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EFFECT OF POLYPROPYLENE FIBERS ON CONCRETE FIRE RESISTANCE

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Abstract. The objective of this study is to investigate the impact of polypropylene fibers on fire resistance of concrete. In order to achieve this, concrete mixtures are prepared by using different percentages of polypropylene; 0%, 0.5% and 1%, by volume. The samples are heated to 200, 400 and 600 °C, for exposures up to 6 hours, and tested for compressive strength. Based on the results of the study, it is concluded that the relative compressive strengths of concretes containing PP fibers were higher than those of concretes without PP fibers. Furthermore, it can be concluded that concrete mixes which are prepared using 0.5% PP fibers, by volume, can significantly promote the residual compressive strength during the heating.

Keywords: polypropylene, fibers, fire resistance, compressive strength, workability, exposure.

1. Introduction

Concrete usually performs well in building fires. However, when it is subjected to prolonged fire exposure or unusually high temperatures, concrete can suffer significant distress. When normal-weight concrete cools after a fire, its residual strength varies depending on the temperature attained, mix proportions and loading conditions during heating. In super-tall buildings refuge floors are used to comply with fire code regulations, Chow and Chow (2009).

Mechanical characteristics of fiber reinforced concrete subjected to high temperatures, are studied by Sideris *et al*. (2009). For this purpose, fiber reinforced concrete is produced by addition of 5 kg/m^3 polypropylene fibers in the mixtures and at the age of 120 days, specimens are heated to maximum temperatures of 100, 300, 500 and 700 °C. Specimens are then allowed to cool in the furnace and tested for compressive strength. Residual strength is reduced almost linearly up to 700 °C. The effect of polypropylene fibers and silica fume on the mechanical properties of lightweight concrete exposed to high temperatures, experimentally and statistically are investigated by Tanyildizi (2009). Mixes containing silica fumes (0% and 10%) and polypropylene fibers (0%, 0.5%, 1% and 2%) are prepared. The compressive and flexural strength of lightweight concrete samples are determined after being exposed to high temperatures (400, 600 and 800 °C). Three control factors (silica fume percentage, polypropylene fiber percentage and high temperature degree) are used in the investigation. It is demonstrated that the compressive and flexural strength of polypropylene fiber reinforced lightweight concrete drops with temperature starting from 400 °C. Poon *et al*. (2004) reported that after exposure to 600 °C the relative compressive strength of ordinary Portland cement concretes was slightly increased if 0.22% (by volume) of PP fibers was added. At 800 °C the relative compressive strengths were the same for concretes with and without PP fibers. Behnood and Ghandehari (2009) and Hoff *et al*. (2000) reported that the relative compressive strengths of heated high-strength concretes containing polypropylene fibers were higher than those of concretes without PP fibers. Chen and Liu (2004) reported that the relative compressive strengths of concretes containing polypropylene fibers were higher than those of concretes without PP fibers, for temperatures up to 600 °C. Komonen and Penttala (2003) investigated the effect of high temperature on the residual properties of polypropylene fiber reinforced Portland cement paste exposed to the temperature of up to 700 °C. It is concluded that polypropylene fibers decrease compressive strengths.

An experimental investigation to predict the behavior of concrete intended for nuclear applications is carried out by Noumowé *et al*. (2009). For this purpose, normal concrete having compressive strength of 40 MPa is designed using limestone aggregates and subjected to heating–cooling cycles at 110, 210 and 310 °C. The results obtained show that concrete containing limestone aggregates may be used in applications involving elevated temperatures. Furthermore, there is not a significant deterioration of the mechanical properties of the concrete between 20 and 110 °C; and the reduction in compressive strength values remains lower than 40% of the initial value even after a temperature of 310 °C. Xiao and König (2004) stated in their article “Study on concrete at high temperature in China – an overview” that as the temperature increases from room temperature to 400 °C, the compressive strength of concrete drops slightly first and then goes up a little. When the temperature reaches above

400 °C, it starts to decrease drastically. At 800 °C, it drops to less than 20% of the compressive strength at room temperature. Chang *et al*. (2006) reported that the residual strength of specimens heated at 400, 600, and 800 °C reduced to 45%, 35% and 15% of the original unheated value. At 200 °C and 300 °C the residual strength retained 90% and 80% of the original strength. Chan *et al*. (1999) concluded that the compressive strength loss is 15% for temperatures up to 400 °C.

Khoury and Willoughby (2008) and Zeiml *et al.* (2006) proved that polypropylene fibers are effective in reducing the probability of explosive spalling of concrete in fire.

2. Significance of this Study

This study focuses on investigating the effect of elevated temperatures, applied for long exposures, on concrete strength and ways of improving it using polypropylene fibers. The importance of the study stems from the fact that there is a lack of local experience in this particular research area, where a large numbers of structures are exposed to fires resulting from breaking out of violence and need to be evaluated for appropriate actions. Furthermore, most available literature related to elevated temperatures applied for short exposures added to the contradicting and somewhat confusing results obtained by some researchers.

3. Experimental Program

3.1. Material Properties

Type 1 ordinary Portland cement conforming to ASTM C150/C150M-09 (2009) was used in the preparation of the concrete specimens. Crushed limestone aggregates with a specific gravity of (SSD) 2.65 and an absorption capacity of 2.05% was used as coarse aggregate. Dune sand with a specific gravity of 2.56 and an absorption capacity of 1.62% was used as fine aggregate. Specific gravities and absorptions of coarse and fine aggregates conformed to ASTM C127-07 (2007) and ASTM C128-07a (2007). Mixing water was tap water obtained from IUG Material and Soil Testing Laboratories. Polypropylene fibers used had a unit weight of 0.90 gm/cm^3, a tensile strength of 35 MPa, a melting point of 175, a thermal conductivity of 0.12 w/m K, a length of 15 mm and a diameter of 100 µm. The shape of these PP fibers is shown in Fig. 1.

Fig. 1. Polypropylene fibers used

3.2. Mix Proportions

The control concrete mix is designed according to ACI 211.1-91 (2003) to attain a 28-day compressive strength of 30 MPa at 28 days, and an 80-mm slump. Details of the three mixes with (0%, 0.5% and 1.0%) polypropylene by volume are shown in Table 1.

Table 1. Details of the concrete mixes used

Materials	Weights per one cubic meter (kg/m^3)		
% of PP	0% PP	0.5% PP	1.0% PP
Cement	410	407.95	405.9
polypropylene	0.00	0.455	0.910
Water	205	203.97	202.95
Coarse aggregate	1026.63	1021.5	1016.36
Fine aggregate	665.39	662	658.7

3.3. Mixing, Casting and Curing Procedures

Mixing is done in a tilting drum mixer. First, 10% of the mixing water is added followed by the aggregates. Then, 90% of the mixing water is added gradually during the mixing process to the solid ingredients. The remaining 10% of the mixing water is added at the end of the mixing procedure. Cement is added inside the mixer after about 10% of the aggregates have been charged, while polypropylene fibers are gradually added to the cement. The compressive strength cubic specimens are prepared and cast in the laboratory, based on ASTM C192/C192M-07 (2007). After casting, the specimens are covered with burlap and thin polyethylene sheets for 24 hours before being demolded and placed in a curing tank until testing time. The slump test is used to determine the workability of concrete, based on ASTM C143/C143M-10 (2010).

3.4. Test Specimens

Ninety 100 mm × 100 mm × 100 mm cubic specimen are prepared to determine the compressive strength at 28 days, based on ASTM C109/C109M-08 (2008). Details of the numbers of specimens used are shown in Table 2.

Table 2. Number of tested specimens

PP Fiber Content	**200 C°**		
	2 hrs	**4 hrs**	**6 hrs**
0% PP	3	3	3
0.5% PP	3	3	3
1% PP	3	3	3
	400 C°		
	2 hrs	**4 hrs**	**6 hrs**
0% PP	3	3	3
0.5% PP	3	3	3
1% PP	3	3	3
	600 C°		
	2 hrs	**4 hrs**	**6 hrs**
0% PP	3	3	3
0.5% PP	3	3	3
1% PP	3	3	3

3.5. Heating Procedure

At a curing age of 28 days, the samples are heated to 200, 400 and 600 °C for 2, 4 and 6 hour exposures. Electrical resistance furnace, shown in Fig. 2, with a heating rate of 10 °C/minute is used for this purpose. At the end of the heating procedure, the specimens are left inside the furnace in order to cool down, and then tested for compressive strength.

Fig. 2. The furnace used for heating the specimens

4. Test Results and Discussion

4.1. Fresh Concrete Tests

Slump test results are measured for the three mixes. The slum values recorded are 75, 50 and 40 mm for 0% PP, 0.5% PP and 1.0% PP, respectively. Thus, the slump values are reduced with increasing PP% in the mix. This is attributed to the adhesion and cohesiveness of the mix provided by polypropylene fibres. During the mixing process, the individual fibers are sheared apart from each other and anchored mechanically to the cement paste due to the large specific surface area.

4.2. Hardened Concrete Tests

4.2.1. Compressive Strength

Concretes without PP fibers

Table 3 shows the reduction in compressive strengths relative to the 0% PP samples at room temperature.

It is seen that at 200 °C the compressive strength decreased between 16.93% and 34.93% compared to the room temperature strength. The reduction in compressive strength for samples heated to 400 °C was between 18.43% and 33.84% compared to the room temperature strength. After heating to 600 °C the compressive strength decreased between 35.75% and 41.34% compared to the room temperature strength. These results are in good agreement with the findings of Chang *et al.* (2006) and Noumowé *et al.* (2009).

A significant decrease in the compressive strength was observed in mixtures heated to 600 °C and mixtures exposed to 6-hour heating. This strength loss is attributed to the weakened bond between the aggregates and the paste, which is caused by the contraction of the paste following loss of water and the expansion of the aggregates. Some researchers reported this strength loss and attributed it to the decomposition of calcium hydroxide which is known to occur between 450 and 500 °C (Hammer 1995; Lin *et al.* 1996).

Table 3. Reductions in compressive strength

% of (PP)	Percentages of reduction in compressive strength at 200 °C		
	2-hour exposure	4-hour exposure	6-hour exposure
0.00%	16.93	27.46	34.93
0.50%	16.08	16.08	8.08
1.00%	25.15	31.57	28.94
% of (PP)	**Percentages of reduction in compressive strength at 400 °C**		
	2-hour exposure	4-hour exposure	6-hour exposure
0.00%	18.43	27.09	33.84
0.50%	9.86	13.11	17.52
1.00%	20.57	25.76	34.81
% of (PP)	**Percentages of reduction in compressive strength at 600 °C**		
	2-hour exposure	4-hour exposure	6-hour exposure
0.00%	35.75	38.31	41.34
0.50%	15.78	20.41	19.03
1.00%	36.31	41.71	43.26

Concretes with PP fibers

The compressive strength of concretes at room temperature and after heating to 200, 400 and 600 °C are presented in Figs 3–5.

For samples tested at room temperature, average compressive strengths are 32 MPa, 36 MPa, and 38 MPa for samples having 0% PP, 0.5% and 1.0% PP, respectively. Thus, Polypropylene fibers have a positive impact on compressive strength. At 0.5%, there is 12.5% gain in compressive strength and at 1.0% PP the gain is 18.75%.

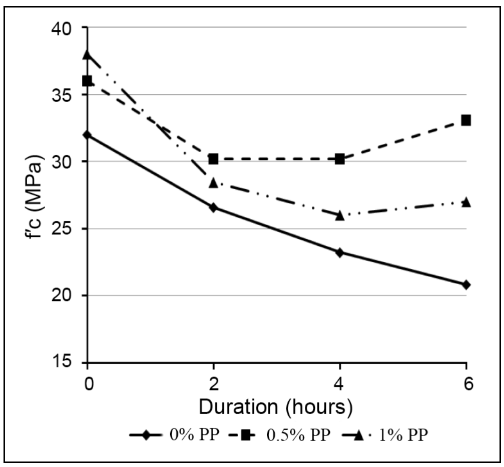

Fig. 3. Compressive strengths for 200 °C

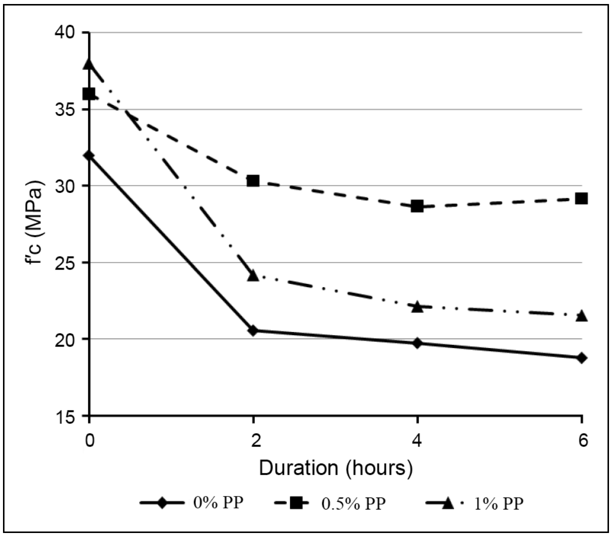

Fig. 4. Compressive strengths for 400 °C

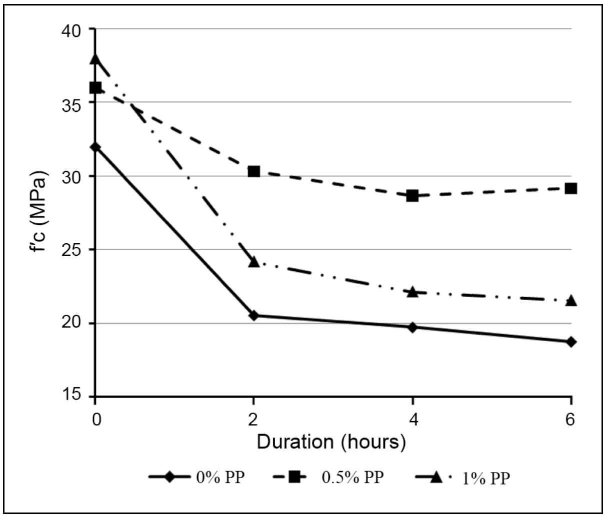

Fig. 5. Compressive strengths for 600 °C

Contradictory test results have been reported by different investigators regarding the effects of polypropylene fibers on the compressive strength of unheated concrete. Alhozaimy *et al*. (1996) stated that polypropylene fibers have no significant effects on compressive strength of concrete. Richardson (2006) and Zollo *et al*. (1984) indicated that it has negative effects on the compressive strength for the ranges used in their experimental programs and Mindess and Vondran (1988) reported favourable effects of fiber addition on compressive strength. These contradictions may be attributed to differences in matrix composition, polypropylene fiber type and volume fraction, and manufacturing conditions.

It is seen that at 200 °C the effect of 0.5% PP fibers on compressive strength is insignificant for the 2 and 4 hour exposures. At 6-hour exposure the reduction in strength is about 8% of the room temperature compressive strength. For 200 and 400 °C temperatures, the 0.5% PP shows the least loss in compressive strength. The maximum recorded loss in strength for this percentage is about 19%, compared with the 41% loss for the 0% PP. Besides to this, the 1% PP shows residual compressive strengths smaller than those for the 0 % PP samples. This may be due to the weak structure created by the extra PP. Hence, one may conclude that the optimum percentage of PP recommended for improving concrete resistance against fire is 0.5%, by volume of the mix. These results are in general agreement with Behnood and Ghandehari (2009), Chen and Liu (2004), Kalifa *et al*. (2001) and Hoff *et al*. (2000). On the other hand, Sideris *et al*. (2009) and Komonen and Penttala (2003) stated that the inclusion of polypropylene fibers reduces the residual compressive strength, a finding in contradiction with the results of this study. It is worth mentioning that Komonen and Penttala (2003) carried out their tests on cement paste samples and the results obtained by Sideris *et al*. (2009) are in contradiction with most of the available literature, including this research work.

4.2.2. Dry weight loss

The reductions in dry weight for the 6 hour heating exposure to 600 °C are 2.45%, 3.55% and 4.12% for 0% PP, 0.5% and 1.0%, respectively. The reduction in dry weight increases with increasing the PP content. This is attributed to the melting of PP fibers.

5. Conclusions

Based on the limited experimental work carried out in this particular study, the following conclusions may be drawn out:

- Polypropylene fibers have a positive impact on compressive strength of concrete at room temperature. At 0.5%, there is about 12% gain in compressive strength, while at 1.0% PP the increase is about 19%.
- The optimum percentage of PP for use in improving fire resistance of concrete is about 0.5%, by volume of concrete mix. For a temperature of 600 °C sustained for 6 hours, the loss in compressive strength is about half of that loss when no PP fibers are used. The lower and higher contents of fibers generally showed worse performance due to the more deteriorations and higher volumes of voids, respectively.
- As the content of PP increases, the slump of the mix decreases. Thus, for heavily reinforced concrete members, it is recommended to use superplasticizers to enhance the workability.

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POLIPROPIRENO PLUOŠTO ĮTAKA BETONO ATSPARUMUI UGNIAI

S. Shihada

Santrauka

Tyrimo tikslas – išnagrinėti polipropireno pluošto įtaką betono atsparumui ugniai. Buvo gaminami betono mišiniai su 0 %, 0,5 % ir 1 % polipropireno dalimis. Bandiniai buvo kaitinami iki 200, 400 ir 600 °C, laikomi šiose temperatūrose 6 valandas ir bandomi nustatant gniuždomąjį stiprį. Remiantis bandymų rezultatais daroma išvada, kad betono su polipropireno pluoštu stipris buvo didesnis už betono be šio priedo stiprį. Kita straipsnio išvada ta, kad betono mišiniai, kurių 0,5 % tūrio sudaro polipropireno pluoštas, leidžia labai padidinti liekamąjį gniuždomąjį įkaitinto betono stiprį.

Reikšminiai žodžiai: polipropirenas, pluoštas, atsparumas ugniai, patogumas kloti, poveikis.

Samir SHIHADA. Associate Professor in structural engineering at the department of civil engineering in the Islamic University of Gaza. He has extensive experience in teaching and practicing structural concrete design where he has published a refereed book entitled "*Reinforced Concrete Design*". His research interests include structural concrete design codes, seismic design and fire-resistant concrete. Furthermore, he has served on several government committees dealing with building damage evaluation and engineering education.