COMPRESSIVE STRENGTH OF POLYPROPYLENE FIBER CONCRETE UNDER THE EFFECTS OF HIGH TEMPERATURES

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Abstract: Polypropylene fiber concrete is a kind of concrete that polymers are used as admixtures and also supplements in. Polymer in concrete has been monitored by Committee 548 of the American Concrete Institute since 1971. One kind of the polymers that are used commonly in concrete is polypropylene fiber polymer. The advantages of polypropylene fibers are: improving mix cohesion and pumpability over long distances, improve freeze-thaw resistance, improve resistance to explosive spalling in case of a severe fire, improve impact resistance and increase resistance to plastic shrinkage during curing.

The purpose of this study is to investigate the strength of polypropylene fiber on fire resistance in concrete. Therefore concrete mixtures are prepared by using different amount of polypropylene; 0, 300, 600 and 900g by volume. In order to consider the test result's accuracy, three specimens were prepared from each group of the concrete mixes. All of them were kept under curing standards for 28 days. After curing period of the specimens, each group were exposed to 23, 300 and 750°C for 2 hours. Then the compressive strengths of the specimens were determined. The maximum compressive strength at 23°C was determined for the group of 300g polypropylene fibers concrete and this increase was about 5.6% in compare with the control specimens (control specimens: concrete without any polypropylene fiber) but the maximum strength was determined for the group of 600g polypropylene fibers concrete at 300°C and its increase was 10.1% in comparison with the control specimens. According to the results, the greatest increase in strength was related to this group. For the last group the maximum compressive strength was determined for the specimens with 300g polypropylene fibers at 750°C. This increasing was 9.2% in compare with the control specimens.

Finally based on the results of the study, it is concluded that the relative compressive strengths of specimens containing some polypropylene fibers were higher than control specimens. Furthermore, it can be concluded that concrete specimens with 300g polypropylene fibers can significantly promote the residual compressive strength during the high temperature. That is because of the melting of the polymers which causes concrete to change to a porous material and prevent explosion of the concrete at high temperatures.

Key words: Polypropylene fiber concrete, Polymer, Compressive strength, Temperatures, Porous material

1. INTRODUCTION

Portland cement concrete is a brittle composite material that performs well in compression, but is less effective when exposed to elevated temperatures. The custom approach is to adhesively bond fiber polymer composites in the concrete in order to have fiber reinforced concrete [1, 2]. The usefulness of fiber reinforced concrete (FRC) in civil engineering fields is certain. Fiber reinforced concrete has so far been successfully used in various applications like offshore structures, thin and thick repairs, hydraulic structures and many other applications. Significant progress has been made in the previous decade in order to understand the performances of fiber reinforced concrete (FRC), and it has been resulted in numbers of innovative applications [3]. But there isn't any fiber type that can contain all the desired properties of concrete in terms of, for example, spalling resistance at elevated temperatures, crack control, providing load bearing capacity at cracked sections, impact and frost resistance and etc. [4]. The concept of polypropylene fiber concrete has added a new dimension to concrete construction since fibers can be premixed in a conventional manner [2]. Polypropylene fiber's high melting point (165°C) and its chemical neutrality make it strong in elevated temperatures [5, 6]. Polypropylene fibers have been receiving an increased attention and their use seems to be on the increase worldwide [7, 8].The woolen polypropylene fibers used in the proportions of 300g, 600g and 900g in the concrete specimens and exposed to the elevated temperatures for 2 hours. The test results have been compared with the control specimens.

2. EXPERIMENTAL PROGRAM

2.1. Materials

2.1.1. Cement

The Portland cement CEM I 42.5 R has been used in this study. Initial and final setting times of the cement were 146 and 215 min, respectively. The specific gravity of cement was 3.21 and the Blaine specific surface area was 3340 cm^2/g. Chemical composition of cement has been given in Table1.

Table1. Chemical composition of cement

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
Cement (%)	19.7	5.6	4.1	64.9	2.1	2.7	0.6	0.3

2.1.2. Woolen Polypropylene (WPP) Fiber

Polypropylene fibers (Fig.1) are affective in the concrete exposed to high temperatures. Additives are used in polypropylene to prevent polymer degradation, resulting from exposure to heat, shear and light fibers in concrete, increase flexure strength due to their higher modulus of elasticity compared to that of the concrete.

Fig.1. Woolen Polypropylene (WPP) fiber

Therefore its post cracking behavior helps to continue absorbing energy as fibers pull out [9,10,11]. Typical properties of Polypropylene fibers are given in Table2.

Table2. Properties of woolen polypropylene fiber

Fiber type	BASF Master fiber 15 MF
Length (mm)	12
Specific Gravity	0.91
Melt Point	160°C
Ignition Point	590°C
Absorption	Nil
Shape	Woolen

2.1.3. Aggregate

Dry and clean aggregate was used in the concrete mixture. The gravel was 16mm maximum size with 1.1% water absorption value and its relative density at saturated surface dry (SSD) condition was 2.60. The water absorption value of the sand was 1.24% and its relative density at saturated surface dry (SSD) condition was 2.53. The presence of aggregate greatly increases the durability of concrete above that of cement, which is a brittle material in its pure state. Thus concrete is a true composite material [12].The properties of aggregates used in this study are given in Table3.

Table 3. The results of aggregates tests

Grain size (mm)	Sieve size (mm) 16	8	4	2	1	0.5	0.2	0.0
0-4	100	100	86.47	62.4	39.47	16.07	4.04	0
4-16	100	31.3	7.52	0.56	0.44	0.36	0.28	0

	Fineness modulus	Specific gravity	Loose unit weight (kg/m3)	Water abs. Ratio 24h (%)
0-4	2.66	2390	1288	2.04
4-16	5.9	2510	1310	0.35

2.1.4. Water

Combining water with a cementations material forms a cement paste by the process of hydration. The cement paste glues the aggregate together, fills voids within it, and makes it flow more freely, [13].

A lower water-to-cement ratio yields a stronger, more durable concrete, whereas more water gives a freer-flowing concrete with a higher slump, [14]. Impure water used to make concrete can cause problems when setting or in causing premature failure of the structure, [15].

Hydration involves many different reactions, often occurring at the same time. As the reactions proceed, the products of the cement hydration process gradually bond together the individual sand and gravel particles and other components of the concrete to form a solid mass, [16].

Reaction:

Cement chemist notation:

$$C_3S + H \rightarrow C\text{-}S\text{-}H + CH$$

Standard notation:

$$Ca_3SiO_5 + H_2O \rightarrow (CaO)\cdot(SiO_2)\cdot(H_2O)(gel) + Ca(OH)_2$$

Balanced:

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3\,(CaO)\cdot 2(SiO_2)\cdot 4(H_2O)(gel) + 3Ca(OH)_2$$

2.2. Experimental Significance

The concrete mix used for casting the specimens is shown in Table 4. Portland cement CEM I 42.5 R, crushed stone coarse aggregates having maximum size 14.5 mm and river sand were used.

Table 4. Concrete mix proportion

water/cement ratio	sand/cement ratio	coarse aggregate/cement ratio
0.46	2.66	2.45

There were four different groups of the concrete specimens which consist of 300, 600 and 900 g/m^3 polypropylene fibers and also control group without any fibers admixtures.

The number of the specimens used in this study was 36, 100x200mm cylindrical specimens that were cured 28 days in water by the PH of 6.9.

The specimens have been divided into three groups and exposed to three different (23, 300 and 750°C) temperatures for 2 hours. The investigated parameters are chosen in accordance with the previous studies. [17, 18]. The 28 days compressive strengths of various mixes are shown in Table 5.

Table 5. Fibrous concrete mixes, compressive strength after exposing to the elevated temperature (MPa)

Fiber volume Fraction	Specimen No.	28 days strength (Mpa) at 23°C	28 days strength (Mpa) at 300°C	28 days strength (Mpa) at 750°C
Control	1	26.37	19.38	5.73
	2	27.42	20.12	4.21
	3	26.22	16.87	5.51
300g WPP	1	28.75	17.18	5.77
	2	27.34	17.77	5.12
	3	28.39	16.86	5.97
600g WPP	1	27.64	22.04	4,43
	2	25.91	20.67	4.96
	3	25.88	19.33	5.67
900g WPP	1	21.08	17.25	3.02
	2	22.98	17.50	3.99
	3	22.04	16.43	2.32

3. RESULTS AND DISCUSSION

3.1. Workability

Slump test is a common, convenient and inexpensive test, but it may not be a good indicator of workability for fiber reinforced concrete (FRC). However, once it has been established that a particular FRC mixture has satisfactory handling and placing characteristics at a given slump, the slump test may be used as a quality control test to monitor the FRC consistency from batch to batch according to the ACI committee 544 [19, 20].

Slump test has been carried out for all the groups and test results are given in Table 6.

Table 6. Concrete specimens slump test result

Concrete Group	Slump Result (cm)
Control	17
0.30 kg W.P.P. Fiber	13
0.60 kg W.P.P. Fiber	11
0.90 kg W.P.P. Fiber	10

According to the Table 6, as the WPP fiber amount increases in the concrete, the slump result comes down.

3.2. Compressive strength

ASTM compressive strength equipment and procedures (ASTM C 31, C 39, and C 192) used for conventional concrete can also be applied for FRC. The cylinders should be 100x200 mm in size and should be made using external vibration or a 1 inch (25mm) nominal width internal vibrator in accordance with ACI committee 544, [18]. The 28 days average compressive strength mixes that were exposed to their specific elevated temperature have been shown in Table 7.

Table 7. Fibrous concrete mixes, average compressive strength after exposing to the elevated temperature (MPa)

Fiber volume Fraction	28 days average compressive strength (MPa) at 23°C	28 days average compressive strength (MPa) at 300°C	28 days average compressive strength (MPa) at 750°C
Control	26.67	18.79	5.15
300g WPP	28.16	17.27	5.62
600g WPP	26.47	20.68	5.02
900g WPP	22.03	17.06	3.11

According to the Table 7, it can be clearly seen that by the increase of temperature, the compressive strength of specimens' decreased. Maximum compressive strength obtained for the specimens with 300 g/m^3 woolen polypropylene fibers at 23°C. As it can be seen from the table, adding polypropylene fibers did not cause any significant increase in the compressive strength at room temperature, [21].

Maximum compressive strength values have been obtained for the concrete with 600 g/m^3 woolen polypropylene fiber at 300°C and finally for the concrete with 300 g/m^3 woolen polypropylene fiber at 750°C, [22]. Compressive strength of concrete specimens exposed to the elevated temperatures has been shown in Fig.2 to Fig.5, which are represented by y= ax+b indicated by the linear trend lines. R^2 is the coefficient of determination to evaluate simulation result. The value of R^2 varies between 0 and 1, where 1 is the perfect fit of the equation to underlying data.

According to the figures, R^2 of control specimens is 0.9997. These values for 300g/m^3, 600g/m^{3}and 900g/m^3 woolen polypropylene specimens are 0.9864, 0.9849 and 0.983 respectively. These values showed a significant relationship among the results of the specimens. There is a strong correlation between the relative measures and predicted maximum pressures by different researchers [18, 22].

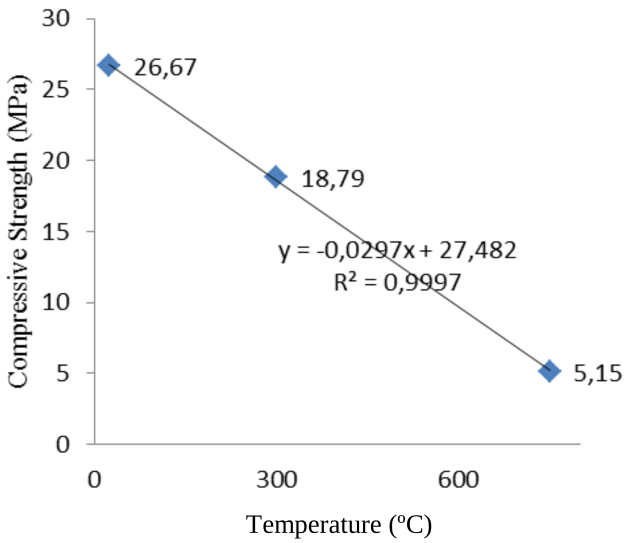

Fig.2. Compressive strength of control specimens

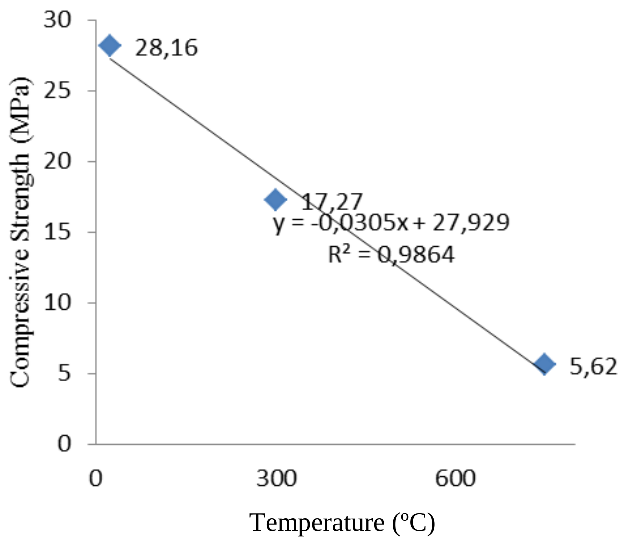

Fig.3. Compressive strength of 300 g WPP specimens

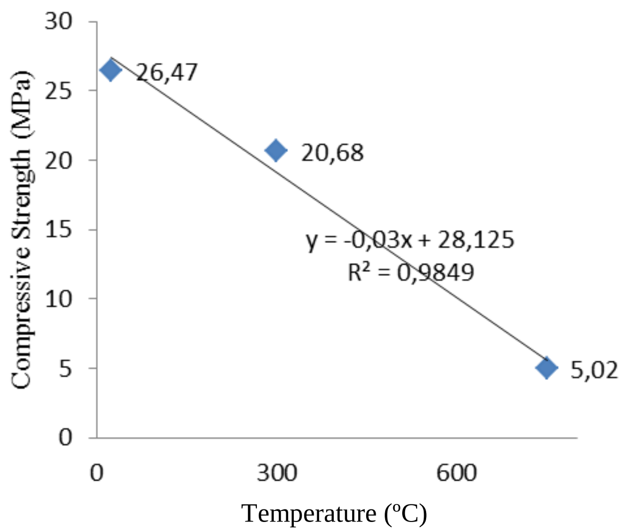

Fig.4. Compressive strength of 600 g WPP specimens

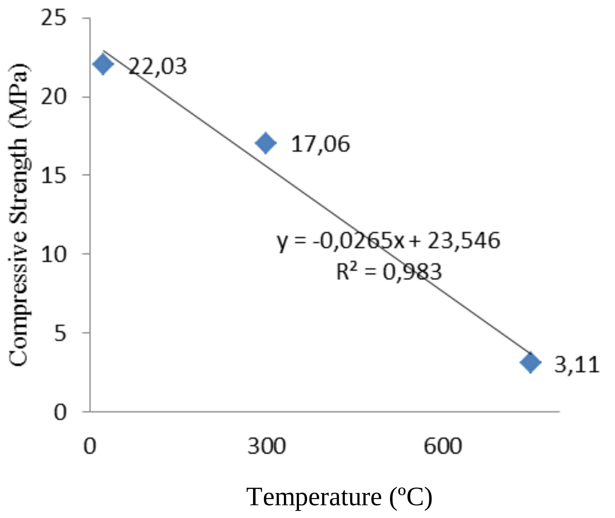

Fig.5. Compressive strength of 900 g WPP specimens

Fig.6. Fiber reinforced concrete (300g WPP) specimens before and after being exposed to 750°C

4. CONCLUSIONS

The main purpose of this study is to investigate the effects of high temperature on the compressive strength of concrete. Therefore, the experiments were carried out by mixing woolen type of polypropylene fiber into the concrete. Woolen polypropylene fiber affects the workability of the fresh concrete adversely and it decreases the slump result almost 31% in comparison with control specimens. The same results have been gotten by other researches [19, 20].

In the compressive strength test, the maximum strength has been obtained for the concrete by mixing 600 g/m^3 woolen polypropylene fiber at 300°C. The strength increasing is about 10.1% in comparing with the control specimens and the minimum strength has been obtained for the concrete by mixing in 900 g/m^3 woolen polypropylene fiber at 750°C. Therefore polypropylene fiber has less influence on the compressive strength of concrete.

The results show that the specimens with 300g WPP fiber and also control specimens give the best results at 750°C. The reason for this is that polypropylene fibers melt and disappeared nearly at 500°C. As well as preventing explosion of concrete it can make the concrete to be a porous material so mixing high doses of polypropylene fiber (600g or 900g) has a negative influence on concrete. The same results have been reached by other researchers [10, 18-20].
According to Fig.6, it can be observed that high elevated temperatures make deep cracks in the concrete and they cause the concrete strength decreasing.

5. REFERENCES

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