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Application of pineapple fiber in the development of sustainable mortars

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Abstract. Due to the great worldwide increase in pineapple production, countries like Brazil and India have problems regarding the correct disposal of residues from the production of this fruit. One of the possibilities is the reuse of these residues in the form of fibers in cementitious materials, as is the case with mortars. As a result, the objective of this work is to evaluate the application of pineapple fibers in mortars in the proportion of 1: 4 (cement: sand) with addition of fiber treated in NaOH in the proportion of 3 and 6%. The properties of mechanical resistance, water absorption, mass density and adhesion were evaluated, aiming to apply the mortar in coatings of rural environments. The results indicate that the fibers reduced the mortar density and increased the mechanical strength. However, there was a reduction in adherence, especially with the use of 6% fiber, in addition to an increase in water absorption. Based on the results, it is concluded that it is feasible to use 3% of pineapple fiber for the production of coating mortars in rural environments because the results obtained in the investigation are compatible with this application and with the established normative limits.

Key words: rural constructions, agro-industrial wastes, sustainability, reuse.

INTRODUCTION

Pineapple (*Ananas comosus*) is one of the main fruits produced in Brazil, being consumed internally and also being one of the main agricultural products exported in the country (Braga et al., 2020). The average annual production between the years 2012 and 2018 was 1.7 billion, making Brazil the second largest producer of this fruit in the world (Scherer et al., 2015; Braga et al., 2020).

The major problem in this fruit production, in Brazil and worldwide, is the waste generated by its, mainly due to the peel and crown of the fruit (Wasserbauer et al., 2019). These wastes are disposed of without any prior care, even with great potential for reuse. Among the known ways to reuse this residue, we can mention: fuel (Chen et al., 2020), cellulose (Faria et al., 2020), spray drying (Braga et al., 2020) and as natural fiber for composites (Ramesh et al., 2016; Ramesh et al., 2017).

About this last application, some research carried out with fibers similar to pineapple, proved the feasibility of applying the material as reinforcement in cementitious matrices (Ramesh Kumar & Kesavan, 2020; Ramesh et al., 2020; Singh & Gupta, 2020). It is known that composite materials have two phases mainly: the matrix phase, which is responsible for the volume of the material, and the dispersed phase, or reinforcement, in general with application of fibers (Castoldi et al., 2019; Ryabchikov et al., 2020). This phase improves or reinforces the mechanical behavior of the matrix. In the case of cementitious materials, fibers are used for two purposes, to increase ductility and improve the tensile strength of the material (Du et al., 2021; Men et al., 2021).

The following works are mentioned as an example of the application of natural fibers: (Akinyemi & Dai, 2020) studied the application of banana fibers in cementitious mortars in the proportion 1: 3 (cement: sand) witch 1.5% of banana fibers in relation to the cement mass. They observed that the fiber increases the mechanical performance of the mortar and ductilizes the material. Similar conclusions are obtained by (Elbehiry et al., 2020) in concrete.

(Sabarish et al., 2020) studied the incorporation of sisal fibers in concrete using a percentage of 1.5% in cement. The authors observed that the use of fibers improved the properties of compressive and flexural strength, in addition to discussing considerably the breaking behavior of the studied concrete elements. The results are confirmed by (de Klerk et al., 2020). Marvila et al. (2020) and de Azevedo et al. (2021) studied the application of açai fiber in cementitious matrices, applying in mortars. The results obtained by the authors prove the possibility of applying natural fibers. The results highlighted in these researches indicate a potential for the application of pineapple fibers, whose composition is cellulose such as banana, sisal and açai fibers, in cementitious matrices. (Bambi et al., 2019) studied the application of bamboo fiber in sustainable mortars for sound insulation, obtaining important results that prove the feasibility of applying the material.

In this context, the objective of this work is to evaluate the application of pineapple fiber, in contents of 3 and 6%, in the properties of the hardened state of a sustainable cement-based mortar. For this, mass density tests were performed in the hardened state, water absorption, flexural tensile strength, compressive strength and adhesion.

MATERIALS AND METHODS

Materials

The pineapple fibers were extracted from an agricultural industry located in São João da Barra - RJ - Brazil. The fibers used come from the crown of the fruit, being dried in an oven at 60 °C after extraction for a period of 24 h. The fibers were treated in a

NaOH solution with 10% mass concentration, being immersed in the treatment solution for 30 minutes. After immersion in sodium hydroxide, the fibers were washed with running water and HCl, to neutralize the pH. They were again dried in greenhouses at 60 °C for 24 h, being thus ready for application.

In addition to the fibers, ordinary Portland cement (OPC) and river washed sand collected in Campos dos Goytacazes - RJ- Brazil were used. The sand used has granulometry with a maximum diameter of 2.4 mm, standardized through the analysis of other studies (de Azevedo et al., 2018; Marvila et al., 2019). Fig. 1 presents the schematic flowchart on the methodology used in this article.

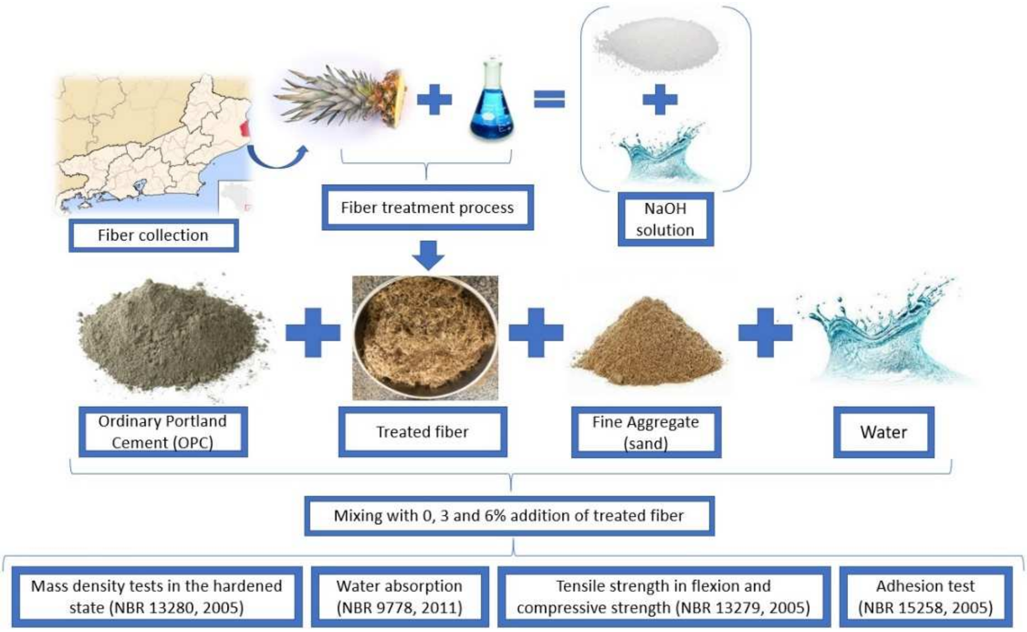

Figure 1. Schematic flowchart of the methodology.

Methods

To evaluate the effects of incorporating pineapple fibers treated in mortars, specimens were produced in the proportion 1:4:1.5 (cement: sand: water), using percentages of 0, 3 and 6% of fiber in relation to cement mass. The specimens produced were in prismatic geometry 40×40×160 mm, according to the Brazilian norms (NBR 13276, 2016). In the mortar mixing stage, the pineapple fiber is added together with water, aiming at greater homogenization of the material, according to some published works (Marvila et al., 2020; A.R.G. de Azevedo et al., 2021).

After being produced, the specimens were stored at room temperature, of approximately 25 °C, for a period of 28 days. Afterwards, the samples were submitted to mass density tests in the hardened state (NBR 13280, 2005), water absorption (NBR 9778, 2011), tensile strength in flexion and compressive strength (NBR 13279, 2005), and adhesion test (NBR 15258, 2005). The tests performed are extremely important to verify the feasibility of applying sustainable mortars. In all studies, 3 samples were used for each mortar composition studied, enabling the calculation of average and standard deviations, indicated in the figures that present the results of each property. Table 1 shows the amounts of mass applied in the study.

Table 1. Mortar compositions used

Composition	Cement (g)	Sand (g)	Water (g)	Pineapple Fiber (g)
0%	250	1,000	375	0
3%	250	1,000	375	7.5
6%	250	1,000	375	15

RESULTS AND DISCUSSION

Fig. 2 shows the density of mortars in the hardened state. It is observed that there was a reduction in density as the pineapple fiber content increased. The density dropped from 2.01 g cm^{-3} (composition 0%) to 1.79 g cm^{-3} (composition with 6%). The reduction in density is due to the characteristic of fibers to increase the volume of mortars, even with little variation in the mass of the material. This information was reported by other researchers, who conducted research with natural fibers in cementitious matrices. (Quiñones-Bolaños et al., 2021) reported a drop in density from 2.06 g cm^{-3} in the reference composition to 1.56 g cm^{-3} in the composition containing 15% coconut fiber. (Sathiparan et al., 2017) obtained a reduction in density from 2.02 g cm^{-3} (0% of coconut fiber) to approximately 1.91 g cm^{-3} with 0.75% of fiber.

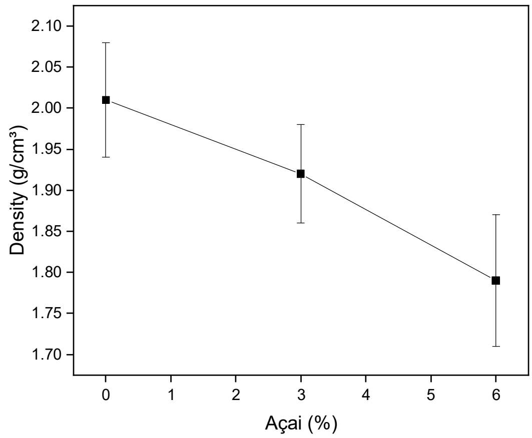

Figure 2. Results of mass density in the hardened state of mortars with pineapple fibers.

In other words, the results obtained are coherent when compared to other studies with natural cellulose fibers. In addition, the reduction of density with the use of fibers is beneficial for coating mortars, as they help to reduce the structure's own weight and relieve the structural loads on the building.

Fig. 3 shows the water absorption of the evaluated mortars. There is an almost linear increase in water absorption as the fibers are incorporated. Absorption increased from 13.25% (reference composition) to 15.23% (with 6% fiber). This is due to the hygroscapillary nature of the fiber, which absorbs water more

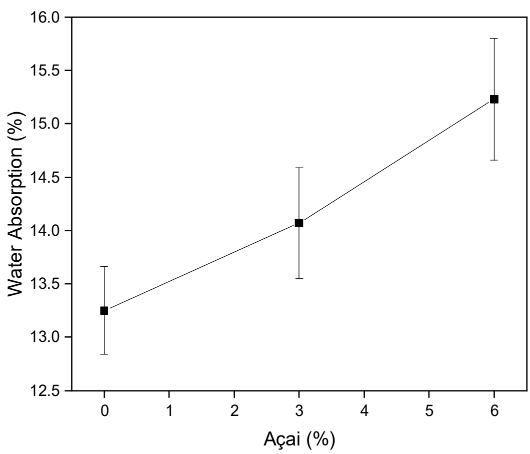

Figure 3. Results of water absorption of mortars with pineapple fibers.

easily than the cementitious matrix. The chemical composition of the fiber, which is predominantly cellulosic, is responsible for this behavior. Some authors who studied cementitious composites with natural fiber obtained the same pattern. This is the case of (Azevedo et al., 2020), who observed an increase in water absorption from 15% (reference composition) to 16.2% in mortars containing curauá fiber. The same pattern was observed by (Sathiparan et al., 2017), whose water absorption increased from 10% to 15% using 0.75% of coconut fiber. The results obtained, therefore, are consistent.

The increase in water absorption caused by the fibers is bad because it can cause pathologies and cracks in the coating to occur. On the other hand, increasing the water absorption can help increase the mechanical resistance due to the greater amount of water available for hydrating the cement, as will be seen in Figs 4 and 5. Thus, the analysis of the water absorption result contributes to the conclusions on the behavior of pineapple fibers, especially when correlated to the other parameters discussed in this study.

Fig. 4 shows the results of tensile strength in flexion. It is observed that there was an increase in the resistance of the composition from 0% to 3%, going from 3.05 to 4.12 MPa containing 3% of fibers. The composition with 6% pineapple fiber has a flexural tensile strength of 3.57 MPa, higher than the reference composition, but lower than the composition with 3% fiber. This is because the use of excess fibers compromises the wettability of the matrix, causing a saturation of the reinforcement phase and creating points of weakness in the material. As a result, it is recommended that the pineapple fiber content used in cementitious materials be a maximum of 3%, so as not to compromise the wettability of the composite.

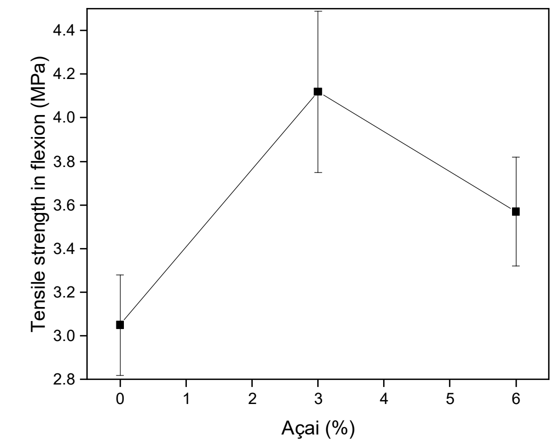

Figure 4. Results of tensile strength flexion of mortars with pineapple fibers.

In addition to the increase in tensile strength in flexion, the use of 3 and 6% fibers improved the ductility of the material, increasing the propagation of cracks before rupture. This information had already been highlighted by other authors who studied natural fibers, as is the case of the works by Azevedo et al. (2020), de Azevedo et al. (2021). It is known that the rupture of cementitious materials is catastrophic and fragile. The use of pineapple fibers is a cheap and ecological alternative to increase the ductility of the cementitious matrix, making the material safer from a structural point of view and proving the importance of using the pineapple fibers studied in this research.

Fig. 5 shows the results of compressive strength. There is a pattern very similar to the results obtained for tensile strength in compression, where the use of 3% fiber improved the strength, when compared to the compositions of 0% and 6%. The same pattern was observed, for example, in the work of (de Azevedo et al., 2021), in which the compressive strength of compositions with 0% was 3.52 MPa, with an increase in strength for compositions with 1.5 and 3% acai fiber to 3.84 and 4.23 MPa, respectively. The composition with 5% açaí fiber, however, dropped to 3.83 MPa. Therefore, the results obtained are consistent.

Fig. 5 shows that the compressive strength was 4.05 MPa in the 0% composition to approximately 4.8 MPa in the 3% composition. This increase of 18.5% is attributed to the better crack propagation provided by the application of pineapple fibers in the cementitious composite and prove the feasibility of applying these vegetable fibers, proposed in this article.

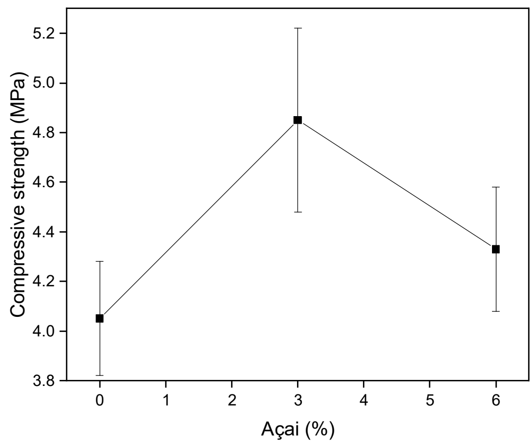

Figure 5. Results of compressive strength of mortars with pineapple fibers.

Fig. 6 shows the results of adherence. A drop in adherence is observed for the 3% and 6% pineapple fiber compositions, justified by the lack of penetration of the mortar in the standard substrate. The pineapple fiber, although individually increases the strength of the mortar, acts as a barrier to the penetration of the mortar cement into the substrate, impairing adherence. The Brazilian standard (NBR 15258, 2005) recommends a minimum value of 0.3 MPa for mortar adherence. It is observed that the composition of 3% of pineapple fiber meets this requirement and can be applied for the production of sustainable mortar.

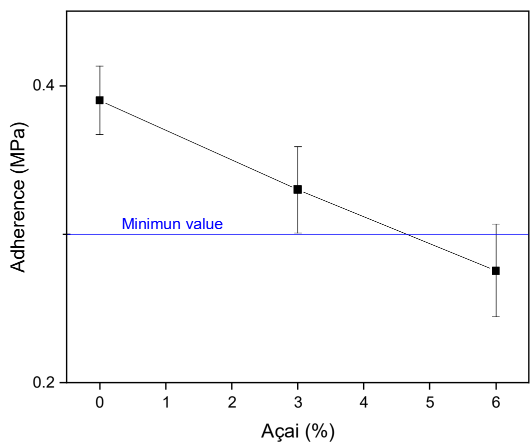

Figure 6. Results of adherence of mortars with pineapple fibers.

The results obtained are similar to those highlighted by other authors who evaluated the application of natural fibers in coating mortars. The work of Azevedo et al. (2020), de Azevedo et al. (2021) stands out, where the authors observed that the use of vegetable fibers provided mortars with adhesion greater than 0.30 MPa.

CONCLUSIONS

The main conclusions obtained in the research are:

The density results demonstrate a reduction of this property with the incorporation of fibers, attributed to the greater volume provided by the pineapple fibers. This is beneficial because it reduces the weight of the hardened material.

Water absorption increased with the incorporation of fibers, due to the hygroscopic nature and the cellulose content in the material. Although this is negative, the increase in water absorption was not high.

The compressive strength and flexural strength of compositions containing 3% fiber are superior to compositions 0% and 6% fiber. This is because the wettability point of the fiber has been reached. As a result, the incorporation of 3% fibers is indicated, which in addition to better resistance, improves the ductility of the material.

Adhesion decreased with the use of 3 and 6% of pineapple fibers, however that the use of 3% met the minimum of the Brazilian norm, of 0.3 MPa. Therefore, it is concluded by the feasibility of applying pineapple fibers in cementitious matrices for the production of sustainable mortars, in a maximum of 3%.

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