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The fire resistance of concrete with polypropylene fibers

F.A. Corpas[1], B. González[2], L. Gómez[1], F. Rosa[1] and J.M Figueroa[2]

[1] *E.P.S de Linares, University of Jaén, Spain*
[2] *GEA 21, Spain*

Abstract. This paper presents the results and conclusions of an experimental study characterization performed on the polypropylene fibers for use in concretes (NPC, Normal Performance Concrete) to produce an improvement in the durability against exposure to high temperatures. It was used only one type of polypropylene fiber with two different lengths, 6 mm and 12 mm, to evaluate the effect of the length.

1. INTRODUCTION

The use of fiber reinforced concrete is moving at a high speed because of constant increase in the price of steel. The profusion of different types of fibers which have appeared in recent years has come into competition with steel fibers more traditional, reason it was decided to study the fibers polypropylene in this research.

Researching the resistance of structures on fire is a fairly complex problem and studied extensively in the last decade. The concrete is a composite material that reacts differently to each of its component when exposed to high temperatures. On fire exposure are produced physical and chemical changes [1] affecting their properties. Spalling effect [2] is the violent interruption or non-violent or chunks of concrete layers on the surface of a structural member to be exposed to high temperature and increases rapidly. Studies [3] on reaction to fire of concrete concur that temperatures from 300-400 °C there are internal changes (loss of water, phase changes) into components that are irreversible, especially in the cement gel. With the incorporation of the fibers in the concrete is achieved lessen or prevent the spalling phenomenon that, as described above, occurs in concrete. The fibers, when it reaches its melting temperature, are decomposed without producing noxious gases [4, 5], this helps to create spaces that act as escape routes, thus reducing the pressure in the pores during heating.

2. FIBER CHARACTERIZATION

It was used only one type of polypropylene fiber but with two different lengths, 6 mm and 12 mm, respectively to evaluate the effect of the length in the evaluation process fire resistance with fiber concrete. Fiber of 6 mm is called Short Fiber, SF, and fiber of 12 mm is called Long Fiber, LF.

2.1 Morphological characterization

The morphological characterization was made by scanning electron microscopy (SEM) of various specimens of fibers, 6 mm to 12 mm. (Fig. 1).

It was made higher magnification micrographs to observe the roughness of the fibers (Fig. 2). It can be deduced that the fiber chain is linear and has not ramifications that could affect the micro-adhesion with concrete.

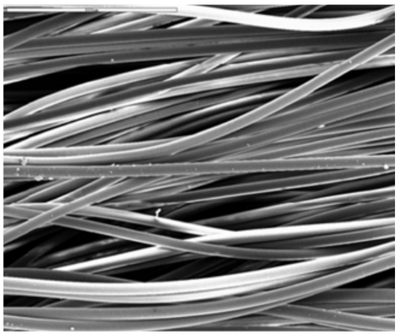

Figure 1. Polypropylene fiber SEM (Photo graphic scale 100 μm).

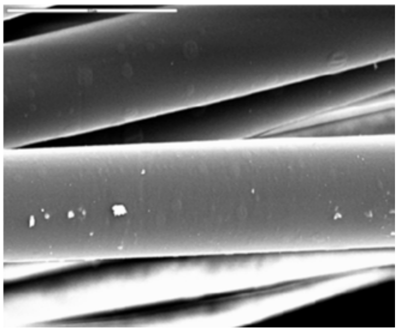

Figure 2. SEM Microscopy Polypropylene Fiber (graphic scale 20 microns).

2.2 Physical properties

2.2.1 Density

The determination of fiber density is used a direct method volume measured from the dimensions of the fiber (length / diameter) and weight by means of an analytical balance. Density average: 0.91 g/cm3.

2.2.2 Humidity

Humidity has been determined from the fibers by weight method before and after being subjected to a temperature of 110 °C for one hour, obtaining a average value of 2.65%.

2.2.3 Absorption

Is determined the absorption of the fibers by immersion test in water for 24 h. It was calculated by the weight difference before and after this test. This parameter is important because the water absorption by the fibers will influence the behavior of the fibers to fire when they are in the concrete matrix. The average value of 0.01%.

2.2.4 Fluency

This parameter will influence the concrete workability measures the amount of fiber flows in 10 seconds through an orifice with a certain size. The value average is 6.12 g/10 seconds.

Figure 3. Fibers after 2 hours of exposure to 90 °C.

Figure 4. Fiber after 2 hours of exposure to 160 °C.

2.2.5 Thickness

The dtex is used as a measure of the thickness of the fibers. This comes from the main unit Tex, which is a unit commonly used for home textile products mainly in Europe and Canada. The tex is a unit of measurement for linear mass density and is defined as the mass in grams per 1000 meters in length, one Tex is equal to 1 gram per kilometer. Is commonly used subunit dtex, equivalent to 0.1 Tex. From this unit and the density of polypropylene, the same for all types of fiber, the fiber diameter can be obtained (Eq. (1))

$$\phi = \sqrt{\frac{4 \cdot 10^{-6} \cdot dtex}{\pi \cdot \rho}}. \tag{1}$$

The average value obtained from the fibers is 6.7 for both fiber lengths.

2.3 Behaviour of fibers in fire

The following analysis has been made direct behavior of the fibers when have been exposed to the fire for 2 hours at a constant temperature, in the range of temperatures from 90 °C to 180 °C, in increments of 10 °C. The maximum limit temperature of 180 °C has been determined to be that temperature it reaches the melting point of the fibers.

As can be appreciated at the temperature of 160 °C (Fig. 4), has started fiber casting, changing the hue and the appearance. At temperature of 180 °C (Fig. 5) the fiber is fully melted, showing the look caramel characteristic.

2.4 Thermal analysis of fiber

The objective of this analysis is to analyze the behavior of polypropylene fibers in air atmosphere, to study the evolution of the fibers facing the fire and in nitrogen atmosphere, to simulate the actual state of the fibers in the concrete shells representing an atmosphere with no oxygen. Test results are obtained three graphs: Green curve (Tg) that indicates the change in mass with temperature, Red Curve (∂Tg), which gives the value of the derivative of the previous curve with respect to time and Blue Curve, giving us heat flow.

Figure 5. Fiber after 2 hours of exposure to 180 °C.

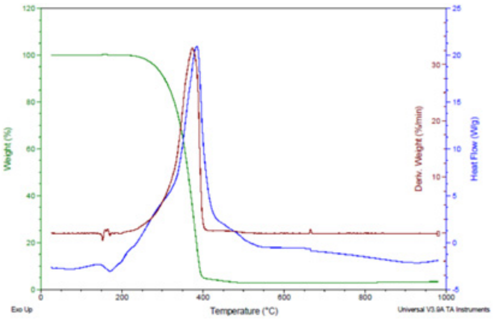

Figure 6. Thermogram of the fibers in air atmosphere.

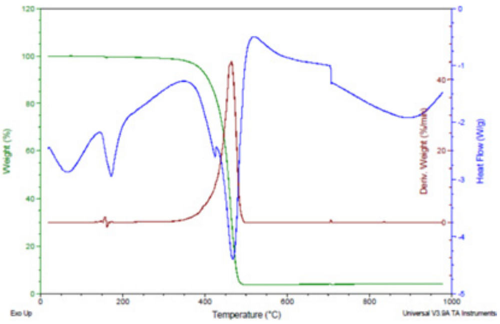

Figure 7. Thermogram of fibers in nitrogen atmosphere.

From the 200 °C, polypropylene fibers begin to deteriorate with mass loss until approximately 400 °C, a loss of its mass 95% (Fig. 6). In the absence of oxygen atmosphere (Fig. 7) the temperature starting from the destruction of the fibers are moved to a temperature of 350 °C and the total destruction, 95%, to the temperature of 500 °C.

3. CONSTRUCTION OF CONCRETE SPECIMENS

Raw materials: cement and aggregates.

3.1 Cement

It was used a commercial cement a multinational company with presence in Andalusia, type CEM II, because not all cements will behave similarly. The mechanical resistance of the cement is greater if the additions are minor but will have more water constitution and exposure to fire will generate more steam.

Table 1. Series of samples and the percentage of fibers.

SERIES	NOUM OF SERIES	NUMBER OF SPECIMENS	% OF FIBERS	TYPES OF FIBERS
1	A	4	0.00%	-
2	B	4	0.50%	SHORT
3	C	4	1.00%	SHORT
4	D	4	1.50%	SHORT
5	E	4	2.00%	SHORT
6	F	4	2.50%	SHORT
7	G	4	3.00%	SHORT
8	H	2	0.50%	LONG
9	I	2	1.00%	LONG
10	J	2	1.50%	LONG
11	K	2	2.00%	LONG
12	L	2	2.50%	LONG
13	M	1	3.00%	LONG

3.2 Aggregates

Of the two types of aggregates can be used, siliceous or limestone, in this research was used limestone aggregate. This aggregate has a higher fire resistance. At temperatures above 750 °C has a decomposition obtaining pores in the concrete mass.

3.3 Design of concrete specimens

The concrete specimens were made with the raw materials listed in the previous sections and using an Additive. It has been added to the concrete mixture CHRYSO commercial additive as super plasticizer. Cement dosing was performed with a water / cement ratio of A/C = 0.50, to achieve a soft consistency (Abrahams cone seat 8), which is a classic consistency in manufacturing of structural concretes building.

Test specimens have been made NPC concrete to be used as HA-25/B/15/IIa in building structures, with different doses of fibers, short and long, in order to study the influence of fiber size. It has been made 13 series of samples, with a total number of 39 specimens (Table 1). These specimens are cylindrical in shape of 30 cm high by 15 cm in diameter and a volume of 53.34 cm^3.

4. EXPERIMENTAL RESULTS

The optimum moisture for proper curing of the concrete is 98%. Specimens they remained for a period of 28 days, before being tested, in the humidity chamber with the degree of saturation of moisture.

4.1 Absorption

The absorption values in the concrete indicate resistance or ease the flow of fluids within the mass of concrete. The concretes having high permeability have better behavior to spalling phenomenon. Determining the absorption of the samples was made the following measures: weight of sample upon receipt of the manufacturing process, dry sample weight after drying in an oven at 110 °C for 24 h and weight of the sample to saturate, by immersion of 24 h in water.

Short fiber samples shows that as the fiber is added is an increase of the values obtained a maximum of 14.67%, for the dosage of a short fiber 1.5%, resulting in a fall in the value for higher dosages. Long fiber sample are observed that as increases the percentage of fiber, the absorption undergoes an initial

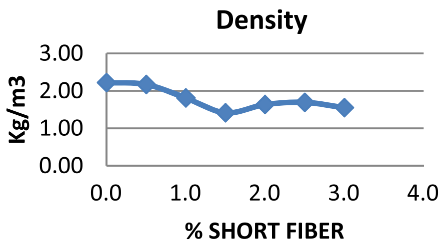

Figure 8. Density evolution in short fiber series.

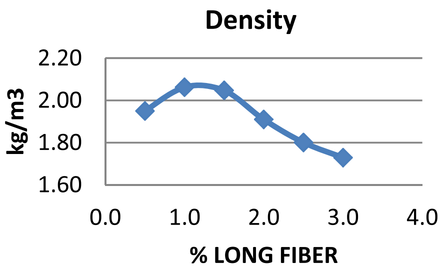

Figure 9. Density evolution in long fiber series.

increase followed by a decrease to having a final increase reaching up to 14, 35% for the fiber dosage of 3.0%.

4.2 Density

Based on the above data for determinate the absorption, the densities are obtained of the specimen (kg/m3).

The values obtained for the density is observed that for short fiber, as more fiber is added, there is a decrease of values. With a maximum for the addition of 1.5% added fiber. Following from that value density, values increased although not significantly. The decreasing density experimenting for the addition of 1.5% short fiber is very important, as it reaches a decrease of 33.50%, so that weight reduction in the structure would be very important. (Fig. 8)

For density values with addition of long fiber, it is noted that as that the percentage of fiber added, the density shows a decrease reaching up to 19.20% for the percentage of 3.0%. This difference in density values obtained for the two types of fibers (long and short) are produced due to the short fiber the three-dimensional lattice is much higher. The different behavior of the change in absorption between the two types of fibers, it has not a clear interpretation. More research is needed on this phenomenon (Fig. 9).

4.3 Resistance to compression

A standardized test is of compressive strength after suffering three states of temperature for a time of one hour: room temperature, 500 °C and 600 °C.

It's appreciating (Table 2) the sharp drop RC_{28} resistance at temperatures 650 °C, which means a loss of 73.8% of the initial one.

RC_{28} values to suffer a decrease in temperature by increasing the dosage of fibers, with a drop to 22.9% of standard resistance, not affecting small dosages less than 0.5%. The maximum values of the RC_{28} in fire exposure are obtained for fiber dosages between 0.5% and 1.0%. In this case the fall of

Table 2. Results of the standard series with the compressive strength achieved in the three states mentioned temperature.

SERIE	% FIBERS	TYPES OF FIBERS	RC_{28} (MPa)		
			AMBIENT TEMPERATURE	500 °C/1h	650 °C/1h
1	0.00%	-	26.0	16.5	6.8

Table 3. RC_{28} values of a series of short fiber samples.

SERIE	% FIBERS	TYPES OF FIBERS	RC_{28} (MPa)		
			AMBIENT TEMPERATURE	500 °C/1h	650 °C/1h
2	0.50%	SHORT	26.2	15.4	9.8
3	1.00%	SHORT	23.5	14.0	15.0
4	1.50%	SHORT	24.0	12.0	12.3
5	2.00%	SHORT	23.8	13.0	12.7
6	2.50%	SHORT	20.5	12.5	13.8
7	3.00%	SHORT	20.2	12.5	14.1

Table 4. RC_{28} values of the series of long fiber samples.

SERIE	% FIBERS	TYPES OF FIBERS	RC_{28} (MPa)		
			AMBIENT TEMPERATURE	500 °C/1h	650 °C/1h
8	0.50%	LONG	20.4	12.3	11.7
9	1.00%	LONG	15.8	13.0	12.8
10	1.50%	LONG	16.3	12.5	11.5
11	2.00%	LONG	14.8	11.6	11.1
12	2.50%	LONG	13.6	10.5	12.6
13	3.00%	LONG	13.0	8.5	12.3

RC_{28} resistance at temperatures 650 °C, is a 41.2% loss on initial dosages of 0.5% fiber, and 36.1% on initial dosages of 1.0% fiber (Table 3).

RC_{28} values at room temperature have decreased by increasing the dosage of fibers, with a drop to 48.0% of standard resistance, affecting small dosages significantly from initial losses of 18.4% of standard resistance. In this type of fiber is also verifies that the maximum values of the RC_{28} in fire exposure dosages are obtained for fibers comprised between 0.5% and 1.0%. In this case the fall of RC_{28} resistance at temperatures 650 °C, at dosages of 0.5% of fiber represents a loss of 42.6% over the initial one. At dosages of 1.0% of fiber represents a loss of 18.9% over the initial one (Table 4).

5. CONCLUSIONS

With 1.5% short fiber are reached a density decrease of 33.50%. At this dosage and type of fiber is reached maximum decrease of this parameter, and therefore, the maximum density of the future network of interconnected channels when the structure is subjected to the action of fire. With long fiber addiction do achieved smaller reductions in density, reaching only to a decrease of 19.20% have to reach a dosage of 3.0% fibers. The difference of values obtained in the standard density reduction as the fiber type is due to the short fiber to the three-dimensional lattice is much higher than that achieved with long fiber, thus there are more pores in the concrete matrix, significantly improving protection against spalling.

There is an increase in value with the addition of more efficient fiber addiction being short fiber. Maximum is obtained 14.67% for dosing 1.5% short fiber, resulting in a drop in the value for higher dosages. The reference value of absorption in the standard series was 5%. They reach similar values of absorption, 14%, for very different dosages depending on the type of fiber, with 1.5% short fiber and

3.0% long fiber. The different behavior of the change in absorption between the two types of fibers needs further investigation of this phenomenon.

The concrete specimens NPC without additions suffer heavy loss of the mechanics of the RC_{28} by action of fire to reach a temperature of 650 °C, leading to a loss of 73% of this capacity, but have a considerable improvement of this loss of capacity RC_{28} mechanics by adding polypropylene fibers between values of 40% in short fiber and 49% in long fiber.

In short fiber can be observed that there is a RC_{28} improves with increasing temperature of 500 °C exposure at 650 °C, this being greater improvement by increasing the dosage of the fibers and peaking in dosages of 3.0%. In long fiber can be observed that there is no improved RC_{28} with increasing the exposure temperature from 500 °C to 650 °C, but decreases with increasing dosage of the fibers to achieve a dosage of 2% and changes in trend improvements required when reached a dosage 3.0%.

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