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A comprehensive study of the polypropylene fibers reinforced conventional concrete

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Abstract. The aim of this study was to study of the properties and characterization of conventional concrete and reinforced concrete with polypropylene fiber. Themes were theoretically addressed: concrete, composites, fibers, polypropylene fibers. In addition, practical tests were carried out, with test specimens of these two materials, of compressive strength, water absorption and heat resistance, to verify the differences in the properties of these two materials. The tests were completed and it can be noted that the application of the polypropylene fiber in the concrete as reinforcement for the concrete is satisfactory, because the water absorption test obtained similar results for the two materials, and performing the test of resistance to compression, it was observed that the test specimens with fiber, obtained better results than the conventional concrete. Finally, the heat resistance test showed that the fiber actually degrades in the temperature range informed by the supplier, being another advantage for its application in tunnels, in front of the fires.

Keywords: Composite, concrete, polypropylene fiber, compressive strength, water absorption, heat resistance.

Introduction

Civil construction is one of the most important industrial sectors in the country, since a large part of the population works in this branch, impacting on the country's economy, besides influencing the country's infrastructure, with new housing, buildings and even new industries, many coming from abroad. Its performance is complex and requires that the work is always done well, using materials with great quality, to avoid damages in the buildings that can have great consequences.

Technology and innovation are always in development, in search of new materials and products, to improve service quality, reduce production time and achieve financial savings. Among them are the composites, material formed by a matrix and a reinforcement.

Conventional concrete, made up of water, cement and aggregates, is the most commonly used material in buildings, as it is the basic material for all work. A construction without the use of concrete is rare. This material has high mechanical strengths, such as compression, traction and bending. However, there are restrictions on some applications, such as on structural parts of a building. In this case, the concrete is usually reinforced with iron structures inside.

Regarding industrial flooring, for example, it is usually made of conventional concrete reinforced with steel meshes but may present cracks after finalization and, depending on the failure, may lead to the interdiction of the site.

Thus, studies of the incorporation of polymer fibers into the concrete, among them, the polypropylene fiber were started, in order to improve the mechanical resistance of the concrete and mainly to reduce the presence of cracks after the concrete application.

KHAN, et al. (2015) verified the compressive strength of concrete with different concentrations of PP fiber, incorporations between 0.5% and 3%. The highest result, 31.5 MPa resistance with 1% fiber. The compression tests were performed according to IS: 5816 - 1999.

At present, the incorporation of the fiber in the concrete can vary according to the desired application. The calculating engineer will be responsible for the structural design that will determine which correct percentage to add.

With the advancement of the studies, new applications were defined for the use of PP fiber in concrete, as its use in tunnel structure.

In addition to applying the concrete well, its disposal must be done correctly, since it can attack

the environment, due to its toxic substances, such as cement. Therefore, there are companies responsible for the disposal and reuse of concrete.

The objective of the study was to compare resistance to compression, heat, water absorption of conventional and polypropylene reinforced concrete in order to verify the importance and advantages of fiber incorporation, as well as to analyze the disposal and reuse of concrete.

Methods

To characterize and understand each material, as well as its strengths and properties, three tests were performed. The first of resistance to compression, the second of water absorption and last of resistance to heat.

For this, it was necessary to use specific raw materials for the manufacture of test bodies of conventional concrete and reinforced with PP fiber.

Specification of Raw Materials

The binder used was Portland cement CP III-40 RS from CSN. The number 40 in the acronym, means that its compressive strength after 28 days - total concrete cure - is 40 MPa.

This cement is classified as RS, since it is resistant to sulphates, standardized by NBR 5737, ie, resistant to sewage water, sea water and some types of soils with aggressive compounds.

The industrial productions are made by milling clinker and granulated blast furnace slag, known as LHS - Steel Hydraulic Binder. The use of blast furnace slag has technical advantages that confer greater durability and lower permeability.

The main applications of CP III-40 RS cement are: foundations, concrete or reinforced concrete structures, mortars of various types, concrete artifacts, special foundations such as marine works and works subject to aggressive water.

The formulation consists of 25 to 65% of clinker and gypsum, 35 to 70% of blast furnace granulated slag and 0 to 5% of carbonaceous material (CSN, 2016).

The sand and gravel used in the experimental part were acquired from ITABRAS Mineração.

It was used the coarse sand, that has granulometry of 2.4 to 4.8 mm, having as main applications. The gravel receives the classification of mixed hail, with granulometry of 4.8 to 12 mm, used in construction, gardening, decoration and paving (ITABRAS Mineração, 2017).

The PP fiber used was Forta Ferro®, Figure 1, this fiber is imported from the United States and marketed in Brazil by Construquímica. FORTA FERRO® is a structural synthetic fiber, composed of 100% virgin copolymer / polypropylene, consisting of a blend of monofilament (non-fibrillated) fibers in twisted and multi-filament fibers (fibrillated - retraction control), Figure 2, which allows to create a high-performance concrete reinforcement system. It

provides ductility to concrete, increase in impact and fatigue strengths, effective control of cracks (secondary and temperature), not being corrosive or magnetic, in addition to being 100% resistant to the alkalis of the concrete, being therefore a material suitable for to replace steel fibers and welded fabrics according to ASTM C-1116 with great technical and economic advantage (Construquímica Comercial Ltda, 2017).



Figure 1 - Fiber FORTA FERRO®



Figure 2 - FORTA FERRO® Polypropylene fiber optic microscopy

Proof bodies

The test specimens for the water compression and water absorption tests were manufactured according to ABNT NBR 5738, which indicates that the test piece should have a height measurement twice the diameter. Diameters may be 10, 15, 20, 25, 30 or 45 cm.

The 10 cm diameter measurement with a height of 20 cm was chosen for the manufacture of the specimens, because it is compatible with the measurement of the press in which the compression tests will be carried out.

The molds for the manufacture of the specimens were made of PVC tubes and cut to the desired size.

Fourteen molds were produced, being 8 molds for the test of resistance to compression and 6 for the test of absorption of humidity. Of these, 7

molds were for conventional concrete and 7 for the reinforced with PP fiber.

Two molds were made for the heat resistance test according to the measurement of the muffle, in this case two specimens measuring 5.5 cm in diameter 2.5 cm in height.

Concrete Trace

For the production of the concrete, the quantity of each raw material must be calculated to carry out the mixing. The trait of the concrete has as meaning, the proportion of the materials in relation to the cement for the manufacture (Ambrozewicz, 2012, p.120)

The concrete trait is defined according to the compressive strength that it must withstand in its application.

According to ABNT NBR 6118/78, the minimum amount of cement for the manufacture of concrete is 300kg to 1 m³ and of small aggregate, in this case sand, it should be 30 to 50% of the aggregate volume, sand and gravel. The water should be added 7 to 10% of the total mixture.

As the objective of the experimental part is not necessarily to achieve the desired compressive strength, but to present the comparison of resistances between conventional and reinforced concrete with PP fiber, the following trait was used:

For every 1 m³ of concrete, it was necessary to:

- 0,8 m³ of gravel;
- 0,6 m³ of sand;
- 300 kg of cement;
- 162 L of water;
- 5 kg of PP fiber.

Thus, in order to determine the quantity of each raw material to be used, it is first necessary to

Table 1- Calculation of quantity of raw materials

Raw material	On 1 m ³	On 0,025 m ³	Specific weight of material	Amount
Portland Cement	300 kg	8 kg	-	8 Kg
Gravel	0,8 m ³	0,02 m ³	1800 kg/m ³	36 Kg
Wet sand	0,6 m ³	0,015 m ³	1700 kg/m ³	26 Kg
Water	162 L	4 L	-	4 Kg
Total weight of the mixture				74 Kg

As PP fiber was added in only half of the specimens, the weight of the specimen was calculated separately for only 0.0125 m³.

For 1 m³ of concrete, it should add 5 kg of fiber. As only 0.0125 m³ of fiber reinforced concrete will be manufactured, 62g of PP fiber will be added.

After calculating the quantities of each material, they were weighed with a balance to carry out the mixing.

Tools used

In order to mix the materials, it was necessary to use the tools, such as: hoe, box for mixing the concrete, known as *masseira* and *trowel*.

calculate the volume of concrete for the manufacture of the specimens, that is, the volume of the molds. The following are the volume calculations of the molds:

Molds for test of resistance to compression and water absorption

Cylinder volume = base area x height

$$V = \pi \times r^2 \times h$$

$$V = \pi \times 5^2 \text{ cm} \times 20 \text{ cm}$$

$$V = 1575 \text{ cm}^3$$

$$\text{Volume of 14 molds: } 1575 \text{ cm}^3 \times 14 = 22050 \text{ cm}^3$$

Molds for heat resistance testing

Cylinder volume = base area x height

$$V = \pi \times r^2 \times h$$

$$V = \pi \times 2,75^2 \text{ cm} \times 2,5 \text{ cm}$$

$$V = 59,6 \text{ cm}^3$$

$$\text{Volume of 2 molds: } 59,6 \text{ cm}^3 \times 2 = 119,1 \text{ cm}^3$$

$$\text{Total volume total: } 22050 \text{ cm}^3 + 119,1 \text{ cm}^3 = 22,169,1 \text{ cm}^3$$

In order to facilitate the calculation of the raw materials, this value was transformed into m³ and 10% of the total value was added as a safety factor, so there was no shortage of concrete to fill the molds.

$$1.000.000 \text{ cm}^3 = 1 \text{ m}^3$$

$$22169,1 \text{ cm}^3 = 0,023 \text{ m}^3$$

$$0,0221691 \text{ m}^3 = 10\% = 0,025 \text{ m}^3$$

From the calculations of the volumes the necessary quantity of each raw material was determined to realize the mixture of the concrete. Table 1 presented the results.

Preparation and mixing of concrete

To perform the concrete mixing, the sand was first placed in the *masseira* and then in sequence: cement, water, and finally the mixed pebble (Figure 3). The mixing was done manually with the spade and trowel, until it became homogeneous.

In the case of concrete with PP fiber, the fiber was added together with the sand and cement, Figure 4, before the hail with water.



Figure 3. Mixing steps for manufacturing conventional concrete



Figure 4 - Addition of fiber in concrete mix

According to ABNT NBR 5738 for 100 mm diameter specimens manually made, the concrete must be filled in the mold in two layers. In these layers there should be 12 blows of densification, with the aid of a cylindrical steel rod of 16 mm in diameter and length of 600 to 800 mm.

First, concrete was added up to half of the molds, soon after, 12 blows of density were made. The molds were completed of concrete and again were carried out another 12 blows. Finally, the surface has been smoothed, since the tests have to be performed with the flat surface.

The same was done with the filling of the molds with the reinforced concrete with PP fiber.

For the heat resistance test, the molds were filled with concrete, however due to their diameter being less than 100 mm, no blows were required.

After 24 hours of filling the molds, by requirement of ABNT NBR 5738, the specimens were demolded and kept submerged in the water to obtain the desired cure until the tests of resistance to compression and water absorption.

Compressive strength test

The compressive strength test was performed according to ABNT NBR 5739, which determines that the test should be done in a hydraulic press.

The first test was done after 7 days of concrete curing.

Tests were done with two specimens of conventional concrete and two reinforced with PP fiber.

After 28 days, the second test was performed, also the first one. Tests with two test specimens without fiber and two fiber reinforced.

The hydraulic press used was Forney, located at Campo Limpo Paulista College, available in the Civil Engineering laboratory. Its working range is from 20 to 100kN and has a display that indicates the force exerted in real time on the concrete in kN meeting the norm NBR 5739. The final force is indicated when the test piece is broken

Water Absorption

The determination of water absorption of the specimens was done according to ABNT NBR 9778. This standard requires that the specimens as well as the compression test be done according to the NBR 5738 standard. In this test, three concrete specimens were made without the fiber and three with the fiber.

The six specimens were left submerged in water for healing until the beginning of the tests done after 28 days. These were placed in a greenhouse, available in the laboratory of UNIFACCAMP, for 72 hours at a temperature of 105 °C, and may have variations in temperature of ± 5 °C.

Every 24 hours, the specimens were weighed on a precision digital scale. After 72 hours,

the specimens were submerged in water, remaining also for 72 hours. And again every 24 hours, the weighings were done.

From the weighing of fresh concrete and saturated concrete, calculations were made to verify the amount of water absorbed.

Heat resistance test

The heat resistance test of the concrete was done based on the article "The action of fire on the concrete components" of Morales, et. al, 2001. In order to perform the test, there were adaptations of the article, mainly in the choice of the peaks of firing temperatures and time in which the specimens were inside the muffle.

The objective of the test was to observe the behavior of concrete and PP fiber in high temperature, as well as the loss of mass after the firing in the peaks of temperatures.

The temperatures chosen as peaks for burning the material and verifying the weighing were: 100 ° C, 200 ° C, 400 ° C and 800 ° C. These temperatures were defined mainly to verify the behavior of the fiber and the concrete, with the elevation geometrically.

Before starting the firing, the two samples were weighed, the non-fiber concrete and the fiber concrete.

The samples were placed in the muffle, available in the FACCAMP laboratory, and this started to heat up to the first chosen temperature, at 100 ° C. The muffle remained at this temperature for 30 minutes. After this time, the muffle was opened, the samples taken and weighed..

After this procedure, the samples were returned to the muffle, and this started to warm up

again to 200 ° C, the samples remained at this temperature in the same manner, for 30 minutes. Afterwards, the samples were again weighed. The same cycle occurred at temperatures of 400 and 800 ° C.

With the aid of a digital optical microscope, samples were taken of the samples before and after the total firing.

Results and discussion

The hydraulic press presented the results automatically in kN (N x 1000), however the standard measure for force of resistance to compression, is in MPa.

To obtain the results it was necessary to use the following calculation:

$\sigma = F / A$, being

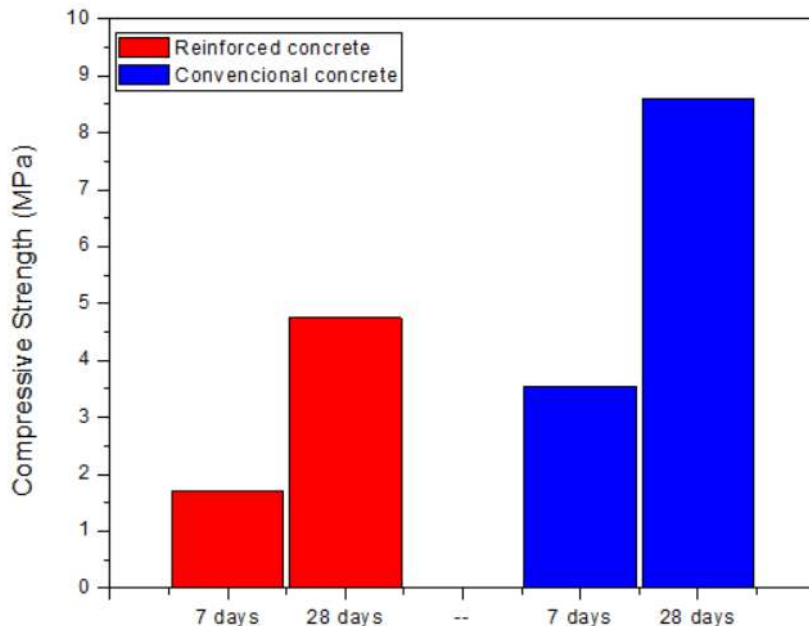
- F = Force;
- A = Area;

ergo:

$\sigma = f_{CK} = \text{Value in N} / [\pi * (\text{radius in mm})^2]$

The area of the specimens is 7853.98 mm². Thus, Graph 1 and Table 2 presents the results of the compression test in kN, value presented in the hydraulic press, in MPa, result obtained from the formula presented above.

The specimens were identified with the letters A and B, where A1 and A2 were the non-fiber proof specimens and B1 and B2 were reinforced with PP fiber.



Graph 2 – Compressive strength results.

Table 2 - Results of the compression tests

Samples and Results	After 7 days of healing		After 28 days of healing	
	kN	MPa	kN	MPa
A1	14,6	1,8	39,4	5,0
A2	12,9	1,6	35,3	4,5
B1	29,5	3,7	72,9	9,3
B2	26,9	3,4	62,5	7,9

According to the Portland cement technical file of CSN CP III - 40, the specimens should break in 7 days with a pressure of greater or equal to 23 MPa and in 28 days, break with a pressure greater or equal to 40 MPa. In Table 2 it can be observed that the results of the pressures did not reach the results described by the technical data of the cement.

There are two main variables that may influence the result lower than expected: they are the amount of excess water added in the mixture and the way the mixture was made. In order to reach high rupture pressures, the concrete should be mixed in a concrete mixer, but this was done manually, and it could generate a mixture with non-homogeneous parts..

However, the objective of the tests was to show the differences in resistance between conventional and PP-concrete. According to the technical specifications of the fiber, this would increase the compressive strength of the concrete.

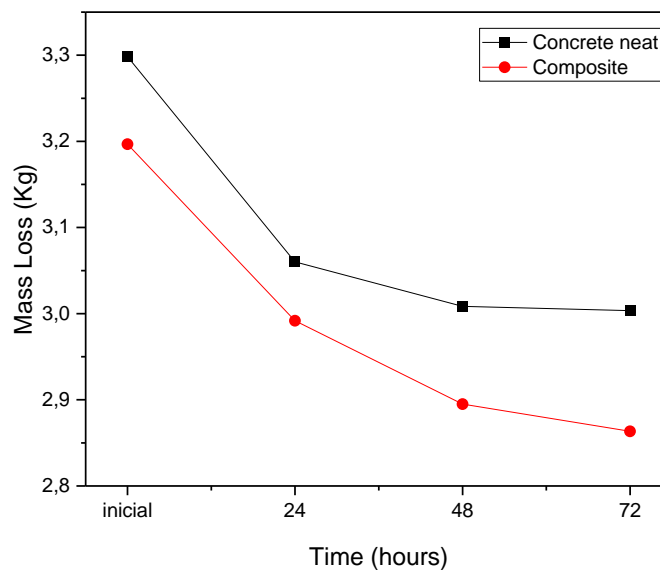
In this case, the result was satisfactory, since according to Table 2, the average burst pressures of the reinforced concrete (B1 and B2) with fiber were almost twice the average of the pressures of conventional concretes (A1 and A2),

both in the tests after 7 days of cure and after 28 days. What shows, that if the mixture were made in the concrete mixer, the results could be even better.

The determination of water absorption of the specimens was done according to ABNT NBR 9778. In this, it is requested that the test be performed with at least three specimens. Six test bodies were made, three without PP fiber (A1, A2 and A3) and three fiber reinforced (B1, B2 and B3).

Table 3 shows the weighings of the specimens and Graph 2 the average of the weighings after drying in the oven at 105 °C, allowing a variation of ± 5 °C. The specimens were initially weighed after the water was removed, which was necessary for the concrete to cure. Subsequently, they were weighed after 24, 48 and 72 hours of drying. Note that the test specimens had a mass decrease of 290 to 345g, referring to the loss of water, obtaining the material completely dry, to later be able to calculate exactly the percentage of water absorbed.

Soon after drying in the kiln, the specimens were submerged in water, and their masses were again checked after 24, 48 and 72 hours. Table 4 and Graph 3 present the results.



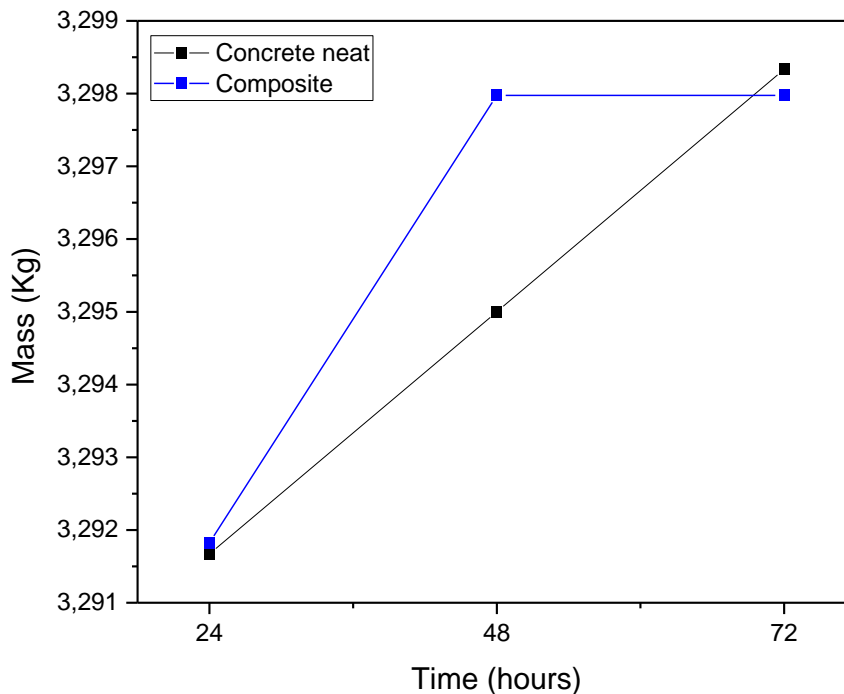
Graph 2 - Weighing of specimens after drying

Table 3 - Weighing of test specimens after drying

Samples and Results (kg)	Before drying	After 24 h	After 48 h	After 72 h
A1	3,330	3,080	3,040	3,035
A2	3,290	3,045	2,990	2,990
A3	3,275	3,055	2,995	2,985
B1	3,205	2,995	2,895	2,875
B2	3,215	3,020	2,920	2,890
B3	3,170	2,960	2,870	2,825

Table 4 - Weighing of test specimens after submersion in water

Samples and Results (kg)	After 24 h	After 48 h	After 72 h
A1	3,325	3,330	3,330
A2	3,285	3,285	3,290
A3	3,265	3,270	3,275
B1	3,200	3,205	3,205
B2	3,210	3,215	3,215
B3	3,165	3,170	3,170



Graph 3 - Weighing of specimens after submersion in water

The results of the mass loss on drying and the amount of water absorbed in the six test specimens were very similar. To confirm the results,

it was necessary to perform the calculations, with the formula below, according to the norm NBR 9778.

$$\text{Percentage of water absorption} = [(B-A) / A] \times 100$$

A = Average mass in g of the oven dried samples;

B = Average mass in g of the samples saturated in water.

Sample A (no fiber): 9.8% water absorption;

Sample B (with fiber): 11.6% water absorption.

Therefore, the averages of the masses in g were calculated, and the results were presented in Table 5, of the fiber-free and fiber-reinforced test bodies, after 72 hours of drying in the greenhouse and after 72 hours of submersion in water, saturated sample.

After calculating the means, the formula was applied, with the following results:

Finally, it is possible to observe the test specimens of conventional and fiber reinforced concrete having similar water absorption. The results were satisfactory, since the test specimens with fiber presented greater resistance to compression, with this, the water absorption will not interfere in the applications of reinforced concretes.

Table 5 - Mean of masses of test specimens

Samples and Results (g)	After drying (A)	After saturation (B)
No PP fiber	3.003	3.298
PP fiber	2.863	3.197

Heat resistance test

The samples of conventional and concrete with PP fiber were placed in the muffle and the temperature gradually raised to the peaks of chosen temperatures, 100 °C, 200 °C, 400 °C and 800 °C.

Before starting the tests and in the peaks of temperatures, the samples were weighed. The results are shown in Table 6.

Table 6 demonstrated that the mass losses of the two samples were very similar, since in all, sample A lost 9.13 g and sample B, 8.17 g. Obtaining a satisfactory result, since the fiber degrades around 160 ° C and because it is very light, it releases space in the concrete, but without significant loss of mass. Its loss is like that of conventional concrete.

It was observed that the PP fiber was melted at 160°C.

ductile even after its degradation. Being its main function in the industrial floors, to reduce the presences of cracks, mainly hours after the concrete application.

Finally, as the temperature rises, there is loss of concrete properties, mainly above 300 ° C and different effects are presented. These results corroborated with that reported by Morales et. al. (2011).

Both conventional concrete and concrete with PP fiber are recyclable, so the excess concrete that remains in the work or that is demolished can be reused.

The use of structural concrete for the construction of beams, pillars and industrial concretes, require high properties. In these cases, the recycled concrete can not be used, since these have inferior properties, because they offer greater deformations than the concretes with virgin raw materials.

Table 6 - Results of weighing at peak temperatures

Sample weight (g)		
Temperature	Sample A	Sample B
25 °C	177,65	169,87
100 °C	176,57	168,64
200 °C	173,89	166,10
400 °C	172,00	164,72
800 °C	168,52	161,70

In this way, recycled concrete is used for simpler applications, such as asphalt, pavement and even decorative objects.

The focus of recycling is not to dispose of concrete in the environment, since its composition composed of harmful components, such as cement, compromise the place where it was dumped.

For this, there are companies that work with concrete recycling.

At 800 ° C, the fiber is no longer seen, only the space left by it. In optical microscopy (Figures 5 and 6) it can be seen that conventional concrete presented more cracks than with fiber, which suggests that the fiber maintains the structure more

If the concrete is not recycled, it is recommended to dispose of it in landfills authorized for this use. On the other hand, if the disposal is done in the correct way associated with the reuse, it can result in sustainability and preservation of the environment.

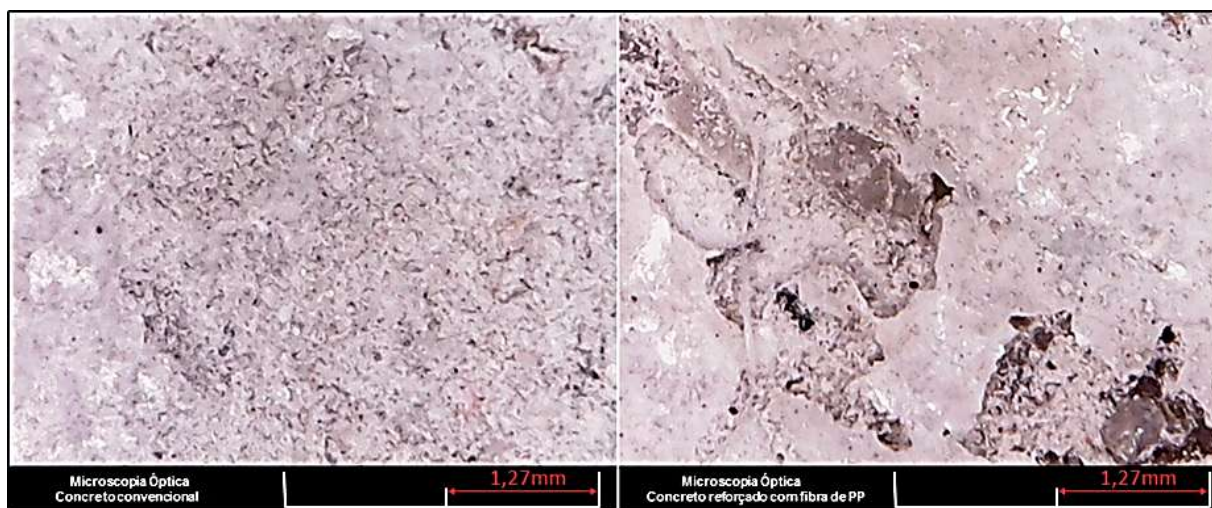


Figure 5 - Optical microscopy of conventional concrete and reinforced with PP fiber before burning

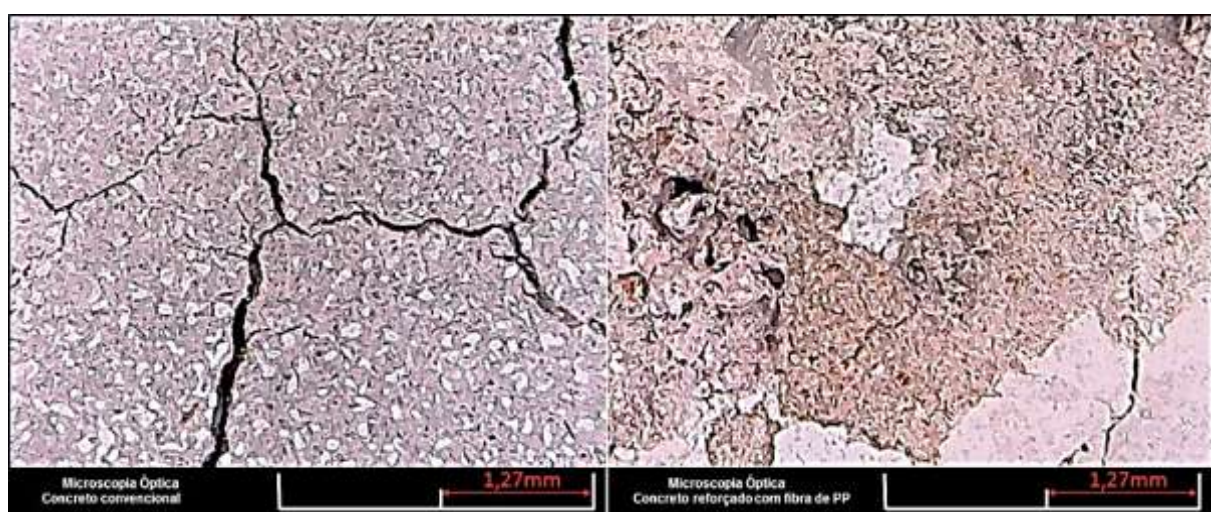


Figure 6 - Optical microscopy of conventional concrete and reinforced with PP fiber after burning in 800 °C

Conclusions

The results allowed to study conventional concrete and reinforced concrete with PP fiber, which are currently used in specific uses. The concrete reinforced with PP fiber has two main applications: a) use for industrial floors, having as main characteristic, to reduce the presence of cracks in the first hours of application; b) possibility of use in tunnels. Fiber-reinforced concrete protects the structure from fires, as the fiber degrades and releases space for the escape of water vapor, avoiding tensions within the concrete. Conventional concrete has several applications, from decorative, flooring, to structural, usually reinforced with steel.

It was evident that the use of fiber as a reinforcement directly impacts on the mechanical strength of the concrete, since the reinforced concrete with fiber presented approximate results to double the resistance. Regarding the water absorption, the two types of concrete presented very similar results, which allows to conclude that the use of the fiber does not leave the concrete with resistance inferior to the weather. Finally, the concrete with fiber presented smaller amount of

cracks after the firing, besides degrading the fiber in temperatures according to the supplier's specification.

In addition, concrete can be harmful to the environment if its disposal is not correct. As an example, in the region of Jundiaí, there are already companies responsible for carrying out the correct disposal of this material, and mainly, to crush and separate the raw materials for reuse.

Due to the importance of the incorporation of the PP fiber in the concrete, as a suggestion for the next work, tensile tests or non destructive tests, to analyze the interior of the samples. Further, reinforced test bodies with different proportions of PP fiber can be fabricated to verify differences in mechanical strength.

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