Journal of Engineering and Development, Vol. 14, No. 2, June (2010) **ISSN 1813-7822**

Experimental Study of Polypropylene Fiber Reinforced Concrete Panels Subjected to Elevated Temperatures

Assist.lec. Aamer Najim abbas
Al-Mustansiriya University College of Engineerin
Civil Eng. Department

Abstract

The objective of this investigation is to study the efficiency of adding polypropylene fiber for improving the properties of concrete and punching shear strength of reinforced concrete flat slab subjected to elevated temperatures .

Twelve panels were tested in this study. The models simulate the region of negative bending moment around an internal column supporting a flat plate roofs. One group of slab specimens were tested in room temperatures and three groups specimens were test with different degree of elevated temperatures. The test loads were applied incrementally up to the ultimate carrying capacity. Deformations, crack patterns and ultimate loads were recorded.

Key words: Elevated Temperatures , Polypropylene Fiber.

الخلاصة:

اعد هذا البحث لدراسة كفاءة الياف البوليبروبيلين لتحسين خواص الخرسانة وكذلك لزيادة مقاومة اجهادات القص الثاقب للبلاطات الصفائحية المستوية المعرضة الى درجات الحرارة العالية .

في هذه الدراسة, تم فحص اثني عشر بلاطة صفائحية مستوية. تمثل هذه النماذج المفحوصة منطقة العزم السالب حول العمود الوسطي الساند لهذه البلاطات. تم فحص مجموعة بدرجة حرارة الغرفة وثلاث مجاميع معرضة الى درجات مختلفة من الحرارة . سلطت الاحمال بصورة متزايدة حتى بلوغ الحمل الاعظم (حمل الفشل).سجل مقدار التشوهات, انماط الشقوق ومقدار الحمل الاعظم .

1. Introduction

One of the major problems for buildings and structures is the exposure to high temperatures. Concrete , the most widely used construction material, is sensitive to thermal effects. For examples, under high temperature conditions , it is well established that the behavior of concrete is affected by factors such as heating rate , peak temperatures and constituent materials. Therefore, to assess the structural safety after a fire, it is essential that the residual mechanical properties of concrete after cycles at a high temperatures be well known.

The purpose of this investigation is to evaluate the effect of polypropylene fiber on the behavior of reinforced concrete slab subjected to elevated temperatures . Also, investigate the influence of adding polypropylene fiber on the punching shear strength, thermal cracks, compressive strength and modulus of rupture.

2. Advantages of flat plate construction

The advantages of using flat plate construction are becoming increasingly recognized. Flat plate without drops (thickened areas of slab around the columns to resist punching shear) can be built faster because formwork is simplified and minimized, and rapid turn-around can be achieved using a combination of early striking and flying systems. The overall speed of construction will then be limited by the rate at which vertical elements can be cast(1).

3. Punching shear

Punching shear is one governing design criteria for flat plate structures in the slab column connection. Brittle punching shear failure can occur as a result of concentration of shear stresses at the slab-column junction ; such failure can initiate a progressive collapse throughout the structure . At an interior column of a flat plate slab structure, punching failure can be caused by the application of a pure gravity loading over the complete floor area. Flexural cracks appear on the slab top surface, also the diagonal shear cracks develop with in the slab thickness . Therefore, up to or close to failure , the diagonal shear cracks are not visible on the slab surface . Once the shear strength of the connection is reached. The diagonal shear cracks cross the full thickness of the slab, forming a truncated pyramid that with the supporting column punches through the slab. This punching failure occurs suddenly without much warning.

There are two main ways to develop resistance to punching shear stresses one deals with reinforcement pattern of slabs and another deals with the materials used to improving the resistance to punching shear.

There are several ways to improve slab against punching shear such as drop panels and columns capitals(2,3), conventional shear stirrups(2,3) , shear head reinforcement(4) and shear studs(5) .

The other ways to improve the punching shear strength is to improve some properties of concrete such as increasing compressive strength of concrete Marzouk and Hussein(6) in their search in 1991 as well as Ahmed(7). As well as the use of fibers is another type of improved mechanical properties as discussed in the study of Al-karkhy(8).

4. Polypropylene fiber reinforced concrete

The use of polypropylene fibers has successfully increased the toughness of concrete. Although polypropylene fibers are characterized by low elastic modulus and poor physiochemical bonding with cement paste, it is quite apparent that the load carrying ability of a structure under flexural loading is considerably increased. A substantial amount of research has been done to evaluate the properties of the fiber reinforced concrete. Test data have been classified for concrete reinforced with polypropylene fibers at volume percentages ranging from 0.1%-10.0%. The material properties of polypropylene fiber reinforced concrete are somewhat variable, depending greatly of fiber concentration and the form of the fiber reinforced.

The other major inherent factor that affects the properties of the fiber reinforced is the bond strength of the polypropylene fiber with cement composite. The effectiveness of the polypropylene fiber as concrete reinforcement depends on the bond between fiber and the matrix. The chemical bond between polypropylene fiber and the cement paste is very poor. In fact, concrete forms are commonly made of polypropylene because of the ease of release after hardening. The bundles of polypropylene fibers added to concrete are separated into millions of individual strands due to the abrasive action of the aggregates. The fibers are distributed throughout the entire matrix, providing support to concrete in all possible directions. This also explains the mechanism of how the interface is formed between the fibers and the cement matrix after incorporating the fibers into concrete.

This research is oriented towards concrete reinforced with polypropylene fibers, so it is most important to understand how polypropylene fibers behave in the cement composite matrix. The study of this mechanism helps model the behavior of the composites in a real world environment.

The plain concrete structure cracks into two pieces when the structure is subjected to the peak tensile load and cannot withstand further load or deformation. The fiber reinforced concrete structure cracks at the same peak tensile load, but does not separate and can maintain a load to very large deformations.

The real advantage of adding fibers is when fibers bridge these cracks and undergo pullout processes, such that the deformation can continue only with the further input of energy from the loading source. Reinforcing fibers stretch more than concrete under loading. Therefore, the composite system of fiber reinforced concrete is assumed to work as if it were nonreinforced until it reaches its "first crack strength." It is from this point that fiber reinforcement takes over and holds the concrete together. With reinforcing, the maximum load carrying capacity is controlled by fibers pulling out of the composite.

Reinforcing fibers do not have a deformed surface unlike larger steel reinforcing bars which have a non smooth surface which helps mechanical bonding. This condition limits performance to a point far less than the yield strength of the fiber itself. This is important because some fibers pull out easier than others when used as reinforcing and will affect the toughness of the concrete product in which they are placed(9).

5. Fire Resistance of Concrete

Concrete is exposed to elevated temperatures by accidental fire in building which usually last for short periods but with high intensity. Sustained high temperature exposure of concrete takes place in some industrial installations, and in nuclear reactor pressure vessels, which stimulated interest in the physical properties of concrete under high temperatures.

The high temperature resistance of concrete structures depends on the resistance of its structural members. The behavior of reinforced concrete structures exposed to high temperature is affected by the properties of steel and concrete after heating(10).

Several investigations (11,12) have shown that deterioration in the structural properties of concrete occur under high temperature exposure. The degree of deterioration is influenced by the type of coarse aggregates and type of concrete used.

6. Outline of test

The concrete used in the test specimens had specific compressive strength (24 MPa) (150*150*150 mm). The effect on punching shear strength , compressive strength and modulus of rupture results from the introduction of polypropylene fiber in to concrete were experimentally investigated to compare with concrete without polypropylene fiber.

As the first step in the current study; the compressive strength and modulus of rupture were measured then the compressive strength of specimens subjected to different temperatures were carried out see Plate (1).

Secondly , punching shear tests of concrete panels were carried out to estimate the effect of polypropylene fiber on punching shear strength with and without polypropylene fiber subjected to elevated temperatures with different amount of polypropylene fiber.

7. Punching shear test

The test specimens were square plates of (450*450*50 mm) and reinforced with one layer of Φ5@75 mm flexural reinforcement positioned on the tension side of the slab, loaded at their center with square steel pressure load of 25*25 mm dimensions to simulate concentrated load. The clear test span was (420 mm) see Figure (1) below. The load was applied by (3000 kN) hydraulic test machine. A dial guage was mounted to measure the central deflection. Four sets of specimens were prepared , one of which were tested under room temperature (G1), and the others were subjected to (250^{o}C, 500^{o}C, 750^{o}C) elevated temperatures for groups (G1,G2 and G3) respectively. Three specimens were used in each group , one of which were made without polypropylene fiber and the others with (0.4 %,0.8%).

8. Loading set up and measuring devices

The tested slabs were mounted as shown in Plate (2). The simple support along each edge was provided by resting on loading frame, made of structural steel L-Beam. All slabs were axially loaded through the central square column by hydraulic jack of (3000 kN) capacity. Deflections on the bottom surface of the slab were measured by dial gauge at the center of slabs its accuracy is (0.01 mm).

Plate (1) Flexural test

Plate (2) Test set-up

9. Materials and Mix Proportions

The materials used for the experiments are given in Tables (1 to 6). A ordinary Portland cement (TYPE I), crushed coarse aggregate and sand were used .

The mix proportions were designed to result a specific compressive strength (24 MPa) (150*150*150 mm) . The mix proportions of the concrete specimens is shown in Table (7).

The polypropylene fiber contents taking in to consideration the distribution of polypropylene fiber in the cement matrix , were set to 0.4 or 0.8% with length about 33mm .

Table (1) Chemical Composition 1 of Cement

Chemical Composition		
Oxides	Sibline Cement	IOS 5:1984 criteria
CaO	62.22	-
SiO_2	22.01	-
Fe_2O_3	3.53	-
Al_2O_3	5.49	-
MgO	2.24	< 5
SO_3	1.92	< 2.8
L.S.F	0.86	0.66 - 1.02
L.O.I	1.1	< 4
I.R	0.50	< 1.5
F.L.	0.94	-
C_3S	38.55	-
C_2S	33.15	-
C_3A	8.58	-
C_4AF	10.73	-

Table (2) – Physical properties of cement

Physical Properties		
Properties	Sibline Cement	IOS 5:1984 criteria
Fineness (Blain)	3100	>2300
Vicat set times(mi		
Initial	2 hours	≥ 45 min.
Final	4.1 hours	≤10 hours
Mortar Compressive strength (MPa) at		
3 days	19.4	> 15
7 days	29.75	> 23
28 days	48.33	-
Soundness: autoclave %	0.19	< 0.8

Table (3) – Grading of fine aggregate

Sieve size(mm)	**% Passing by weight**	**Limits of the Iraqi specification No.45/1984 (zone 2)**
4.75	100	90-100
2.36	92.1	75-100
1.18	82.0	55-90
0.60	58.8	35-59
0.30	27.0	8-30
0.15	7.15	0-10
Fineness Modulus = 2.33		

Table (4) – Physical properties of fine aggregate

Physical Properties	Test Results	Limits of the Iraqi specification No.45/1984
Specific gravity	2.60	-
Sulfate content	0.08 %	≤ 0.50 %
Absorption	0.75 %	-

Table (5) Grading of coarse aggregate

Sieve size (mm)	% Passing by weight	Limits of the Iraqi specification No.45/1984
14	100	100
10	88.6	85-100
5	10.8	0-25
2.36	0	0-5

Table (6) Physical properties of coarse aggregate

Physical Properties	Test Results	Limits of the Iraqi specification No.45/1984
Specific gravity	2.63	-
Sulfate content	0.06 %	≤ 0.1 %
Absorption	0.63 %	-

Table (7) Mix proportions of concrete specimens

Group	W/C	Water kg/m^3	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Polypropylene fiber(%)
1	0.48	190	400	593	1185	0
2	0.48	190	400	593	1185	0.4
3	0.48	190	400	593	1185	0.8

10. Mechanical properties

Compressive strength and modulus of ruptures tests were performed according to ASTM C39 and C78-84 respectively by using hydraulic machine available in materials laboratory of Engineering college of Al-mustansiriya university see Table (8).

11. Test results

Table (8) shows the results of test specimens with and without fire exposure for different ratio of polypropylene fiber. This Table shows that there is a small improvement in compressive strength of concrete.

When polypropylene fiber is mixed compressive strength increased by 12.7% when used 0.4% polypropylene fiber with respect to specimens without polypropylene fiber, the same manner can be seen when used 0.8% polypropylene fiber. The increase in compressive strength was 21.8%.

A good enhancement in modulus of rupture with increasing polypropylene fiber to 97% when adding 0.8% polypropylene fiber to the concrete mix. Also the behavior of beam with polypropylene fiber during load application was more ductile than the specimens without polypropylene fiber because the polypropylene fibers stretch more than concrete under loading.

Therefore, the composite system of fiber reinforced concrete is assumed to work as if it were non reinforced until it reaches its (first crack strength).

It is from this point that fiber reinforcement takes over and hold the concrete together , the maximum load carrying capacity is controlled by fibers pulling out of the composite.

Table (8) Compressive strength and modulus of rupture of concrete specimens

Specimens	Compressive Strength (MPa)				Modulus of Rupture (MPa)
	Room Temperature	250^{o}C	500^{o}C	750^{o}C	
Without PPF*	23.2	27.7	23.8	10.1	3.1
0.4% PPF	24.8	32.24	26.6	10.8	4.95
0.8%PPF	26.3	34.9	27.3	5.7	6.12

*Reference specimens

12. 12. Fire effect on compressive strength

It was observed that at 250°C there is an increase in compressive strength for specimens with polypropylene fiber and without polypropylene fiber, after that there is a decrease in compressive strength but still more than control specimens. At 750°C there a clear reduction in compressive strength of the samples with respect to control specimens.

From Table (8) it can be seen that the using of polypropylene fiber to be effective in improving fire resistance , where the increase in compressive strength for control specimens at 250 oC as example was (19.4 %) with respect to control specimens, on the other hand the increase in compressive strength with (4%) polypropylene fiber was (30%) and the increase in compressive strength for specimens with (0.8%) polypropylene fiber was (32.7%) with respect to control specimens, this is because the polypropylene fiber melting and being absorbed in the cement matrix; the fiber voids then provide expansion chambers for steam thus reducing the risk of reduction in concrete strength.

13. 13. Punching shear test results

13.1 Mode of failure

In general the first crack of the tested slab was observed in the tension face of slab., at this time the stresses in concrete exceeds the tensile strength of the concrete. The test results showed that adding polypropylene fiber effect on appearing of first crack in specimens slightly. The first crack opened at the center and extend to the edges of tested slab , with increasing the load the transverse cracks can be seen that then led to punching shear failure . This behavior can be seen in all slabs except slabs with (0.8 %) polypropylene fiber (R1 and B250CPPF0.8) , in this case the polypropylene fiber is effective in increasing punching shear strength , this reason make the slab fail in flexural. The specimens which subjected to 750°C fails by crushing the concrete at supports , see Plates below.

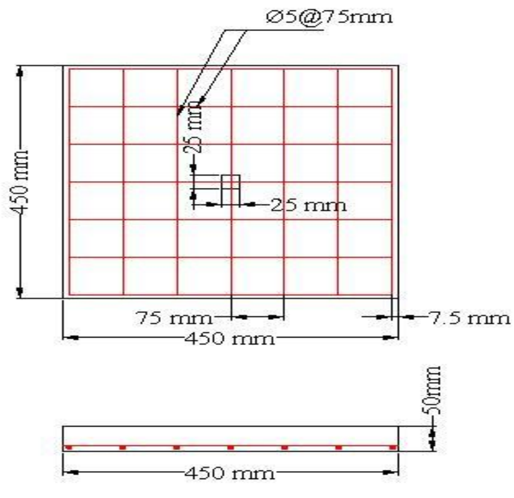

Figure (1) tested slab details

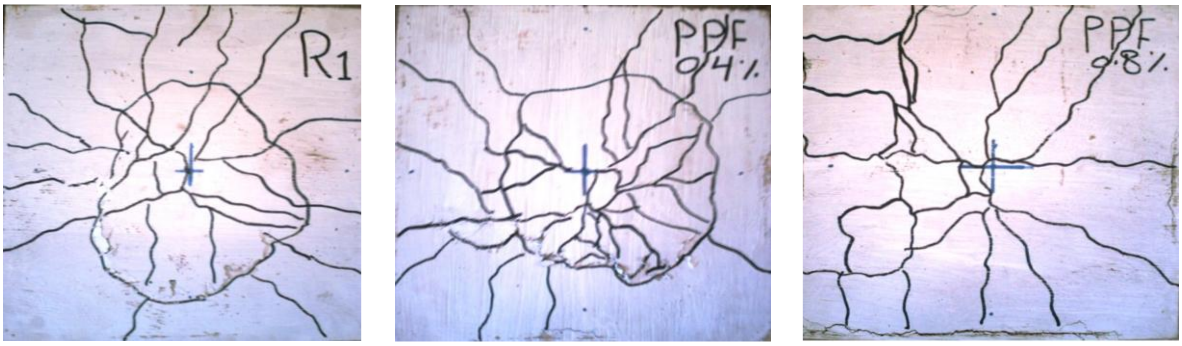

Plate (3) Failure mode for G1 slabs

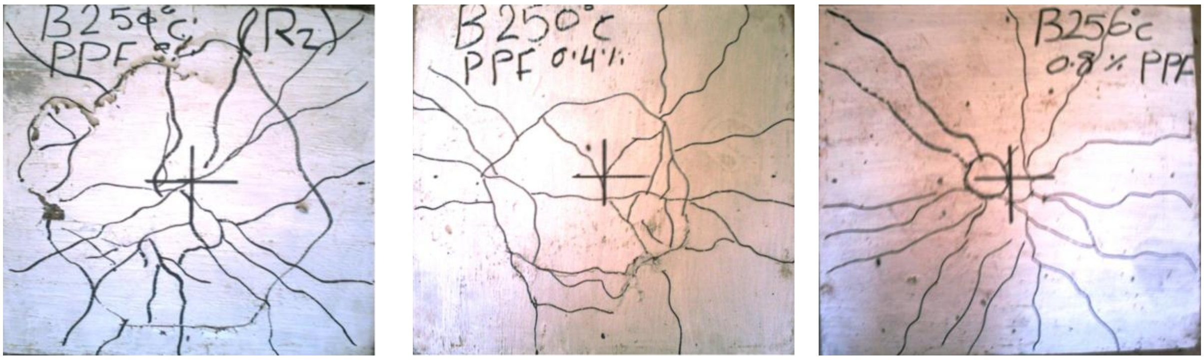

Plate (4) Failure mode for G2 slabs

Plate (5) Failure mode for G3 slabs

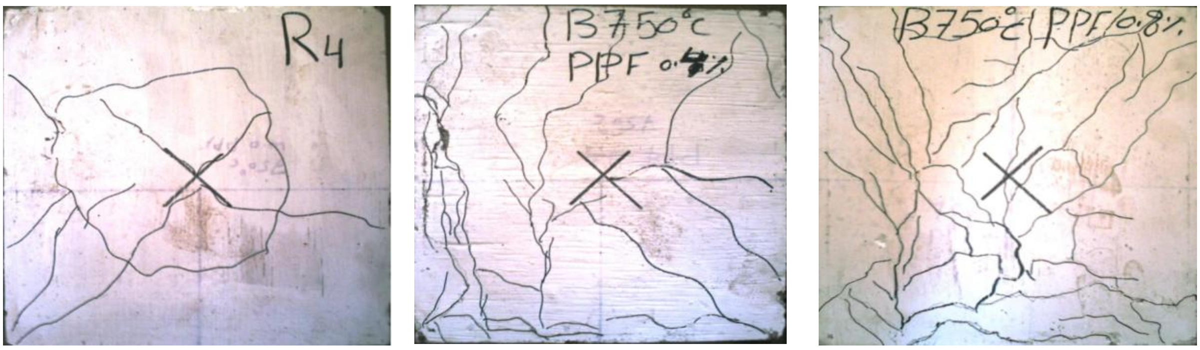

Plate (6) Failure mode for G4 slabs

13.2 Ultimate load capacity

The ultimate loads are listed in Table (9). According to these results, Samples with (0.4%) and (0.8%) polypropylene fiber had the highest ultimate failure load than the slab without polypropylene fiber by about (8.7 % and 34.8%) respectively because the polypropylene fiber effective in connection sides of the tension cracks , thereby increasing the slabs shear strength. At (250 ^{o}C) (G2: R2, B250CPPF0.4, B250CPPF0.8) had highest ultimate load than the samples in (G2) (without subjected to elevated temperatures) the reason is that the compressive strength of these samples (at 250^{o}C) was increased (see Table (9)). At 500^{o}C and over there is a drop in the ultimate failure load because there are a great drop in compressive strength and tensile strength of concrete.

Table (9) Ultimate load capacity

Group No.	*Specimen*	*Ultimate load (kN)*	*%Increase in ultimate load*
G1	R1	23	--
	PPF0.4	25	8.7
	PPF0.8	31	34.8
G2	R2	25	--
	B250CPPF0.4	28	12
	B250CPPF0.8	31	24
G3	R3	15	--
	B500CPPF0.4	15.5	3.3
	B500CPPF0.8	17	13.3
G4	R4	9	--
	B750CPPF0.4	4	--
	B750CPPF0.8	5	--

13.3 Load – deflection behavior

The load-deflection curve for all tested specimens are shown in Figures (2,3,4,5) each of four plots contains three curves ; one for the control specimen (without polypropylene fiber) and two for the specimens reinforced randomly distributed polypropylene fiber (0.4 and 0.8 %) respectively.

Deflection was measured at the center of tested specimens by means of (0.01 mm) dial gauge, and readings from this gauge were recorded for each load increment. There are three main stages can be seen in load-deflection curve, first linear zone shows that there is a linear relationship between load and deflection up to appearing first crack at the tension face of tested specimens, second linear zone can be seen after appearing first crack, at the advanced stages of loading application there are rapid increase in deflection with small increments in load, at the failure the deflection increase rapidly without any increment in load.

At the same stage of load application (at room temperature) the specimens with large amount of polypropylene fiber show a higher deflection than the specimens without polypropylene fiber, this beneficial result belong to increase in modulus of rupture for specimens with polypropylene fiber. At high temperatures this effect can't be seen because of melting of the polypropylene fiber in the concrete. At specimens (with room temperature and $250^{O}C$) were the concrete have a good properties the maximum deflection at failure higher than the specimens subjected to high temperatures.

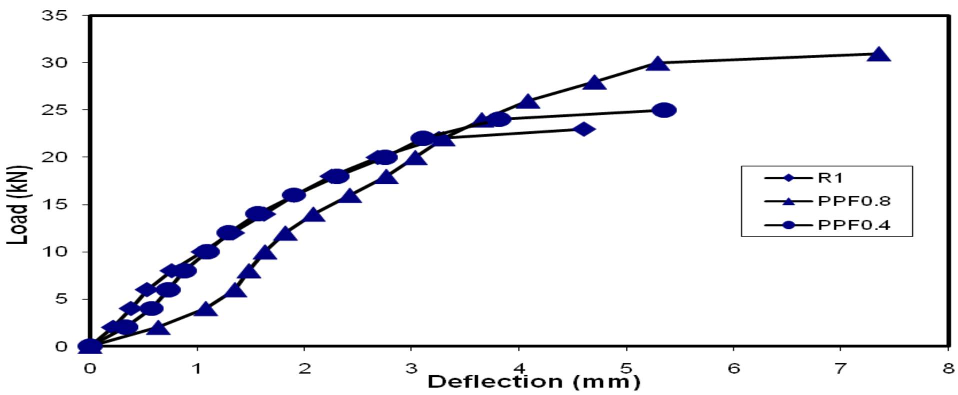

Figure (2) Load – deflection Curve for Slab(R1, PPF0.4, PPF0.8) at Room Temperature

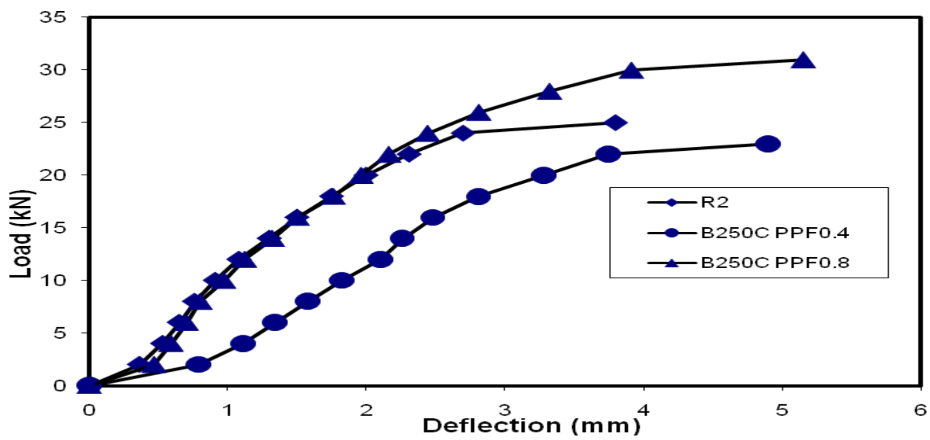

Figure (4) Load – deflection Curve for Slab(R3, B500PPF0.4, B500PPF0.8) at $500^{O}C$

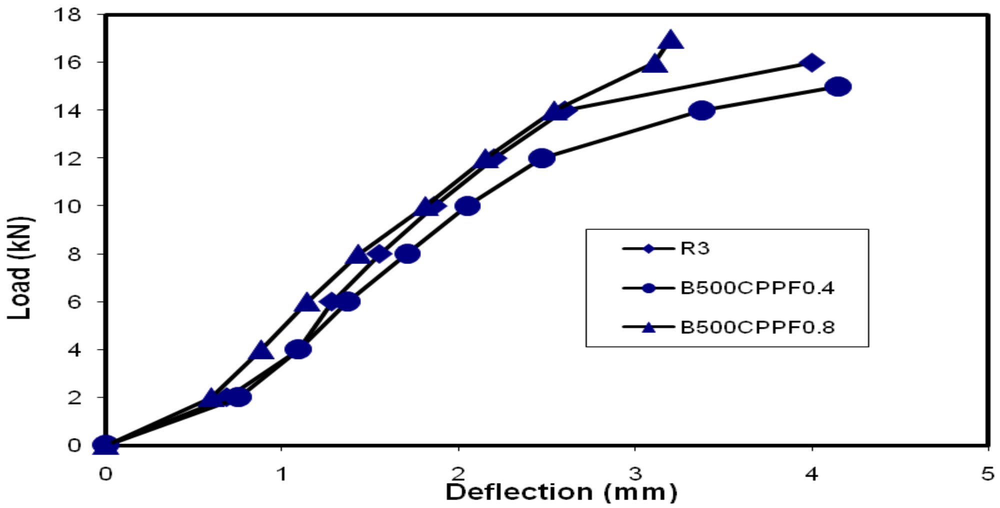

Figure (5) Load – deflection Curve for Slab(R3, B500PPF0.4, B500PPF0.8) at 500^{O}C

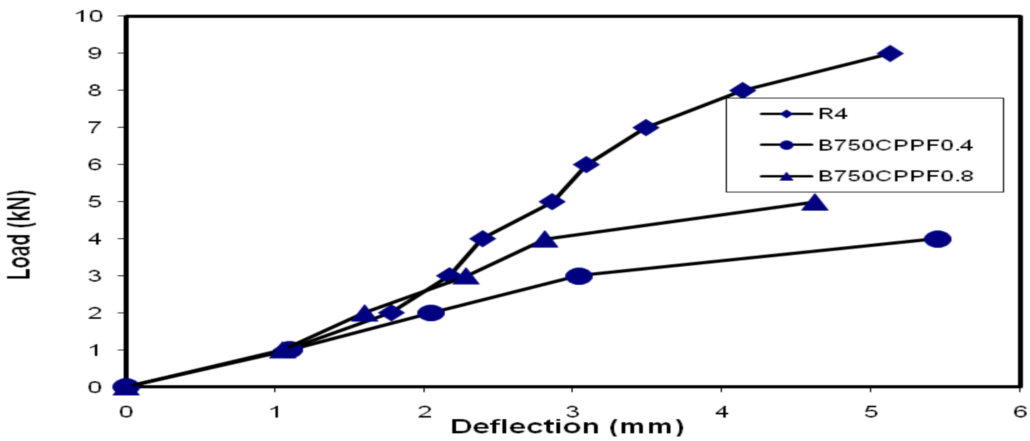

Figure (5) Load – deflection Curve for Slab Group (3) at 750^{O}C

14.Cracking due to elevated temperatures (thermal cracks)

In samples that contain polypropylene fiber, melting of polypropylene fiber at its fusion points will create a percolated network which is effective in increasing the amount of cracks in concrete panels and the specimens that contain the largest proportion of fiber has the largest amount of cracks this may be lead to increase permeability coefficient after heating, see Plates (7,8 and 9) below.

Plate (7) Thermal Cracking in panels without PPF

Plate (8) Thermal cracking in panels with (0.4%)PPF

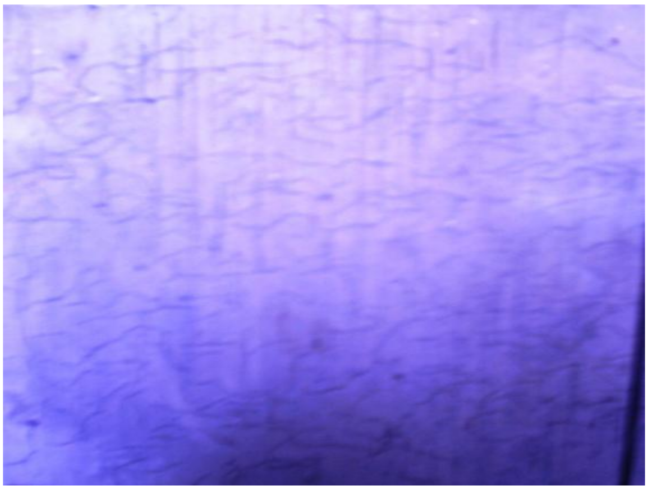

Plate (9) Thermal cracking in panels with(0.8%) PPF

From the plates above we see that the amount of cracks in the specimens which do not contain polypropylene fiber less than cracks in samples that contain (0.4%) polypropylene fiber, and the specimens which contain (0.4%) polypropylene fiber less than cracks in samples that contain (0.8%) polypropylene fiber Because the amount of fluid resulting from melting fiber in samples that contain fiber is greater than the amount of fluid dissolved in the samples do not contain fiber.

15. Conclusions

1. In general, there is a small improvement in compressive strength when adding polypropylene fiber.
2. There is a good improvement in modulus of rupture when increasing polypropylene fiber.
3. The compressive strength increase with increasing temperature up to 250^{O}C then there is reduction in compressive strength after 250^{O}C.
4. The specimens that are devoid and which contain (0.4%) polypropylene fiber fail by punching shear, and the specimens which contain (0.8%) polypropylene fiber fail by flexural, this gives the idea that the polypropylene fiber effective in increasing punching shear resistance.
5. Adding polypropylene fiber to specimens lead to increase the maximum load capacity at failure.
6. Specimens at room temperature and exposed to the temperature of 250^{O}C have carrying load capacity more the specimens exposed to 500^{O}C and above, when using the same percent of polypropylene fiber.
7. The deflection in the specimens that contain the largest quantity of polypropylene fiber is greater than deflection in the specimens that contain small amount.
8. The amount of cracks is directly proportional to increase the amount of polypropylene fiber.

16. References

1. R. Moss, "Flat Slabs for Efficient Concrete Construction", 2001, 4PP, www.cementindustry.co.uk .

2. ACI Code (318-08)," Building Code Requirements for Reinforced Concrete" American Concrete Institute, Detroit, Mich. 2008.

3. Nelson, A.H., " Design of Concrete Structures," The McGraw-Hill Co., 1997,780 pp.

4. Hawkins, N.M.," Shear Strength of Slabs with Shear Reinforcement", ACI special Publication, SP42-34, 1974, PP785-815.

5. Elgabry, A. and Ghali, A.," Design of Stud Shear Reinforcement For Slabs", ACI Structural Journal, Vol.87, No.3, May-June, 1990,PP350-361.

6. Marzouk, H. and Hussein, A.," Experimental Investigation on The Behavior of High Strength Concrete Slabs", ACI Structural Journal, Vol.88, No.6, Nov.-Dec. 1991, pp701-713.

7. Ahmed, F.R.," Punching Strength and Time-dependent Response of High Strength Concrete Panels", Ph.D Thesis, College of Engineering, Baghdad University, Baghdad, Iraq, November 2005,133P.

8. Al-Karkhy,H.F., " Punching Shear Strength of Polymer and Fiber Reinforced Polymer Modified", M.Sc Thesis , Al-Mustansiriya University, September- 2004.

9. R. Brown, A. Shukla and K.R. Natarajan "Fiber Reinforcement of Concrete Structures", University of Rhode Island, September 2002, 51PP, www.uritc.uri.edu.

10. ASTM E119-2000a," Standard Test Method for Fire Tests of Building Construction and Materials" , Annual Book of ASTM Standard, Vol.04.07, 2000, 21P.

11. Fahmi, H.M., " Influence of High Temperatures on Compressive and Tensile Strengths of Concrete", Journal of Building Research, Vol.5, No.2, 1986, PP85-102.

12. Nura, J.M., " Residual Strengths of Reinforced Normal Strength, High Strength, Lightweight Concrete Panels Exposed to High Temperatures ", M.Sc Thesis , Al-Mustansiriya University, May-2007.