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The influence of elevated temperatures on the mechanical properties of polypropylene fiber reinforced concrete

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ABSTRACT

This paper describes the strength of Polypropylene Fiber Reinforced Concrete (PFRC) exposed to the elevated temperatures. In the study, control specimens without any fibers and the concrete specimens with the ratios of 0.30, 0.60, 0.90 and 1.20 kg/m^3 polypropylene fibers both in woolen and bar shape fiber have been produced. The specimens have been kept in the laboratory conditions for 28 days. Shortly after the curing period was completed, every group was heated at 23, 150, 300, 450, 600 and 750°C for two hours then the compressive strengths of them were determined. The maximum compressive strength was obtained by the specimens including 0.30 kg/m^3 woolen polypropylene. For this group, the compressive strength increase was 8% according to the control specimens. The compressive strengths of bar polypropylene fiber concrete were higher than the wool fibers under elevated temperatures. On the other hand, more compressive strength values are obtained from the control specimens than fiber groups at 600°C temperature. Melting the polypropylene fiber at 500°C formed some pore spaces in concrete and caused reduction of the compressive strength.

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1. Introduction

In the field of civil engineering, the importance of fiber concrete is rapidly increasing. Polypropylene fiber reinforced concrete (PFRC) is the mixture of cement, aggregate, water and polypropylene fibers. Concrete undergoes significant damages when it is under the influence of elevated temperature. This may cause undesirable structural defects; however, addition of polypropylene fibers is one of the methods used to reduce this damage. According to the researches, the increase of plasticity and bending strength are the extra advantages of adding the fibers to the concrete. Two kinds of fiber that often used in the concrete are: steel fiber and polypropylene fiber (Kakooei et al., 2012; Mazaheripour et al., 2012). The evaporation of concrete surface water is a component in creating the contract paste fracture in concrete that leads to the formation of tension stress since the concrete starts to strengthen (Mazaheripour et al., 2012).

Recently, it has been found that fibers can also improve the residual properties of concrete being exposed to elevated temperatures. Polypropylene fibers have been used to reduce spalling and cracking and also to enhance the strength (Nishida and Yamazaki, 1995; Kalifa et al., 2001). But minimal or even negative effects of polypropylene fibers on the residual performance of the heated concrete were also observed (Chan et al., 2000; Poon et al., 2004). The fiber melts at approximately 160-170°C and causes expansion channels in the concrete. Therefore the additional porosity and small channels created by polypropylene fibers melting may lower internal vapor pressure in the concrete and reduce the likelihood of spalling (Noumowe, 2005; Uysal and Tanyıldızı, 2012). The loss in strength of concrete at high temperature was attributed to three major factors, namely vapor pressure of capillary and gel water, decomposition of cement hydration products, and possible collapse of filling aggregate (Haddad et al., 2008). Other researches have also shown that some organic fibers

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such as polyvinyl alcohol (PVA) and nylon are also effective in mitigating spalling during the time that other materials like cellulose (Heo et al., 2009) and polyethylene fibers are not more effective (Knack, 2009; Bangi and Horiguchi, 2012).

The reductions in compressive strength of concrete, when exposed to elevated temperatures, can be attributed to the dehydration of concrete by driving out of free water and chemically combined water. The loss of physically bound water significantly affects the mechanical properties of the concrete exposed to elevated temperatures (Bastami et al., 2011). The fire resistance capacity of concrete is not complicated just because concrete is a composite material, in which components exhibit different thermal characteristics, but it is also for properties depending on the porosity and moisture of concrete. As the cement paste is exposed to increasing temperatures, the following process occurs: (1) the expulsion of steam water at a temperature of 100°C, (2) the beginning of the dehydration of the hydrates of calcium silicate at 180°C, (3) the decomposition of calcium hydroxide at a temperature of 500°C and (4) the decomposition of hydrate calcium silicate that begins around 700°C. The alterations produced by high temperatures are more evident when the temperature exceeds 500°C (Uysal et al., 2012; Khaliq and Kodur, 2011). Damage to the concrete exposed to elevated temperature includes weight loss, reductions in strength, modulus of elasticity and the formation of cracks and also large pores (Janotka and Mojumdar, 2005). In this study the strength of polypropylene concrete specimens exposed to the high temperature is achieved.

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 140 min and 205 min, respectively. The specific gravity of cement was 3.16 and the Blaine specific surface area was 3250 cm²/g. Chemical composition of cement has been given in Table 1.

Table 1. Chemical composition of cement (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl^-	Loss on Ignition
18.73	4.56	3.07	63.91	2.08	2.92	0.62	0.29	0.01	3.81

2.1.2. Woolen polypropylene (WPP) fiber

It is widely shown that polypropylene fibers are more affective in the concrete exposed to elevated temperatures (Suhaendi and Horiguchi, 2006; Bingöl and Atashafrazeh, 2015). Additives are used in polypropylene to prevent polymer degradation, resulting from exposure to heat, shear and light. Those additives broaden the property and application range by providing higher functionality and enhanced performance. As colorants, organic pigments provide solutions of high technical standard and are almost suitable for polyolefin. By polypropylene applications, the requirements for organic pigments expand and demand excellent processing properties as heat resistance or dispersibility and durable end-use properties as heat and weather fastness. Typical properties of polypropylene fiber (woolen type) have been shown in Table 2.

Table 2. 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
Shape	Woolen

2.1.3. Bar polypropylene (BPP) fiber

Addition of polypropylene fibers to concrete enhances the longevity of the structure by controlling micro cracks. Also, these fibers reduce water permeability, rebound "splattering" of concrete and shotcrete. Incorporating fibers increases concrete strength because of the high modulus of elasticity to compare with the concrete or mortar binder. Its post cracking behavior helps the continuity of absorbing energy as fibers pull out (Krishna et al., 2011). Typical properties of bar polypropylene fibers, used in this study, are given in Table 3.

Table 3. Properties of bar polypropylene fiber.

Fiber Type	Meyco Fiber SP 540
Length (mm)	40
Diameter (mm)	0.9
Fineness	44
Shape	Bar
Minimum Tension Strength (MPa)	295
Unit No. (fiber/kg)	4600

2.1.4. Aggregate

Thermal properties of concrete are mainly interrelated with the type of aggregates used in. Dry and clean natural, river aggregate was used in concrete mixture. The gravel was 16mm maximum nominal size with 1.1% water absorption value and relative density of it at saturated surface dry (SSD) condition was 2.70. The water absorption value of the sand used was 1.2% and the relative density at saturated surface dry (SSD) condition was 2.61. The properties of aggregates used in this study have been given in Table 4.

2.2. Experimental significance

According to the ACI Committee 211 (2002) concrete is composed of aggregates, Portland cement, and water, and may contain other cementations' materials and chemical admixtures. The concrete mix that is used in this study for casting the specimens has been shown in Table 5. Portland cement CEM I 42.5 R, crushed stone course aggregates the maximum size of 16mm and river sand have been used. The specimens incorporated two different aspect fibers.

There were 9 different groups of the concrete specimens that consist of 0.30, 0.60, 0.90 and 1.20 kg/m^3 polypropylene fibers group both in woolen and bar types and also control group without any fibers admixtures. In this study totally 162 cylindrical concrete specimens were cast with the size of 200x100 mm. The specimens have been divided into six groups and exposed to six different (23, 150, 300, 450, 600 and 750°C) temperatures for 2 hours. The investigated parameters are chosen in accordance with the previous studies (Netinger et al., 2011; Gao et al., 2012; Aslani and Samali, 2012).

Table 4. The results of aggregates tests.

Grain Size (mm)	Sieve Size (mm)							Fineness Modulus	Specific Gravity	Loose Unit Weight (kg/m^3)	Unit Weight (kg/m^3)	Water abs. Ratio 24h (%)
	16	8	4	2	1	0.5	0.2					
0 - 4	100	100	86	62	39	16	4	2.66	2390	1288	1420	2.04
4 -16	100	31	8	1	0	0	0	5.9	2510	1310	1470	0.35

Table 5. Concrete mix proportion.

Water/Cement Ratio	Sand/Cement Ratio	Coarse Aggregate/Cement Ratio
0.46	2.66	2.45

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 FRC (Song et al., 2005). 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 (1988). Fresh mixes were tested for workability by slump test. 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 B.P.P. Fiber	16
0.60 kg B.P.P. Fiber	18
0.90 kg B.P.P. Fiber	19
1.20 kg B.P.P. Fiber	16
0.30 kg W.P.P. Fiber	13
0.60 kg W.P.P. Fiber	11
0.90 kg W.P.P. Fiber	11
1.20 kg W.P.P. Fiber	10

As the woolen polypropylene fiber amount increases in the concrete, the slump result comes down but increasing the bar polypropylene fiber does not have a significant influence on the slump results.

3.2. Weight loss

In this research concrete specimens (150 specimens) have been weighed before and after being exposed to the elevated temperatures. Weight loss percentages of them have been presented in Figs. 1 and 2 for bar and woolen polypropylene fibers, respectively.

It can be clearly seen that weight loss percentages of woolen polypropylene fiber concrete are more than the other one. It can also be seen in Fig. 1, for the bar polypropylene fiber concretes, minimum weight loss was observed in the group with 0.60 kg/m^3 fiber, when the maximum value was at 0.90 kg/m^3.

Fig. 2 shows weight loss of different groups of woolen polypropylene concrete in comparison with control group of specimens. It can be clearly seen that the group with 0.30 kg/m^3 woolen polypropylene has the minimum weight loss and maximum weight loss is observed for the group with 1.20 kg/m^3 woolen polypropylene fiber. Many potential causes of weight loss occur in the concrete being exposed to the high temperature (Bingöl and Atashafrazeh, 2015). However, expulsions of chunks or spalling of the concrete on the surface layers are main reasons of weight loss (Uysal et al., 2012).

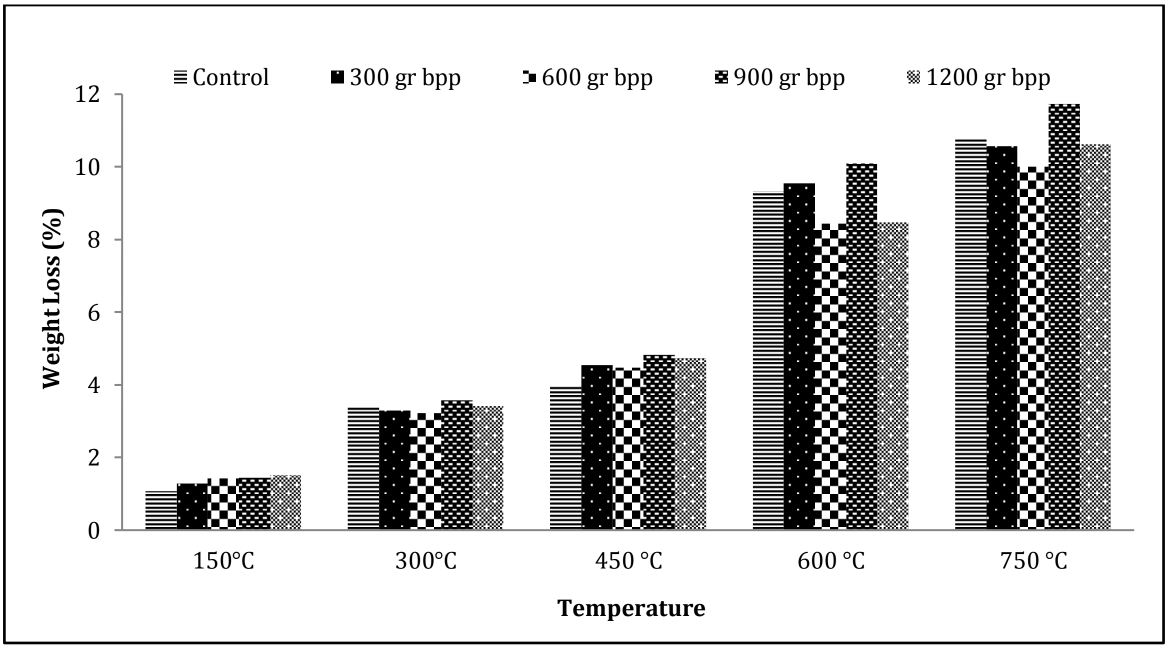

Fig. 1. Weight loss of bar polypropylene concrete in comparison with control concrete in different temperatures.

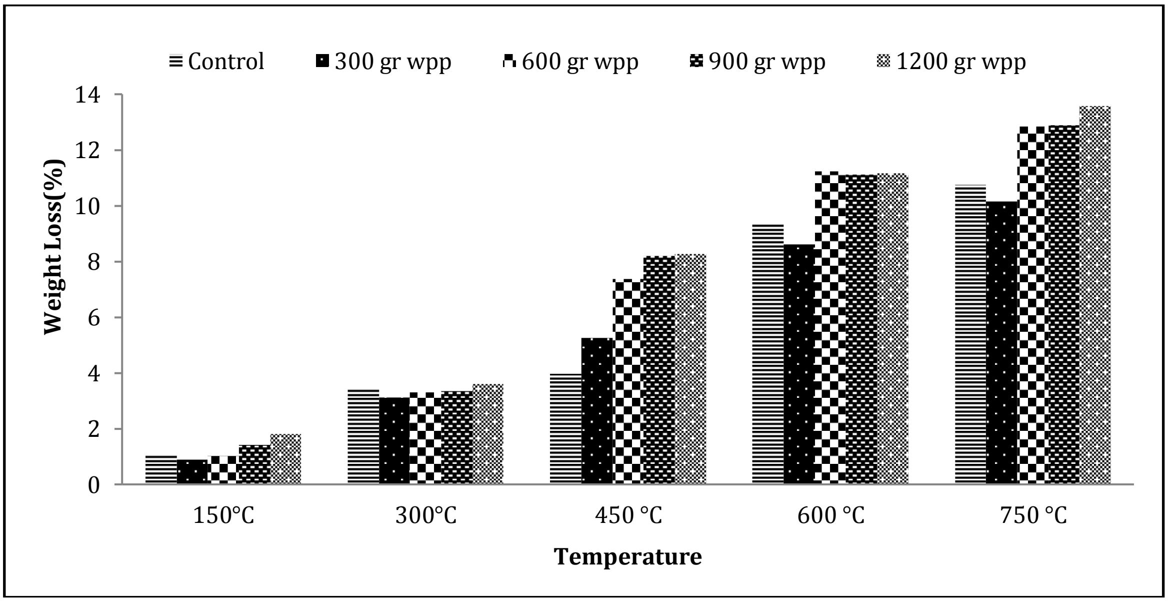

Fig. 2. Weight loss of woolen polypropylene concrete in comparison with control concrete in different temperatures.

3.3. Compressive strength

ASTM compressive strength equipment and procedures 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 (25 mm) nominal width internal vibrator in accordance with ACI committee 544 (1988). Compressive performance of concrete at high temperature is important for the evaluation and repair of concrete structures (Zheng et al., 2012). The 28 days average compressive strength of specimens (totally 162 specimens) that were exposed to their specific elevated temperature has been shown in Table 7.

According to Table 7, it can be clearly seen that by the increase of the temperature, the compressive strength of specimens' decreased except at 450°C. Maximum compressive strength obtained for the specimens with 0.30 kg/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 (Behnood and Ghandehar M, 2009; Aulia, 2002). Maximum compressive strength for the concrete with 0.60 kg/m^3 bar polypropylene fiber was obtained at 150°C. It has been shown in the previous studies (Poon et al., 2004; Bastami et al., 2011) that heating up to temperature of 200°C does not have significant effects on the compressive strength of concretes. Maximum compressive strength values have been obtained for the concrete with 1.20 kg/m^3 bar polypropylene fiber at 300°C, for the concrete with 0.60 kg/m^3 bar polypropylene fiber at 450°C, for the control specimens at 600°C and finally for the concrete with 1.20 kg/m³ bar polypropylene fiber at 750°C. But it is significantly observed that, at 450°C the fibers had no influence on the compressive strength of concrete (Poon et al., 2004; Qian and Stroeven, 2000; Morris et al., 2002). The lower compressive strength of the concrete prepared with the polypropylene fibers may be because of the insufficient dispersing of the fibers in the concrete during mixing (Xiao and Falkner, 2006). The reduction in the compressive strength of concrete was significantly large for the specimens exposed to the high temperatures more than 600°C (Demirel and Keleştemur, 2010).

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

Fiber Volume Fraction	23°C	150°C	300°C	450°C	600°C	750°C
Control	27.74	25.66	19.97	20.80	16.25	5.27
0.30 kg B.P.P Fiber	27.39	24.89	19.69	22.74	16.16	5.05
0.60 kg B.P.P Fiber	24.73	27.16	21.72	23.44	14.89	5.31
0.90 kg B.P.P Fiber	26.93	26.89	22.75	21.42	13.70	4.77
1.20 kg B.P.P Fiber	27.14	26.30	23.24	21.73	13.95	5.74
0.30 kg W.P.P Fiber	28.97	23.92	19.08	15.04	10.11	5.69
0.60 kg W.P.P Fiber	27.88	25.51	22.09	12.17	8.20	5.49
0.90 kg W.P.P Fiber	23.04	22.50	16.98	19.15	8.95	4.79
1.20 kg W.P.P Fiber	24.53	26.97	16.70	13.32	8.53	4.73

Compressive strength of concrete specimens exposed to the elevated temperatures has been shown in Figs. 3 and 4, 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 (Zheng et al., 2012; Khaliq and Kodur, 2011).

All the specimens are compared with control specimens. Therefore, two figures have been shown, according to the figures, R^2 of control specimens is 0.8705. This value for 0.30, 0.60, 0.90 and 1.20 kg/m³ bar polypropylene concrete specimens were 0.8076, 0.8349, 0.8775 and 0.8811 and for 0.30, 0.60, 0.90 and 1.20 kg/m³ woolen polypropylene specimens are 0.9992, 0.9592, 0.8648 and 0.9268, respectively. These values showed a significant relationship among the results of the specimens.

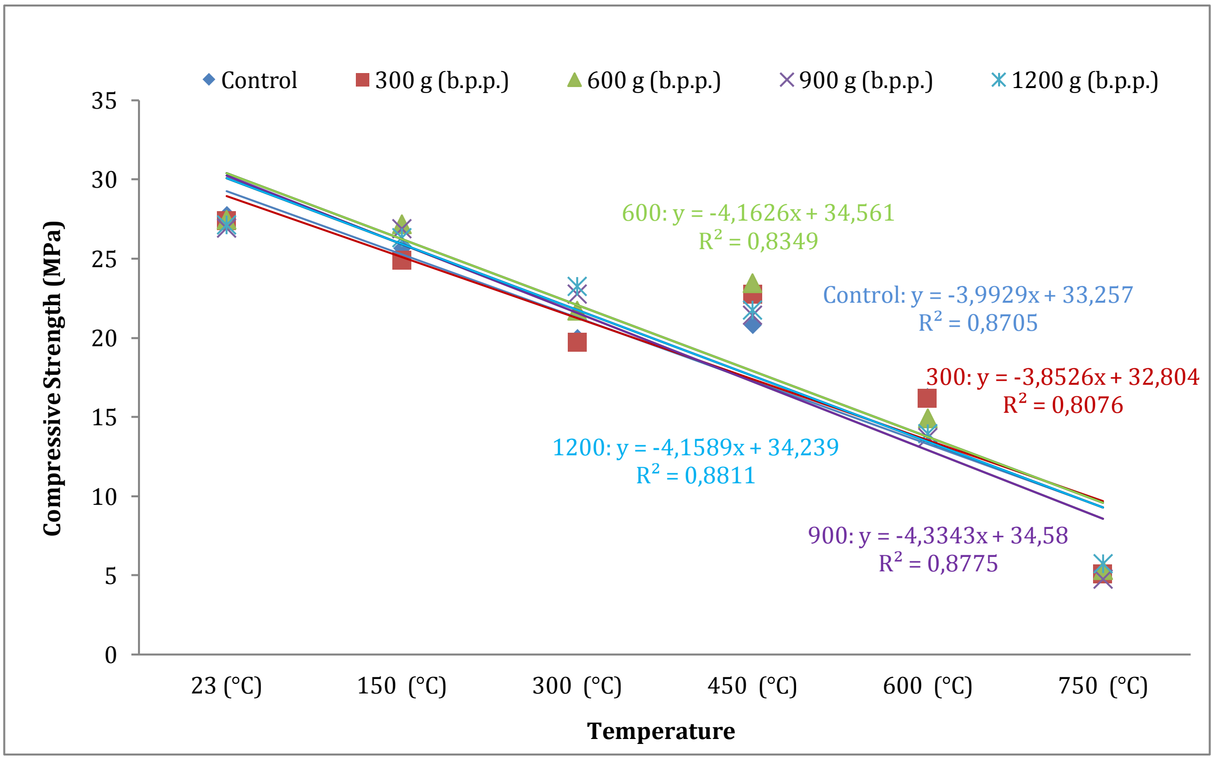

Fig. 3. Compressive strength of control and bar polypropylene fiber concrete.

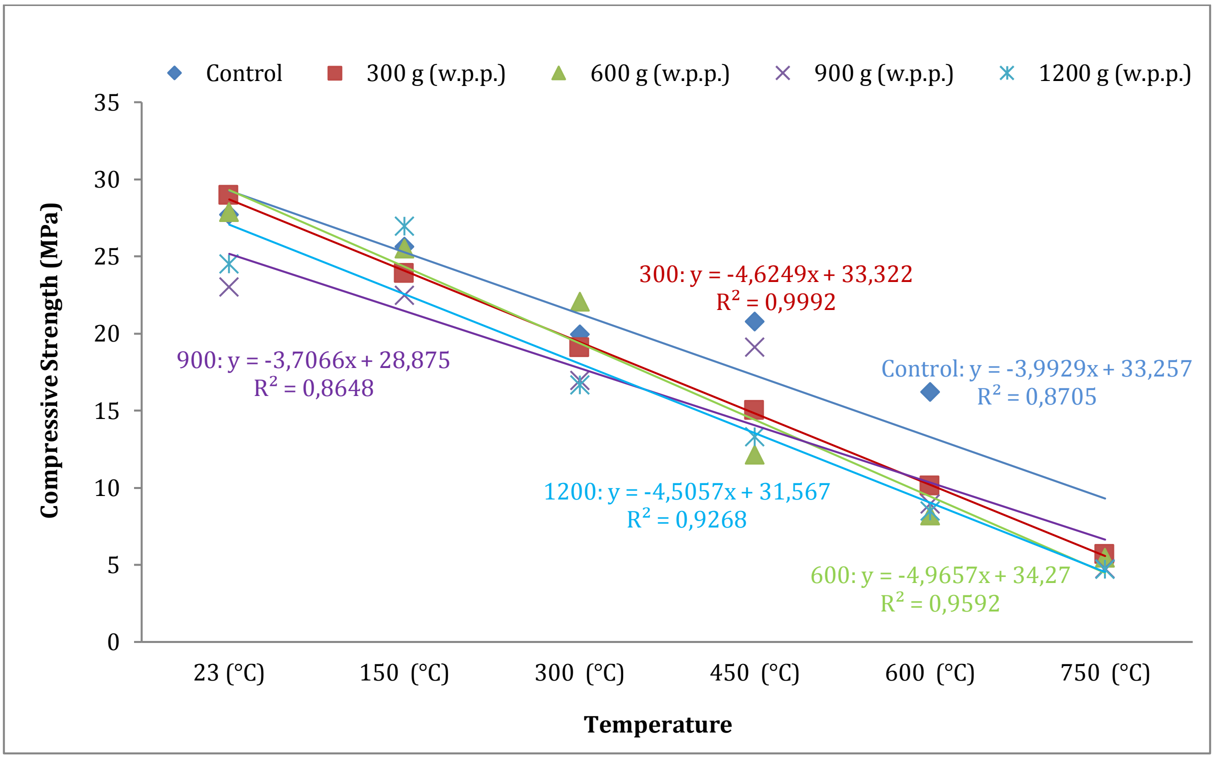

Fig. 4. Compressive strength of control and woolen polypropylene fiber concrete.

4. Conclusions

The main purpose of this study is investigating the effects of high temperature on the compressive strength of concrete. Therefore, the experiments were carried out by mixing woolen and bar types of polypropylene fiber into the concrete. The results obtained advantages compared to current knowledge and further specify with insertion.

- Less influence on the workability of bar polypropylene fibers on concrete has been determined. Therefore, the use of bar polypropylene fiber is thought to be appropriate in the pumped concretes. But woolen polypropylene fiber affects the workability of the fresh concrete adversely and it reduces the slump result almost 31% in comparison with control specimens' result.
- Polypropylene fiber has less influence on the compressive strength of concrete, and on the other hand, mixing in 1.20 kg/m³ polypropylene fiber was being observed as a negative influence on them.
- In the compressive strength test, the maximum strength has been obtained for the concrete by mixing in 0.30 kg/m³ woolen polypropylene fiber. The strength increase is about 8% in comparison with the control specimens.
- Bar polypropylene fiber is more effective than woolen type after being exposed to the elevated temperatures.
- In the specimens by mixing in 0.60 kg/m³ bar polypropylene fiber, the highest strength has been obtained at 150°C (27.16 MPa). This result was 23.24 MPa for the specimens by mixing in 1.20 kg/m³ bar polypropylene fiber at 300°C. And at 450°C, the maximum strength was 23.44 MPa for the concrete by the 0.60 kg/m³ bar polypropylene fiber and finally control specimens gave the best results both at 600 and 750°C.
- The statistics show that the specimens without any fibers (control group) give the best results at 600°C. In the PFRC specimens, polypropylene fibers melt at 160-170°C and by increasing the temperature they vapor at 500°C, as well as preventing explosion of concrete, they can also influence the concrete to be a porous material. Therefore it leads to PFRC strength decreasing more than the control specimens.

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