ASSESSMENT OF NEW GENERATION POLYPROPYLENE FIBER AS REINFORCEMENT OF AIR-CURED FIBER CEMENT COMPOSITES

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ABSTRACT

The objective of this piece of work was to study the influence of three different types of polypropylene (PP) monofilament fibers tailored for fiber cement production, supplied by BRASKEM S.A., on the performance and durability of cementitious composites in comparison with other commercial fibers used in the cement prefabrication industry. Flat plates were produced by the slurry dewatering and pressing process on a laboratory scale and compared with the corresponding fiber cement flat pads taken directly from the industrial Hatcheck process produced by INFIBRA S.A., Brazil. The mechanical, physical and microstructural characteristics were evaluated at 10 days (10d) of age and after 100 aging soak-dry cycles (100C). Mechanical performance was evaluated in the four-point bending test. Specimens extracted from flat pads with the PP fibers showed higher modulus of rupture (MOR) values of (9.5 ± 0.5) MPa compared to their counterparts reinforced with commercial PP fibers, which achieved (7.5 ± 0.45) MPa at 10 days. The effectiveness of the anchorage mechanism may be related to the good PP fiber-matrix adhesion, due to the densification of the transition zone, also to the homogeneous dispersion of the PP fibers in the cementitious matrix. The 100 cycles caused microcracks, between the fiber and the cement matrix, forming micro-defects in the transition zone. However, composites reinforced with PP fiber performed superior flexural behavior with MOR of (13.6 ± 0.61) MPa compared to their counterparts reinforced with commercial PP fiber with MOR equal to (10 ± 0.59) MPa, indicating the feasibility and effective potential of these new technologies for the use of polypropylene in cementitious composites.

KEYWORDS:

Mechanical performance; synthetic fiber; cellulosic pulp; scanning electronic microscopy; Ordinary Portland cement.

INTRODUCTION

The use of composite materials in construction, such as concrete and mortar reinforced with fibers has grown considerably in recent years. Fiber-cement products had been widely used in the world due to their versatility as corrugated and flat roofing materials, cladding panels and tubes that are present in a significant number of building and agriculture applications (Teixeira et al., 2019a). The main reason for incorporating fibers into the cement matrix is to improve the toughness, tensile strength, and the cracking deformation characteristics of the resultant composite (Azevedo et al., 2022).

The use of cellulose fibers in cement composites is important because of the retention of cement particles in industrial processes and some reinforcement effect in the early ages (Filomeno et al., 2020) . However, the untreated natural fibers are very sensitive to the alkaline environment and are rapidly degraded, causing reduction in the composite durability (Teixeira et al., 2019b) . The issue of reinforcement can be solved by the use of synthetic fibers, which are less sensitive to alkali attack and develop acceptable mechanical behavior, resulting in composites with better performance in the long-term (Mohseni et al., 2016). Synthetic fibers, such as polypropylene (PP) and polyvinyl alcohol (PVA) fibers, lead to the improvement of the post peak ductility, performance under fatigue, impact strength and, also, help to reduction of the shrinkage cracking (Zhang et al., 2022).

The use of PP and PVA fibers represents an option to maintain the toughness of the composites in the long term, while the cellulose pulp fibers are responsible to the necessary rheology and capturing the cement particles during the manufacturing process. PP fibers have been studied, over the years, as alternative fiber for the reinforcement in fiber cement roofing products (Teixeira et al., 2014). These fibers present high ductility and they are resistant to alkaline attack. Other alternative, are the PVA fibers that performs good dispersion, can be uniformly distributed in the cementitious composites, and possess favorable behavior, such as high strength, high elastic modulus, nontoxicity, hydrophilicity, and superior acid and alkali resistances. In addition, PVA has an acceptable toughness for application in fiber cement products (Trindade et al., 2019).

Flat pads were manufactured in a production line using the procedure known as the Hatschek process. The process involves pouring a dilute slurry of fibers, cementitious materials and aggregates (e.g., quartz powder) over a fine sieve, which collects the solids in saturated condition and forms thin layers. The thin layers are stacked on top of each other until a desired board thickness is reached. The resulting composite is then vacuum dewatered and pressed to drain the excess water (Dias et al., 2010). After this process the flat sheets are corrugated.

This study was conducted to produce a viable cementing material using cellulosic pulp and polypropylene in comparison to polyvinyl alcohol fiber as reinforcing elements. Cementitious composites were produced by the slurry-dewatering and pressing technique in laboratory conditions. The composite aging was assessed by accelerated tests, whose advantage is to provide results in a smaller time interval (Savastano et al., 2005). The main objective was to evaluate a new generation of composites reinforced with PP fibers with better behavior for fiber cement production. The study covered materials produced on a laboratory and industrial scale, evaluating their performance at early ages and after 100 cycles of accelerated aging.

EXPERIMENTAL

Synthetic fiber and cellulosic pulp

Three distinct types of polypropylene (PP) fibers used in this study were furnished by Braskem S.A., Brazil. Polypropylene (PP) fibers and polyvinyl alcohol (PVA) fiber both commercially used in the fiber cement industry were chosen for comparison. Some physical properties of the fibers are presented in Table 1.

Table 1 – Physical properties of the polypropylene fiber (Teixeira et al., 2019b; Zhang et al., 2022).

	PP COM*	K1	K2	B6	PVA
Nominal length (mm)	9	9	9	9	6
Nominal thickness (μm)	7	7	7	7	7
Density (g/cm^3)	0.91	0.94	0.96	0.93	1.34
Aspect Ratio	~129	~129	~129	~129	~86

*PP Com – K1, K2, B6 – PP Braskem and PVA.

Figures 1a and 1b show the SEM micrographs of polypropylene (PP) and polyvinyl alcohol (PVA), which have good resistance to alkalinity, moisture and heat exposition (Teixeira et al., 2019b; Zhang et al., 2022). Bleached unrefined eucalyptus kraft pulp (Eucalyptus grandis) supplied by Suzano S/A, Brazil, was used as a secondary reinforcement and process material for industrial and laboratory productions.

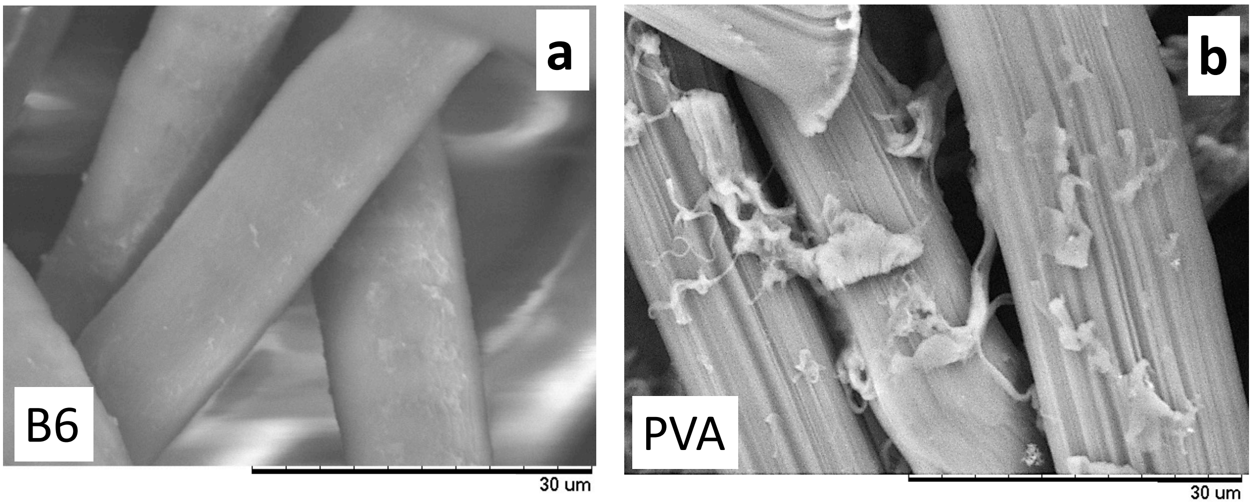


Figure 1 – (a) B6 polypropylene (PP) and (b) polyvinyl alcohol (PVA) fiber: morphological characteristics observed by scanning electron microscopy.

Cement matrix raw materials

Ordinary Portland cement (OPC) type CP V corresponding to ASTM C 150, Type III was selected because of its low amount of mineral additions, finer particle size and higher reactivity in relation to the cement Portland Type I. Additionally, this type of cement contains higher levels of tricalcium silicate (C3S) and dicalcium silicate (C2S) for the formation of C–S–H. Ground limestone is widely consumed in the Brazilian fiber cement industries and was used as a *filler* compound. The cement and limestone *filler* particles distributions were evaluated by a laser particle size analyzer (Malvern Mastersizer S long bed, version 2.19). Cement and limestone particles showed 50% of its mass less than 10.09 and 12.96 µm respectively. Both raw materials exhibit similar particle size distributions.

The quantitative chemical analysis was performed using PANalytical Axios Advanced X-ray fluorescence equipment. The main oxide compositions of cement are: SiO_2: 14.70, CaO: 67.20, Al_2O_3: 4.07, Fe_2O_3: 3.50, MgO: 3.13 and the limestone are: SiO_2: 9.40, CaO: 39.10, Al_2O_3: 2.16, Fe_2O_3: 1.25, MgO: 8.90. The specific surface area (determined using the BET method) and specific density of raw materials were measured. OPC showed specific density 3.10 g/cm^3 and 1.10 m^2/g of specific surface area and limestone 2.80 g/cm^3 and 1.14 m^2/g of specific surface area.

Formulations

The formulations, both for the Hatschek and slurry dewatering & pressing process were based elsewhere (Filomeno et al., 2020; Teixeira et al., 2019b) with 1.5% of synthetic fiber, approximately. The following procedures were performed using the slurry dewatering & pressing process: initially, the commercial bleached hardwood kraft pulp of eucalyptus was dispersed in water at 3000 rpm for 5 min. The ordinary Portland cement and limestone were added, and the mixture was stirred at 1000 rpm for additional 5 min. The mixture was rapidly poured in a casting box with negative pressure (80 kPa) applied to remove the excess of water in the process. After this step, the fiber-cement composites were pressed at 3.2 MPa for 5 min. The fiber-cement composites were cured in saturated air (sealed plastic bags) at (29 ± 2) °°C for 2 days. The plates were placed in a thermal bath at 60°C for 5 days. The process was completed with 2 days on the bench (ambient temperature) and another 24 h immersed in water before the tests, totaling 10 days.

Preparation of cementitious composites

Industrial Hatschek process

The Hatschek process is the most widely utilized one for producing fiber cement components. It consists of producing fiber cement sheets by stacking thin laminas made from a suspension (slurry) of cement, fibers, mineral admixtures, and water, in a process that resembles the production of paper (Dias et al., 2010). The flat pads were cured by an industrial process. After moulding, they were stacked and passed through a curing tunnel that lasts around 24 hours and after they were placed on the specific pallets for accommodation packed with plastic film. Accelerated aging cycles were also performed. Each cycle has a duration of 6 h, which comprises immersion in water and heat of 60°C in the samples. The flat were evaluated after 10 days (10 d) and after 100 cycles (100 C).

Slurry dewatering & pressing process

The slurry dewatering & pressing is a laboratory scale method that crudely simulates the industrial method of fiber cement production. The slurry dewatering & pressing process was used to produce composites reinforced with cellulosic pulp and synthetic fiber. In this study, the formulations were established based on commercial raw materials currently used in the fiber cement industry. Figure 2 depicts a schematic representation of the steps of the slurry dewatering & pressing process for the production of cementitious composites.

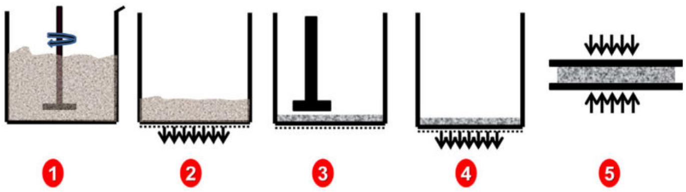


Figure 2 – Details of the s*lurry dewatering & pressing* process mechanism: (1) suspension with approximately 20% of solid materials; (2) mold box subjected to initial negative pressure to remove excess water, forming a solid surface; (3) compaction of the wet pad; (4) negative pressure reapplied; and (5) the mixture was then transferred to a lubricated steel plate, and pressing applied for density increase and further extraction of water. Based on Santos et al. (2017).

Mechanical characterization of the composites

The specimens were cut in the main (longitudinal) direction of the plates, so that the fibers were preferably aligned perpendicular to the bending load. Mechanical tests were performed in a universal testing machine EMIC, model DL 30000 equipped with 1 kN load cell and a deflectometer with a deflection of 30 cm. A four-point bending configuration was utilized for the determination of modulus of rupture (MOR), limit of proportionality (LOP), modulus of elasticity (MOE) and specific energy (SE) values. SE is related to the energy absorbed during the deflection of the sample. A 75 mm span and 5 mm/min deflection rate were adopted in bending test. MOR, LOP, MOE and SE values were calculated from the average of ten specimens for each mix design, following the study by Teixeira et al. (2012).

Physical characterization tests

Water absorption (WA), apparent porosity (AP) and bulk density (DA) values were calculated from the average of ten specimens for each mix design, following procedures specified by ASTM C 948-81 Standards.

Soak/dry accelerated ageing cycles

The soak/dry accelerated ageing test involved comparative analysis of physical and mechanical composites performance, before and after soak/dry cycles. Specimens were successively immersed in water at (20 ± 5) °C during 170 min, followed by the interval of 10 min, and then exposed to the air at (70 ± 5) °C for 170 min in a ventilated oven and with the final interval of 10 min. This procedure was based on recommendations of the EN 494 Standards. Each soak/dry set represents one cycle and was performed for 100 cycles and the results were achieved from the average of ten specimens for each mix design.

Scanning electron microscopy

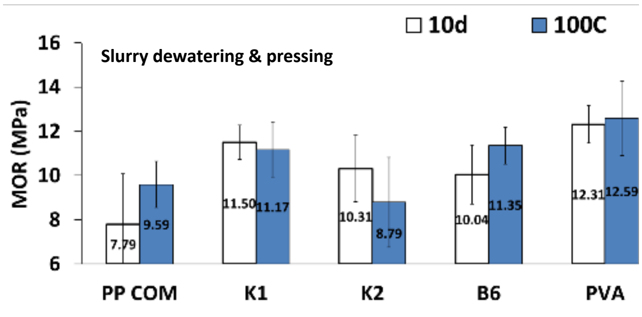
Scanning electron microscopy (SEM) was applied with secondary electron detector, operated at 10.0 kV accelerating voltage, for visualization of the surface fibre morphologies. Energy dispersive X-ray spectroscopy (EDS) analyses were also conducted (Santos et al., 2015). These were performed on the same surface of the specimens to obtain semi-quantitative compositional information. Samples were carbon coated before being analyzed in a Zeiss LEO 440 microscope.

Statistical analyzes

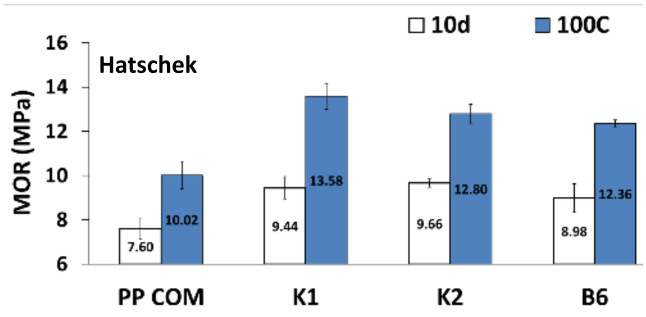
The mechanical and physical tests were conducted under a completely randomized design with five treatments (PP COM, K1, K2, B6 and PVA) and ten replications cured at 10 days and after 100 cycles. The effects of MOR, LOP, MOE, SE, WA, DA and PA were compared via statistical contrast by Tukey test at 5% of significance. The ACTION statistical, version 3.2, program was used.

RESULTS

Figures 3a to 3h show the mechanical properties (modulus of rupture (MOR), limit of proportionality (LOP), modulus of elasticity (MOE), and specific energy (SE)) of cementitious composites produced by slurry dewatering & pressing and Hatschek process cured at 10 days (10 d) and after 100 accelerated aging cycles (100 C) respectively. Tables 2 and 3 list the average values, standard deviations and statistical analyses of mechanical properties and physical characteristics respectively.



(a)



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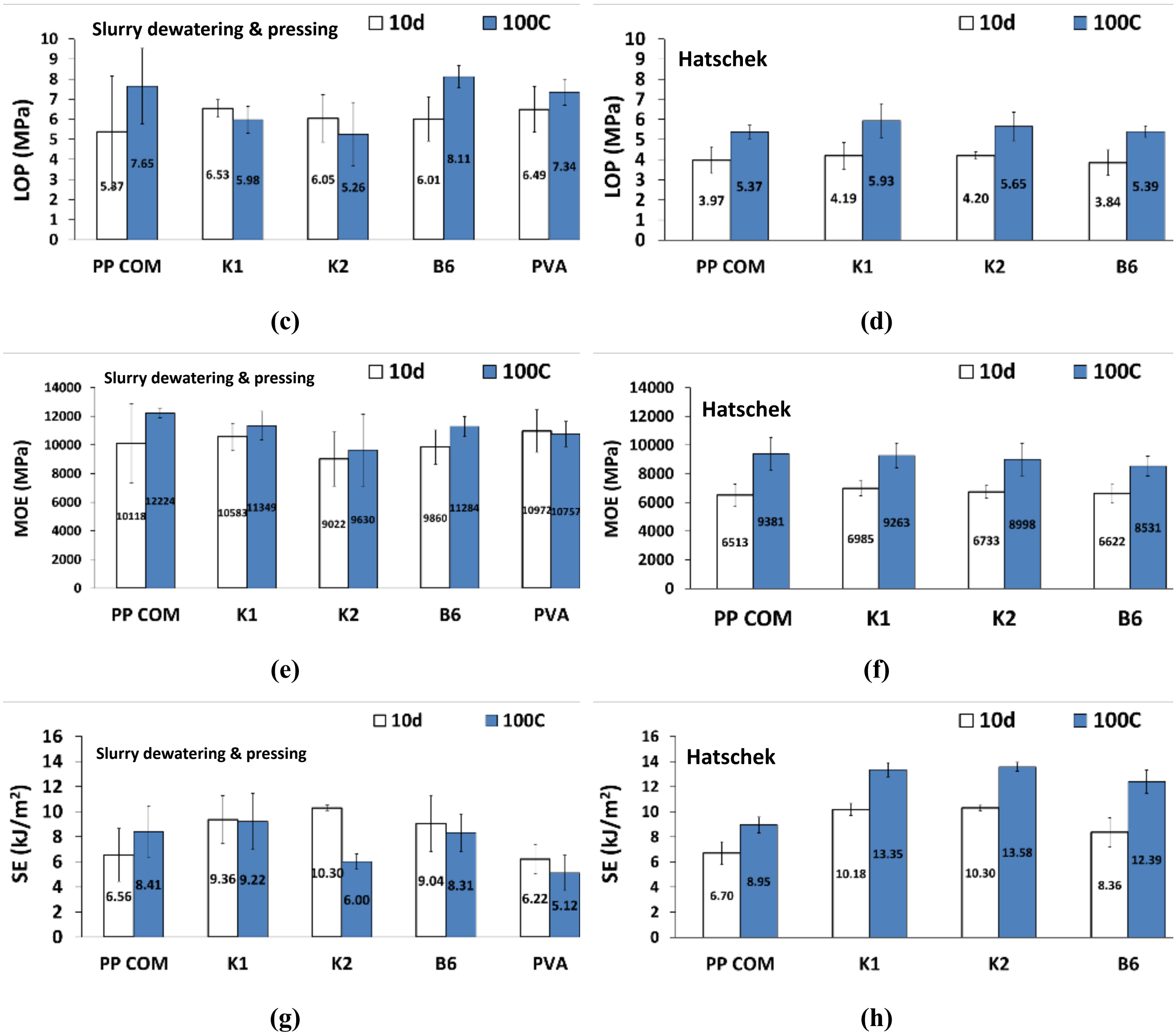


Figure 3 – Average values and standard deviation: (a and b) modulus of rupture (MOR), (c and d) limit of proportionality (LOP), (e and f) modulus of elasticity (MOE), and (g and h) specific energy (SE) of cementitious composites produced by slurry dewatering & pressing and Hatschek processes cured at 10 days (10d) and after accelerated aging (100C), respectively.

The modulus of rupture (MOR) indicates the tensile strength in bending, as well as the interaction and strain distribution between the fiber and the matrix. The cementitious composites reinforced with K1, K2 and PVA fibers at 10 days of curing (10 d) produced by slurry dewatering & pressing and Hatschek showed the increased results in relation to the other reinforcements, respectively, according to the statistical analysis. These results may be linked to the physical characteristics (aspect ratio) of the fibers, which improve the distribution of fibers within the composites. Another factor contributing to these values are the new technology for processing and manufacturing PP fibers, which favors the increase of their overall performance. This increase in the MOR results was 48% and 32% for composites with new generation K1 fiber was 24% and 27% with K2 fibers in relation to their counterparts with PP COM fiber produced by the slurry dewatering & pressing process and Hatschek commercially used in the fiber cement industries, respectively. This condition can be observed in Figure 4, which presents a SEM micrograph image between K1 and PP COM fibers and the cement matrix, which shows an improvement in the interaction of the fibers with the cement matrix, contributing to a better distribution of the tension between the fiber and the matrix.

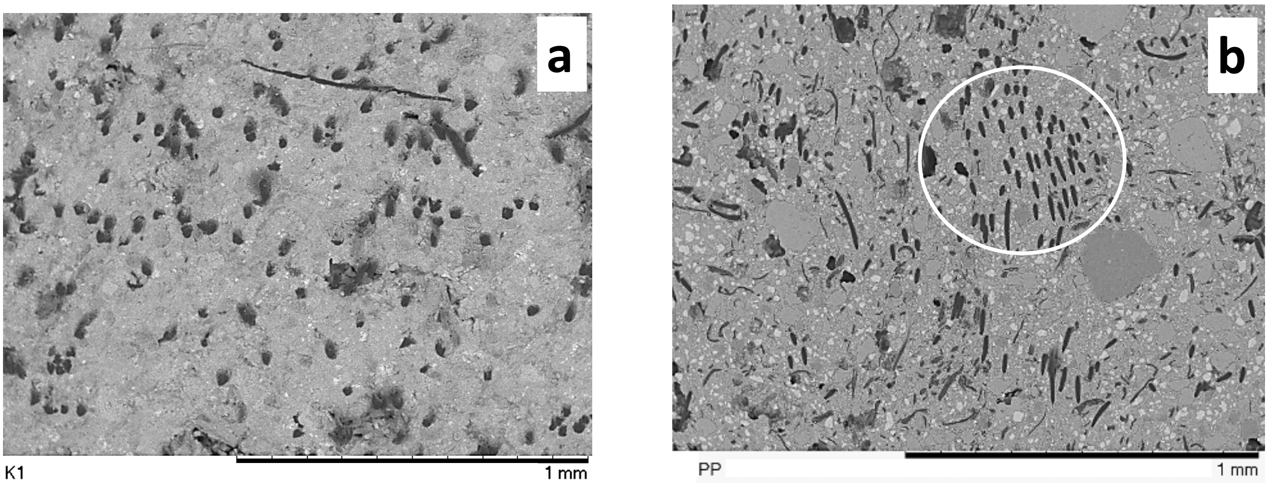


Figure 4 – (a and b) Backscattering electron image, scanning electron microscopy (SEM-BSE) of polished surfaces of composites reinforced with K1 and PP COM fiber produced by slurry dewatering & pressing, respectively. K1 fibers are indicated in the images by black dots and show good interaction and distribution in the cement matrix. PP COM fibers agglomerated in the matrix indicated with a circle in the image.

After accelerated aging (100 C), composite reinforced with K1 produced by both processes increased the MOR values in relation to 10 d, possibly due to the synergy between synthetic fibers and cement matrix that densifies the composite after the continuous process of cement hydration that improves the fiber-matrix interface. Other factor is that polypropylene fibers are hydrophobic and do not absorb water (Teixeira et al., 2019b). In most cases, PVA fiber presents better modulus of rupture results than PP fiber in the cementitious matrices, as discussed by the specialized literature (Zhang et al., 2022). Note that the K1 fibers also showed an increase in relation to the PVA fibers. Zhao et al. (2021) evaluated the functionalization of PP fibers in cementitious composites by bending test. The best results found by the authors were approximately 8 MPa for 28 days of curing. However, in this work, the MOR for cement composites with K1 fiber was 11.50 MPa for 10 days.

Table 2 – Average values and standard deviations of modulus rupture (MOR), limit of proportionality (LOP), modulus of elasticity (MOE), specific energy (SE), water absorption (WA), bulk density (BD) and apparent porosity (AP) of the composite cementitious reinforced with polypropylene fiber (PP COM, K1, K2, B6) and polyvinyl alcohol fiber (PVA) produced by slurry dewatering & pressing process in the conditions at 10 days (10d) of curing and after 100 accelerated aging cycles (100C)*.

Formulations	**Slurry dewatering & pressing**	MOR (MPa)	LOP (MPa)	MOE (MPa)	SE (kJ/m^2)	WA (%)	BD (g/cm^3)	AP (%)
PP COM	10 days	7.79 ± 2.29 c	5.37 ± 2.79 a	10118 ± 2778 a	6.56 ± 2.11 b,c	19.44 ± 1.55 a	1.59 ± 0.05 a	30.24 ± 1.54 b
K1		11.50 ± 0.78 a,b	6.53 ± 0.44 a	10583 ± 937 a	9.36 ± 1.91 a	20.65 ± 1.97 a	1.56 ± 0.05 a	32.18 ± 1.30 a,b
K2		10.31 ± 1.50 b	6.05 ± 1.18 a	9022 ± 1877 a	10.30 ± 0.22 a	20.72 ± 1.36 a	1.56 ± 0.05 a	32.23 ± 1.17 a
B6		10.04 ± 1.33 b	6.01 ± 1.10 a	9860 ± 1191 a	9.04 ± 2.25 a,b	19.37 ± 1.79 a	1.59 ± 0.07 a	30.75 ± 1.64 a,b
PVA COM		12.31 ± 0.85 a	6.49 ± 1.14 a	10972 ± 148 a	6.22 ± 1.18 c	19.86 ± 0.77 a	1.58 ± 0.03 a	31.33 ± 0.81 a,b
PP COM	100 cycles	9.59 ± 1.05 2	7.65 ± 1.88 1,2	12224 ± 310 1	8.41 ± 2.04 1	19.02 ± 0.63 1	1.59 ± 0.03 1	30.22 ± 0.50 2
K1		11.17 ± 1.23 1	5.98 ± 0.67 2,3	11349 ± 1004 1	9.22 ± 2.24 1	20.32 ± 0.05 1	1.57 ± 0.05 1	31.76 ± 1.01 1
K2		8.79 ± 2.03 2	5.26 ± 1.58 3	9630 ± 2502 2	6.00 ± 0.62 2	19.72 ± 1.57 1	1.59 ± 0.06 1	31.18 ± 1.23 1
B6		11.35 ± 0.83 1	8.11 ± 0.55 1	11284 ± 695 1	8.31 ± 1.50 1	19.65 ± 1.48 1	1.60 ± 0.06 1	31.42 ± 1.21 1
PVA		12.59 ± 1.69 1	7.34 ± 0.65 2	10757 ± 877 1	5.12 ± 1.40 2	19.39 ± 0.89 1	1.58 ± 0.05 1	30.68 ± 1.15 1

* Lowercase letters and numbers (a, b and c; 1,2 and 3) in the same column represent comparisons between formulation of the composites at 10d and 100 cycles respectively. Different letters and numbers indicate significant differences amongst the properties of the composites.

Figure 3c illustrates the results of the limit of proportionality (LOP), which infers the performance and behavior of the composite before the cracking stage. The results show no significant difference between the formulations at 10 d. In general, after 100 C, the composites showed better results, with emphasis on the composites with PP COM and K1. This behavior of PP COM and K1 possibly represents an improvement in the adhesion between fiber and matrix. Flat pads produced by the Hatschek process showed no difference in LOP and modulus of proportionality (MOE) both for 10 d and after 100 C showed in Figures 3d and 3f, respectively.

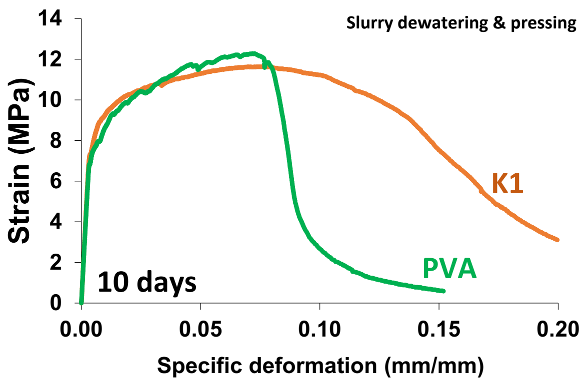
The MOE values indicate the stiffness of the specimens. The MOE values of cementitious composites (Figure 3e) reinforced with PP and PVA showed no significant difference between the formulations, both for 10 d and 100 C. After 100 C, there was an increasing trend in MOE values, demonstrating that PP and PVA fibers are effective for increasing the stiffness of the specimens (Zhang et al., 2022).

Table 3 – Average values and standard deviations of modulus rupture (MOR), Limit of proportionality (LOP), modulus of elasticity (MOE), specific energy (SE), water absorption (WA), bulk density (BD) and apparent porosity (AP) of the flat pads reinforced with polypropylene fiber (PP COM, K1, K2, B6) and polyvinyl alcohol fiber (PVA) produced by Hatschek process in the conditions at 10 days (10d) of curing and after 100 accelerated aging cycles (100C)*.

Formulations	**Hatschek**	MOR (MPa)	LOP (MPa)	MOE (MPa)	SE (kJ/m^2)	WA (%)	BD (g/cm^3)	AP (%)
PP COM	10 days	7.60 ± 0.48 b	3.97 ± 0.66 a	6513 ± 753 a	6.70 ± 0.92 c	31.82 ± 1.13 a	1.36 ± 0.03 a,b	43.10 ± 0.75 a
K1		9.44 ± 0.50 a,b	4.19 ± 0.66 a	6985 ± 521 a	10.18 ± 0.49 a	30.39 ± 0.40 b	1.38 ± 0.01 a	41.83 ± 0.25 b,c
K2		9.66 ± 0.19 a	4.20 ± 0.19 a	6733 ± 439 a	10.30 ± 0.22 a	31.42 ± 0.83 a,b	1.35 ± 0.02 b	42.38 ± 0.58 a,b
B6		8.98 ± 0.65 b	3.84 ± 0.63 a	6622 ± 625 a	8.36 ± 1.17 b	31.16 ± 0.92 a,b	1.36 ± 0.02 a,b	42.29 ± 0.64 b,c
PP COM	100 cycles	10.02 ± 0.61 3	5.37 ± 0.34 1	9381 ± 1134 1	8.95 ± 0.64 3	28.49 ± 0.97 1	1.42 ± 0.02 1	40.50 ± 0.70 1
K1		13.58 ± 0.59 1	5.93 ± 0.84 1	9263 ± 863 1	13.35 ± 0.55 1	28.11 ± 0.44 1	1.42 ± 0.01 1	39.44 ± 0.33 2
K2		12.80± 0.42 2	5.65 ± 0.71 1	8998 ± 1122 1	13.58 ± 0.35 1	28.90 ± 0.66 1	1.41 ± 0.01 1	40.60 ± 0.51 2
B6		12.36± 0.16 2	5.39 ± 0.28 1	8531 ± 678 1	12.39 ± 0.93 2	28.41 ± 0.66 1	1.42 ± 0.02 1	40.23 ± 0.49 1,2

* Lowercase letters and numbers (a, b and c; 1,2 and 3) in the same column represent comparisons between formulation of the flat pads at 10d and 100 cycles respectively. Different letters and numbers indicate significant differences amongst the properties of the composites.

Cementitious composites and flat pads reinforced with K1 show higher specific energy (SE) results at 10 d and after 100 C showed in Figure 4g and 4h, respectively. The fact that the fibers present similar surface area can say that the K1 fiber showed better interaction with the cement matrix, increasing the slip capacity during bending and, thus, increasing the energy absorption, as observed by the specific energy value showed in Figures 5a and 5b. However, after 100C, there was a tendency to increase for the composites reinforced by all the different fibers, due to cement rehydration, but not showing the same behavior as K1 fiber.



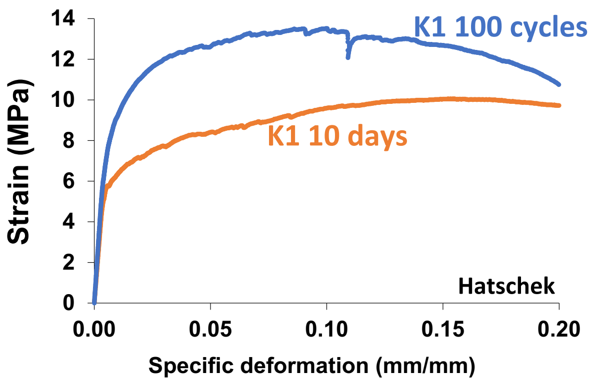


Figure 5 – Typical curves between strain vs specific deformation: (a) composites cementitious reinforced with K1 and PVA fibers produced by the slurry dewatering & pressing process and (b) flat pads reinforced with K1 fibers at 10 days and after 100 cycles produced by the Hatschek process (main machine direction).

The toughening of the cement composite is related to several phenomena that occur during its fracture, such as: debonding of the matrix, pulling-out, bridging, stretching and, finally, the breaking (fracturing) of the fibers (Almeida et al., 2013). Fiber pull-out is the main responsible for the toughening mechanism and energy absorption by the composite. This strong bond between fiber and matrix can be seen in the fracture surface image of the composite reinforced with K1 fiber (Figure 6a) which showed a good adhesion compared to the PVA fiber (Figure 6b) which reflected the SE results after 100C.

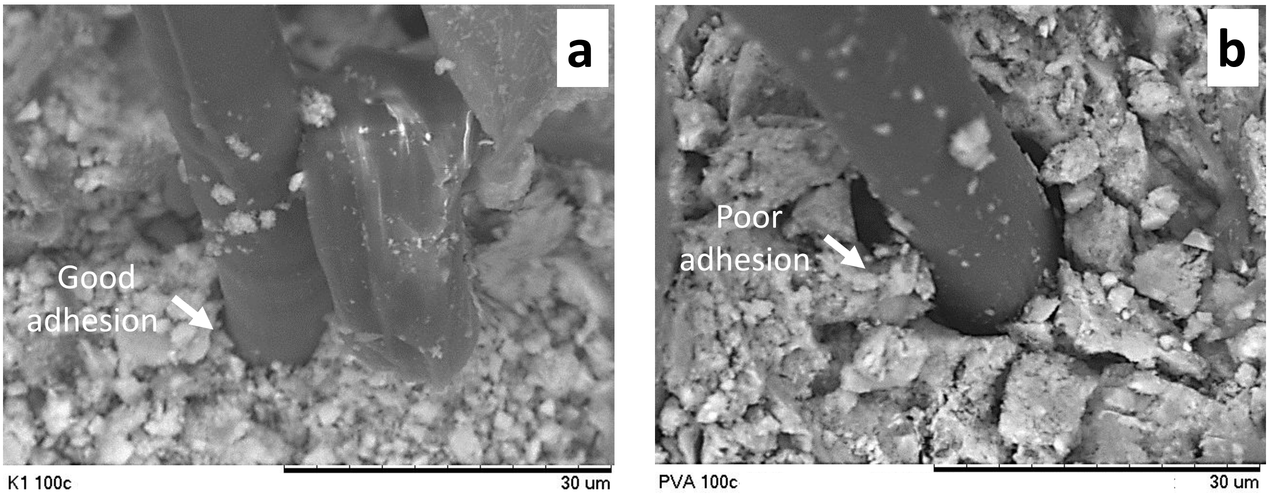


Figure 6 – SEM micrographs of the composite produced by the slurry dewatering & pressing method and after the aging cycles (100C). (a) the arrow shows K1 fiber with good adhesion between matrix fiber, however in figure (b) the PVA fiber indicates lower adhesion.

In general, the physical results did not show significant differences in water absorption (WA) and apparent porosity (AP) in cementitious composites (Table 2 and 3). However, there was a small decrease in the porosity of the composites reinforced with PP COM at 10 days and after 100 C, on the other hand, they did not differ in relation to the other formulations. Flat pads reinforced with PP COM showed higher water absorption and porosity between the reinforcing fibers at 10 d. This behavior may possibly be related to the distribution of fibers in the matrix and also the influence of the production process that induces the difficulty of packaging the composite and, thus, contributes to the greater absorption and porosity. Another factor is a lower adhesion between matrix fiber, which induces a predominance of fiber pullout with a lower SE value. This characteristic can be a negative aspect, generating defects in the microstructure of the composites.

CONCLUSION

According to the results of the work, the K1, K2 and B6 new generation polypropylene fiber directly influenced the mechanical performance in composites. K1 and K2 fibers showed better mechanical results for modulus of rupture (MOR) and specific energy (SE) according to ANOVA at 10D and after 100C. Value of MOR was 48% for composites and 24% flat pads with new generation K1 fiber in relation to the PP COM fiber produced by the slurry dewatering & pressing process and Hatschek normally used commercially in the cement industries respectively. These values are the new technology for processing and manufacturing PP fibers, which favors the increase of their overall performance. Scanning electron microscopy of the fracture surface indicated that the pullout mechanism of the K1 fibers was effective in influencing the specific energy (SE) values of the composites produced by slurry dewatering & pressing and Hatschek at 10 days and after 100 cycles. Flat pads reinforced with PP COM showed higher water absorption and porosity between the reinforcing fibers at 10D possibly due to the distribution of fibers in the matrix and the influence of the production process that induces the difficulty of packaging the composite and, thus, contributes to the greater absorption and porosity. These new technologies for processing and manufacturing a new generation of polypropylene fibers with their use in cementitious composites based on experimental results are promising for fiber cement products soon.

ACKNOWLEDGEMENTS

The authors thank the Brazilian companies BRASKEM S.A. and INFIBRA S.A. for the supply of fibers and raw materials and technical support for the development of this work.

REFERENCES

Almeida, A.E.F.S., Tonoli, G.H.D., Santos, S.F., Savastano, H., 2013. Improved durability of vegetable fiber reinforced cement composite subject to accelerated carbonation at early age. Cem Concr Compos 42, 49–58. https://doi.org/10.1016/j.cemconcomp.2013.05.001

ASTM C 150, 2011. American Society for Testing and Materials – ASTM C150/C150M-11. Standard specification for Portland cement.

ASTM C 948-81, 1982. American Society for Testing and Materials. ASTM C 948-82: Test method for dry and wet bulk density, water absorption, and apparent porosity of thin sections of glass-fibre reinforced concrete. West Conshohocken, PA, USA.,.

Azevedo, A.R.G., Amin, M., Hadzima-Nyarko, M., Saad Agwa, I., Zeyad, A.M., Tayeh, B.A., Adesina, A., 2022. Possibilities for the application of agro-industrial wastes in cementitious materials: A brief review of the Brazilian perspective. Cleaner Materials 3, 100040. https://doi.org/10.1016/j.clema.2021.100040

Dias, C.M.R., Savastano Jr., H., John, V.M., 2010. Exploring the potential of functionally graded materials concept for the development of fiber cement. Constr Build Mater 24, 140–146. https://doi.org/10.1016/j.conbuildmat.2008.01.017

EN 494, 1994. EUROPEAN COMMITTEE FOR STANDARDIZATION. EN 494: fibre-cement profiled sheets and fittings for roofing – products specification and test methods. London, UK.: BSI – British Standards Institution.,.

Filomeno, R.H., Rodier, L.B., Ballesteros, J.E.M., Rossignolo, J.A., Savastano, H., 2020. Optimizing the modified atmosphere parameters in the carbonation process for improved fiber-cement performance. Journal of Building Engineering 32, 101676. https://doi.org/10.1016/j.jobe.2020.101676

Mohseni, E., Khotbehsara, M.M., Naseri, F., Monazami, M., Sarker, P., 2016. Polypropylene fiber reinforced cement mortars containing rice husk ash and nano-alumina. Constr Build Mater 111, 429–439. https://doi.org/10.1016/j.conbuildmat.2016.02.124

Santos, S.F., Schmidt, R., Almeida, A.E.F.S., Tonoli, G.H.D., Savastano Jr, H., 2015. Supercritical carbonation treatment on extruded fibre–cement reinforced with vegetable fibres. Cem Concr Compos 56, 84–94. https://doi.org/10.1016/j.cemconcomp.2014.11.007

Santos, S.F., Teixeira, R.S., Savastano Jr., H., 2017. Interfacial transition zone between lignocellulosic fiber and matrix in cement-based composites, in: Sustainable and Nonconventional Construction Materials Using Inorganic Bonded Fiber Composites. Editors: Holmer Savastano Junior, Juliano Fiorelli and Sergio Francisco dos Santos, Woodhead Publishing, 2017. 494p., pp. 27–68.

Savastano, H., Warden, P.G., Coutts, R.S.P., 2005. Microstructure and mechanical properties of waste fibre-cement composites. Cem Concr Compos 27, 583–592. https://doi.org/10.1016/j.cemconcomp.2004.09.009

Teixeira, R.S., Santos, S.F., Christoforo, A.L., Paya, J.B., Savastano, H., Lahr, F.A.R., 2019a. Impact of content and length of curauá fibers on mechanical behavior of extruded cementitious composites: Analysis of variance. Cem Concr Compos 102, 134–144. https://doi.org/10.1016/j.cemconcomp.2019.04.022

Teixeira, R.S., Santos, S.F., Christoforo, A.L., Savastano Jr, H., Lahr, F.A.R., 2019b. Extrudability of cement-based composites reinforced with curauá (Ananas erectifolius) or polypropylene fibers. Constr Build Mater 205, 97–110. https://doi.org/10.1016/j.conbuildmat.2019.02.010

Teixeira, R.S., Tonoli, G.H.D., Santos, S.F., Fiorelli, J., Savastano Jr., H., Lahr, F.A.R., 2012. Extruded Cement Based Composites Reinforced with Sugar Cane Bagasse Fibres. Key Eng Mater 517, 450–457. https://doi.org/10.4028/www.scientific.net/KEM.517.450

Teixeira, R.S., Tonoli, G.H.D., Santos, S.F., Savastano Jr, H., Protásio, T.P., Toro, E.F., Maldonado, J., Lahr, F.A.R., Delvasto, S., 2014. Different ageing conditions on cementitious roofing tiles reinforced with alternative vegetable and synthetic fibres. Mater Struct 47, 433–446. https://doi.org/10.1617/s11527-013-0070-0

Trindade, A.C.C., Borges, P.H.R., de Andrade Silva, F., 2019. Mechanical behavior of strain-hardening geopolymer composites reinforced with natural and PVA fibers. Mater Today Proc 8, 753–759. https://doi.org/10.1016/j.matpr.2019.02.017

Zhang, P., Wei, S., Wu, J., Zhang, Y., Zheng, Y., 2022. Investigation of mechanical properties of PVA fiber-reinforced cementitious composites under the coupling effect of wet-thermal and chloride salt environment. Case Studies in Construction Materials 17, e01325. https://doi.org/10.1016/j.cscm.2022.e01325

Zhao, D., Wang, Z., Wang, M., Lu, S., Chi, L., 2021. Functionalized PP fiber to improve compressive strength and solidification/stabilization performance of cement with heavy metals. Constr Build Mater 278, 122412. https://doi.org/10.1016/j.conbuildmat.2021.122412