Assessing the influence of cellulosic pulp replacement with polypropylene on cement matrix properties

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Abstract. Cellulosic pulp is widely used in the production of cement composite due to its sustainable characteristics, availability and low cost. To improve durability and mechanical properties, synthetic fibers such as polypropylene (PP) are added to the matrix. In this study, fiber cements were reinforced with 1.4% PP fibers, replacing Kraft pulp at concentrations of 5% and 10% in relation to the cement mass. The performance of the cementitious composites was evaluated after 28 days age and 200 cycles of accelerated aging. The results showed that the combination of PP fibers with Kraft pine pulp is a viable option for the production of fiber cement, resulting in significant improvements in crack resistance. The presence of PP fibers increased the flexural strength (MOR), reaching 10 MPa for the $PNB_{3.6\%}PP_{1.4\%}$ treatment. Furthermore, there was an improvement in toughness and a decrease in porosity and water absorption with the replacement. These fibers play a crucial role in improving the mechanical and physical properties of cementitious composites.

Keywords: Durability, synthetic fibers, accelerated aging, Kraft pulp.

1 Introduction

In several fiber cement sectors, cellulosic pulps are mechanically treated through refining, promoting fibrillation of the fiber surface, increasing their contact surface and improving particle retention in the cement matrix [1][2].

Fiber cement has gradually become an irreplaceable construction material in civil engineering due to its abundant access to raw materials, and can be defined as a composite formed mainly by cement, with the absence of aggregates, presence of minerals and fibers, which They serve to strengthen, in a distributed manner, the entire cement matrix and prove to be a viable option due to its low cost. Furthermore, this composite exhibits toughness, ductility, flexural capacity and crack resistance compared to non-fiber-reinforced cement-based materials [3][4].

Synthetic fibers are added to the matrix to improve durability and mechanical properties. The addition of fiber to concrete changes some of its mechanical properties, such as the composite's greater tensile strength, flexural strength, impact resistance and toughness and, consequently, resistance to cracking [5]. PVA fibers, alkali-resistant glass fibers and, more recently, polypropylene (PP) fibers are examples of synthetic fibers used on a large scale in the fiber cement industry [6].

Therefore, the objective of the study was to evaluate the effect of adding polypropylene fibers on the physical and mechanical properties of cementitious composites, before (on the 28th day of curing) and after the accelerated aging technique (200 cycles).

2 Methods

The sheets of unbleached Kraft pulp (*Pinus* spp.) from an industrial process were used in the experiments after undergoing fibrillation (refinement of 35 ºSR, Schopper Riegler Grade), according to parameters used in the fiber cement sector.

To create the matrix, we used Portland cement CPV-ARI [7] and agricultural limestone as a carbonate filler. The choice of this particular cement as deliberate, as it lacks blast furnace slag or pozzolanic materials commonly found in other cement compositions. By incorporating calcitic limestone as a partial replacement for Portland cement, we aimed to effectively lower production costs for fiber cement, a technique employed by various industries in the sector [8].

2.1 Unbleached cellulosic fibers and polypropylene fibers

Fibers from unbleached Kraft pine pulp and polypropylene were visualized under an optical microscope. All samples were diluted to a concentration of 0.1% suspended solids and viewed under an optical microscope model BA210E (Motic brand) using 4x magnification. Fiber diameters were measured for at least 100 individual structures using ImageJ software.

2.2 Cementitious composites (flat slabs)

The variables and levels to be evaluated resulted in 4 different treatments, with variations in the content of unbleached Pine pulp (3.6%, 5.0%, 8.6% and 10%) and the presence or absence of polypropylene fibers (1.4%) whether or not accelerated aging is employed. The list of treatments and the respective formulations (%) tested are represented in Table 1.

Table 1. Formulation of fiber cement composites/boards.

Treatment	Cement	Limestone (%)	Kraft fibers	PP fibers
$PNB_{5\%}$	79.7	15.3	5	-
$PNB_{3.6\%}PP_{1.4\%}$	79.7	15.3	3.6	1.4
$PNB_{10\%}$	77.2	12.8	10	-
$PNB_{8.6\%}PP_{1.4\%}$	77.2	12.8	8.6	1.4

To prepare the fiber cement boards, alkaline water (pH~12-13) was used, simulating water commonly reused in the fiber cement manufacturing process. Water preparation followed the methodology of [10]. A solution with 15% solids was prepared in a container with 1 L of water and 150 g of cement. After decanting the solid part (~15 min), the alkaline water was removed and stored for use. The hydrogen potential (pH) of the solution was evaluated with a previously calibrated pH meter (W38 BEL ENGINEERING).

The composites were molded on a laboratory scale using the adapted technique of draining the mixture under vacuum and subsequent pressing (simulation of the Hatschek process), following the methodology of [11], [12] and [10]. The plates were made with dimensions of 200 mm x 200 mm x 5 mm, totaling 330 g (~17% solids) in dry mass.

2.3 Accelerated aging of cementitious composites

The methodology employed in this study was adapted from the EN 494 [13] and involved immersion and drying cycles. A total of 200 cycles were performed, where the specimens were fully immersed in water for 170 minutes to ensure pore saturation. Following this, the composites were left inert for a 10-minute interval before undergoing the drying process to remove moisture from the pores. Drying was carried out at a temperature of 70 ºC for duration of 170 minutes. This immersion and drying cycle method allowed for the evaluation of composite degradation after accelerated aging.

2.4 Physical characterization of cementitious composites

To perform the water absorption (WA) and apparent porosity (AP) analyzes, [14] standard was followed, using an average of twelve specimens for each formulation. The physical characterization of the composites was carried out after 28 days of curing and after 200 cycles of accelerated aging.

2.5 Mechanical characterization of cementitious composites

The mechanical bending test followed the recommendations of the [15], using the universal test machine Emic DL-30.000 equipped with a load of 1 kN. The configuration adopted was four supports (cleavers), with a distance between the lower supports equal to 135 mm and the upper ones equal to 45 mm, with a deflection rate of 0.5 mm/min, with the tension values being determined at the limit of proportionality (LOP), modulus of rupture (MOR), modulus of elastic (MOE) and specific energy (SE) of the specimens, as described by [12]. The composites were tested wet after immersion in water for 24h, to normalize the moisture condition.

3 Results and discussion

In estimates made using an optical microscope, the vegetable fibers had a length of approximately 1.76 mm and an average width of 0.03 mm. Polypropylene fibers are 6 mm long and 26 µm in diameter, Figure 1.

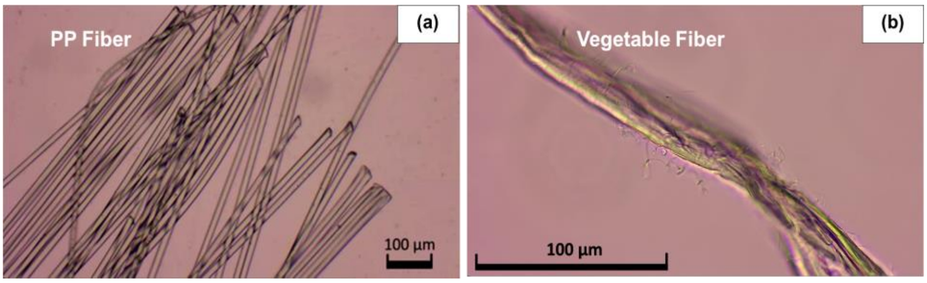

Fig. 1. Light microscopy image of (A) polypropylene fibers and (B) unbleached cellulosic pulps.

3.1 Effect of adding polypropylene (PP) fibers: physical properties

To understand the effect of partial replacement of polypropylene fibers, the test specimens were reinforced with 1.4% PP fibers, being replaced in the composites with 5% and 10% pulp. The results show that the insertion of PP fibers increases the water absorption (Figure 2A) and porosity (Figure 2B) of the composites, when compared between treatments with only 5% cellulosic pulp. However, when we increase the pulp content (10%), the presence of PP reduces these properties. This fact can be attributed to the compatibility of the reinforcement with the cement matrix and possibly reduced fiber manipulation to alkaline attack.

Figure 2(A-B) shows that the accelerated aging process decreased the physical properties of fiber cement for all concentrations of cellulosic pulp fibers (3.6%; 5%; 8.6% and 10%), which can be attributed filling the matrix pores by continuing the cement hydration process during the 200 cycles. The results of the composites with the presence of PP fibers, after aging, show that the water absorption data had no significant differences when compared to those without PP fibers, but there was an increase in apparent porosity, which can be attributed due to the greater number of fibers per unit volume, causing greater volumes of voids in the cement matrix.

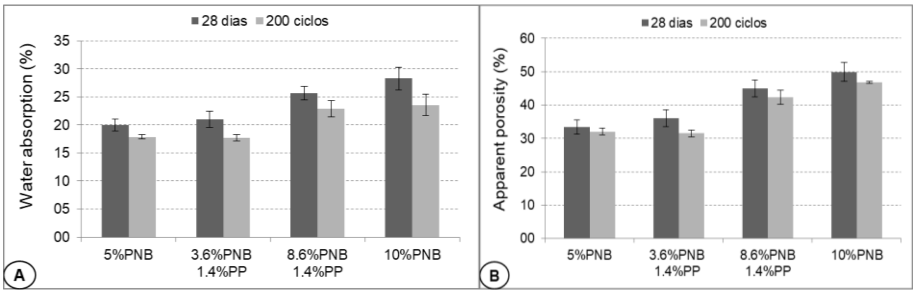

Fig. 2. Mean values and standard deviation of physical properties: (A) water absorption (WA); and (B) apparent porosity (PA) before and after accelerated aging of composites with polypropylene fibers.

3.2 Effect of adding polypropylene (PP) fibers: mechanical properties

The mechanical data, Figure 3, for the treatment with a smaller amount of pulp (3.6% and 5%), show that the replacement of cellulosic pulps by PP fibers significantly increases the modulus of rupture (MOR), Figure 3A, and the specific energy (EE), Figure 3D, of the composites, creating the possibility of working in the post-cracked stage and improving the adhesion between fiber and cement matrix. The limit of proportionality (LOP), Figure 3B, presents equivalent values, however, the elastic modulus (MOE), Figure 3C, remains higher for the treatment without PP fibers. For composites with higher fiber contents (8.6% and 10%), the substitution increases the mechanical properties MOR, LOP and EE, while the MOE values are higher for composites without the presence of PP.

The composites, after undergoing accelerated aging and without the presence of PP, showed a decrease in MOR and LOP properties, while those with the partial replacement of vegetable fibers by PP fibers had equivalent or greater results for rupture modulus (Figure 3A) and proportionality limit (Figure 3B), this fact occurs due to mineralization, a phenomenon in which the vegetable fiber, during the curing process, absorbs highly alkaline water and hydration products from the cement, which can induce the stiffening of the fibers and cause losses in the MOR. The elastic modulus (Figure 3C) was increased after 200 cycles, for both treatments (with and without PP), related to the rehydration of the cement hydration products, filling the pores and improving the interface between the fiber and the matrix. The specific energy (Figure 3D) decreased significantly, especially for treatments without the presence of PP fibers, being an important property, as it prevents brittle rupture of the material during transportation or installation, due to dynamic efforts involved.

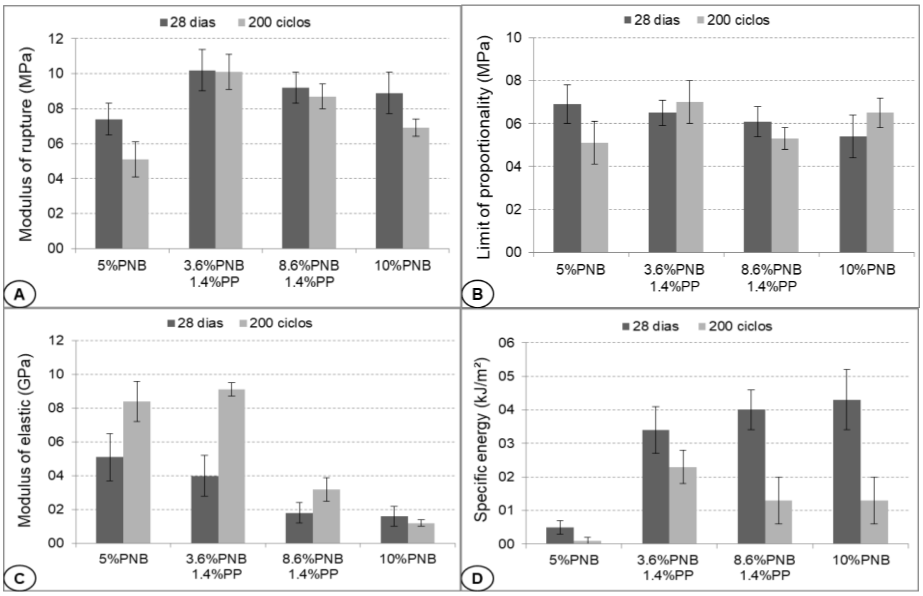

Fig. 3. Mean values and standard deviation of mechanical properties (a) MOR, (b) LOP, (c) MOE and (d) EE before and after accelerated aging of composites with polypropylene fibers.

4 Conclusions

The combination of synthetic polypropylene (PP) fibers with Kraft pine pulp is a technically viable alternative for the production of fiber cement, providing improvements in the performance of fiber cement composites and effective in improving resistance to cracking. The addition of PP fibers increased flexural strength and toughness, in addition, they can reduce porosity and water absorption. Synthetic fibers allowed the maintenance of mechanical properties after aging.

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