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Analysis of the properties of mortars produced with coconut fibers treated with triethroxy(octyl)silane

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ABSTRACT

The aim of this study was to assess the effect of triethoxy(octyl)silane treatment on coconut fiberswhen incorporated into mortars. Vegetable fibers are commonly utilized in such composites. However, they can degrade in alkaline environments. The experimental approach involved treating coconut fibers with triethoxy(octyl)silane at different mass percentages relative to the cement. The findings revealed that cementitious composites incorporating treated vegetable fibers demonstrated enhanced workability, water retention, and water absorption properties compared to untreated materials. Moreover, there was no notable decline in mechanical properties. These results highlight the potential of triethoxy(octyl)silane treatment as a means to improve the performance and durability of cementitious composites incorporating vegetable fibers, thus contributing to the development of sustainable and resilient construction materials.

Keywords: coconut fiber; triethroxy(octyl)silane; mortars; performance enhancement.

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Análisis de las propiedades de morteros elaborados con fibras de coco tratadas con trietroxi(octil)silano

RESUMEN

El objetivo de este estudio fue evaluar el efecto del tratamiento con trietoxi(octil)silano en las fibras de coco cuando se incorporan en morteros. Las fibras vegetales se utilizan comúnmente en este tipo de compuestos. Sin embargo, pueden degradarse en entornos alcalinos. El enfoque experimental consistió en tratar las fibras de coco con trietoxi(octil)silano en diferentes porcentajes en masa en relación al cemento. Los resultados revelaron que los compuestos cementicios que incorporaron fibras vegetales tratadas mostraron una mejor trabajabilidad, retención de agua y propiedades de absorción de agua en comparación con los materiales no tratados. Además, no se observó una disminución notable en las propiedades mecánicas. Estos resultados resaltan el potencial del tratamiento con trietoxi(octil)silano como un medio para mejorar el rendimiento y la durabilidad de los compuestos cementicios que incorporan fibras vegetales, contribuyendo así al desarrollo de materiales de construcción sostenibles y resilientes.

Palabras clave: Fibra de coco; Trietoxi(octil)silano; Morteros; Mejora del rendimiento.

Análises das propriedades de argamassas produzidas com fibras de coco tratadas com trietroxi(octil)silano

RESUMO

O objetivo deste estudo foi avaliar o efeito do tratamento com trietoxi(octil)silano em fibras de coco quando incorporadas em argamassas. Fibras vegetais são comumente utilizadas nesses tipos de compósitos. No entanto, elas podem degradar em ambientes alcalinos. A abordagem experimental envolveu o tratamento das fibras de coco com trietoxi(octil)silano em diferentes porcentagens em massa relativas ao cimento. Os resultados revelaram que as argamassas que incorporaram fibras vegetais tratadas apresentaram melhor trabalhabilidade, retenção de água e propriedades de absorção de água em comparação com materiais não tratados. Além disso, não houve declínio notável nas propriedades mecânicas. Esses resultados destacam o potencial do tratamento com trietoxi(octil)silano como um meio para melhorar o desempenho e a durabilidade dos compósitos cimentícios que incorporam fibras vegetais, contribuindo assim para o desenvolvimento de materiais de construção sustentáveis e resilientes.

Palabras chave: Fibra de coco; Trietoxi(octil)silano; Argamassas; Melhoria de desempenho.

1. INTRODUCTION

Cracking and detachment are the most common construction anomalies in coating systems, as stresses in the coating layer are often caused by physical, mechanical, or cyclic factors such as temperature gradients (PEREIRA, 2011). One approach to mitigate the occurrence of these pathological manifestations in rendering mortars has been the use of fibers as reinforcement within the cementitious matrix (MANCIOSKI, *et al*., 2017; FONSECA, 2021; PEREIRA, 2011).
Vegetable fibers possess hydrophilic groups within their chemical structure, and their incorporation into mixtures exhibits a weak interfacial interaction, resulting in final products with inferior mechanical properties compared to pure polymers (ALBINANTE *et al*., 2013).
Coconut fibers, derived from coconut husks, offer advantages such as low weight, cost-

effectiveness, easy processing, and thermal and acoustic insulation properties (SABRI *et al*., 2013). However, coconut fiber also exhibits undesirable properties, including dimensional instability, flammability, and moisture-related degradation.
To achieve a uniform composite with desirable properties, it is important to enhance the interaction between the components, which can be achieved by subjecting the fiber to chemical treatment. In this regard, Albinante *et al*. (2013) emphasize that understanding the internal structure and chemical composition of lignocellulosic fibers is crucial for comprehending their influence on composite characteristics and guiding the selection of chemical treatments.
One of the reasons for employing fiber treatments is to enhance the interfacial adhesion between natural fibers and the cementitious composite. Consequently, various strategies, including chemical treatments, have been proposed. The effects of these treatments vary depending on the fiber composition, particularly the cellulose proportion.
Chemical treatments are commonly used to enhance the interfacial adhesion between the fiber and the cementitious matrix. Simultaneously, these treatments reduce water absorption by the fibers. Several methods have been studied to improve adhesion in composites, such as sodium hydroxide, silane, or combined treatments like alkaline-silane, alkaline-heat, alkaline beam irradiation, alkaline bleaching treatment, etc. However, the effectiveness of fiber treatment methods in improving the bond between the matrix and the fiber varies, as they have different effects on each fiber type (HAMIDON *et al*., 2019).
One of the employed treatments is silanization, a chemical treatment involving silicon compounds. The molecules of these compounds have a hydrophobic terminal group at one end, which can develop van der Waals interactions with the composite matrix, and a hydrophilic group at the other end, which can react with the OH groups of the fiber, forming a bridge (COLOM *et al*., 2003; ICHAZO *et al*., 2001).
Paul *et al*. (2008) demonstrated a polypropylene composite reinforced with banana fiber treated with silane agents [triethoxy(octyl)silane]. They observed that the polymerized silane forms a bridge at the interface between the banana fiber and the matrix, enhancing the bond between these two incompatible materials.
Other studies supporting the use of silane include Saucedo (2021) and Oliveira's (2022) research, which demonstrated that the use of a triethoxy(octyl)silane-based hydrophobic agent helps maintain the superhydrophobic property on the surface of various ceramic substrates. In the case of Saucedo (2021), the author highlighted that ceramic substrates treated with triethoxyoctylsilane exhibited less deterioration when exposed to ammonium chloride, sodium hypochlorite, citric acid, potassium hydroxide, and hydrochloric acid.
Therefore, the objective of this study is to analyze the behavior of cementitious matrices dosed with coconut fibers treated with triethoxy(octyl)silane.

2. MATERIALS AND METHODS

Figure 1 depicts the proposed experimental program in this study.

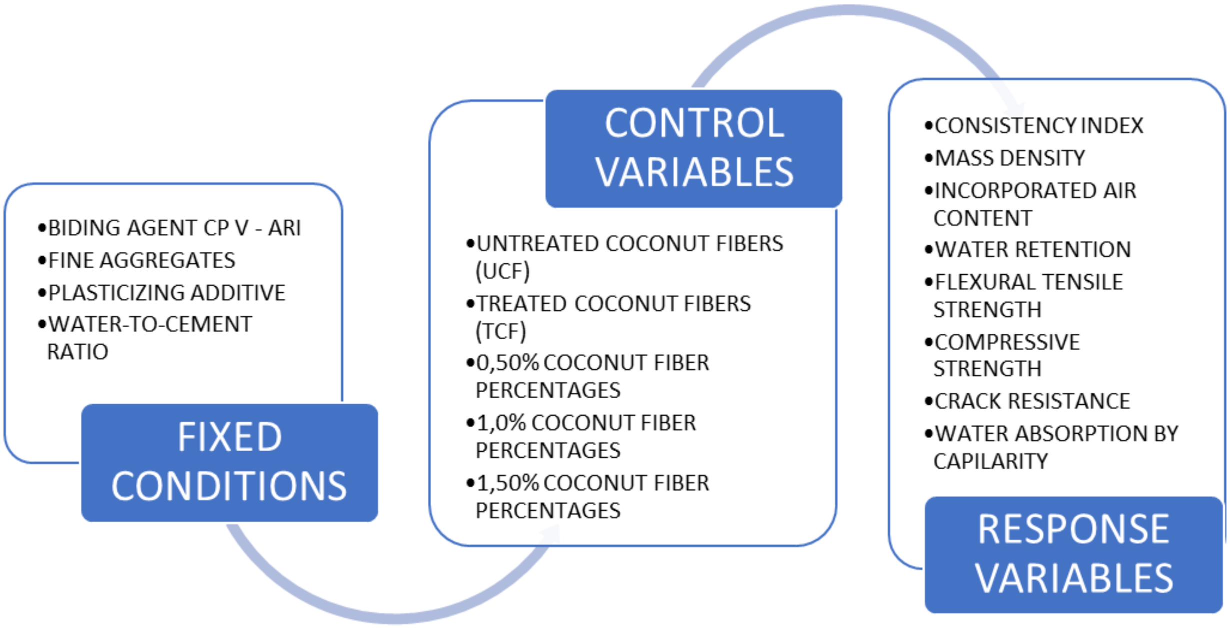

Figure 1. Experimental program

The proposed experimental program considered fixed conditions for the binder, aggregate, additive, and water/binder ratio. As for the control variables, the proposal was to use percentages of 0.50%, 1.0%, and 1.50% of natural and treated coconut fibers based on the binder mass. In order to address the overall objective of the study, the response variables are the fresh state properties and the mechanical properties, including flexural tensile strength, compressive strength, and water absorption of the mortars produced with these materials.

2.1 Materials

The research involves several stages, from the treatment of fibers to their incorporation into the mortars. The materials used in the mortar production included CP V - ARI cement, washed sand with a characteristic diameter below 1.20mm, a plasticizing admixture, and both natural and treated coconut fibers, all cut to a length of 6mm ± 1mm.

The fibers were treated with a hydrophobic agent based on triethoxyoctylsilane, as this product reduces water absorption in substrates (COSTA, 2014; OLIVEIRA, 2022). The adopted admixture was a plasticizer to improve the workability of the mortars. Table 1 provides the technical data of the Characteristics of triethoxyoctylsilane.

Table 1. Characteristics of triethoxyoctylsilane.

Density (at 25ºC)	~ 0,77 a 0,83 g/cm^3
Solids content	2.0 to 2.5%
Total product drying	24 hours

2.2 Experimental procedure

The fibers were initially cut into lengths of 6+/- 1mm and subsequently immersed in triethoxyoctylsilane for a period of 24 hours. During the mixing of materials in the production of mortars in a mechanical mixer, the fibers were added so as not to form lumps and to be properly homogenized.
The mortar mixing method employed followed the guidelines outlined in NBR 16541 (ABNT, 2016), and the consistency of the mortars and the influence of the fibers were assessed by producing a reference mortar with a slump value of 260±5mm, as per NBR 13276 (ABNT, 2016). The mixing ratio used was 1:5 (binder:fine aggregate) by mass. In the fresh state, tests for bulk density and air content were conducted in accordance with NBR 13278 (ABNT, 2005).
To compare water retention between the reference mortar and the mortars produced with natural fibers, devices specified in NBR 13277 (ABNT, 2005) were utilized.
Finally, in the hardened state, the mortars were evaluated for flexural tensile strength and compressive strength in accordance with NBR 13279 (ABNT, 2005), and water absorption by capillarity was measured following RILEM T – 116 (1994).

3. RESULTS AND DISCUSSION

The results are presented according to the proposed control variables for the study. Figure 2 illustrates the data obtained for the consistency index of the mortars. The nomenclature used for the mortars produced with coconut fibers treated with triethoxy(octyl)silane is TCF, while UCF refers to the untreated fibers.

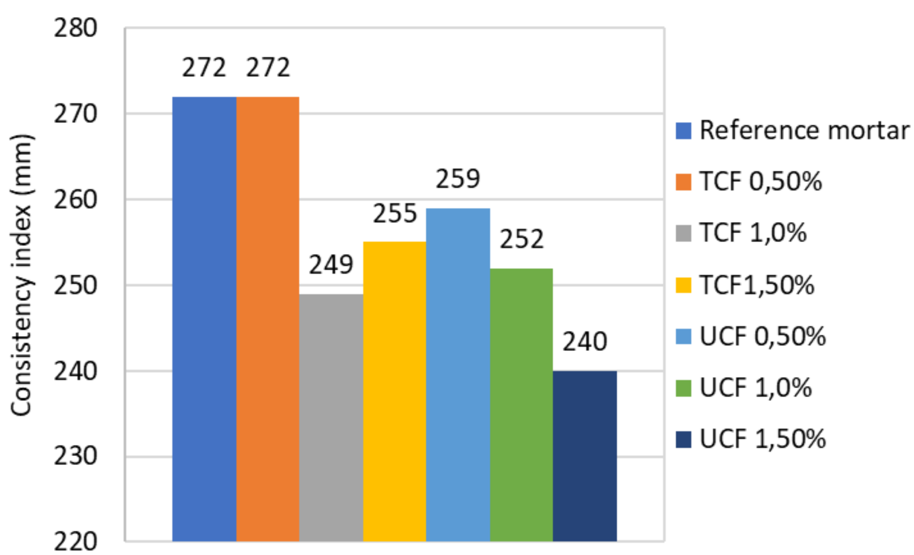

Figure 2. Mortar consistency index.

It was observed that the consistency index decreases as the percentage of fibers increases. However, triethoxyoctylsilane reduced the water absorption by the natural fibers, thereby preventing a significant decrease in the spread until the 0.50% percentage. Alberton *et al*. (2022) also demonstrated a loss of workability as the fiber content increased in composites dosed with untreated coconut fibers. Figure 3 illustrates the results of bulk density and air content.

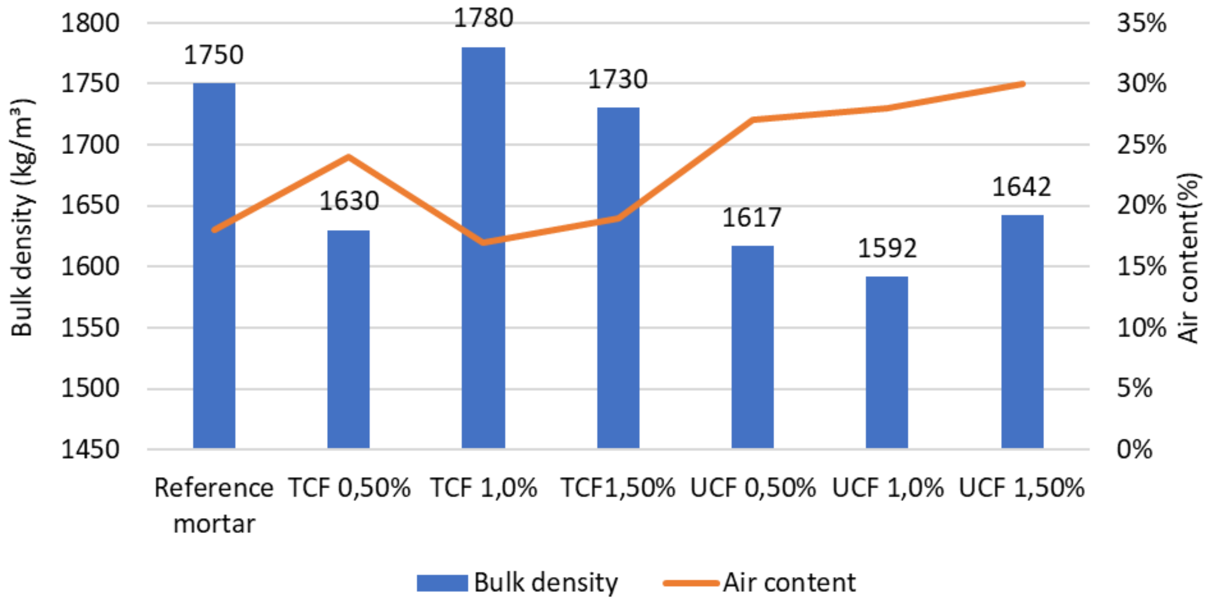

Figure 3. Bulk density and air content

Bulk density is inversely proportional to the air content, as stated by Bauer *et al*. (2015). UCF mortars incorporate more air than TCF mortars and therefore have lower densities when compared to the treated fibers.

The water retention results were similar for all the mortars, with a value of 94% ± 1%. The hypothesis is that triethoxy(octyl)silane alters the surface tension and reduces water absorption (COSTA, 2014; OLIVEIRA, 2022) of the treated fibers. However, the hydrophobic agent does not act as fines when incorporated into cementitious composites and therefore does not absorb water from the mortar, improving water retention. Figure 4 shows the results of flexural tensile strength.

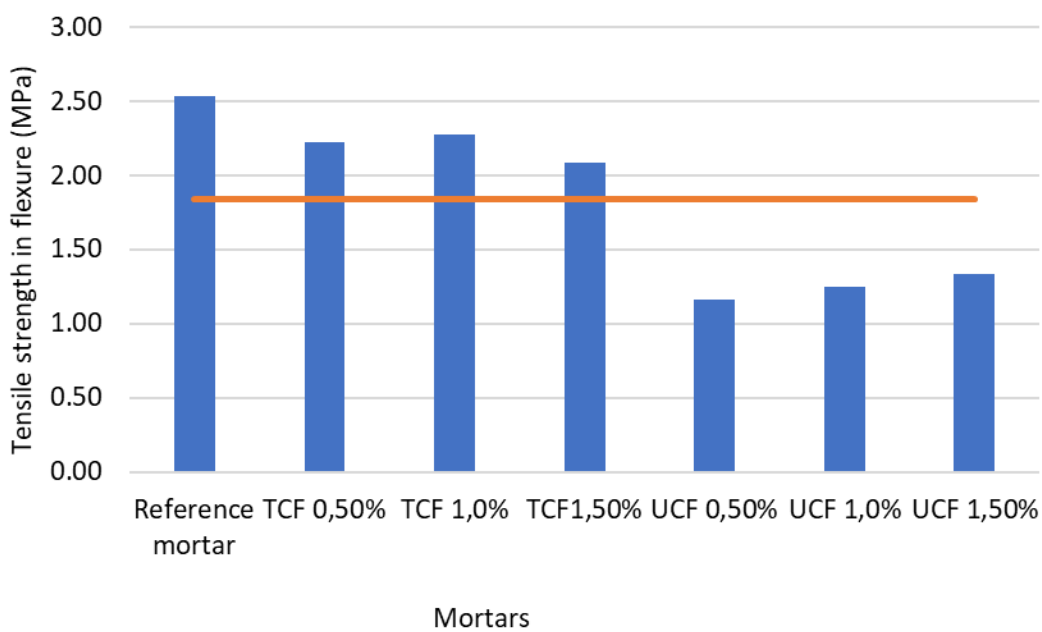

Figure 4. Flexural tensile strength.

The TCF mortars reduced flexural tensile strengths by approximately 12%, while the UCF mortars showed a significant reduction of around 54% in this mechanical property. It can be observed that the treatment with triethoxy(octyl)silane not only maintains water retention in the mortar but also does not significantly alter the flexural tensile strength. In this regard, Veiga (1998) explains that the higher the tensile strength of the mortar, the greater the ability of the coating to deform without cracking (VEIGA, 1998). Figure 5 illustrates the compressive strength results.

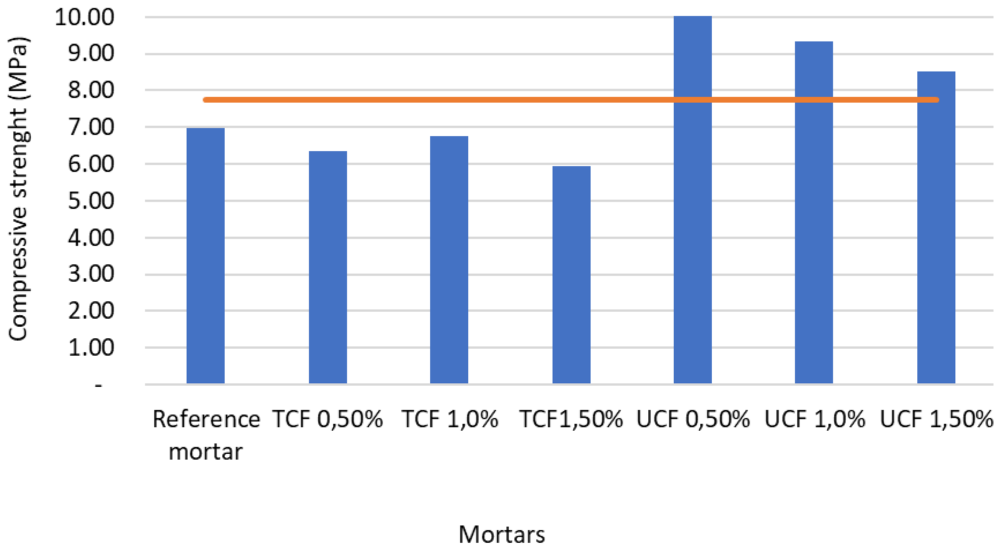

Figure 5. Compressive strength.

The compressive strengths (CS) exhibited opposite results to the tensile flexural strength (TFS), where the UCF mortars showed greater increases in mechanical properties compared to the reference and TCF mortars. However, the mechanical properties do not allow for an individual analysis.

In this regard, Bauer *et al.* (2015) explain that the relationship between tensile flexural strength (TSF) and compressive strength (CS) can indicate an important parameter for understanding the ductility of mortars. A ratio closer to 1.0 indicates a more ductile material, as the variation between tensile and compressive rupture is primarily due to fragility (VEIGA, 1998). Figure 6 illustrates the results of the TFS/CS ratio.

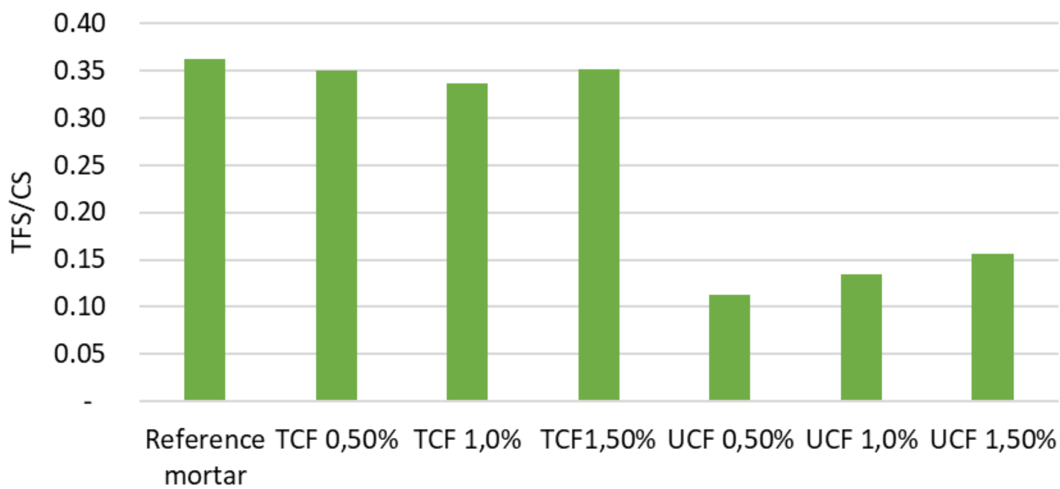

Figure 6. Cracking resistance

The ductility of the mortars was enhanced when coconut fibers were added under the condition of treatment with triethoxy(octyl)silane. Crack resistance is an important property to be evaluated in coating systems, as the daily temperature fluctuations to which the coatings are exposed generate internal temperature gradients. Consequently, these gradients lead to the emergence of thermal stresses and deformations, which may or may not cause early deterioration through the development of microcracks, increasing porosity and resulting in the loss of their mechanical strength (CARASEK; FREITAS; CASCUDO 2014). Figure 7 illustrates the results of the Water absorption.

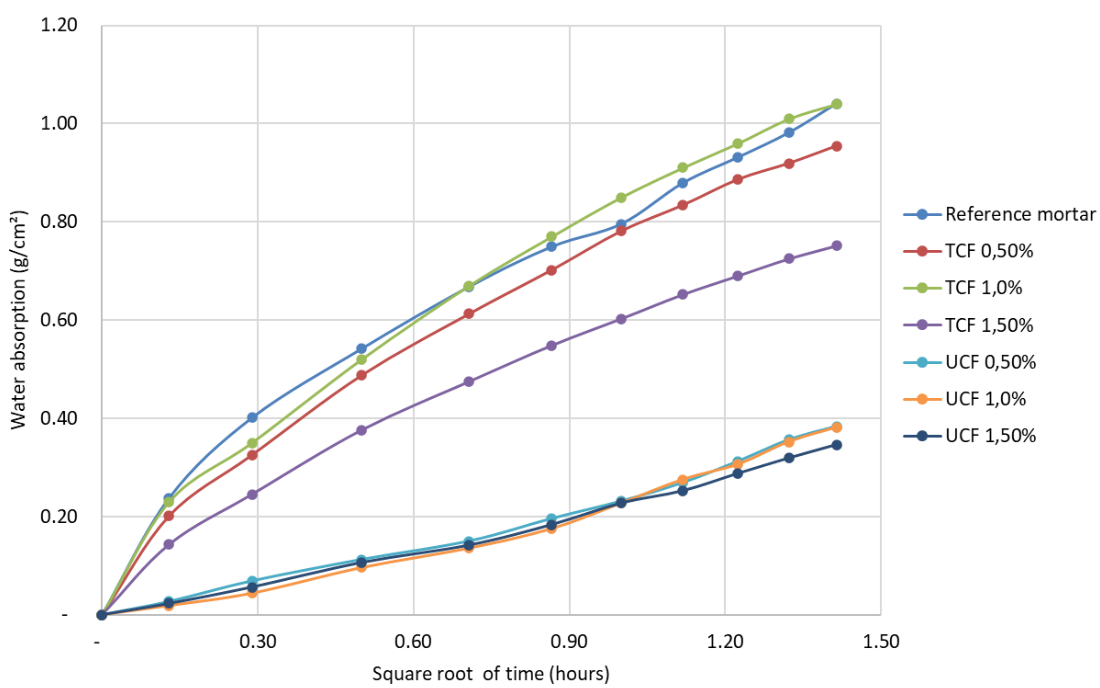

Figure 7. Water absorption by capillarity

There was no significant difference in water absorption between the reference mortar and the TCF mortars. However, in the case of UCF mortars, water absorption was lower. A plausible hypothesis is that the fibers absorbed water from the mortar, and the pores in the fiber envelope were refined. In the case of treated fibers, water repellency occurred around the fibers, which could result in higher porosity, consequently leading to increased water absorption and loss of compressive strength.

4. CONCLUSION

The objective of this study was to evaluate the impact of triethoxy(octyl)silane treatment on coconut fibers incorporated into cementitious composites. The results obtained shed light on the performance enhancement achieved through this treatment. The key findings and conclusions are summarized as follows:

- The consistency index of the mortars decreased with an increasing percentage of fibers. However, the triethoxy(octyl)silane treatment helped mitigate the decrease in workability, particularly at lower fiber percentages.
- The incorporation of untreated coconut fibers (UCF) led to higher air content and lower bulk density compared to mortars with treated fibers (TCF). This result highlights the influence of the treatment on reducing air incorporation.
- The water retention properties were similar for all mortars, with a value of 94% ± 1%. The triethoxy(octyl)silane treatment reduced water absorption by the fibers, contributing to improved water retention in the mortar.
- The flexural tensile strength of the mortars decreased with the addition of fibers. However, the triethoxy(octyl)silane treatment helped maintain the flexural tensile strength, minimizing the reduction observed in the untreated fiber mortars.
- The UCF mortars exhibited greater increases in compressive strength compared to the reference and TCF mortars. The relationship between flexural tensile strength and compressive strength indicated improved ductility in the mortars with treated fibers.
- No significant difference in water absorption was observed between the reference mortar and the TCF mortars. However, the UCF mortars exhibited lower water absorption. This can be attributed to the refined pores in the fiber envelope and the water repellency effect of the treated fibers.

In conclusion, this study investigated the effect of triethoxy(octyl)silane treatment on coconut fibers when incorporated into cementitious composites. The results demonstrated that the use of treated coconut fibers in cementitious composites led to several enhancements in material properties. The incorporation of treated fibers improved the workability, water retention, and water absorption properties of the composites compared to those with untreated fibers. Additionally, no significant los in mechanical properties was observed, indicating that the treatment did not compromise the overall strength of the composites.

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