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From coconut waste to the production of cementitious composites as an alternative for civil construction

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ABSTRACT

Economic development based on cleaner industrial technologies has been increasingly studied in recent years. Cementitious composites reinforced with lignocellulosic fibers can be a sustainable alternative for use in engineering. The study aimed to evaluate the technological properties of cementitious composites produced from natural and industrial coconut fiber to compare the reinforcement with wood particles. Physical tests (density, water absorption, and thickness swelling) and mechanical tests (static bending) were carried out in four treatments, which varied the fiber and cement contents. It was found that treatment with natural coconut fiber had the lowest density value, 0.59 g/cm^3, and treatment with industrial coconut fiber had the lowest water absorption value for the times and times of 2 and 24 h, 0.19, and 0.38%, respectively, and the treatment with wood particles, the highest values of modulus of elasticity and rupture, 1,897 MPa and 2.44 MPa. The study of the use of lignocellulosic materials as protection in cementitious composites is essential for applications in building constructions to reduce the environmental impacts generated by the generation of waste and use of non-renewable materials and to promote sustainable development.

Keywords: Lignocellulosic fibers; *Cocos nucifera;* Sawdust; Sustainable building.

1. INTRODUCTION

Environmental and energy issues are widely discussed in the global sustainable development perspective. Civil construction, specifically the housing sector, uses energy intensively, emits greenhouse gases, and consumes significant natural resources [1]. In this context, wood-cement composites are being increasingly studied and produced to be used as an alternative to conventional construction materials due to their reduced environmental impact and the use of natural raw materials [2].

These composites are manufactured from the mixture and pressing of wood particles, mineral binder (cement), and water. Some additives can also be added to the mixture to reduce the cement curing time and accelerate the bonding process [3]. Compared to composites with resin, they present lower processing temperatures, reduced carbon dioxide (CO_2) emissions and less atmospheric pollution, greater acoustic and thermal insulation, dimensional stability, greater resistance to water in finished products, and biodegradability [4].

Natural fibers or agricultural residues are promising structural materials for sustainable growth to reinforce cementitious composites [5]. These materials can significantly reduce greenhouse gas emissions in the construction industry and result in low-cost cement composites for civil construction [6]. In addition, manufacturing this panel type reduces solid waste generated by the agro-industrial sector [7].

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Lignocellulosic plant fibers can be obtained from stems (jute, hemp, raffia, kenaf, sugarcane bagasse, bamboo), leaves (sisal, caroá, curauá, banana, piassava, henequem), fruits (cotton, coconut, loofah) and of trunks (wood). Despite the differences, all of these have common components in their constitution, cellulose, lignin, and hemicelluloses [8].

Among these lignocellulosic fibers, those derived from the coconut culture are noteworthy and can be considered neutral regarding CO_2 emissions. The fruit is grown mainly in tropical and subtropical areas and is essential to economic development. These fibers, in general, are discarded into the environment after removing the fruits and coconut water [9]. Using this material in cementitious composites can significantly reduce impacts generated by improper disposal and improve efficiency in using resources from the coconut production chain.

Wood residues also represent a significant economic and environmental issue. The search for sustainable applications to recycle these residues is fundamental for sustainability [10]. Using these particles in cementitious composites can offer an exciting alternative in civil construction, used in the constitution of products such as mortar and concrete. Its use can provide greater lightness to the material due to the reduced proportion of cement, making the composite economically viable and sustainable. In addition, the interaction between wood particles and coconut fibers in the reinforcement of composites can generate material with less porosity and more attractive ductility when comparing cementitious panels with only wood reinforcement [11].

The work brings an interesting approach to how lignocellulosic fibers from different origins can exert various influences on the characteristics of the final composite material. Commercial coconut residue fibers were compared to natural fibers as matrix reinforcement, evaluating their potential resistance provider. This work aimed to assess the technological properties of cementitious panels reinforced with different proportions of natural coconut fiber and Portland cement as a sustainable alternative for civil construction to conventional cementitious panels produced with wood particles.

2. MATERIAL AND METHODS

2.1. Raw material

Cocos nucifera L fibers were collected from a commercial plantation in a rural area and the wood particles from sawmills in an urban area. Both sites are in Mossoró, State of Rio Grande do Norte, Brazil. For comparison purposes, commercial coconut fibers were used, purchased from local businesses in the city of Mossoró. The mineral component (Portland cement - CP II-E) was purchased for the matrix. It had in its composition the mass percentages of 94 – 56 of clinker + calcium sulfates, 6 – 34 of granulated blast furnace slag, and resistance class 32 MPa (NBR 11578 – ABNT) [12]. After the purchase and collection stages, the fibers were extracted from the coconut mesocarp and processed as particles using an agricultural forage shredder (model TRF 400 Super 3cv Mono Trapp) and eucalyptus wood particles. Before the panel manufacturing stage, the *Eucalyptus* wood splinter particles were sieved and retained in a mesh with granulometry between 20 (0.841 mm) and 40 (0.420 mm).

2.2. Manufacture of the composites

The molds for forming the panels were made of wood in 300 × 300 × 300 mm, with a regulator to ensure a thickness of 10 mm for the final material. The different types of reinforcements were uniformly distributed in plastic containers together with the CP-II-E Portland cement matrix. The mixture was made considering different proportions (Table 1). The materials were manually homogenized while still dry. To accelerate the curing process, water was added to the mixture and 4% of calcium chloride catalyst (CaCl2) in relation to the cement mass. Subsequently, the mixtures were inserted into the molds to form the panels, which were closed and pressed using a manual wooden press for 72 h. Afterward, the molds with the materials were placed in ambient conditions for 28 days for total cure. Finally, the panels were demoulded to make the test specimens.

Tabela 1: Composition of different panels produced with Portland cement matrix with reinforcements of coconut fibers and wood particles.

TREATMENT	RATIO CEMENT:FIBER	RATIO WATER:CEMENT	RAW MATERIAL
T1	1:3	1:2	Coconut fiber *in natura*
T2	1:5	1:5	Coconut fiber *in natura*
T3	1:3	1:2	Commercial coconut fiber
T4	1:3	1:2	Wood particles

2.3. Preparation of test specimens and performance of physical and mechanical tests

Specimens were made to perform the physical tests of a density, water absorption, and thickness swelling and the mechanical tests of resistance and rigidity to static bending based on the ASTM D 1037 standard [13]. The specimens were made by cutting the different panels manufactured using a saw. These were molded in the formats and dimensions established for the standard evaluation test of the properties of the fiber and wood-based particle according to the standard.

Each sample was attached to a wooden support to determine the density and positioned on an analytical balance containing a beaker with water. The support was lowered with the sample until it was completely submerged in the water. The values of the density was determined by dividing the mass by the sample volume. The samples were inserted into plastic vats containing water for the water absorption and thickness swelling tests. After 2 and 24 h of immersion, the samples were removed for evaluation, weighing, and processing of the data obtained. Static bending and stiffness tests were performed following the parameters of the ASTM D1037 standard [13]. A universal testing machine, model EMIC DL10000, was used, where each specimen was positioned in the equipment and tested until fracture.

2.4. Analysis of results

The data obtained were organized, and later the Shapiro-Wilk test was applied to verify normality and the Levene test to verify heterogeneity. Then, the parametric analysis of variance (ANOVA) test was applied, with subsequent comparison by average test for the factors detected as significant by the F test. Multiple comparisons of averages were performed using Tukey's test at 95% confidence.

3. RESULTS

3.1. Physical properties

The results obtained through the apparent density tests showed that the coconut fibers (T1, T2, and T3) treatments presented lower density values than those composed of wood particles (T4). Treatment T4, corresponding to the cement panel – wood particles in the proportion 1:3, presented the highest density value, 1.21 g/cm^3. Treatment T2, corresponding to the cement panel – in natural coconut fiber in a 1:5 ratio, had a lower density, 0.59 g/cm^3 (Figure 1). It is clear, therefore, that the increase in the proportion of coconut fiber in natura decreases the density of the compound, contributing to the rise in the lightness of the cementitious composite, especially when compared to the other treatments developed.

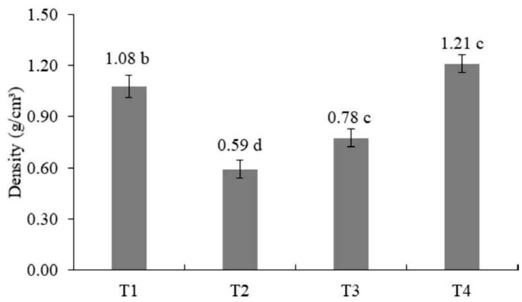

Figure 1: Density for the different cementitious composites evaluated.

Table 2: Water absorption and thickness swelling after 2 and 24 h of immersion, for composites produced with Portland cement, coconut fiber and wood particles.

TREATMENTS	WATER ABSORPTION (%)		THICKNESS SWELLING (%)	
	2 h	24 h	2 h	24 h
T1	28.96 c	32.78 c	0.61 a	0.72 b
T2	91.21 a	100.20 a	0.66 a	0.77 ab
T3	48.37 b	54.31 b	0.19 b	0.38 b
T4	14.73 d	16.18 d	0.59 ab	1.60 a

Values followed by the same letter in the columns do not differ statistically.

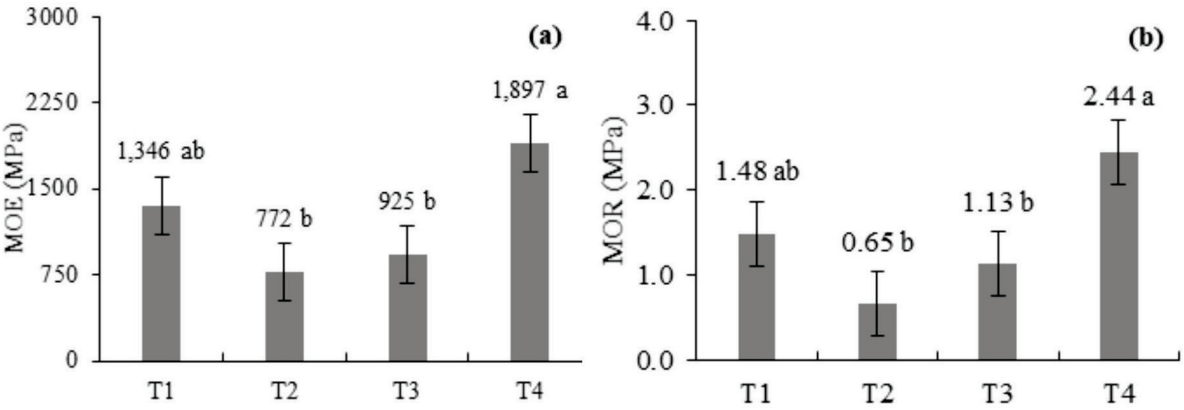

Figure 2: Strength and rigidity to static bending for the different treatments carried out. (a) Mean values of modulus of elasticity (MOE); (b) Modulus of rupture (MOR).

The water absorption (Table 2) showed that the T4 treatment demonstrated the best performance compared to the other treatments, presenting the lowest absorption values, 14.7 and 16.9%, for the respective periods of 2 and 24 h immersion water. Treatment T2 showed the highest absorption values among the tested treatments, 91 and 100% for the respective periods.

The T3 showed the lowest thickness swelling value, presenting 0.19 and 0.38% in the respective periods of 2 and 24 h immersion in water. Treatment T2 was the one that presented the highest value of swelling in thickness in the period of 2 h of immersion, being 0.66%, respectively. However, this value did not differ statistically from the values indicated by treatments T1 and T4. In the period of 24 h of immersion, the T4 treatment was the one that presented the highest value of swelling in thickness, being 1.60%. This result did not differ statistically from the value found for the T2 treatment (Table 2).

3.2. Mechanical properties

The analysis of the static flexion tests on three supports in the treatments showed that the T4 treatment presented the highest modulus of elasticity (Figure 2a) and rupture (Figure 2b), 1,897 MPa and 2.44 MPa, respectively. The T2 treatment showed the lowest modulus of elasticity, 772 MPa, and break, 0.65 MPa. When comparing the modulus of elasticity and rupture between the two treatments manufactured with coconut fibers in natura in different proportions (T1 and T2), it is verified that treatment T1 presented a modulus of elasticity of 1,346 MPa (Figure 2a) and modulus of rupture of 1.48 MPa (Figure 2b), more significant than those given in the T2 treatment. However, the treatments did not show statistically significant differences between them. The increase in the proportion of coconut fibers in cementitious composites can cause a decrease in stiffness and, consequently, a greater elastic deformation of these materials.

4. DISCUSSION

The physical properties of density and moisture content are essential in composites, as they influence the mechanical properties of these materials in situations of use. Composites reinforced with wood particles or vegetal fibers are still being sought to characterize them to insert them in the market in partition, lining, furniture, flooring, and sealing applications [14].

According to SILVA *et al*. [15], the reduction in the density values of the composites when incorporating coconut fibers is caused by the replacement of Portland cement by the fiber. In addition, the incorporation of coconut fiber in cementitious matrices also improves the composite's thermoacoustic performance compared to the cementitious composite without its presence.

WEBER *et al*. [16] state that the greater the proportion of wood particles in the composite, the more significant the decrease in density in the dry and saturated samples. This occurs due to the mixture's presence of wood and pores, which increases in the same proportion as the amount of wood due to the difficulty of compacting the mixture.

GARCEZ *et al*. [17, 18] point out that higher values of density, compressive strength, and modulus of elasticity are characteristic of more rigid composites. However, in some cases, using composites with lower density can be advantageous concerning other requirements, such as transportation, handling, and assembly of lighter parts. In this way, it is observed that a low density does not necessarily represent a poor quality of the composite, which can be used for specific purposes that require less dense panels.

For DHARMARATNE *et al*. [19], the increase in the content of coconut fibers in composites contributes to the increase in water absorption of these materials due to the affinity of the fiber to absorb water and the porosity present in the matrix. For WEBER *et al*. [16], the vegetal fiber content significantly alters water absorption, and the higher the percentage added to the composite, the higher the indices of this parameter.

In their research with cementitious panels manufactured with wood particles and coconut fiber, SOUZA *et al*. [20] verified that adding up to 30% of coconut fiber promoted better dimensional stability, the most indicated percentage for producing panels. The authors also noticed that for rates greater than 30%, the swelling in material thickness increased significantly, even with the reduction of water absorption [20].

GARCEZ *et al*. [17,18] state that adding wood particles in the formation of composites can influence the physical and mechanical properties of the material. Increasing the percentage of wood particles promotes higher moisture content, lower density, higher void ratio, higher water absorption, lower compressive strength, and lower dynamic modulus of elasticity [17,18].

The thickness swelling of the material is directly linked to the increase in the amount of wood particles and the increase in density. The concentration of wood particles absorbs a greater amount of water, and the composite tends to expand due to the hygroscopicity of the wood [21].

According to DOTUN *et al*. [22], the modulus of elasticity of cementitious composites is directly proportional to the number of sawdust particles and binding agents. Therefore, the greater the amount of sawdust, the greater the mechanical resistance properties of the cementitious composites. When analyzing the results of the modulus of elasticity for the four treatments (Figure 2a), the behavior and results of the modulus of rupture exposed were already expected, considering that stiffness is a property directly linked to the resistance of the material to deformation. In addition, increasing the proportion of fiber can cause a decrease in this property. This decrease can also be directly related to the anisotropic characteristic of the fibers. Knowledge and alignment control of these natural materials is essential for the results. A deviation in fiber alignment can promote a decrease in resistance, pointing to a worsening of stress transmission between the fiber and the matrix [23].

5. CONCLUSION

The composites analyzed in the study showed distinct characteristics in their physical and mechanical properties. By relating the physical properties of the cementitious composites produced, it was verified that the T2 treatment was the one that presented the lowest value of density and a greater capacity of water absorption in comparison to the other treatments.

In the thickness swelling property analysis, the T3 treatment showed the lowest values among the different treatments at 2 and 24 h of immersion in water. Treatment T4 led to the highest values of density and swelling in thickness (in 24 h) when subjected to physical tests. However, when subjected to static bending efforts, it presented the highest values of elasticity and rupture.

Although the analyzed materials present some physical and mechanical characteristics that make their use unfeasible in some applications. Even so, it can be used in applications such as partition panels, shelf panels, and work benches. For better performance of these composites, it is necessary to study them to seek a better combination of properties and promote the increased use of inputs from renewable sources – in civil construction, aiming to contribute positively to the population’s economic, social, and environment.

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