, (b) Top View of the Plates, (c) Test Specimens after Cutting the Plates**

*2.4 Equipments*

Several pieces of equipments were used to prepare and characterize the samples. A Kern PCB 6000-0 precision digital bench scale and a MYLABOR digital mechanical mixer were used. A custom-made metal mold for producing cement slabs in the institution's laboratories, with an area of 160x160 mm, and a vacuum pump were used for molding. A Mitutoyo Absolute digital caliper with a sensitivity of 0.01 mm was used to measure the samples. The mechanical tests were performed on an EMIC mechanical testing press, and the deflection during the bending test was measured with a deflectometer with a precision of 0.001 mm and a stroke of 2.5 mm.

*2.5 Test Methodology*

The test methodology was conducted to evaluate the mechanical properties of fiber cement composites, which allowed analyzing the impact of adding RHA and reinforcing with jute and cellulose pulps. The TS tests were performed following rigorous procedures to ensure that the results were reliable and reproducible.

The three-point bending test performed in accordance with RILEM recommendations was essential to determine the Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Rupture Load and Specific Energy (SE) of the composites. This test widely used to characterize brittle materials such as fiber cement works as follows: an increasing load is applied to the center of the test specimen supported at two points, until it breaks or deforms so much that the deflectometer can no longer measure it. The three-point bending test was adopted because it is simple to perform and provides important information about the flexural strength and deformation capacity of the material, properties that are crucial for several applications.

The TS measuring approximately 40x160x8mm were carefully positioned in the universal testing machine ensuring that the distance between the supports was 120mm. The loading rate was kept constant at 0.5mm/min, following RILEM guidelines for cementitious materials. The deflection, which is the vertical displacement of the center of the test specimen, was continuously measured by a high-precision deflectometer (0.001mm), placed on the tensioned part, in the middle of the span. Measuring the deflection accurately is essential to calculate the MOE, which indicates the rigidity of the material and its ability to resist elastic deformation. The tests were carried out 21 days after molding the parts, in accordance with RILEM recommendations (1984), for all CPs of each type of plate (with and without RHA). The loading rate was the same for all tests. Using the flexural test data, the MOR, which shows the maximum stress that the material can withstand before it begins to break, and the MOE, which reflects the material's stiffness, were calculated. In addition, the E.E. was calculated by the area under the stress-strain curve up to 40% of the MOR, which represents the material's toughness, i.e., its ability to absorb energy before failing. Calculating the E.E. is especially important for evaluating fiber-reinforced composites, as it indicates how well the material can resist crack propagation and prevent sudden rupture. Figure 3 shows the 3-point flexural test, with the specimen in the press and the deflectometer measuring the deflection.

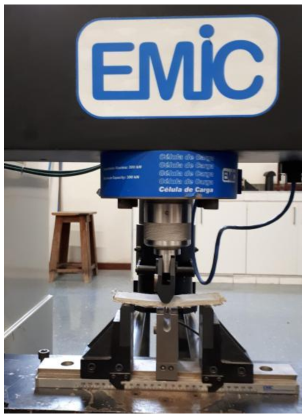



**Figure 3. 3-point Bending Test. Test Specimen Positioned in the Press for Bending Test**

The processing of the test data was a fundamental step to ensure that the results were valid and well interpreted. First, the raw data from the three-point bending tests were entered into electronic spreadsheets, ensuring the integrity and traceability of the information. Then, descriptive statistical techniques were used to summarize and characterize the data, calculating the mean, standard deviation, median, and maximum and minimum values for each experimental group. These measures provided an overview of the mechanical properties of the fiber cement composites, helping to identify trends and differences between the groups.

Analysis of variance (ANOVA) was performed to verify whether there were statistically significant differences between the means of the experimental groups. ANOVA is a statistical tool that compares the means of two or more groups, taking into account the variation within each group and between them. In this study, ANOVA aimed to determine whether the addition of RHA significantly affected the MOR, MOE, breaking load and E.E. of the composites. Minitab statistical software was used for the analysis, with a significance level of 5% ($\alpha = 0.05$). This means that, for a difference between the means to be considered statistically significant, the chance of it occurring by chance must be less than 5%.

Outliers (atypical values) were identified using Minitab software, using descriptive statistics. These are data that deviate greatly from the general pattern and can compromise the validity of the statistical analysis. To find them, scatter plots were analyzed and specific statistical tests were applied, such as the Grubbs test or the Dixon test. Once identified, outliers were treated appropriately, either by removing them from the data set or by data transformation techniques to reduce their influence. The choice of method for treating outliers was based on statistical criteria and the nature of the data and objectives of the analysis.

The MOR was calculated using Equation (1):

$$MOR = \frac{3.F.L}{2.b.h^2} \quad (1)$$

Where F is the maximum breaking force in Newtons (N), L is the distance between the supports (120 mm), b is the average width of the test specimen (mm) and h is the average thickness of the test specimen (mm).

The MOE values were calculated using Equation (2), after processing the data from each plate test. The Load x Displacement value pairs were plotted on a graph and a linear regression was performed on the elastic part, which allowed the identification of the slope of the line, $\tan\theta = (\Delta F/\Delta\delta)$.

$$MOE = \frac{\tan\theta.L^3}{6.h} \quad (2)$$

Where L is the distance between the supports (120 mm), b is the average width of the TS (mm) and h is the average thickness of the specimen (mm).

The calculation of the E.E. was performed from the stress-strain curves, defining it as the area under the curve up to 40% of the rupture load, after failure.

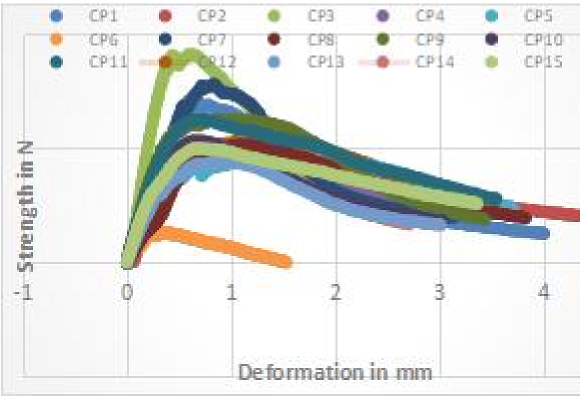
In summary, the data were organized and processed rigorously, using appropriate statistical techniques to ensure the validity and accuracy of the interpretation of the results. Analysis of variance (ANOVA) helped to identify statistically significant differences between the experimental groups. The identification and treatment of outliers ensured the robustness of the statistical analysis.

## 3. Results and Discussion

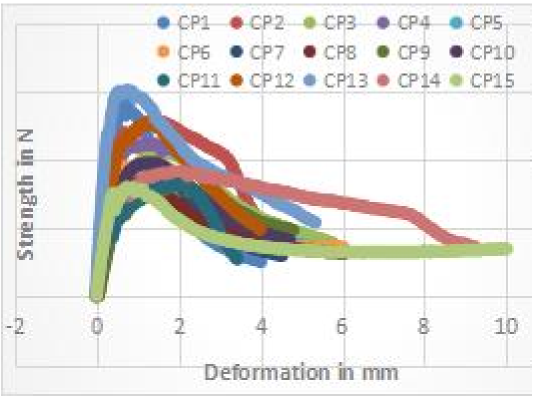
The analysis of the mechanical performance of fiber cement composites reinforced with jute mesh and cellulose pulp, and with or without partial replacement of cement by RHA, provided important information about their properties and their potential for use in sustainable construction materials. The results of the three-point bending tests were subjected to rigorous statistical analysis to verify the significance of the differences found.

*3.1 Force-Displacement Behavior*

The force versus displacement curves shown in Figure 4 provide a clear view of how the composites behave mechanically under load. Figure 4a presents the curves for the SCCA specimens, while Figure 4b displays the curves for the CCCA TS.




a) - Test specimens SCCA




b) - Test specimens CCCA

Both groups of samples, SCCA and CCCA, showed strain hardening behavior after peak load. This means that they continued to support load even after cracking had begun. This behavior is even more evident in the CCCA samples, indicating that they became tougher and absorbed more energy. Strain hardening is a very good characteristic of fiber-reinforced cementitious materials, as it gives the composite more resistance to crack propagation and makes the failure more ductile, unlike the brittle failure common in unreinforced cementitious materials.

The jute mesh and cellulose pulps, used as hybrid reinforcement, are crucial to this behavior. The jute mesh, with its high tensile strength and good compatibility with the cementitious matrix, acts as a "bridge" across the cracks, distributing the stresses and preventing the cracks from spreading uncontrollably, as pointed out by Ubayi et al. (2024) and Shahinur et al. (2022). Cellulosic pulps help to improve the matrix microstructure and the toughness of the composite, as suggested by Song et al. (2021), who noted that adding fibers can increase the strength and decrease the brittleness of CC.

*3.2 Descriptive Statistics of Mechanical Properties*

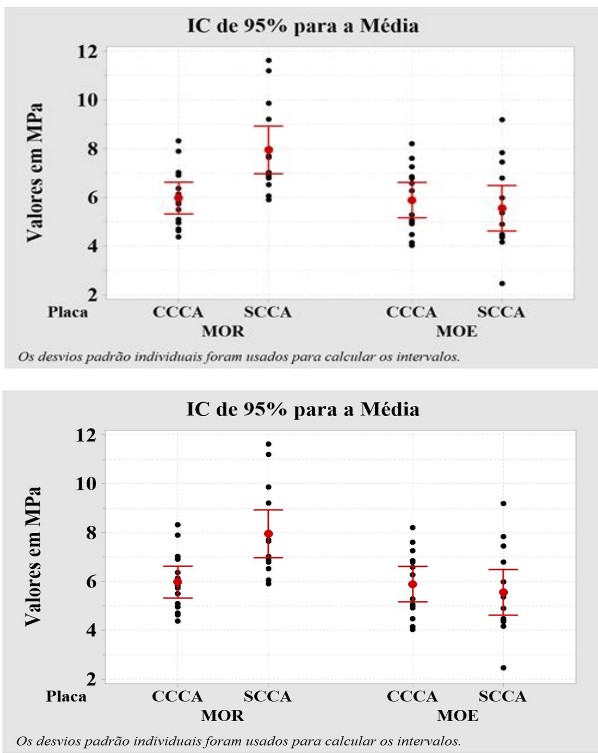
Table 4 shows the descriptive statistics for MOR, MOE and E.E. for the two sample groups (SCCA and CCCA).

**Table 4. Descriptive Statistics for MOR, MOE and E.E**

| Parameters | SCCA | | | CCCA | | |
|---|---|---|---|---|---|---|
| | MOR | MOE | E.E. | MOR | MOE | E.E. |
| Number of tests | 15 | 15 | 15 | 15 | 15 | 15 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Minimum | 5,89 | 4,38 | 2,46 | 4,02 | 0,36 | 0,59 |
| Maximum | 11,61 | 8,31 | 9,18 | 8,19 | 0,89 | 1,85 |
| Average | 7,95 | 5,97 | 5,55 | 5,88 | 0,71 | 0,99 |
| Standard deviation | 1,83 | 1,18 | 1,76 | 1,31 | 0,16 | 0,32 |
| Coefficient of variation (%) | 23,05 | 19,74 | 31,64 | 22,24 | 22,32 | 32,49 |

The coefficients of variation (CV) for most parameters ranged from 19.74% to 32.49%. A CV between 15% and 30% is generally considered to be a medium spread, indicating that the test results are quite consistent, even with the natural variability of composite materials and the manufacturing process. For E.E., a CV slightly above 30% (31.64% for SCCA and 32.49% for CCCA) suggests a greater spread in the toughness data. This can be explained by the complexity of energy absorption in fibrous composites and by the variation in fiber distribution. Figure 5, with the test results, complements Table 4, showing the individual values of each test, along with the mean and 95% confidence interval for the population mean. This visualization contributes to a better understanding of the distribution of the data and the overlap of the confidence intervals between the groups, serving as a visual basis for interpreting the results of the analysis of variance.




a) Results for MOR and MOE b) Results for E.E.

**Figure 5. Test results. a) – For MOR and MOE, b) For E.E.**

*3.3 Analysis of Variance (ANOVA) and Comparative Discussion*

To verify whether the differences between the means of the properties of the CCCA and SCCA groups were statistically significant, an Analysis of Variance (ANOVA) was performed, with a significance level of $\alpha = 0.05$. Table 5 summarizes the results of the ANOVA, including the p-values and 95% confidence intervals for the differences between the means. For a difference to be considered statistically significant, the p-value must be less than or equal to $\alpha$ (0.05), and the confidence interval of the difference between the means cannot include zero. The analysis of the residuals confirmed that they are distributed equidistantly in relation to zero and follow a normal distribution, which validates the application of the ANOVA.

**Table 5. Hypothesis of null Difference**

| Hypothesis of null difference between MOR__CCCA and MOR_SCCA with significance level α=0.05 | | | |
|---|---|---|---|
| p-value | 95% CI | Residual distribution | Normality Residuals |
| 0.002 | (-3.144; -0.814) | Distributed equidistantly in relation to zero | Follows a normal distribution |
| Hypothesis of null difference between MOE__CCCA and MOE_SCCA with significance level α =0.05 | | | |
| 0,562 | (-0,838; 1,510) | Distributed equidistantly in relation to zero | Follows a normal distribution |
| Hypothesis of null difference between EE__CCCA and EE_SCCA with significance level α =0.05 | | | |
| 0.006 | (0.0862 ; 0.4756) | Distributed equidistantly in relation to zero | Follows a normal distribution |

3.3.1 Modulus of Rupture (MOR)

In the case of the Modulus of Rupture (MOR), a p-value of 0.002 ($p \leq 0.05$) and a 95% confidence interval (-3.144; -0.814), which does not include zero, were observed. These results show that the difference between the MOR means of the CCCA and SCCA groups is statistically significant. More specifically, the CCCA plates presented MOR values considerably higher than those of the SCCA plates. This finding is very important: the partial replacement of cement by RHA, combined with hybrid reinforcement, led to a clear increase in the flexural strength of the materials analyzed.

Interestingly, these findings diverge from some previous studies. It is stated in the literature in the area that the mere addition of jute fibers to concrete, without the partial replacement of cement by RHA, can restrict or even decrease the mechanical properties of the composite at certain concentrations. Ahmad et al. (2022), for example, suggest not exceeding 2% FJ to avoid compromises, while Khan et al. (2023) obtained better results with only 0.10% FJ by weight, noting negative effects at higher concentrations. This research, however, indicates that the strategic combination of hybrid reinforcement — combining jute mesh and cellulose pulps—with the incorporation of RHA, can overcome these limitations and provide significant gains in the material properties. It is worth highlighting the crucial role of RHA in this process. Rich in amorphous silica, it acts as a pozzolanic material, reacting with the calcium hydroxide released during cement hydration and forming extra hydrated compounds. These new compounds, in turn, densify the composite matrix, increasing its strength and durability, as demonstrated by Ullal et al. (2022). Thus, the synergistic interaction between fibrous reinforcement and the pozzolanic activity of RHA is decisive for the performance advances identified in this investigation.

3.3.2 Modulus of Elasticity (MOE)

Regarding the MOE, the p-value of 0.562 ($p > 0.05$) and the 95% confidence interval (-0.838; 1.510), which includes zero, indicate that there is no statistically significant difference between the MOE means for the CCCA and SCCA groups. This suggests that the addition of RHA, under the conditions studied, did not significantly change the stiffness of the material. Although RHA helps to densify the matrix, the overall stiffness of the composite can be more influenced by the type and amount of fibrous reinforcement and by the base cementitious matrix itself. Maintaining the MOE is a positive point, as it shows that the incorporation of RHA did not impair the material's ability to resist elastic deformation.

3.3.3 Specific Energy (SE)

For the E.S., the p-value of 0.006 ($p \leq 0.05$) and the 95% confidence interval (0.0862; 0.4756), which does not include zero, show that the difference between the E.S. means for the CCCA and SCCA groups is statistically significant. The CCCA samples presented a notably higher E.S.. Specific Energy measures the toughness of the material, that is, how much it can absorb energy before failing. The increase in E.S. in the samples with RHA is in agreement with the work hardening behavior observed in the force-displacement curves (Figure 4).

This result reinforces how the hybrid reinforcement system, together with RHA, is effective in improving the ductility and energy absorption capacity of fiber cement. Greater toughness is an essential characteristic for civil construction, as it gives the material more resistance to impacts and crack propagation, leading to a more controlled and less sudden failure. The literature confirms the importance of adding natural fibers to increase the toughness and ductility of CC (Song et al., 2021; Ubayi et al., 2024), and this research shows that RHA amplifies this effect.

In summary, adding rice husk ash (RHA) to fiber cement composites reinforced with jute mesh and cellulose pulps has proven to be an effective strategy to improve mechanical performance, especially in relation to MOR and E.E. The combination of hybrid reinforcement with the pozzolanic action of RHA results in a stronger and tougher material, crucial characteristics to create more sustainable and durable construction solutions.

## 4. Conclusions

In this study, the mechanical performance of fiber cement composites with hybrid reinforcement of jute mesh and cellulose pulps was investigated, both with and without partial replacement of cement by rice husk ash (RHA). The main conclusions are:

Both groups of samples (SCCA and CCCA) showed strain hardening behavior, indicating a more ductile failure and higher energy absorption capacity after peak load. This behavior was especially noticeable in the samples with RHA, which demonstrates the effectiveness of the hybrid reinforcement together with the pozzolanic addition.

The inclusion of 15% RHA resulted in a statistically significant increase in the Modulus of Rupture (MOR) of the fiber cement boards. This finding is crucial, as it shows that RHA, acting as a pozzolanic material, helps to densify the cementitious matrix and increase the flexural strength of the composite, overcoming possible limitations seen in studies using only jute fibers in concrete without pozzolanic additives.

No statistically significant difference was found in the Modulus of Elasticity (MOE) between the samples with and without RHA. This indicates that the addition of RHA, in the proportions studied, did not impair the rigidity of the material, maintaining its ability to resist elastic deformation.

The samples with RHA presented a significantly higher Specific Energy (SE), confirming a substantial improvement in the material's toughness and energy absorption capacity. This result is of great importance for durability and safety in construction applications, as it gives fiber cement greater resistance to impacts and crack propagation.

The combination of jute mesh, cellulose pulps and rice husk ash represents a promising approach to develop more sustainable construction materials. Using abundant natural fibers and an agro-industrial residue such as RHA not only improves the mechanical properties of fiber cement, but also helps to reduce the environmental impact of the construction industry.

This study fills a gap in the literature by investigating the specific combination of cement with partial replacement by RHA and hybrid reinforcement of pulp and jute mesh. The results provide valuable information for researchers, engineers and architects, driving the development of more efficient and environmentally friendly cementitious composite materials.

For future research, it is suggested to investigate the long-term durability of these composites, including resistance to humidity and wet-drying cycles, in addition to optimizing the proportions of RHA and fibers to maximize mechanical performance and sustainability. Detailed microstructural analysis could also provide more information on the interaction between the components and the reinforcement mechanisms.

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