Mechanical Properties of RC Beams with Polypropylene Fibers under High Temperature

Samir Shihada and Mohammed Arafa

Abstract

The objective of this study is to examine the impact of polypropylene fibers on fire resistance of steel reinforced concrete beams. In order to achieve this, concrete mixtures are prepared by using different contents of polypropylene; 0, 0.45 and 0.67 kg/m3. Simply supported beams are heated in an electric furnace to a temperature of 400° for exposure up to 4.5 hours and tested under a static point load on a universal loading frame. Based on the results of this study, it is concluded that the ultimate residual strengths of RC beams containing polypropylene fibers are higher than those without polypropylene fibers. Furthermore, the researchers find out that RC beams which are prepared using 0.67 kg/m3 of polypropylene fibers can significantly promote the residual ultimate strengths during heating.

Index Terms—Reinforced Concrete, Polypropylene Fibers, Beams, Fire resistance, Flexural strength.

I. INTRODUCTION

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Concrete beams are subject to shearing forces and bending moment. Therefore, the capacity of fire-damaged concrete beams vital to the safety of the structure.

Chang et al. [1] reported that the residual strength of concrete specimens heated at 400 C° were reduced to 45% of the original unheated value. Komonen and Penttala [2] studied the impact of high temperature on the residual properties of polypropylene fiber reinforced cement pastes exposed to temperatures up to 700 C°. It was concluded that polypropylene fibers decrease compressive strengths.

Shihada [3] examined the impact of polypropylene fibers on fire resistance of concrete by heating samples to 200 C°, 400 C° and 600 C° for exposure up to 6 hours. Based on the results of the study, it was concluded that the relative compressive strengths of concretes containing PP fibers were higher than those of without PP fibers. The optimum percentage of PP for use in improving fire resistance of concrete was 0.45 kg/m3. For a temperature of 600 C° sustained for 6 hours, the loss in compressive strength was about half of that loss when PP fibers were not used.

Ünlüoğlu et al. [4] examined the mechanical properties of steel reinforcement embedded into mortar after exposure to high temperatures for 3 hours. They concluded that for temperatures up to 500 C°, the reinforcing steel specimens with cover had the same yield and tensile strength as that of the reinforcing steels without high temperature exposure. In their study, Topçu and IşIkdağ [5] studied the mechanical properties of structural rebars after exposure of elevated temperatures. The cover reduced the losses in yield and tensile strengths of rebar and ensured 15% higher strength compared to rebar without cover. For temperatures up to 300 C°, rebar with cover had the same yield and tensile strength as that of the rebar without cover when exposed to elevated temperatures.

However, when the temperature increased up to 800 C°, the rebar without cover lost an average of 80% of its strength capacities compared to a 20% loss for the rebars with cover.

Shihada [6] studied the effect of high temperatures on longitudinal reinforcement of columns. The columns were heated to 200 C°, 400 C° and 600 C° respectively for 2 and 4 hours for each of the three temperatures. Based on the results of the experimental program, it was concluded that increasing the concrete cover had a positive effect on the elongation results, but had no definite effect on yield and ultimate strength results.

Xiao and König [7] indicated by fire tests that as the temperature increased from room temperature to 400 C°, the strength of low-carbon and low-alloy rebar increased, but the ductility decreased. On the other hand, for temperatures above 400 C° the strength decreased and only 20% of that at room temperature is left when the temperature reached 700 C°.

Suji et al. [8] presented the results of an experimental study to program the influence of polypropylene fibers on concrete beams, using 0.9, 1.8 and 2.7 kg/m3. They found out that the flexural strength increased by 21 % to 23% of plain concrete specimens. Kumar [9] generated experimental data on residual strength of reinforced concrete beams subjected to fire for long duration. For 2 hour fire duration, the residual flexural strength was about 50% load of the unheated beam. Rao et al. [10] concluded that the ultimate flexural and shear strength of fly ash concrete deep beams increased with the addition of polypropylene fiber and the increase was more than 5% as the fiber content increased from 0.5% to 1%. Wu [11] carried out experiments on polypropylene fiber reinforced concrete beams using contents of 0.2%, 0.5%, 1.0% and 1.5%, by volume. He found out that the flexural

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strength was reduced by adding polypropylene fibers, compared to unreinforced concrete beams. El-Hawary et al. [12] studied the effect of fire on the flexural behavior of RC beams exposed to fire at 650°C. They concluded that the ultimate loads for beams exposed to fire for 30, 60 and 120 minutes were less than that for the reference beam by about 11.8%, 19.3% and 38.7% respectively. El-Hawary et al. [13] examined the effect of fire on the shear behavior of RC beams exposed to fire at 650°C for three time durations. They concluded that the ultimate loads of the beams exposed to fire for 30, 60 and 120 minutes were less than those of the reference beams. The reductions in the ultimate loads for beams with a cover thickness of 2 cm were 0.9, 2.9 and 34.3%, respectively, and for beams with a cover thickness of 4 cm were 1.1, 3.0 and 47.3%, respectively, of the values recorded for the reference beams. Alhozaimy et al. [14] concluded that polypropylene fibers of 0.3%, by volume had no significant effects on flexural strength of concrete beams. Shi and Guo [15] showed that the bottom concrete cover of concrete beams had a major influence on the specimen ultimate loading capacity but this influence decreased with an increase in the cover thickness.

However, this study focuses on examining the effect of polypropylene fibers on ultimate strength of steel reinforced concrete beams when subjected to high temperature exposure of 2.5 and 4.5 hours. The importance of the study stems from the fact that there is a lack of local experience in this particular research area. Given the fact that due to the geopolitical situation of our region, large numbers of structures are exposed to fires, resulting from breaking out of violence, that last for long durations, and , hence, they need to be evaluated for appropriate actions.

What distinguishes this particular study, which conducted at the department of civil Engineering, IU- Gaza in 2011, is that there is not any available literature related to the subject of the study. Available literature deals either with reinforced concrete beams containing no polypropylene fibers subject to elevated temperatures or with fibrous concrete beams at room temperature.

II. EXPERIMENTAL PROGRAM

A. Material Properties

Type 1 ordinary Portland cement conforming to ASTM C 150 [16] is used in the preparation of the concrete specimens. Crushed limestone aggregates with a specific gravity of (SSD) 2.77 and an absorption capacity of 2.04 % is used as coarse aggregate. Dune sand with a specific gravity of 2.65 and an absorption capacity of 1.57 % is used as fine aggregate. Specific gravities and absorptions of coarse and fine aggregates conformed to ASTM C 127 [17] and ASTM C 128 [18]. Mixing water is about tap water obtained from IUG Material and Soil Testing Laboratories. Polypropylene fibers used have a unit weight of 0.90 gm/ cm3, 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 Figure 1.

Figure (1): Polypropylene fibers used

B. Mix Proportions

The control concrete mix is designed according to ACI 211.1 [19] to attain a compressive strength of 30 MPa at 28 days and a slump of 80 mm. Each cubic meter of the concrete mix consists of 665.3 kg/m3 of sand, 1026.6 kg/m3 of coarse aggregates, 410 kg/m3 of cement and 205 kg/m3 of water. Three concrete mixes are prepared using 0, 0.45 and 0.67 kg/m3 of polypropylene fibers.

C. Mixing, Casting and Curing Procedures

All mixtures are mixed in a conventional rotary drum concrete mixer with a capacity of 0.4 m3. The mixer is first loaded with the coarse aggregate and a portion of the mixing water. After starting the mixer, the fine aggregate, cement, and the rest of water are added and mixed for 3 minutes. This is followed by 3 minutes and another 2 minutes of mixing. The fibers, in the case of fibrous mixtures, are added following the addition of all other mixed ingredients. After casting, the specimens are covered with burlap and thin polyethylene sheets for 24 hours before being demolded and cured in a curing basin for 3 days. Then, all the beams are stored under laboratory air-drying conditions prior to high-temperature exposure at 28 days of age (see Figure 2).

Figure (2): The moulds before casting of concrete

D. 2-4 Test Specimens:

The test specimens are reinforced concrete beams 500 mm long and 125 mm x 150 mm in cross section, shown in Figure 3. High yield strength deformed bars (Grade 420), are used for flexural reinforcement and Grade 280 for shear reinforcement. Each of these beams has two 10-mm in diameter straight bars at bottom face. Two

8-mm in diameter straight bars are used as anchor bars at top face of the beams. In addition, 6 mm closed stirrups are provided at a spacing of 75 mm, center-to-center, throughout the span. All the beams are designed as tension-controlled sections conforming to ACI 318-08 Code [20]. The shear span depth is equal to 1.6 and the height to clear span ratio is 0.3125, thus the beams are classified as shallow beams according to article 10.7.1 of ACI 318-08 [20]. Out of the fifty four cast beams, eighteen are tested at room temperature and considered as reference beams.

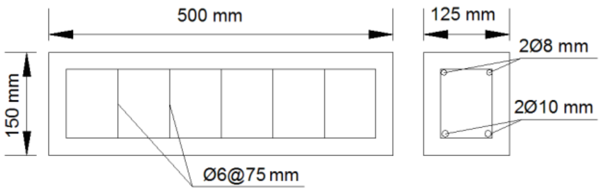

Figure (3): Beam reinforcement

E. Heating Procedure

At an age of 28 days, the samples are heated to 400 C° for 2.5 and 4.5 hour exposure. Electrical resistance furnace 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 ultimate strength.

F. Loading Test

Each of the fifty four beams is tested for ultimate strength under a static point load at its mid span on 150 kN Universal Loading Frame, until failure (shown in Figure 4).

Figure (4): 50-C1400/Universal loading frame

III. TEST RESULTS AND DISCUSSION

A. Slump

Slump test results are measured for the three mixes. The recorded slum values are 80 mm, 55 mm and 45 mm for 0, 0.45 and 0.67 kg/m3 of polypropylene respectively. Thus, the slump values are reduced with increasing PP content in the mix. This may be 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.

B. Loading Test Results

Ultimate loads for two values of concrete cover, different polypropylene contents and heating durations are shown in Table 1. Furthermore, differences in ultimate strengths compared to reference beams not having polypropylene fibers are also included in the same table.

Table 1. Ultimate Strength (kN)

Heating Duration	**2.5 cm Concrete Cover**				
	0.0 kg/m^3 PP	**0.45 kg/m^3 PP**	**Difference (%)**	**0.67 kg/m^3**	**Difference (%)**
	Ultimate Strength (kN)			**Ultimate Strength (kN)**	
0.0 Hours	37.17	39.20	5.50	40.54	9.10
2.5 Hours	16.16	19.22	18.9	21.87	35.3
4.5 Hours	13.71	19.64	43.3	22.44	63.7
Heating Duration	**1.5 cm Concrete Cover**				
	0.0 kg/m^3 PP	**0.45 kg/m^3 PP**	**Difference (%)**	**0.67 kg/m^3**	**Difference (%)**
0.0 Hours	36.22	38.04	5.00	39.30	8.50
2.5 Hours	14.61	16.87	15.5	18.90	29.4
4.5 Hours	11.73	17.44	48.7	19.31	64.6

C. Effect of Polypropylene Content

1) Unheated Beams

For unheated beams (2.5 cm cover), the ultimate loads for 0.45 and 0.67 kg/m3 of polypropylene are 5.5 % and 9.1 %, respectively, higher than those for beams without polypropylene.

For unheated beams (1.5 cm cover), the ultimate loads for 0.45 and 0.67 kg/m3 of polypropylene are 5.0 % and 8.5 %, respectively higher than those for beams without polypropylene.

This slight increase in ultimate load is to be attributed to the increase in tensile strength as a result of the inclusion of polypropylene fibers .

2) Heated Beams

For beams heated for 2.5 hours (2.5 cm cover), the ultimate loads for 0.45 and 0.67 kg/m3 of polypropylene are 18.9 % and 35.3 % respectively higher than those for beams without polypropylene. Furthermore, the ultimate loads for beams heated for 4.5 hours are 43.3 % and 63.7 % respectively higher than those for beams without polypropylene.

For beams heated for 2.5 hours (1.5 cm cover), the ultimate loads for 0.45 and 0.67 kg/m3 of polypropylene are 15.5 % and 29.4 %, respectively, higher than those for beams without polypropylene. Moreover, the ultimate loads for beams heated for 4.5 hours are 48.7 % and 64.6 % respectively higher than those for beams without polypropylene. Figures 5 and 6 show clearly this effect. The addition of polypropylene fibers to the concrete mixes seems to be very efficient. When melted and partially absorbed by the cement matrix, the fibers leave a pathway for gas. Hence, they contribute to the creation of a network more permeable than the matrix which allows the outward migration of gas and results in the reduction of pore pressure.

Table 1 shows a drop in ultimate strength of mixes without polypropylene fibers. Reductions of 63.12 % (2.5 cm cover) and 67.61 % (1.5 cm cover) are reported for beams exposed to 4.5 hours of heating. It is noticed that the greater the exposure time is, the greater is the decline in strength. For mixes containing polypropylene fibers, the 2.5 hour exposure time shows a decline in ultimate strength followed by a slight increase for 4. hour exposure. This result, which seems against expectations for un-reinforced concrete beams, needs to be explained. The impact of heating exposure on steel reinforced concrete beams is twofold; the first of which is negative resulting in deterioration of concrete strength while the second is positive resulting in a slight increase in yield strength of steel reinforcement. This trend is supported by Shihada [6] and Xiao and König [7]. For this particular study, the output is a slight increase in residual ultimate strength.

For unheated concrete, Rao et. al. [10] reported 6.5 % and 9.8 % gains in ultimate loads for concretes containing 0.45 and 0.67 kg/m3 of polypropylene respectively. Furthermore, Suji et al. [8] reported 20 % gain in flexural strength of concrete beams reinforced with 0.90 kg/m3 of polypropylene fibers. These results are in general agreement with the findings of this particular study. On the other hand, Wu [11] reported reductions in strength of fibrous concrete beams, a result which is in contradiction of available literature including this study. These contradictions may be attributed to differences in matrix composition, polypropylene fiber type, volume fractions and manufacturing conditions.

Concerning steel reinforced concrete beams having no polypropylene fibers and subject to elevated temperatures, Kumar [9] reported 50 % reductions in ultimate load, for 2-hour exposure, compared to reference beams. El-Hawary et al. [12] & [13] reported reductions in ultimate loads of ranging from 34 % to 52% after 2 hour exposure when beams are heated to 650°, results that are in common agreement with the findings of this study.

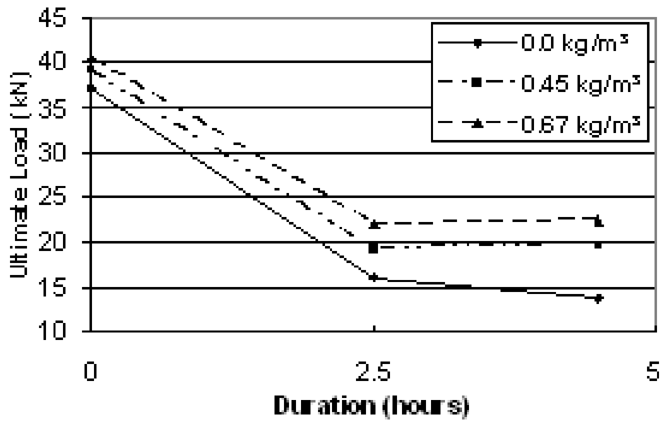

Figure (5): Ultimate loads (cover= 2.5 cm

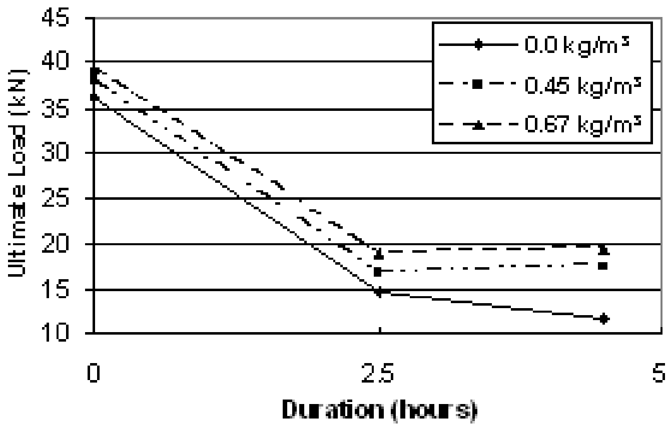

Figure (6): Ultimate loads (cover= 1.5 cm**)**

3) Effect of Concrete Cover

The increase in concrete cover to the reinforcement has a slight positive impact on ultimate strength for unheated beams and for beams heated for 2.5 hours. The increase is less than 6 % for the best obtained result. For beams heated to 4.5 hours the increase in cover has less impact on ultimate strength, with differences not exceeding 2 % of the results for the smaller concrete cover. Thus, it is improper to increase excessively the bottom concrete cover to the reinforcement to improve fire resistance. This result is in agreement with Shi and Guo [15]. Figures 7 through 9 indicate the effect of concrete cover on residual ultimate strength of RC beams having different contents of polypropylene fibers.

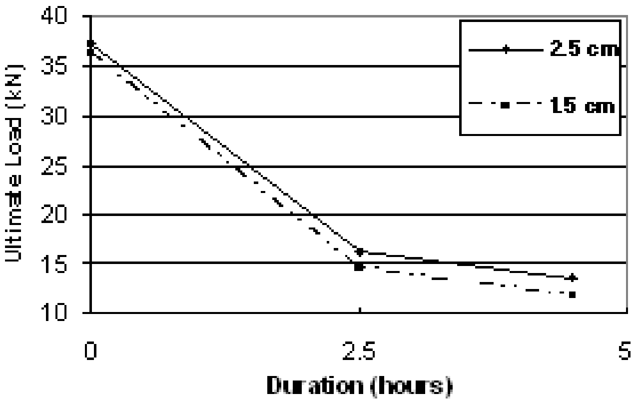

Figure (7): Ultimate loads (0.0 kg/m^3 of PP)

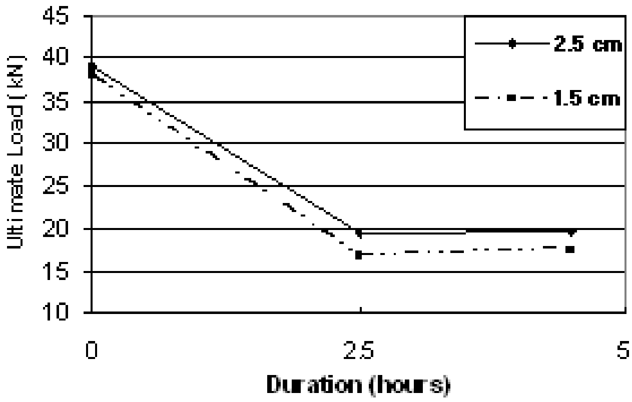

Figure (8): Ultimate loads (0.45 kg/m^3 of PP)

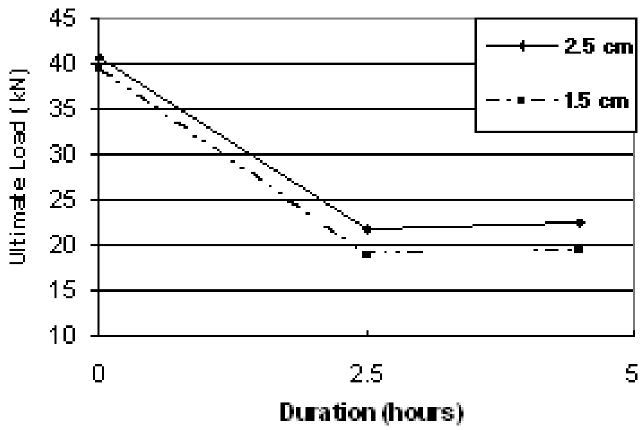

Figure (9): Ultimate loads (0.67 kg/m^3 of PP)

D. 3-3 Modes of Failure

In this study, it is observed that failure in concrete beam specimens occurred in different modes. In some specimens, the failure occurred due to flexure while in other cases took place either due to shear or to combined flexure and shear. Shear failure happened in specimens without heating and 2.5-hour heating while flexural failure occurred in specimens heated for 4.5 hours (see Figures 10 through 12).

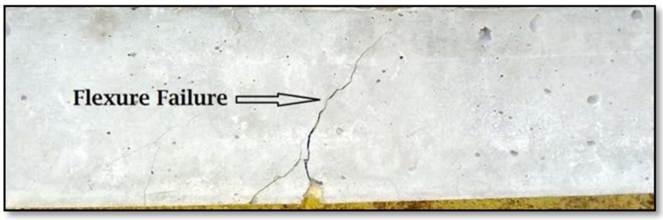

Figure (10): Flexural failure

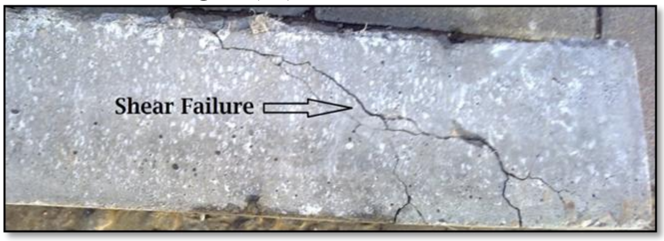

Figure (11): Shear failure

Figure (12): Flexure-shear failure

IV. CONCLUSIONS

Based on the executed experimental work in this particular study, one may conclude the following:

- A severe strength loss was observed for all reinforced concrete beam samples having no polypropylene fibers. The loss is more than 60 % for a heating duration of 4.5 hours.
- Polypropylene fibers have a slight positive impact on ultimate strength of unheated tested beams. At 0.45 kg/m3 content, there is about 5 % gain in strength, while at 0.67 kg/m3 content the increase is more than 8 %.
- Polypropylene fibers have a positive impact on ultimate strength of heated beams. For a heating duration of 4.5 hours, the residual ultimate strength is larger than the corresponding strength of beams without polypropylene fibers by more than 60 %.
- The optimum percentage of polypropylene for use in improving fire resistance of reinforced concrete beams is about 0.67 kg/m3. For a temperature of 400 C° sustained for 4.5 hours, the loss in ultimate strength is less than half of that loss when no polypropylene fibers are used.
- As the content of PP increases, the slump of the mix decreases. Hence, for heavily reinforced concrete members, it is recommended to use superplasticizers to enhance the workability.
- The concrete cover to the reinforcement is insignificant in terms of promoting ultimate strength, especially at 4.5-hour duration.
- No sudden failures are observed in all beams containing polypropylene fibers.

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REFERENCES

[1] Chang Y., Chen Y., Sheu M. and Yao GC., 2006, Residual Stress–Strain Relationship for Concrete after Exposure to High Temperatures, Cement and Concrete Research, Vol. 36, No. 10, pp: 1999–2005. doi:10.1016/j.cemconres.2006.05.029

[2] Komonen, J., and Penttala, V., 2003, Effects of High Temperature on the Pore Structure and Strength of Plain and Polypropylene Fiber Reinforced Cement Pastes, Fire Technology, Vol. 39, No. 1, p: 23–34. DOI: 10.1023/A:1021723126005

[3] Shihada, S., 2011- Effect of Polypropylene Fibers on Concrete Fire Resistance, Journal of Civil Engineering and Management, Accepted for Publication.

[4] Ünlüoğlu E., Topçu İ. and Yalaman B., 2007- Concrete Cover Effect on Reinforced Concrete Bars Exposed to High Temperatures, Construction and Building Materials, Vol. 21, p: 1155–1160. doi:10.1016/j.conbuildmat.2006.11.019

[5] Topçu İ. and IşIkdağ B., 2008, The Effect of Cover Thickness on Rebars Exposed to Elevated Temperatures, Construction and Building Materials, Vol. 22, pp. 2053-2058. doi:10.1016/j.conbuildmat.2007.07.026

[6] Shihada, S., 2010- Impact of High Temperatures on Column's Longitudinal Reinforcement, Journal of Al Azhar University Engineering Sector, Vol. 5, No. 16, pp. 1059-1066.

[7] Xiao, J. and König, G., 2004- Study on Concrete at High Temperature

in China—An Overview, Fire Safety Journal, Vol. 39 (1), pp. 89–103. doi:10.1016/S0379-7112(03)00093-6
[8] Suji, D., Natesan, S. and Murugesan, R., 2007, Experimental Study on Behaviors of Polypropylene Fibrous Concrete Beams, Journal of Zhejiang University SCIENCE A, Vol. 8, No. 7, pp. 1101-1109. DOI: 10.1631/jzus.2007.A1101
[9] Kumar, V., 2011- Behaviour of RCC Beams after Exposure to Elevated Temperatures, Inst. Eng.J, India, Vol. 84, pp. 165-170. DOI:10.1260/2040-2317.2.2.123
[10] Rao, M., Murthy, N. and Kumar, V., 2011, Behaviour of Polypropylene Fibre Reinforced Fly Ash Concrete Deep Beams in Flexure and Shear, Asian Journal of Civil Engineering, Vol. 12, No. 2, pp. 143-154. Link
[11] Wu, Y., 2002, Flexural Strength and Behavior of Polypropylene Fiber Reinforced Concrete Beams, Journal of Wuhan University of Technology, Vol. 17, No. 2, pp. 54-57. DOI: 10.1007/BF02832623
[12] El-Hawary, M., Ragab, A., Abd El-Azim, A. and Elibiari, S., 1996- Effect of Fire on Flexural Behaviour of RC beams, Construction and Building Materials, Vol. 10, No. 2, pp. 147-150. doi:10.1016/0950-0618(95)00041-0
[13] El-Hawary, M., Ragab, A., Abd El-Azim, A. and Elibiari, S., 1997- Effect of Fire on Shear Behaviour of RC Beams, Computers and Structures, Vol. 65, No. 2, pp. 281-287. doi:10.1016/S0045-7949(95)00356-8
[14] Alhozaimy, A., Soroushian, P. and Mirza, F., 1996- Mechanical Properties of Polypropylene Fiber Reinforced Concrete and the Effect of Pozzolanic Materials, Cement and Concrete Composites, Vol. 18, No. 2, pp. 85-92. doi:10.1016/0958-9465(95)00003-8
[15] Shi, X. and Guo, Z., 2004, Influence of Concrete Cover on Fire Resistance of Reinforced Concrete Flexural Members, Journal of Structural Engineering, Vol. 130, No. 8, pp. 1225-1232. doi:10.1061/(ASCE)0733-9445(2004)130:8(1225)
[16] ASTM C150, 2009- Standard Specification for Portland Cement, American Society for Testing and Materials, Philadelphia, Pennsylvania.
[17] ASTM C127, 2009- Standard Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate, American Society for Testing and Materials, Philadelphia, Pennsylvania.
[18] ASTM C128, 2007- Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, American Society for Testing and Materials, Philadelphia, Pennsylvania.
[19] ACI Committee 211.1, 2003- Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, ACI Manual of Concrete Practice Part 1.
[20] American Concrete Institute, 2008- Building Code Requirements for Structural Concrete (ACI 318M-08), Farmington Hills, Michigan.

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