ANALYSIS OF MORTAR PERFORMANCE WITH TUCUMÃ VEGETABLE FIBERS TREATED WITH SILANE-SILOXANE

ANÁLISE DO DESEMPENHO DE ARGAMASSAS COM FIBRAS VEGETAIS DE TUCUMÃ TRATADAS COM SILANO-SILOXANO

ANÁLISIS DEL COMPORTAMIENTO DE MORTEROS CON FIBRAS VEGETALES DE TUCUMÃ TRATADOS CON SILANO-SILOXANO

CARMELITA BLODOW DO NASCIMENTO | IFRO – Instituto Federal de Rondônia, Brasil
VALÉRIA COSTA DE OLIVEIRA, Dra. | IFRO – Instituto Federal de Rondônia, Brasil
RODRIGO CESAR PIEROZAN, Dr. | UTFPR – Universidade Tecnológica Federal do Paraná, Brasil
LÍDIA BRUNA TELES GONZAGA | UNB – Universidade de Brasília, Brasil
FRANCISCO ROGER CARNEIRO RIBEIRO | UFRGS – Universidade Federal do Rio Grande do Sul, Brasil

ABSTRACT
Polypropylene fibers have been widely used in civil construction due to their good performance and low cost. However, plant fibers represent a viable alternative due to their favorable mechanical properties capable of mitigating construction anomalies, such as cracks, in addition to offering economic and sustainable characteristics. This study aimed to assess the incorporation of tucumã fibers, derived from a native plant in the Amazon region, as a substitute for polypropylene fibers in coating mortars. For this purpose, mortars with varying fiber content (0.5%, 1%, and 1.5% additions) were produced and treated with a silane-siloxane-based hydrophobic agent, as fibers are prone to degradation. Subsequently, tests were conducted in the fresh state, including consistency index, water retention, bulk density, and air content, as well as tests in the hardened state, such as flexural tensile strength, compressive strength, tensile adhesion, ductility analysis, and capillary water absorption. Regarding the results in the fresh state from the respective tests, the addition of tucumã fibers increased the consistency index and decreased bulk density and water retention. It was also observed that fiber addition reduced water absorption with increasing content, and the results from mechanical strength tests, namely flexural tensile and compressive strength, decreased. Moreover, both types of fibers exhibited positive results in terms of adhesion and ductility. Thus, this study demonstrated satisfactory outcomes for the use of tucumã fibers as a sustainable alternative to enhance the properties of coating mortars.

KEYWORDS
Plant fibers; Tucumã fibers; Coating mortars; Mechanical behavior; Sustainable construction.

RESUMO
As fibras de polipropileno têm sido amplamente utilizadas na construção civil devido ao seu bom desempenho e baixo custo. Porém, as fibras vegetais representam uma alternativa viável devido às suas propriedades mecânicas favoráveis capazes de atenuar anomalias construtivas, como fissuras, além de oferecerem características econômicas e sustentáveis. Este estudo teve como objetivo avaliar a incorporação de fibras de tucumã, derivadas de planta nativa da região amazônica, em substituição às fibras de polipropileno em argamassas de revestimento. Para tanto, foram produzidas argamassas com teores variados de fibras (0,5%, 1% e 1,5% de adições) e tratadas com agente hidrofóbico à base de silano-siloxano, pois as fibras são propensas à degradação. Posteriormente, foram realizados ensaios no estado fresco, incluindo

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índice de consistência, retenção de água, densidade aparente e teor de ar, bem como ensaios no estado endurecido, como resistência à tração por flexão, resistência à compressão, adesão à tração, análise de ductilidade e capilaridade. absorção de água. Em relação aos resultados no estado fresco dos respectivos testes, a adição de fibras de tucumã aumentou o índice de consistência e diminuiu a densidade aparente e a retenção de água. Observou-se também que a adição de fibras reduziu a absorção de água com o aumento do teor, e os resultados dos ensaios de resistência mecânica, nomeadamente resistência à tração à flexão e à compressão, diminuíram. Além disso, ambos os tipos de fibras apresentaram resultados positivos em termos de adesão e ductilidade. Assim, este estudo demonstrou resultados satisfatórios para a utilização de fibras de tucumã como alternativa sustentável para melhorar as propriedades de argamassas de revestimento.

PALAVRAS-CHAVE
Fibras vegetais; Fibras de tucumã; Argamassas de revestimento; Comportamento mecânico; Construção sustentável.

RESUMEN
Las fibras de polipropileno han sido ampliamente utilizadas en la construcción civil debido a su buen desempeño y bajo costo. Sin embargo, las fibras vegetales representan una alternativa viable por sus favorables propiedades mecánicas capaces de mitigar anomalías constructivas, como grietas, además de ofrecer características económicas y sustentables. Este estudio tuvo como objetivo evaluar la incorporación de fibras de tucumã, derivadas de una planta nativa de la región amazónica, como sustituto de fibras de polipropileno en morteros de revestimiento. Para ello, se produjeron morteros con diferente contenido de fibra (adiciones de 0,5%, 1% y 1,5%) y se trataron con un agente hidrófobo a base de silano-siloxano, ya que las fibras son propensas a degradarse. Posteriormente se realizaron pruebas en estado fresco, incluyendo índice de consistencia, retención de agua, densidad aparente y contenido de aire, así como pruebas en estado endurecido, como resistencia a la tracción a flexión, resistencia a la compresión, adhesión a la tracción, análisis de ductilidad y capilaridad. absorción de agua. Respecto a los resultados en estado fresco de las respectivas pruebas, la adición de fibras de tucumã aumentó el índice de consistencia y disminuyó la densidad aparente y la retención de agua. También se observó que la adición de fibra reducía la absorción de agua al aumentar el contenido, y los resultados de las pruebas de resistencia mecánica, es decir, la resistencia a la flexión, a la tracción y a la compresión, disminuían. Además, ambos tipos de fibras mostraron resultados positivos en términos de adhesión y ductilidad. Así, este estudio demostró resultados satisfactorios para el uso de fibras de tucumã como alternativa sustentable para mejorar las propiedades de los morteros de revestimiento.

PALABRAS CLAVE
Fibras vegetales; Fibras de tucumã; Morteros de revestimento; Comportamiento mecânico; Construcción sostenible.

1. INTRODUCTION

Cracking and delamination in coating mortars are prominent construction anomalies, particularly evident in sealing systems, given that stresses in the coating layer often arise from physical, mechanical, or cyclic efforts, such as temperature gradients. In an effort to prevent the occurrence of these pathological manifestations in coating mortars, researchers have sought solutions to minimize these construction anomalies. One alternative has been the use of fibers as reinforcement in the cementitious matrix (PEREIRA, 2011; MACIOSKI *et al.*, 2017; FONSECA, 2021).

Various types of fibers have been reported for diverse applications in cement matrices, including basalt fibers (KHANDELWAL; RHEE, 2020; IORIO *et al.*, 2021), glass fibers (YLMAZ *et al.*, 1991), carbon fibers (YANG *et al.*, 2022), graphene fibers (ZHANG *et al.*, 2021), plastic fibers (AHMED; MIHASHI, 2011), and natural fibers (do AMARAL *et al.*, 2022). Natural fibers such as flax (SAWSEN *et al.*, 2015), tucumã (FONSECA, 2021), and coconut (MARTINELLI *et al.*, 2023) emerge as competitive options compared to other types due to their sustainable and ecological characteristics.

Through the addition of polyester fibers to cementitious matrix mortars, Souza *et al.* (2019) analyzed the consistency and bulk density in the fresh state, as well as flexural tensile strength and bulk density in the hardened state. The results obtained through the consistency index revealed an inversely proportional decrease as the quantity of fibers increased. Furthermore, mortars with fibers demonstrated reduced weight both in the fresh and hardened states. The results also indicated a 28% increase in flexural tensile strength, contributing to the material's enhanced ductility.

In order to assess the influence of adding kraft paper fibers derived from recycled cement packaging on mortars, Pereira (2023) replaced aggregate volume at levels of 0.1%, 0.25%, 0.50%, and 1.00%. The analysis encompassed both the fresh and hardened states, evaluating the consumption of superplasticizer additive needed to achieve the specified workability, as well as flexural tensile strength, compressive strength, and water absorption through capillarity and immersion. It was observed that the required amount of additive to attain the specified workability increases with the fiber content. Additionally, the addition of fibers was found to enhance flexural tensile strength, although mortars without fiber additions exhibited better results in compression. Concerning water absorption, the introduction of fibers increased the void index.

Sandre *et al.* (2019) aimed to investigate whether the incorporation of bamboo fibers in mortars would enhance resistivity. They achieved this by adding 10%, 20%, and 30% of fibers to the composition. Through axial compression tests, they observed a decrease in strength; however, there was a noticeable shift in the cracking pattern. The addition of fibers led to a bonding effect between the mortar components, preventing the specimen from shattering.

Dias *et al.* (2021) incorporated sisal fibers into mortars to investigate their effects on physical and mechanical properties. The study involved tests for consistency index, water retention, capillary water absorption, dynamic modulus of elasticity, as well as axial compressive and diametral tensile strength. The authors observed that as the quantity of added fibers increased, the spreadability decreased. Regarding water retention, a higher fiber content resulted in increased water retention. Concerning mechanical strength, a decrease in compressive strength was noted, while tensile strength through diametral compression significantly increased. Water absorption did not show significant differences across different fiber proportions. Lastly, the modulus of elasticity was obtained, revealing a reduction with the incorporation of sisal fibers.

Fibers from the tucumã palm (Astrocaryum aculeatum) have emerged as a promising alternative to polymeric fibers. Native to the Amazon region and belonging to the Arecaceae family, this palm is known by various common names in northern Brazil, including tucumã, tucumã-do-amazonas, tucum-açu, tucum-do-mato, tucumã-arara, among others. Beyond its cultural diversity, the tucumã palm finds versatile applications, ranging from the utilization of its fruits to the extraction of fibers from its fronds (LIMA *et al.*, 1986). In Fonseca's study (2021), treatments applied to tucum fibers (Astrocaryum chambira Burret) yielded promising results in terms of compressive and tensile strength. The fibers underwent a hybridization treatment, resulting in a significant increase in strength from 67.2 MPa to 318.8 MPa.

The applicability of mortars with plant fibers exhibits both advantages and disadvantages. Among the advantages, it is generally noted that plant fibers possess low density, low cost, and flexibility. However, due to their hydrophilic nature, there is a compromise in the stability of the composite, along with significant variability in physical and mechanical properties (PEREIRA, 2011). Therefore, it becomes essential to carry out surface modification of natural fibers to enhance the interfacial bonding between the fiber and the matrix, aiming to achieve improved performance in the resulting composites (FERRARA *et al.*, 2019).

Sepe *et al.* (2018) and Bollino *et al.* (2023) investigated the impact of chemical treatments on the mechanical behavior of hemp fabric-reinforced epoxy matrix composites. Test results reveal that silane treatment of hemp fibers enhances the tensile and flexural properties of the composites, proving more effective in preventing failure induced by water absorption. Theoretically, reducing the hydrophilic nature of the fiber to minimize its contraction and expansion in cementitious composites represents an effective strategy to enhance interfacial adhesion. Various fiber surface treatment methods have been explored to strengthen these matrices, including silane treatment (BILBA; ARSENE, 2008), hornification (CLARAMUNT *et al.*, 2010), and polymeric coating (FIDELIS *et al.*, 2016, 2019). These treatments have demonstrated positive impacts on fiber-matrix adhesion and the mechanical properties of cementitious composites.

In the presented context, tucumã fibers, renowned for their strength, hold potential to drive economic development and open avenues for research under various chemical treatments that modify their structure and enhance interfacial bonding between fiber and matrix. Therefore, this study aims to analyze the influence of adding silane-siloxane-treated tucumã fibers in coating mortars, with the goal of determining the optimal addition content that yields superior properties compared to the use of synthetic polypropylene microfibers.

2. MATERIALS AND METHODS

In the formulation of the mortars, Portland CP-V ARI cement served as the binder, accompanied by natural fine aggregate (fine river sand) featuring a characteristic maximum diameter of 1.18 mm and specific mass of 2.62 g/cm³. Additionally, the mix incorporated synthetic polypropylene microfibers, natural fibers derived from tucumã straw, and a superplasticizing chemical additive (at a content of 0.2% relative to the mass of cement). Figure 1 provides visual representations of the tucumã fiber both before and after the beneficiation process.

(a)

(b)

Figure 1: Tucumã fibers: (a) Commercially available product, and (b) After preparation for testing
Source: Authors.

The tucumã fibers used were commercially obtained from an indigenous village located in Novo Airão, Amazonas. These fibers were provided in a collection of various straw lengths and thicknesses in their natural state. To be incorporated into the mortars, the fibers were manually cut to a size of 6 ± 1 mm, using rulers and scissors to standardize the sizes similarly to the polypropylene microfibers with a density of 0.93 g/cm³, diameter of 18 μm, elongation of 80% and tensile strength of 300 MPa.

Three distinct percentages of natural fiber were proposed, namely 0.50%, 1.00%, and 1.50%, relative to the mass of the binder. These percentages were based on studies by Oliveira (2021).

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To treat the tucumã plant fibers, a silane-siloxane-based water repellent was employed, with an addition of 0.3% relative to the fiber mass for a duration of 24 hours. This treatment is essential as the fibers may undergo degradation in a moist and alkaline environment, leading to increased water absorption and heterogeneity in the physical and mechanical properties of the natural fibers. Such variations can have a detrimental impact on their overall performance. Figure 2 illustrates the impact of silane-siloxane treatment on tucumã fibers via scanning electron microscopy (SEM). It is possible to see that the chemical admixture provided a protective layer on the fiber, thus reducing its porosity.

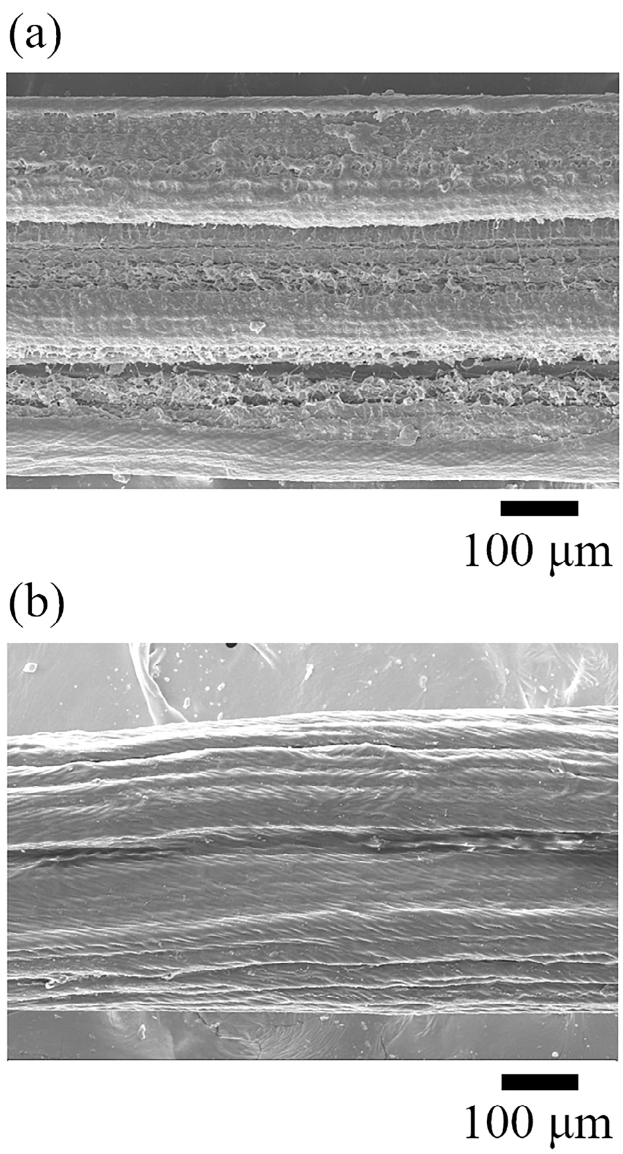

Figure 2: Tucumã fibers: (a) Natural fiber, and (b) Treated fiber.
Source: Authors.

The mortar mixing method adhered to the guidelines outlined in NBR 16541 (ABNT, 2016). The dosage ratio applied in this study was consistent with that used by Alberton (2022), maintaining a 1:5 ratio (cement:sand) by mass. The materials used to produce mortars remained in fixed quantities. 417 g of cement, 2083 g of fine aggregate, 0.83 g of plasticizing additive, and a water/binder ratio of 0.96 were used.

The mortar's consistency index was set at 270 ± 5 mm, given that the mortars with the spreading indicated by the standard proved to be inadequate, as the samples became dry and exhibited compromised workability.

Subsequently, tests were conducted in the fresh state, and specimens were produced. It is noteworthy that fresh state tests were performed immediately after sample production, followed by the molding of specimens. After a 24-hour period, the specimens were demolded and kept in an ambient cure at 25 ± 2ºC and a relative humidity of 85%.

The molding of the test specimens followed the procedures outlined in NBR 13279 (ABNT, 2005). The considered response variables encompassed properties in both the fresh and hardened states. In the fresh state, assessments included consistency index (ABNT NBR 13276, 2016; ASTM C305, 2020), water retention (ABNT NBR 13277, 1995), bulk density, and air content (ABNT NBR 13278, 2005; ASTM C185, 2020). After a curing period of 28 days for the specimens, evaluations in the hardened state involved flexural tensile strength and axial compressive strength (ABNT NBR 13279, 2005), bulk density (ABNT NBR 13278, 2005), tensile adhesion strength (ABNT NBR 15258, 2016), and capillary water absorption (ABNT NBR 15259, 2005; ASTM C1794, 2019). The plaster mixtures were prepared and applied to the substrates following the guidelines of NBR 7200 (ABNT, 1998). Only the mortars containing 1.0% of various fibers were tested for tensile adhesion strength.

It is important to note that in the tensile adhesion strength test, eighteen ceramic bricks (9x19x19cm) were employed for each mixture. The mortars were molded using EVA molds with circular sections and diameters of 50 mm on substrates that had previously been coated with plaster. The press utilized was an EMIC model, equipped with a 5kN load cell, operating at a speed of 0.08 mm/s.

3. ANALYSIS AND DISCUSSION OF RESULTS

The analysis of consistency indices revealed that, even when maintaining a constant water/cement ratio, mortars with fiber additions exhibited variations as the percentages of fibers increased, in comparison to the reference mortar. Results obtained with additions of 0.5% and 1.0% of polypropylene and tucumã fibers indicate an increase in the consistency index. Conversely, percentages of 1.5% for both fibers resulted in a decrease in workability, as shown in Figure 3.

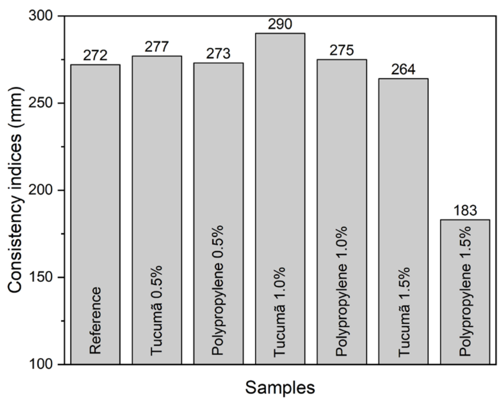

Figure 3: Consistency index of samples.
Source: Authors.

In the study conducted by Tiscoski (2016), a reduction in the consistency index was also observed as the content of polypropylene fibers increased. This resulted in an increase in the water/cement ratio necessary to maintain a constant index. Similarly, Alberton *et al.* (2023) investigated the influence of coconut fiber additions, resulting in a gradual decrease in the mean consistency as the percentage of fiber addition increased. The study by Centofante and Dagostini (2014) also indicated a decrease in the consistency index of mortars with fiber additions. Notably, mixtures containing additions of polypropylene fibers showed a reduction in the workability of mortars compared to those without fiber additions. These workability reductions can be attributed to fiber clustering and difficulty in proper dispersion during mortar preparation.

Regarding the increase in indices caused by tucumã fiber additions up to 1.0%, one of the possible influencing factors may be related to fiber treatment. This is evidenced in the studies of Oliveira (2001), Macioski *et al.* (2017) and Alberton *et al.* (2023), where untreated fibers negatively impacted mortar workability. Therefore, a plausible hypothesis is that the use of the water repellent may have contributed to the increase in indices, as this product has water-repelling properties on treated surfaces, as described by Costa (2014).

Figure 4 presents the results obtained for bulk density, where it can be observed that mortars with additions of both fibers exhibited a decrease in mass compared to the reference mortar, making them lighter.

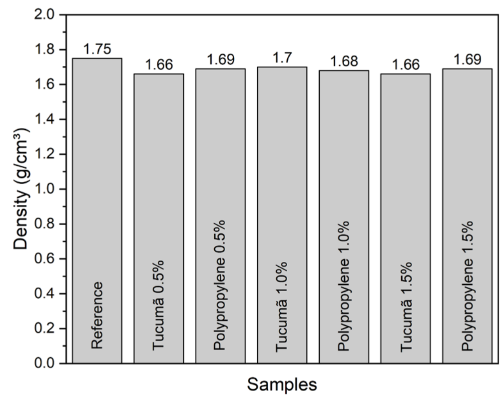

Figure 4: Bulk density of samples.
Source: Authors.

According to Carasek (2010), mortars with bulk density ranging from 2.30 to 1.40 g/cm³ are classified as normal mortars. Therefore, all mortars produced in this study fall within this classification. The reduction in bulk density when adding polypropylene fibers is a consistent finding in previous studies, such as that of Centofante and Dagostini (2014). Additionally, similar results regarding bulk density were obtained when using natural fibers like curauá, sisal, and coconut, as observed in the studies by Alberton (2022) and Nascimento *et al.* (2023).

The air content in mortars is directly related to bulk density. Therefore, as the bulk density decreases, the incorporated air content increases, as illustrated in Figure 5.

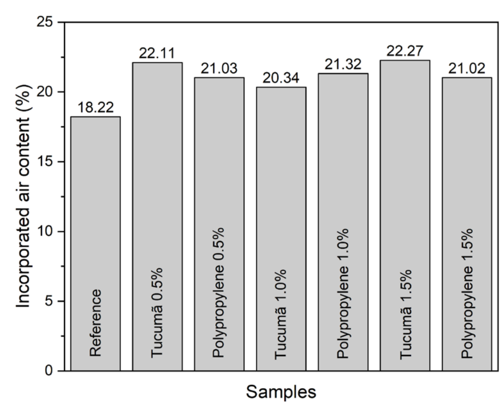

Figure 5: Incorporated air content of samples.
Source: Authors.

The mortars with fiber additions have a significant impact that influences an increase in the incorporated air in the samples. It is observed that the mortar with tucumã fiber additions up to 1.0% showed a reduction in the air content, as it obtained a higher apparent density for the same sample. This behavior is consistent with the results obtained by Alberton (2022), who used natural coconut fibers, and Nascimento *et al.* (2023), who used natural curauá and sisal fibers, as well as microfibers of polypropylene.

Regarding water retention, it was observed that all mortars (Figure 6), except those using 1.5% polypropylene fibers, exhibited approximate values of 94%. This finding aligns with the study by Nascimento *et al.* (2023), which also reported no significant differences in water retention with the addition of fibers. According to the Centre Scientifique Et Technique Du Batiment (CSTB, 1993), water retention for external coatings should fall within the range of 80% to 90%. However, for atmospheric conditions characterized by hot or windy climates, mortars should ideally have values between 91% and 100%. ASTM C270:12a (2012) stipulates that values should not be lower than 75%. Consequently, all mortars presented in this study demonstrated a retention exceeding 90%. This implies that mortars containing fibers maintain their workability for a longer duration when subjected to conditions causing water loss during mixing. A similar observation was made in Pczieczek's (2017) study, which analyzed the properties of coating mortars using fly ash and waste from non-recyclable tire rubber.

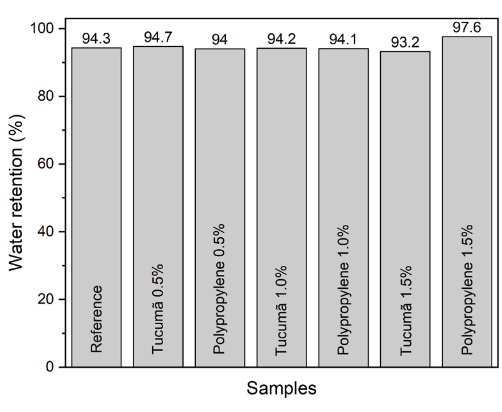

Figure 6: Water retention of samples.
Source: Authors.

Figure 7 provides the values of average and individual tensile strengths, along with the standard deviation for each tested formulation.

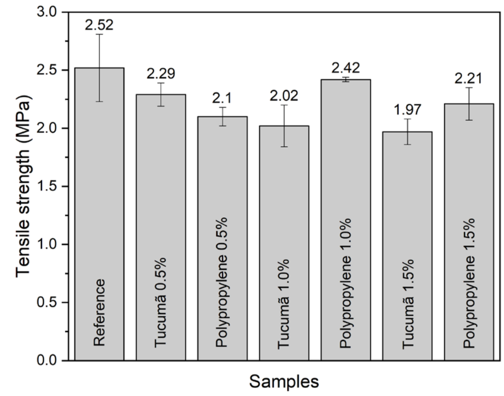

Figure 7: Summary of tensile strength results for samples.
Source: Authors.

It is observed that specimens with fiber additions exhibit a decrease in flexural tensile strength compared to the reference mortar. These results contradict the findings of Pereira *et al.* (2023), where the authors noted a significant enhancement in flexural tensile strength properties with the addition of polypropylene fibers, both in conventional and industrial mortars, when compared to the reference mix.

Fonseca (2021) found that the flexural tensile strength of composites with the addition of both treated and untreated tucum fibers increased compared to the reference sample. Furthermore, it was observed that hybridization treatment, particularly with the addition of 4.5% tucum fibers, significantly improved the mechanical performance in flexural tensile strength. This enhancement also resulted in an increase in direct tensile strength in the fiber, rising from 67.2 MPa to 318.81 MPa.

The results of the axial compression strength tests for the mortars are detailed in Figure 8.

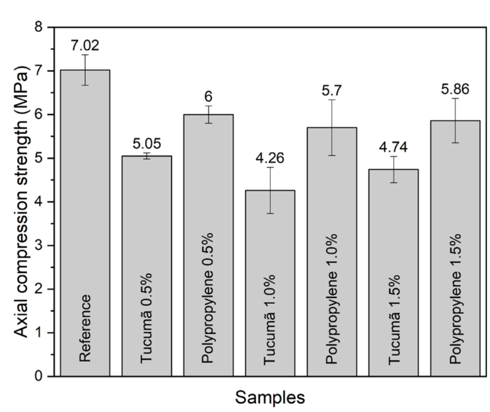

Figure 8: Summary of axial compression strength results for samples.
Source: Authors.

The obtained results indicate that the addition of fibers reduces the compressive strength of mortars compared to the reference mortar. Mortars with tucumã fibers, when compared to those containing polypropylene fibers, showed an average reduction of approximately 1.3% across all analyzed addition levels for this property. It is noteworthy that mortars with the addition of 0.5% of both fibers exhibited superior results compared to other addition levels.

The decrease in compressive strength was also observed in the studies of Alberton (2022), and Nascimento *et al.* (2023). They found that additions of coconut fibers, curauá fibers, sisal fibers, and microfibers of polypropylene, respectively, resulted in a reduction compared to the reference mortar. In Fonseca's study (2021), tucum fibers, both treated and untreated, also exhibited a reduction in compressive strength when compared to the reference mortar, consistent with the findings presented in this study for tucumã fibers.

With the results of tensile and axial compressive strength, the relationship between the parameters of flexural tensile strength and axial compressive strength was determined. This relationship allows for obtaining the ductility values of the mortars. The tested mortars exhibited an average range of 0.35 to 0.47% in the ratios (Rf/Rc) of the strengths of the tested samples. It is observed that the addition of fibers to coating mortars can significantly enhance their ductility, as evidenced in the study by Maia *et al.* (2018).

Furthermore, samples with additions of tucumã fibers exhibited higher ductility values compared to both polypropylene and reference mortars. Therefore, the incorporation of vegetable fibers enhances the structure of the composites, providing them with improved ductility and post-cracking energy absorption (FONSECA, 2021). Additionally, Johnston (1992) argues that the addition of fibers in a cementitious matrix tends to enhance the ductility and toughness of a naturally brittle matrix.

Figure 9 presents the results obtained in the tensile bond strength test of the mortars.

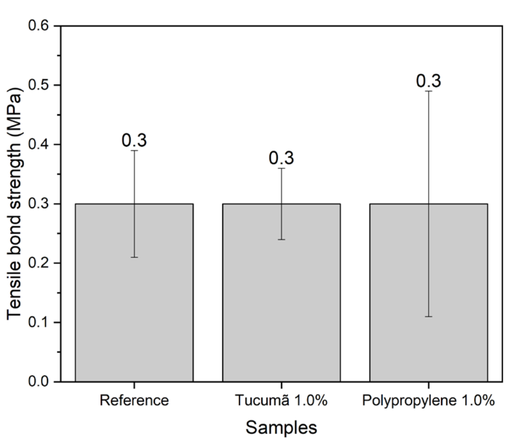

Figure 9: Tensile bond strength of samples.
Source: Authors.

From the obtained data, it was observed that all tested samples had an average of 0.30 MPa, thereby meeting the criteria established by the NBR 13749 standard (ABNT, 2005). Additionally, mortars produced with the addition of polypropylene fibers exhibited high coefficients of variation (58%) and standard deviations (0.19), whereas mortars with tucumã fiber additions showed the lowest standard deviations (0.06) and coefficient of variation (20%).

Silva *et al.* (2023) observed that the adhesion of tucumã fibers, when treated with silane-siloxane, yielded satisfactory results. These findings emphasize the positive influence of these treated fibers on this mechanical property. The increase in adhesion with the addition of polypropylene fibers, compared to the reference sample, was also observed in the study by Tiscoski (2016). However, the values found by this author were below the specified standard, possibly due to the direct application on the substrate, which may have influenced the results.

Concerning the failure mode, a visual inspection of the fractured specimens was conducted, identifying only four types of failure modes (Figure 10) in the tests performed for a plastering system and a set of layers (adhesive, tile, and mortar). The results of the failure modes are presented in Table 1.

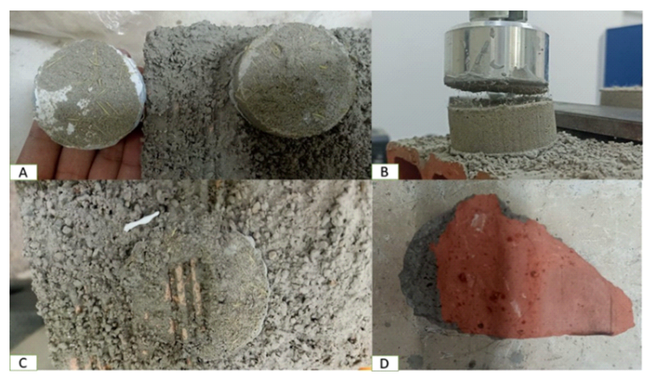

Figure 10: Visual appearance of fractured specimens.
Source: Authors.

Sample Type	Reference	Tucumã 1%	Polypropylene 1%
	Number of Samples		
Chapisco	1	6	
Mortar/ Adhesive	2		2
Adhesive		6	
Adhesive/ Tile	2		
Substrate			4
Note: The table represents the number of specimens for each type of failure mode observed in the tests			

Table 1: Summary of failure mode characteristics of specimens.
Source: Authors.

The specimens of the reference mortar showed failures at the adhesive/tile interface. In these cases, NBR 13755 (ABNT, 2017) suggests disregarding these obtained values as they indicate imperfections in the tile bonding. For the samples that failed in the plaster, adhesive, and mortar/adhesive interfaces, the standard indicates that the test values are superior to those obtained. As shown in Table 5, it was found that 50% of the mortars produced with tucumã fibers failed at the upper face of the adhesive mortar, demonstrating that the adhesion at the substrate interface has values exceeding 0.30 MPa.

On the other hand, the samples of mortars with additions of polypropylene fibers, for the most part, failed at the substrates. In contrast to the study by Tiscoski (2016), which examined 48 specimens, including reference mortar samples and mortar samples with additions of polypropylene fibers, it was observed that only two samples failed at the substrate, two at the mortar/adhesive interface, and the remaining 44 samples failed at the substrate/mortar interface.

The results of the capillary water absorption tests are illustrated in Figure 11.

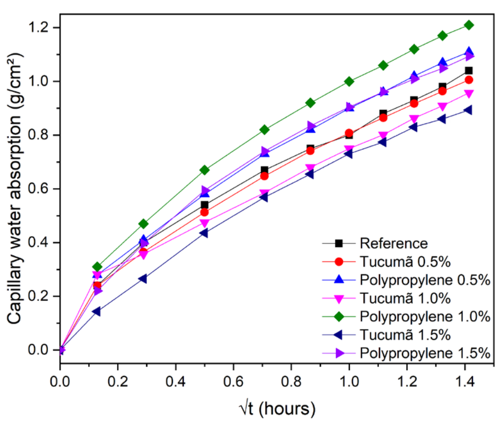

Figure 11: Results of capillary water absorption tests.
Source: Authors.

According to the data, it is evident that the addition of tucumã fibers reduces water absorption as the additions increase progressively, compared to both the reference and polypropylene mortars. Therefore, mortars with tucumã fiber additions exhibited a lower rate of absorption over the test period. Thus, these mortars demonstrated better performance in terms of impermeability.

The percentage reduction in water absorption in mortars with tucumã fibers can be explained by Fonseca (2021), who found that treating fibers with silanes, commonly used as water repellents, can alter the morphology of the fibers, causing swelling and increased porosity, resulting in reduced water absorption by the fibers. In the same referenced study, the author observed lower results for tucum fibers with treatments using baking and hot water, while treatments with NaOH and hybridization resulted in higher water absorption. Additionally, untreated fibers exhibited water absorption values higher than those of the reference mortar.

The polypropylene fibers exhibited higher water absorption values when compared to both the reference and tucumã mortars. However, Centofante and Dagostini (2014) observed a reduction in water absorption values with the addition of polypropylene fibers. They explained that polypropylene fibers are effective in reducing porosity, consequently making the mortar more impermeable. The difference in findings may be attributed to variations in experimental conditions, mix proportions, or fiber characteristics between different studies.

Cavalheiro *et al.* (2023) observed that mortars with additions of treated coconut fibers did not show a significant difference when compared to the reference mortar. On the other hand, the mortar with the addition of untreated fibers resulted in lower water absorption for this property. This highlights the impact of fiber treatment on water absorption properties, with untreated fibers potentially exhibiting improved performance in certain cases.

4. CONCLUSIONS

In conclusion, the investigation into the fresh and hardened states of mortars with tucumã and polypropylene fiber additions has provided valuable insights into their properties and performance. The following key findings and implications can be drawn from this research:

- The consistency indices of mortars with fiber additions exhibited variations compared to the reference mortar. While 0.5% and 1.0% additions of both polypropylene and tucumã fibers increased the consistency index, 1.5% additions resulted in a decrease in workability.
- The reduction in bulk density was observed in mortars with fiber additions, making them lighter. This aligns with previous studies on the influence of natural and synthetic fibers on mortar density.
- All mortars, except those with 1.5% polypropylene fibers, demonstrated approximately 94% water retention. This exceeds the recommended range for external coatings, suggesting that fiber-containing mortars maintain workability for an extended period.

- Compressive strength of mortars decreased with fiber additions, indicating a trade-off between flexibility (ductility) and compressive strength. Notably, 0.5% additions of both fibers showed superior results.
- The relationship between flexural tensile strength and compressive strength ratios revealed that mortars with fiber additions exhibited improved ductility. Tucumã fibers contributed to higher ductility values compared to polypropylene and reference mortars.
- Mortars with fiber additions exhibited an average tensile bond strength of 0.30 MPa, meeting standards. Tucumã fibers, especially when treated, positively influenced adhesion, while polypropylene fibers exhibited higher variability.
- Tucumã fiber-containing mortars predominantly failed at the upper face of the adhesive mortar, indicating superior adhesion at the substrate interface. Polypropylene fiber-containing mortars mainly failed at the substrate, in contrast to previous studies.
- Tucumã fibers reduced water absorption with increasing additions, outperforming polypropylene fibers. Fiber treatment with silanes played a crucial role in decreasing water absorption, highlighting the importance of fiber treatment.

These findings collectively underscore the complex interplay between different fibers and their impact on various mortar properties. The study contributes valuable data to the ongoing discourse on fiber-reinforced mortars, emphasizing the need for a nuanced understanding of the trade-offs between different performance parameters. Further research could delve into optimizing fiber proportions for specific applications and exploring additional treatment methods to enhance overall mortar performance.

REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 13277: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da retenção de água.** Rio de Janeiro, 1995.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 7200: Execução de revestimento de paredes e tetos de argamassas inorgânicas – Procedimento.** Rio de Janeiro, 1998.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 13278: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da densidade de massa e do teor de ar incorporado.** Rio de Janeiro, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 13279: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da resistência à tração na flexão e à compressão.** Rio de Janeiro, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 15259: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da absorção de água por capilaridade e do coeficiente de capilaridade.** Rio de Janeiro, 2005.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 13276: Argamassa para assentamento e revestimento de paredes e tetos – Determinação do índice de consistência.** Rio de Janeiro, 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 15258: Argamassa para revestimento de paredes e tetos - Determinação da resistência potencial de aderência à tração.** Rio de Janeiro, 2021.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 16541: Argamassa para assentamento e revestimento de paredes e tetos - Preparo da mistura para a realização de ensaios.** Rio de Janeiro, 2016.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 13755: Revestimentos cerâmicos de fachadas e paredes externas com utilização de argamassa colante - Projeto, execução, inspeção e aceitação – Procedimento.** Rio de Janeiro, 2017.

AHMED, S.F.U.; MIHASHI, H. Strain hardening behavior of lightweight hybrid polyvinyl alcohol (PVA) fiber reinforced cement composites. **Materials and Structures**, 44(6):1179–91, 2011.

ALBERTON, K. S. Análise da influência da adição de fibras de coco nas propriedades das argamassas de revestimento. Trabalho de Conclusão de Curso em Engenharia Civil — Instituto Federal de Educação, Ciência e Tecnologia de Rondônia, Campus Porto Velho Calama, Rondônia, 2022.

ALBERTON, K.S.; NASCIMENTO, C. B.; CAVALHEIRO, R. B.; OLIVEIRA, V. C.; GONZAGA, L. B. T. G.; PIEROZAN, R. C. Properties of coconut fiber-reinforced mortars for sustainable solutions. **Journal of Building Pathology and Rehabilitation**, 8.44, 2023.

AMERICAN SOCIETY FOR TESTING AND MATERIALS INTERNATIONAL (ASTM). **C1794: Standard test methods for determination of the water absorption coefficient by partial immersion.** West Conshohocken, EUA, 2019.

AMERICAN SOCIETY FOR TESTING AND MATERIALS INTERNATIONAL (ASTM). **C185: Standard test method for air content of hydraulic cement mortar.** West Conshohocken, EUA, 2020.

AMERICAN SOCIETY FOR TESTING AND MATERIALS INTERNATIONAL (ASTM). **C270: Standard specification for mortar for unit masonry.** West Conshohocken, EUA, 2012.

AMERICAN SOCIETY FOR TESTING AND MATERIALS INTERNATIONAL (ASTM). **C305: Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency.** West Conshohocken, EUA, 2020.

BILBA, K.; ARSENE, M-A. Silane treatment of bagasse fiber for reinforcement of cementitious composites. Composites Part A: **Applied Science and Manufacturing**, 39(9):1488–95, 2008.

BOLLINO, F.; GIANNELLA VENANZIO, A. E.; SEPE, R. Mechanical behavior of chemically treated hemp fibers reinforced composites subjected to moisture absorption. **Journal of Materials Research and Technology**, 22:762–75, 2023.

CARASEK, H. **Argamassas.** In: Isaias, G.C. (ed.). Materiais de Construção Civil e Princípios de Ciência e Engenharia de Materiais, São Paulo, IBRACON, pp. 892-944, 2010.

CAVALHEIRO *et al.* Analysis of the properties of mortars produced with coconut fibers treated with triethroxy(octyl)silane. XVII Congreso Latinoamericano de Patología de Construcción y XVIX Congreso de Control de Calidad en la Construcción, (CONPAT). Santa Cruz de la Sierra, p. 1-12, 2023.

CENTOFANTE, G.; DAGOSTINI, C. M. Análise das propriedades de argamassas de revestimento com adição de fibras de polipropileno. **Unoesc & Ciência-ACET,** p. 7-16, 2014.

CLARAMUNT, J.; ARDANUY, M.; GARCÍA-HORTAL, J.A. Effect of drying and rewetting cycles on the structure and physicochemical characteristics of softwood fibers for reinforcement of cementitious composites. **Carbohydrate Polymers**, 79(1):200–5, 2010.

COSTA, E.B.C. Análise de parâmetros influentes na aderência de matrizes cimentícias. Tese (Doutorado) - Escola Politécnica da Universidade de São Paulo, São Paulo, 2014.

CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT (CSTB). Certification CSTB desenduits monocouches d'imperméabilisation – Cahier MERUC. Livraison 341, cahier 2669-3, juillet-août. Paris, 1993.

DIAS, L.S.; BESERRA, A.V.S.; SANTOS, R.A.; SOUSA, A.A.; LIRA NETO, A.B.; LANDIM, A.E.F.G.; BARROZO, G.F.; SILVA, C.J.V. Incorporation of waste from the production of sisal fibers into mortar: Effects on physical and mechanical properties. **Revista Matéria**, 26(3), 2021.

DO AMARAL, L.M.; DE SOUZA RODRIGUES, C.; POGGIALI, F.S.J. Hornification on vegetable fibers to improve fiber-cement composites: a critical review. **Journal of Building Engineering**, 48:103947, 2022.

FERRARA, G.; PEPE, M.; MARTINELLI, E.; DIAS TOLÊDO FILHO, R. Influence of an impregnation treatment on the morphology and mechanical behavior of flax yarns embedded in hydraulic lime mortar. **Fibers**, 7(4):30, 2019.

FIDELIS, M.E.A.; DIAS TOLÊDO FILHO, R.; SILVA, F.A.; MECHTCHERINE, V.; BUTLER, M.; HEMPEL, S. The effect of accelerated aging on the interface of jute textile reinforced concrete. **Cement and Concrete Composites**, 74:7-15, 2016.

FIDELIS, M.E.A.; DIAS TOLÊDO FILHO, R.; SILVA, F.A.; MOBASHER, B.; MULLER, S.; MECHTCHERINE, V. Interface characteristics of jute fiber systems in a cementitious matrix. **Cement and Concrete Research**, 116(21):252-265, 2019.

FONSECA, R.P. Influência de diferentes tipos de fibras vegetais amazônicas no desempenho de uma argamassa à base de cimento Portland e Metacaulim. 2021. Tese de Doutorado - Universidade Federal de Santa Catarina, Centro Tecnológico, Programa de Pós-Graduação em Engenharia Civil, Florianópolis, 2021.

IORIO, M.; MARRA, F.; SANTARELLI, M.; GONZÁLEZ-BENITO, J. Reinforcement-matrix interactions and their consequences on the mechanical behavior of basalt fibers-cement composites. **Construction and Building Materials**, 309:125103, 2021.

JOHNSTON, C. D. **Fibre-reinforced cement and concrete.** In: V. M. MALHOTRA. Advances in Concrete Tecnology. 2a edition. Ottawa: V. M. Malhotra, 1992.

KHANDELWAL, S.; RHEE, K.Y. Recent advances in basalt-fiber-reinforced composites: Tailoring the fiber--matrix interface. **Composites Part B: Engineering**, 192:108011, 2020.

LIMA, R.R.; TRASSATO, L.C.; COELHO, V. O tucumã (Astrocaryum vulgare Mart.) - Principais características e potencialidade agroindustrial. EMBRAPA, **Boletim de Pesquisa**, n. 75, 1986.

MAIA, C.; VEIGA, M. R.; BRITO, J. Comportamento à fendilhação de argamassas com incorporação de fibras sintéticas. In: Construção: reabilitar e construir de forma sustentável, Porto, 2018.

MACIOSKI, G.; MARTINS, L.A.; MUELLER, T.; MATOSKI, A. Avaliação das propriedades de argamassas com adição de fibra de Curauá (Ananas Erectifolius). **Revista Engenharia e Construção Civil**, v. 3, n. 2, 2017.

MARTINELLI, F.R.; RIBEIRO, F.R.; MARVILA, M.T.; MONTEIRO, S.N.; FILHO, F.D.; AZEVEDO, A.R. A review of the use of coconut fiber in cement composites. **Polymers**, 15(5):1309, 2023.

NASCIMENTO, C.B.; BARBOSA, V.M.; BARBOSA, C.E.S.M.; MOTAO, W.K.B.; OLIVEIRA, V.C. Analise das propriedades de argamassas de revestimentos produzidas com diferentes fibras naturais. XIV Simpósio Brasileiro de Tecnologia das Argamassas (SBTA). João Pessoa, Paraíba, 2023.

OLIVEIRA, M. L. L. Influência da adição de fibras de polipropileno em argamassa. Dissertação de mestrado. Universidade de Santa Catarina. Santa Catarina, SC, 2001.

PCZIECZEK, A.; SCHACKOW, A.; EFFTING, C.; DIAS, T.F.; GOMES, I.R. Properties of mortars containing tire rubber waste and expanded polystyrene (EPS). **Journal of Urban and Environmental Engineering**, v. 11, n. 2, p. 219-225, 2017.

PEREIRA, C. H. A. F. Contribuição ao estudo da fissuração, da retração e do mecanismo de descolamento do revestimento à base de argamassa. Tese de Doutorado em Engenharia Civil. Universidade de Brasília, Brasília, 2007.

PEREIRA, R. J. P. O desempenho reológico e mecânico de argamassas de revestimento reforçadas com fibras. Tese de Doutorado em Engenharia Civil, Universidade da Beira Interior, Covilhã, Portugal, 2011.

PEREIRA, J. R.; PEREIRA, M.C.B.; REZENDE, T.; SANTOS, G.S. Análise da influência da adição de fibra de polipropileno na argamassa de revestimento em relação à resistência à retração por secagem. In: Anais da Mostra de Pesquisa em Ciência e Tecnologia, 2019.

SANDRE, D.S.B., TRENTIN, T.F.S., CAVAZZANA, T.L. Viabilidade para implementação de fibras de bambu em argamassas. **Revista Científica ANAP Brasil,** 12(24), 86-100, 2019.

SAWSEN, C., FOUZIA, K., MOHAMED, B., MOUSSA, G. Effect of flax fibers treatments on the rheological and the mechanical behavior of a cement composite. **Construction and Building Materials**, 79:229–35, 2015.

SEPE, R., BOLLINO, F., BOCCARUSSO, L., CAPUTO, F. Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites. **Composites Part B: Engineering**, 133:210–7, 2018.

SILVA, *et al.* Análise da aderência à tração de fibras vegetais em matriz cimentícia com fibras de coco, sisal e tucumã. In: Anais do 64º Congresso Brasileiro do Concreto (CBC), Florianópolis, Santa Catarina, 2023.

SOUSA, L.F., SANTOS JUNIOR, A.G., SANTOS, M.L.L.O. Avaliação do desempenho de argamassas cimentícias reforçadas com fibras de poliéster. **Brazilian Applied Science Review**, 3(6), 2565-2576, 2019.

TISCOSKI, B. L. Análise do efeito da adição de fibras de polipropileno na resistência de aderência à tração em argamassa de revestimento. Trabalho de Conclusão de Curso em Engenharia Civil, Universidade do Extremo Sul Catarinense, Criciúma, 2016.

YANG, Z., YANG, J., SHUAI, B., NIU, Y., YONG, Z., WU, K., ZHANG, C., QIAO, X., ZHANG, Y. Superflexible yet robust functionalized carbon nanotube fiber reinforced sulphoaluminate cement-based grouting materials with excellent mechanical, electrical and thermal properties. **Construction and Building Materials**, 328:126999, 2022.

YLMAZ, V.T., LACHOWSKI, E.E., GLASSER, F.P. Chemical and microstructural changes at alkali-resistant glass fiber–cement interfaces. **Journal of the American Ceramic Society**, 74(12):3054–60, 1991.

ZHANG, C., SHUAI, B., JIA, S., LV, X., YANG, T., CHEN, T., YANG, Z. Plasma-functionalized graphene fiber reinforced sulphoaluminate cement-based grouting materials. **Ceramics International**, 47(11):15392–9, 2021.

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AUTHORS

ORCID: 0009-0004-2155-8502
Carmelita Blodow do Nascimento | Graduada em Engenharia Civil | Instituto Federal de Educação, Ciência e Tecnologia de Rondônia (IFRO) | Coordenação em Engenharia Civil | Porto Velho, RS, Brasil/ Av. Calama, 4985, 76820-441, Porto Velho – RO | e-mail: carmelitablodow11@gmail.com

ORCID: 0000-0002-7025-575X
Valéria Costa de Oliveira | Doutora em Engenharia Civil | Instituto Federal de Educação, Ciência e Tecnologia de Rondônia (IFRO) | Coordenação em Engenharia Civil | Porto Velho, RS, Brasil | Av. Calama, 4985, 76820-441, Porto Velho – RO | e-mail: valeria.oliveira@ifro.edu.br

ORCID: 0000-0002-2585-0840
Rodrigo Cesar Pierozan | Doutor em Geotecnia | Universidade Tecnológica Federal do Paraná (UTFPR-CM) | Departamento Acadêmico de Construção Civil | Campo Mourão, PR, Brasil | Via Rosalina Maria dos Santos, 1233, 87301-899, Campo Mourão - PR | email: rodrigopierozan@utfpr.edu.br

ORCID: 0000-0003-4740-6537
Lídia Bruna Teles Gonzaga | Doutoranda em Geotecnia | Universidade de Brasília (UnB-DF) | PPG em Geotecnia | Brasília, DF, Brasil Z Av. L3 Norte, SG12, 70.910-900, Brasília – DF/ email: lidiabrunateles@gmail.com

ORCID: 0000-0001-8790-3023
Francisco Roger Carneiro Ribeiro | Doutorando em Engenharia Civil | Universidade Federal do Rio Grande do Sul (UFRGS-RS) | PPG em Engenharia Civil | Porto Alegre, RS, Brasil | Av. Osvaldo Aranha, 99, 90035-190, Porto Alegre – RS | email: roger.ribeiro_@hotmail.com

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