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EVALUATION OF THE MECHANICAL BEHAVIOR OF MIXTURES OF STANDARD CONCRETE, CONCRETE REINFORCED WITH GLASS MICROFIBER AND POLYMERIC MICROFIBER

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ABSTRACT:
This study investigates the comparison of conventional concrete with microfiber reinforced concrete at the ages of 7, 14, 21, 28, 60 and 90 days. In order to increase the ductility and mechanical strength of concrete against compressive, tensile and flexural loads, the addition of microfibers can be implemented to reduce the problems associated with concrete brittleness. The research evaluated the workability of concrete in fresh state, the mechanical properties of compressive strength, tensile strength and flexural strength reinforced with glass microfiber and polypropylene microfiber. Considering the amount of fiber and glass powder used, compression and tension specimens with dimensions of 10×20cm and bending beam specimens with dimensions of 50×15×15 cm were prepared. The microfibers have an average diameter and length of 18μm and (12 to 15)μm, respectively, demonstrated in a microscopy assay. The results of the X-ray diffraction data confirm the electron microscopy data regarding the composition of the mixtures. The experimental results indicated that the workability was highly influenced by the fibers in the concrete, regardless of the type. The additions reduced the workability of the cement mixture in greater proportion in the glass microfibers. Both types of microfiber improved flexural strength, tensile strength and had less of an effect on compression values. Additions of polypropylene microfibers increased mechanical strength more effectively than glass fibers. The concrete properties were improved with the addition of microfibers, justifying their viability.

KEY WORDS: *Concrete, mechanical strength, glass microfibers, polypropylene microfibers.*

1 . LITERATURE REVIEW

One of the reasons for the high use of concrete in civil construction is the low cost and rapid availability of materials for use. The components for the production of concrete, cement, aggregates and water are relatively cheap and easily found all over the world (1). According to Brunauer and Copeland (2) concrete is the most used building material, where 63 million tons of Portland cement can produce up to 500 million tons of concrete. According to the ACI Committee 116R (3) and ASTM (4) concrete is a composite essentially consisting of a binding medium between which particles or aggregate fragments are agglutinated. Portland cement concrete is formed by a binder composed of a mixture of hydraulic cement and water. O concreto é um material composto e muitas de suas características não seguem as regras das misturas. When subjected to compressive loads, both aggregate and cement paste, when tested separately, show elastic failure, while concrete shows inelastic failure. While the strength of the mixture is much lower than the individual strength of cement paste and aggregate. These behavior characteristics of concrete can be clarified based on its microstructure, mainly due to the great importance between the transition zone at the interface between coarse aggregate and cement paste (1).

Aggregates, due to their size, shape and surface texture, make it difficult to distribute water in the fresh concrete mix, preventing the homogeneous distribution of water, causing an effect called "wall", which tends to accumulate water on the surface of the aggregates. The transition zone when compared to the cement paste as a whole is characterized by the presence of large pores and large crystalline products of hydration, causing serious problems for the strength of the concrete, as well as the beginning of crack propagation (5), (6).

Since concrete is a fragile material and has internal and surface defects, its mechanical characteristics of compression, traction and flexion are influenced, especially when these characteristics are combined with the effects of structural loads, temperature and ambient humidity, seriously interfering with the elements. structures produced by concrete. Reinforcement with fiber addition is usually a method to improve mainly bending, tensile and tenacity efforts, controlling or delaying the initiation and propagation of cracks. (7), (15).

Cement composites engineered with fibers are new types of concrete that generally increase the ductility and also improve the low tensile strength of concretes. The ductility of shotcrete with microfibers increases by more than 2%, when compared to conventional concrete, while the tensile strength can vary in the range of 4-20MPa, as it mainly reinforces the paste-aggregate transition zone, delaying the start and the crack propagation which is one of the most significant behavioral abilities of fiber reinforced concrete (7), (8), (9), (10).

Several studies have shown that natural and synthetic microfibers have excellent potential to reduce the width and formation of cracks in concrete and mortar, in addition to being used as reinforcement materials (11), (12). Mechanical tests shown by Beaudoin and Low (13) demonstrated that the addition of natural fibers to cementitious composites containing silica fume and natural microfibers ensured an increase in flexural strength. In the experiments developed by Day et al (14) they stated that there was a 30% increase in the compressive strength of cementitious composites as a result of the replacement of 10% of cement by natural fiber of Wallastonite.

Polypropylene fibers have high tenacity, consist of a core with good tensile strength and an outer layer with surface properties favorable to the hydration rate of concrete (16), (17). Polypropylene microfibers, when acting as reinforcement in concrete, have the function of controlling cracks resulting from the change in volume in cement mixtures that occurs during hardening, and their use is recommended in structural elements such as slabs, floors and structures with large surface areas (18).), (19).

The objective of the research was to analyze the influence of the addition of glass microfibers (MFV) and polypropylene microfibers (MFPP), from a mixture taken as reference (MR), on the mechanical properties of compressive strength, tensile strength by diametral compression and bending resistance. Additionally, observations were made of the fractured surfaces by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS), to analyze the bond between the microfibers and identify the elemental composition in the concrete matrix.

2. EXPERIMENTAL PROGRAM

2.1 MICROFIBERS

Two types of microfibers were used in this research with properties detailed in Table 2. The fibers were sourced from Empresa NovaInfra Brasil. Both microfibers have high resistance to alkali and acids, making them suitable for highly corrosive environments. This also means that they are resistant to the high alkalinity of concretes. In addition, their respective melting points, as shown in Table 1, are above 160°C, which makes them resistant to damage during hydration with increasing temperature gradient. SEM images of the fiber surfaces are shown in Figure 1. As seen in the SEM images, glass microfibers have more regular shapes than polypropylene microfibers.

Table 1. Characteristics of microfibers used in concrete mixtures

Fiber ID	Length (mm)	Diameter	Fusion point	Ignition point	Specific density	Deformation at break
FPP	12 a 15	18 µm	160°C	365°C	0,92g/cm^2	25%
FVD	18	14 µm	860°C	900°C	2,68g/m^3	0,3%

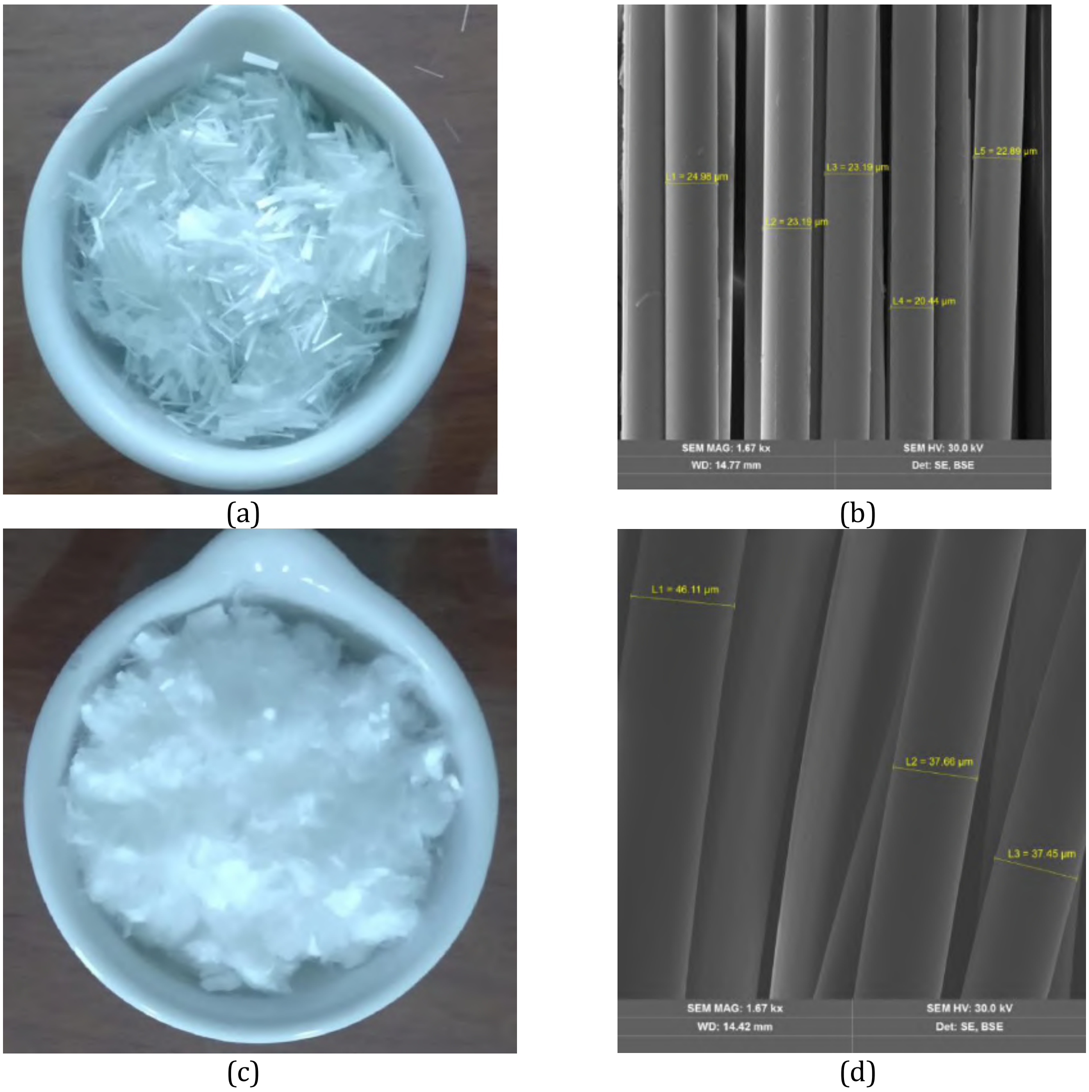


Figure 1. SEM images of glass microfibers and polypropylene microfiber, (a) glass microfiber, (b) glass microfiber SEM, (c) polypropylene microfiber, (d) polypropylene microfiber SEM.

2.2 MECHANICAL TESTS

The basic concrete for analysis was a reference concrete (MR) composed of Portland Cement CP II - F, manufactured in Brazil, river sand, crushed granite with a maximum diameter of 9.5 mm, and superplasticizer additive, with pH 8.0, specific mass 1.2 g/cm3 and solids content of 38.0%. TEC-FLUID 1000 was used to reduce the amount of mixing water in the concrete, water/cement was set at 0.425. The consistency of concrete mixtures measured by the slump test was kept at the level (210 ± 20mm) in order to keep the w/c factor constant for all the mixtures studied. Details of the mixture proportions investigated in this study are presented in Table 2.

Table 2. Mixing proportions used in mechanical tests

Mixture	Mixing ratio (kg/m^3)					
	Cement	Sand	Gravel	SP	Fiber volume	Water
MR	1	1,98	2,21	2%	-	0,425
MFV	1	1,98	2,21	2%	600g/m^3	0,425
MFPP	1	1,98	2,21	2%	600g/m^3	0,425

2.2.1 COMPRESSION TEST

For the compressive strength test, three batches of concrete MR, MFV and MFP were carried out in cylindrical specimens of 10mm in diameter and 20mm in height with three samples for each age 7, 14, 21, 28, 60 and 90 days, using a universal press with a capacity of 60t. Twenty-four hours after molding, the specimens were demolded and cured in lime-saturated water for up to 24 hours before being tested.

2.2.3 DIAMETRAL COMPRESSION TENSILE TEST

For the tensile strength test by diametral compression, three batches of concrete MR, MFV and MFP were carried out in cylindrical specimens of 10 mm in diameter and 20 mm in height with three samples for each age 7, 14, 21, 28, 60 and 90 days, using a universal press with a capacity of 60t. Twenty-four hours after molding, the specimens were demolded and cured in lime-saturated water for up to 24 hours before being tested.

2.2.4 FLEXION TEST

The flexural strength test was investigated by three-point bending loading performed on three batches of MR, MFV and MFP concrete in cubic specimens of 50cm length, span of 45cm between the supports, height of 15cm and width of 15cm. The three-point bending test was performed on three samples for each age 7, 14, and 28 days, using a universal press with a capacity of 60t. Twenty-four hours after molding, the specimens were demolded and cured in lime-saturated water for up to 24 hours before being tested.

2.3 SCANNING ELECTRON MICROSCOPY (SEM)

The microstructure of the concretes was analyzed by: observation of the morphology of the fracture surfaces, analysis of cross-sectional images of samples and scanning electron microscopy (SEM). Observations of the microstructure as well as the morphology of the interfacial transition zone between the cement paste and the microfibers added to the mixtures. The fractured surfaces were obtained during the mechanical tests. The SEM/EDS observations were performed on samples with dimensions of approximately 5 and 6 mm in diameter.

A TESCAN VEGA3 high and medium vacuum scanning electron microscope (SEM) with tungsten filament electron source, SEM coupled with fine window EDS was used for elemental composition analysis. The fractured surfaces were gold plated and mounted on an aluminum stub using carbon tape. An acceleration voltage of 30 kV, a rated emission current of 20 μA and a working distance of 15.74 mm were used. They were used to observe the surface of the microfibers FPP, FVD and the fractured surfaces of the concrete mixtures MR, MFV and MFPP at 90 days of curing.

3. RESULTS

3.1 WORKABILITY OF MIXTURES

The experimental results of the slumps are shown in Figure 2. The main reason for the decrease in the slump is that the polypropylene microfibers are very fine filaments that are easily dispersed in the concrete mixture, preventing concrete segregation, but with a specific surface area greater than glass microfiber, and also because they are materials that were added to the conventional concrete mix.

According to Soliman and Nehdi (20) their experimental results indicated that the addition of wollastonite microfibers with a proportion of 10% and 19% reduced the workability of the mixture compared to the control mixture without wollastonite microfibers, while in the proportion of addition of 5% of microfibers increases the workability of the mixture. The authors state that when the microfiber addition is high, the decrease in the workability of the mixture is mainly caused by the intertwining of acicular wollastonite microfibers. However, when wollastonite microfibers are too small in size, they can provide an internal lubricating effect, resulting in a reduction in water demand.

The decrease in the workability of cementitious composites with the addition of microfibers is justified by the large specific surface area of the microfibers that increase the demand for water, in addition to the needle shape of the microfibers which increases the intertwining between the microfibers and the cement paste (21) , (22).

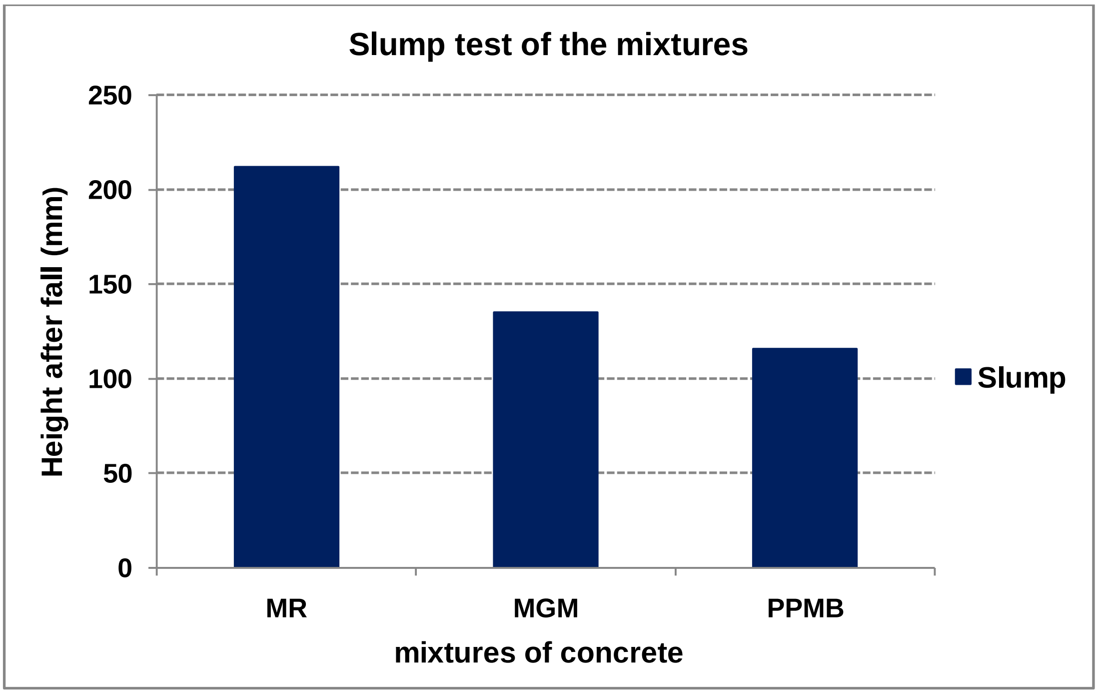


Figure 2. Drop test "slump test", average drop heights of MR, MFV and MFPP concrete.

3.2 AXIAL COMPRESSION

Compressive strength values from 7 to 90 days increased continuously for all mixtures, as shown in Figure 3, as expected. Conventional concrete mixtures had growth of 14%, 32%, 45%. 53% and 56% in reference to strength at 7 days, respectively, while the mixtures with polypropylene fiber, which were the best results, grew at the rate of 30%, 36%, 40%, 53% and 57%. The two mixtures with fiber addition, at all ages, were slightly superior to the control mixture, showing the efficiency of microfibers in controlling the formation of cracks in the mixture still in the hardening phase, avoiding the formation of early cracks in the phases. initial curing of concrete to more advanced ages.

Yoo et al (23) studied the efficiency of fibers in cementitious composites as a way of controlling the expansion by compensating for the general shrinkage, they studied the efficiency of the shrinkage-reducing mixture (0 - 2%). The study found that the highest fiber content, 2% fiber addition reduced shrinkage by 28% at 28 days, that is, resulted in lower shrinkage and cracking potential, in the same way that it slightly increased the compressive strength of concrete. at 28 days.

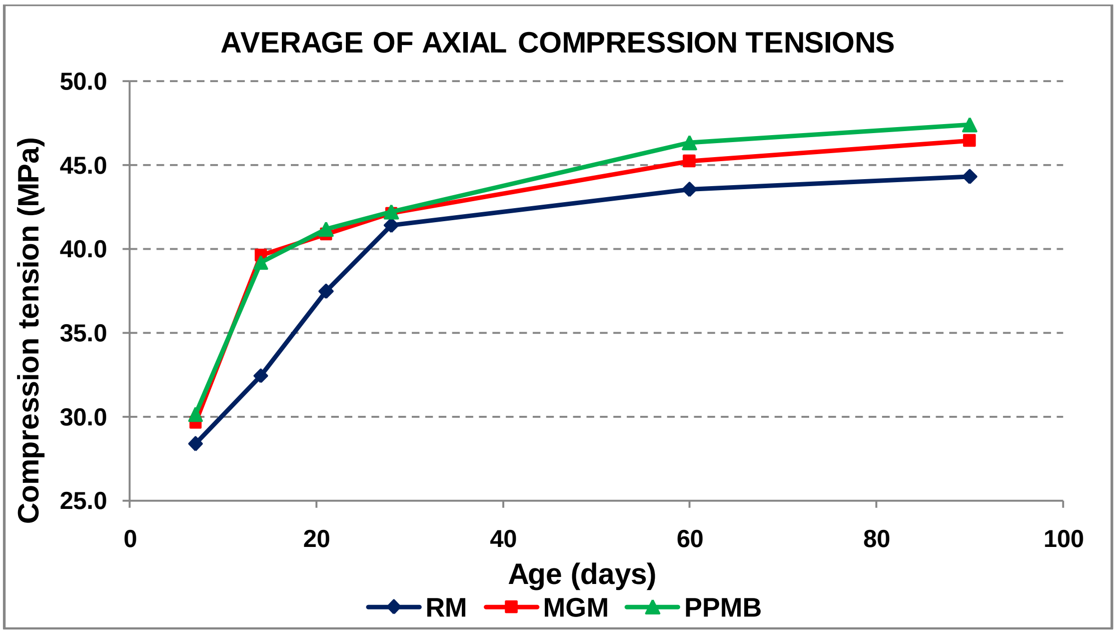


Figure 3. Average of the stresses of three samples of axial compression concrete MR, MFV and MFPP, for the ages of 7, 14, 21, 28, 60 and 90 days.

Garcez et al (24) found that the addition of microfibers can improve the compressive strength of concrete and contain the formation of macro-cracks in concrete. And yet according to Bing Liu et. al. (25), the microfibers work mainly before the macrocracks appear, allowing an improvement in the axial compressive strength of up to 6.08%.

It is worth noting that with the addition of microfibers, especially in polypropylene, the number and width of macrocracks after the failure of the specimen decreased, because the microfibers located in the macrocracks play a bridging role, as shown in Figure 4.

(a) (b)

Figure 4 . Fracture characteristics of MR and MFPP concrete: (a) MR concrete brittle fracture; (b) MFPP ductile fracture concrete.

3.3 TENSILE TENSION BY DIAMETRAL COMPRESSION

The average stress curves of the three concrete mixtures are shown in Figure 5. As we have seen, the behavioral characteristics of traction in the three situations follow the same characteristics of axial compression, but with more efficient results when using microfibers as an addition to concrete composites. A greater dispersion can be observed in conventional concrete, where the average of the results at 21 days came very close to the strength at 7 days. Such dispersion can be once again justified by the influence of the fibers that act as a bridge between the aggregate and the cementitious mass, showing the positive synergy for both types of microfiber.

According to Table 3, we found that at practically all ages, conventional concrete presents the highest standard deviations of the samples tested, while for concretes added with carbon fiber, the strong bridging effect and the tensile strength of the carbon fibers carbon result in more improved properties. Positive efficiency means that the increase in tensile performance is greater than the increase in compressive strength. The mixtures with polypropylene fiber grew in the proportion of 6%, 20%, 9%, 2%, 6% and 7% compared to conventional concrete, and in relation to the tested ages 7, 14, 21, 28, 60 and 90 days, respectively, while tensile stresses increased by 21%, 28%, 35%, 13%, 27% and 20% for the same ages.

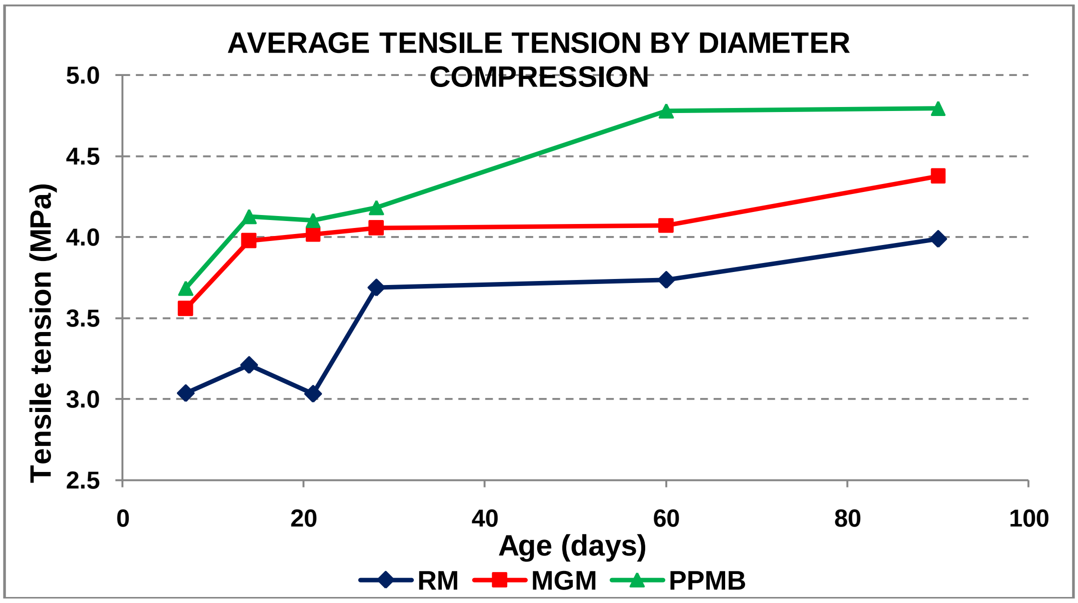


Figure 5. Average tensile stresses by diametral compression of three samples for each mixture of MR, MFV and MFPP concrete, for the ages of 7, 14, 21, 28, 60 and 90 days.

Table 3. Average tensile tension by diametral compression and standard deviation of the MFV and MFPP mixtures tested

Conventional concrete						
Age	7	14	21	28	60	90
Average	3,039	3,212	3,036	3,691	3,738	3,991
S. deviation	0,223	0,143	0,517	0,313	0,329	0,159
Concrete with fiberglass addition						
Average	3,559	3,979	4,016	4,056	4,074	4,377
S. deviation	0,223	0,143	0,517	0,313	0,329	0,159
Concrete with the addition of polypropylene fiber						
Average	3,685	4,127	4,104	4,184	4,780	4,794
S. deviation	0,065	0,202	0,292	0,036	0,293	0,087

For concretes added with microfibers, the main failure pattern is pullout, but another very relevant factor is breakage, glass fibers are more subjected to pullout from the cement matrix, because they are smoother, they have lower tensile stresses when compared to polypropylene fibers (26), (27), (28).

In addition to pullout and breakage failures, according to Choi and Lee (29) the strong chemical bond with the cement matrix leads to greater tensile strength. In their research, unlike other types of fiber, basalt fibers proved to be more efficient in improving cracking resistance, compared to other types of fibers, as it is composed of minerals similar to those of cementitious materials.

3.4 FLEXURAL STRENGTH

As shown in Figure 6, it is clear the significant difference between the performance of the MFPP samples, characterized by average values of flexural strength of 1.163MPa, 1.193MPa and 1.243 MPa, in relation to the MR reference concrete samples, without the addition of microfibers , characterized by mean stress values of 0.733 MPa, 0.947MPa and 1.017MPa for the ages of 7, 14 and 28 days, respectively. As can be seen from these results, the highest values of flexural strength and deflection of the tested beams were obtained from the mixtures with polypropylene microfibers.

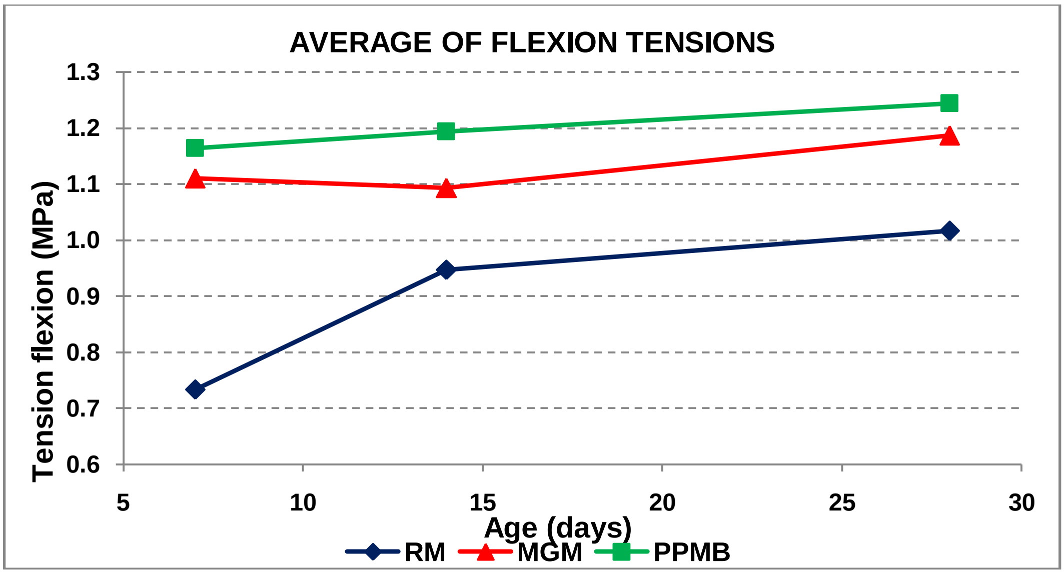


Figure 6. Average bending stresses of three samples for each MR, MFV and MFPP concrete mixture, for the ages of 7, 14 and 28 days.

The mixtures added with glass microfiber showed an average performance of 1,110MPa, 1,093MPa and 1,187MPa. Comparing to the reference concrete samples, they offered an increase of 51%, 15% and 16% at the ages of 7, 14 and 28 days, respectively.

It is also noteworthy that the addition of microfibers allows the material to go from a brittle fracture to a ductile behavior, highlighting the excellent result of the use of such microfibers in structural concrete, as highlighted in Figures 7 (a) and (b).

(a) (b)

Figure 7 . Fracture characteristics of MR and MFPP concrete: (a) MR concrete brittle fracture; (b) MFPP ductile fracture concrete.

The microfibers used increase the ductility of the concrete, increase the amount of absorbable energy and reduce the opening of cracks, allowing the flexural strength to reach high levels compared to the compressive strength. For Ni et al (30) the interfacial bond between the microfibers and the cement provides greater flexural strength to cement composites.

According to H. E. Yücel et al (31) the increase in the microfiber content increases the deflection value in the middle of the beam compared to the control beam, and in relation to all ages studied due to the elastic modulus of the fibers. In addition, the fibrous nature of microfibers slows the propagation of cracks in cementitious composites and is beneficial in improving ductility (32), (33).

In structural theory, in addition to comparing the final failure stress result, it is also important to analyze the service deflection, where the allowable deflection is determined by the ratio of the beam length by 250. Then, the service deflection (δs) for the Concrete blends added with microfibers best meet the criteria for safety and structural appearance, as demonstrated in the test in Figure 7.

The cracks occurred only below the loads, at the central point of the concrete beams. In addition, there were no visible horizontal microcracks in all beams tested, indicating good adhesion between the concrete matrix and the glass and polypropylene microfibers. For S. Lee (34) the presence of microfiber inside the concrete matrix restricts the propagation of cracks by the bridging action made by the fiber through the cracks, which is a behavior dependent on the physical properties and amount of microfiber present in the mixture.

3.5 ENERGY DISPERSIVE SPECTROSCOPY ANALYSIS (EDS)

The EDS analysis was performed to identify the elemental composition existing in the samples of hardened concrete at 90 days curing. This was carried out to identify the primary elements formed in the concrete matrix when different aluminosilicate parent materials are used, and also to determine the suitability of the fibers for the concretes studied.

From the EDS analysis, as shown in Figures 7 (d) and 8 (d), it is observed that there is a large percentage of Silicon and Calcium content in both MFV and MFPP samples. This confirms the formation of the CSH bond during the hardening process of the two types of concrete.

The sharp peaks of Si and Ca, which are associated with the hydrated products of Portland cement and its hardness, are developed by chemical reactions with water, among which the main constituents are tricalcium silicate ($3CaO\text{-}SiO_2$) and dicalcium silicate. ($2CaO\text{-}SiO_2$) (35). As glass microfibers represent typical applications of glasses, they consist of non-crystalline silicates that contain other oxides, notably SiO_2, CaO, Na_2O, K_2O and Al_2O_3, as we can see in the elemental composition of Figure 7 (a). It can be expected that the rough spots on the surfaces of Figures 7 (b), 7 (c), 8 (b) and 8

(c) correspond to hydrated products and a possible interaction between the fiber and the matrix, not being essentially promoted. by friction between the matrix and the fiber. In Figure 7 (a) the breakage and cracking of the glass microfiber can be verified, probably in the direction of application of the load, where the geometry of the dispersed phase, the shape, size, distribution and orientation of the microfibers, are decisive for the characteristic of rupture and intensity of tension (35), (36).

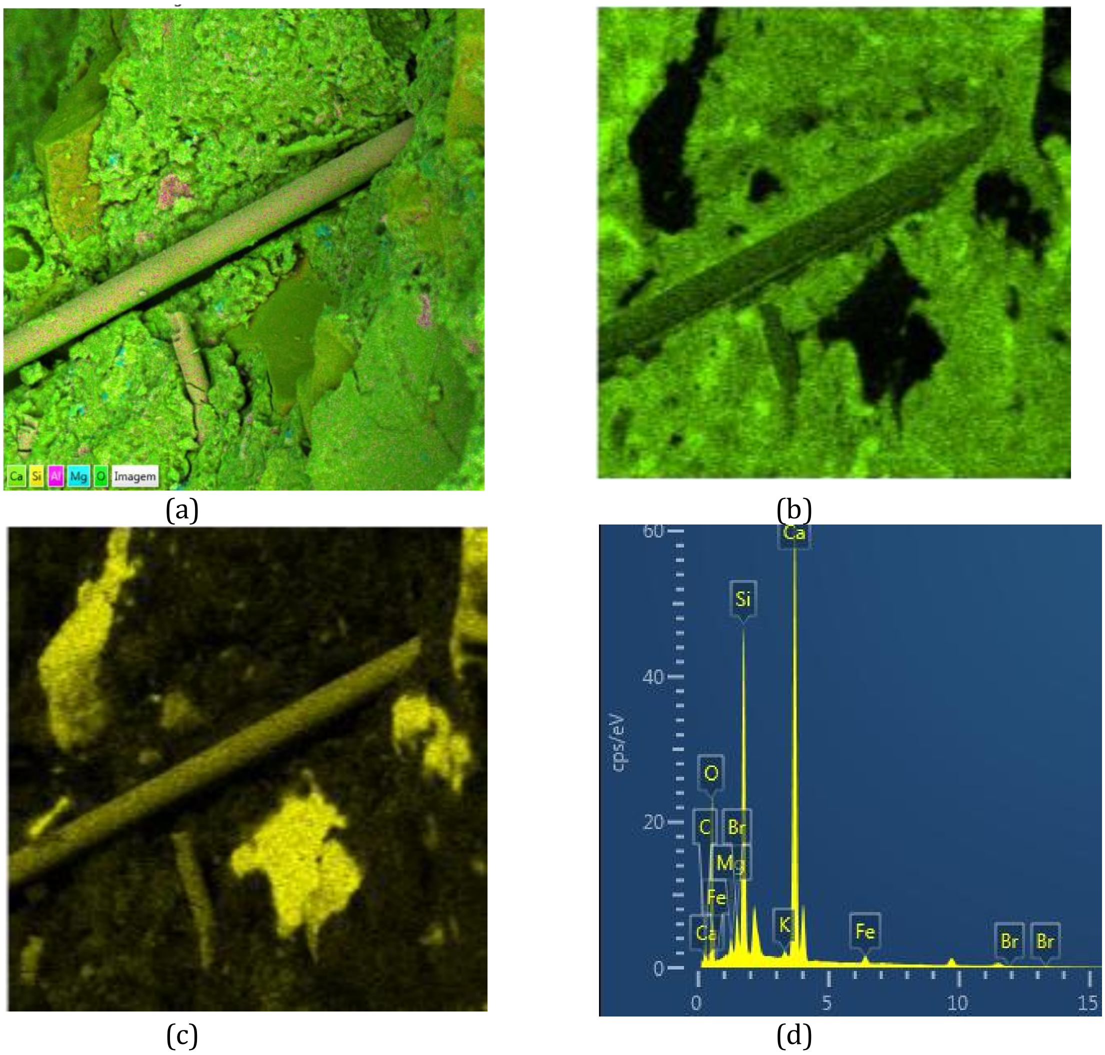
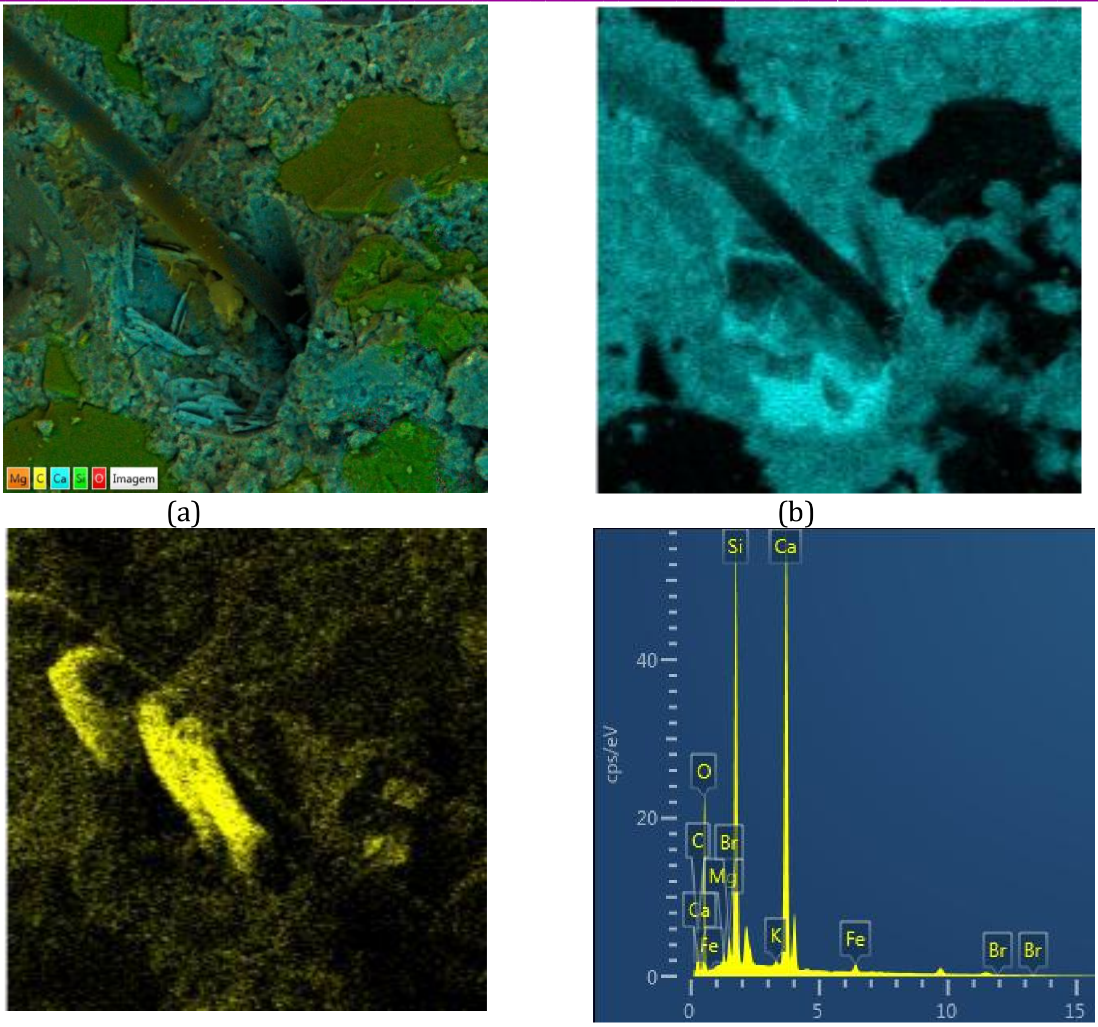


Figure 7 . Chemical mapping of the fractured surface of the concrete mixture with MFV microfiber glass: (a) Overlapping of chemical elements; (b) calcium elemental composition; (c) elemental composition of silicon; (d) spectrogram showing mainly the presence of silicon and calcium.



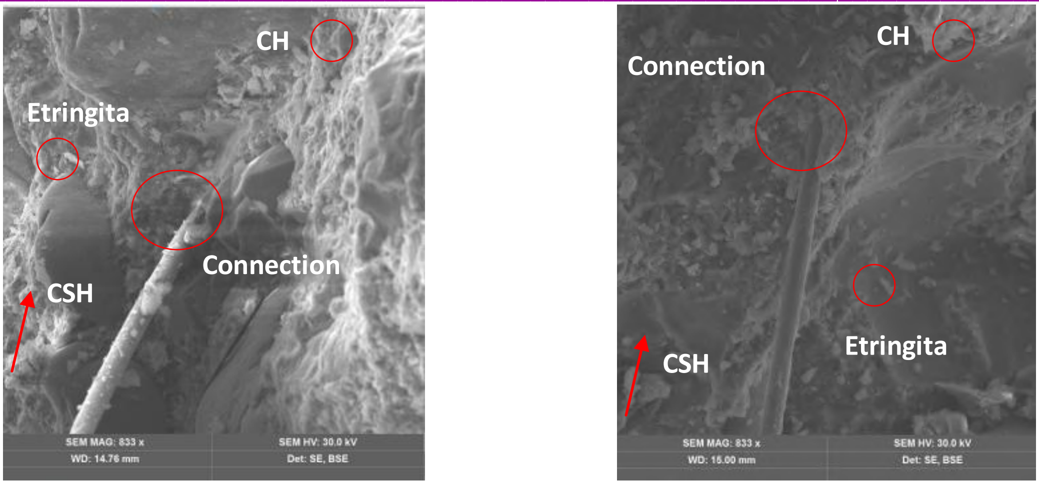
(c) (d)

Figure 8 . Chemical mapping of the fractured surface of the concrete mixture with MFPP polypropylene microfiber: (a) Overlay of chemical elements; (b) calcium elemental composition; (c) elemental composition of silicon; (d) spectrogram showing mainly the presence of silicon and calcium.

3.6 SCANNING ELECTRON MICROSCOPY (SEM)

The concretes with microfibers, MFV and MFPP, present very similar microstructure, evidenced from the SEM micrographs with 833x magnification. Furthermore, the fibers distributed within the matrix as micro-reinforcements, as shown in Figures 9 (a) and (b). A good bond between the microfibers and the binding matrix was observed, which improved the stress transfer process, thus improving the mechanical properties. The contact zones between the microfibers and the cement matrix are correctly shaped. No visible microcracks were observed in the anchoring areas of the MFV and MFPP microfibers and the matrix.

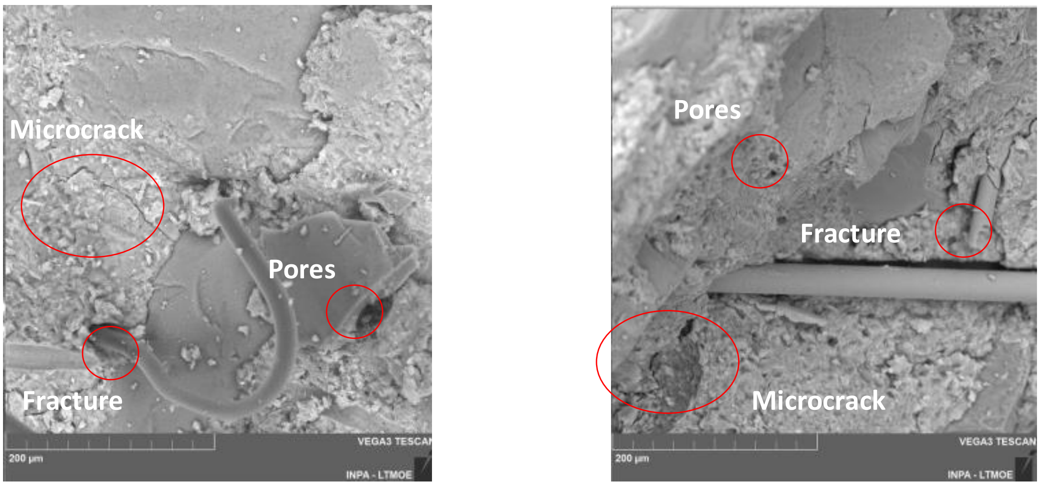
A large amount of ettringite needles, calcium hydroxide (CH) and calcium silicate hydrate (CSH) were observed and characterized by spectroscopy. This is because the increase in porosity in the concrete provided the space for the growth of ettringite and CH crystals. The deposition of these phases in the microstructure is quite distinct, CH precipitates in water-filled pores, while CSH is mainly deposited around the cement grains.



(a) (b)

Figure 9 . Scanning electron microscopy (SEM) of fractured surfaces: identification of points with ettringite, calcium hydroxide (CH), hydrated calcium silicate (CSH) and bonding of the fibers with the cementitious mass (a) MFV mixture; (b) MFPP blend.

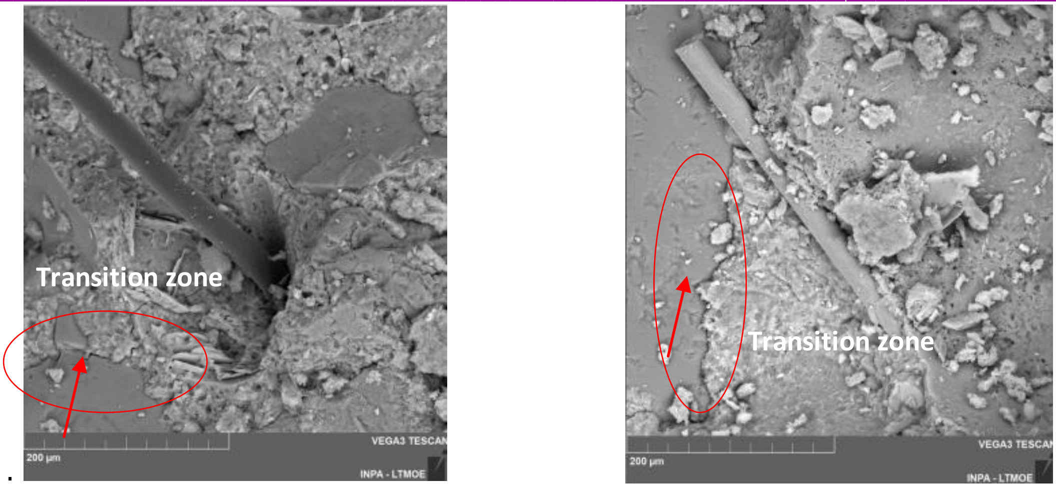
Figures 10 (a) and (b) demonstrate that the pore distribution is not uniform and the size varies greatly. Small microcracks were observed in the two MFV and MFPP mixtures, which resulted from the evaporation of water during the preparation process, due to the failures of the consolidation process, due to severe drying shrinkage and by the fracture process of the concrete samples, which to demonstrate its origin and propagation process. Both MFV and MFPP microfibers are clearly visible on SEM images, where the main failure mode is by rupture.



(a) (b)

Figure 10. Scanning electron microscopy (SEM) of fractured surfaces: identification of microcracks, pores and microfiber fracture (a) MFV mixture; (b) MFPP mixture.

The fracture surface of the flat material highlights the typical brittle fault with crack propagation along the interfacial transition zone between the cementitious matrix and the aggregate Figures 11 (a) and (b).



(a) (b)

Figure 11. Scanning electron microscopy (SEM) of fractured surfaces: identification of the transition zone (a) MFV mixture; (b) MFPP mixture.

CONCLUSIONS

This work investigated the comparison of reference concrete and concrete reinforced with glass microfiber and polypropylene microfiber, through mechanical tests of axial compression, diametral compression tensile and flexural strength, in addition to SEM/EDS observations of fractured surfaces. Based on the experimental results, the following conclusions were drawn:

The incorporation of microfiber significantly affected the workability of MFV and MFPP mixtures. The addition of microfibers reduced the slump of the blends compared to the reference mixtures

In general, the incorporation of microfibers progressively increased the compressive strength, diametrical tensile strength and flexural strength of both types of concrete compared to the reference concrete.

SEM/EDS analysis indicated the chemical interaction between glass and polypropylene microfibers. A large percentage of silicon and calcium content was observed, confirming the formation of the CSH bond during the hardening processes of the two types of mixture.

The mixtures with polypropylene microfibers showed the best results, in addition to improving the mechanical strength, they improved the ductility of the specimens. A good bond between the MFPP and the matrix was noticed in the SEM images, which improved the stress transfer process and improved the mechanical properties.

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