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FLEXURAL BEHAVIOR OF REACTIVE POWDER CONCRETE BEAMS WITH VARIOUS TYPES OF FIBERS

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ABSTRACT

In this paper, experimental investigation were carried out to study the effect of two types of fibers (steel fibers SF and polypropylene fibers PPF) on flexural behavior as well as some important mechanical properties (compressive strength and splitting tensile strength) of Reactive Powder Concrete (RPC) compared with normal strength concrete (NSC). Ten reinforced concrete beams with dimensions of (100×150×1300) mm were tested to investigate the effect of fibers type, fibers volumetric ratio and concrete type on ultimate load (fcu), cracking load (fcr), ultimate deflection (Δ max), load-mid span deflection behavior and mid span strain distribution of all beams. Results indicated that the use of fibers in reinforced RPC beams is better than reinforced NSC beams due to more significant increase in first crack load and ultimate carrying capacity. Also, it was found that the deflection and strain were decreased as fibers content for both (SF and PPF) increased at all stages of loading while at ultimate load stage, as fibers content increases the deflection and strain will be reduced for beam with SF and they will be increased significantly for beams with PPF compared with non-fibrous beams.

Keywords: Reactive Powder Concrete (RPC), steel fibers (SF), polypropylene fibers (PPF).

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1. INTRODUCTION

The concrete industry in recent years has achieved success in producing new cement-based materials, which are characterized by several advantages not only high strength but also high flexibility (ductility), low permeability, low porosity ,limited shrinkage and high tensile strength. This type of concrete is known as reactive powder concrete (RPC) and also known as ultra-high strength concrete (UHPC) (Ibrahim, 2008)[1]. RPC is a cementitious material that exhibits high-performance properties such as limited shrinkage and creep, low permeability, ultra-high strength and increased protection against corrosion(Hekmet, 2014)[2]. (Yoo and Yoon, 2015)[3] investigated effect of using different fibres on the flexural behavior of reinforced UHPFRC beams. It was found that the ultimate moment capacity was not influenced by the fibers geometry whereas the post peak response and ductility was considerably improved by long steel fibres. (Yu et all, 2014)[4] investigated the impacts of cocktail fibers (steel fibers and polypropylene fibers) and nano-silica on the mechanical properties of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) blending waste bottom ash (WBA). The results of the test show that because of the presence of metallic aluminum particles in WBA, the created hydrogen can cause some visible macro cracks in the concrete, which could decrease the mechanical properties of UHPFRC. However, the flexural strength of UHPFRC can be improved and the negative impact resulting from WBA can be reduced by dual usage of cocktail fibers and nano-silica. The increase in silica fume content and steel fibers volumetric ratio lead to enhance load- deflection behavior and thus higher ductility and toughness of RPC (Ismael, 2013)[5].The 28-day compressive strength was increased by 2.5% when using of polypropylene fibers and by 6% when using of steel fibers compared with non-fibrous mixes. Without reliance of the longitudinal steel reinforcement ratio, it was found that the steel fibers were more efficient in increasing both the first crack and ultimate load. The ultimate loads was increased by 13% when used steel fibers in the beams with lower reinforcement ratios and web reinforcement.(Kamal et al., 2014)[6][7]. The used of polypropylene fibers in RPC lead to increase in compressive and tensile strengths (28 days) of concrete by almost 135% and 130% respectively, so high strength concrete can be produced economically. Also its found that the optimum PP-fibers content for compressive strength is 0.5% (by weight) (Rahman et al., 2016)[8]. The improvement in compressive strength of RPC return to the contribution of the steel fibers to the tensile capacity of the RPC, given an acceptable perception that concrete under a uniaxial compressive load failed because of lateral tensile strain induced by Poisson's ratio effects(Lee et al., 2005)[9].

2. EXPERIMENTAL WORK

2.1. Introduction

The experimental work of the present study will be clarified, which includes study the effect of fiber type on the flexural behavior (load deflection relationship, Longitudinal strains at mid-span by using demec points, first crack load and ultimate load capacity) of the RPC and NSC rectangular beams. Ten beams of RPC and NSC with dimension (100×150×1300) mm. Seven RPC beams were tested; one nonfibrous and three had (0.25%,0.5% and 0.75%) PPF volumetric ratio and the other three beams had (1%,1.5% and 2%) SF and three NSC beams were tested; one nonfibrous and one with o.25% PPF and the other beams had 1% SF compared with three beams of RPC containing (0%V_f,0.25% PPF,1%SF) respectively.

2.2. Materials Properties

2.2.1. Cement

Ordinary Portland cement (Type I) was used in this study produced from north of Iraq commercially known *Karasta*. It was conformed with (IQS NO.5/1984).

2.2.2. Fine Aggregate

For production of NSC, *Al-Ekhaider* natural sand with maximize of 4.75mm was used as fine aggregate. For production of RPC, very fine sand with maximum size of 600μm was used conform with the Iraqi Specification requirements IQS No.45/1984.

2.2.3. Coarse Aggregate

For production of NSC, crushed gravel with maximum size of 20mm was used conform to Iraqi Specification requirements IQS No. 45/1984.

2.2.4. Silica Fume

Silica is a ultra-fine powder which is pozzolanic materials consisting of round granules with a rate size of 0.15 micrometer which conform to requirements of (ASTM C1240/2005)[10]. These pozzolanic materials reacts with calcium hydroxide $Ca(OH)_2$ which results from the hydration of cement with water, resulting another calcium silicate hydrate (auxiliary gel).

2.2.5. Fibers

Two types of fibers were used in this study , Ultra-Fine Steel Fibers or Micro steel fiber (SF) and Micro polypropylene fibers (PPF). Figure (1) and (2) show the fibers used in this study. The properties of the used steel fibers and polypropylene fibers are presented in Table(1).

Figure 1 Ultra-Fine Steel fibers

Figure 2 Micro polypropylene fibers

Table 1 Properties of the fibers used

Type of fibers	Diameter mm	Length mm	Tensile strength MPa	Density Kg/m^3	Shape
SF	0.2±0.05	13	2300	7860	Straight
PPF	0.032	12	600-700	910	Straight

2.2.6. Mixing Water

Normal tap water was used for mixing and curing of concrete specimens.

2.2.7. High Range Water Reducing Admixture (HRWRA)

Hyperplast PC200 (Type G) complies with **(ASTM C494/2001)**.

2.2.8. Steel Reinforcement Bars

Two size of deformed steel reinforcement bars with nominal diameter (Ø8 and Ø6) were used in the design of all RPC and NSC beams conformed to **(ASTM A615-86)**.For main reinforcement deformed bars of nominal diameter (Ø8) were used in all RPC and NSC beams, and to prevent shear failure, lateral reinforcement (stirrups) deformed steel bars with nominal diameter (Ø6) were used in all RPC and NSC beams. Also,(Ø6) deformed steel bars were used in the upper reinforcement which had the only purpose to fix the stirrups.

2.3. Concrete Mix Design:

Two types of concrete mixes were used in this study:

2.3.1. Normal Concrete Mix:

The design of normal concrete mix according to **(ACI 211-1-91)**.

2.3.2. Reactive Powder Concrete Mixes:

According to previous researches, many trails mixes were used to get maximum compressive strength and flow (110±5)mm according to (ASTM C109; C109M/2002) and (ASTM C1437, 2005) Table (2) shows the concrete mixture used in this study.

Table 2 The concrete mixture which used in this study.

mix	**Mix proportion**							
	Cement Kg/m^3	**Sand kg/m^3**	**Gravel Kg/m^3**	**Silica Fume Kg/m^3**	**SF %**	**PPF %**	**w/cm & w/c ratio**	**super plasticizer (by wt. of cm) %**
RPC0	950	1010	-	250	0	0	0.17	6
RPC1	950	1010	-	250	1	-	0.17	6
RPC1.5	950	1010	-	250	1.5	-	0.17	6
RPC2	950	1010	-	250	2	-	0.17	6
RPC0.25	950	1010	-	250		0.25	0.17	6
RPC0.5	950	1010	-	250		0.5	0.17	6
RPC0.75	950	1010	-	20		0.75	0.17	6
NSC0	488	652	1010	-	0	0	0.42	-
NSC1	488	652	1010	-	1		0.42	-
NSC0.25	488	652	1010	-		0.25	0.42	-

2.4. Mixing Procedures

The mixing process of the RPC is very important and it is effective on the results of the workability. The mixing time must pay attention to it. The mixing time of the RPC is higher than the mixing time of the NSC because the mixture contains high cementitious materials and low w/cm ratio need more time to make superplasticizer penetrates between cementitious granules. In the current research, a small mixer of 0.01m3 was used for all trial mixtures, while a pan mixer of 0.1m3 was used for all the mixtures used in the cast of specimens and beams. At the beginning of mixing, it has been put all cementitious materials (cement + silica) and mixed in dry state for a period of (2 min) after that the addition of sand to a mixture of cementitious materials and mixing process was continuing for another (3min) to spread cementitious granules uniformly between the sand particles after that superplasticizer was dissolved in water and (80-85)% of the solution (superplasticizer + water) was added gradually to the dry mix for (3min) after that the mixing process was continuing for(5min) until access to the workability (liquidity) appropriate after that fiber were added gradually for period (2min) in a sprinkling motion to ensure the uniform dispersion and avoid of fibers balling. After the completions of the added fibers, mixing stop and cleaning the sides of the mixer if there are substances that are not included in the mixing process, this process takes about one minute. After that, restart operation of the mixer and add the remaining (superplasticizer + water) solution (20-15%). This addition improves the workability and the mixing of the fiber. The mixing process is continued for an additional (5 min) after that the mixture becomes ready to be poured. The fresh concrete shall be placed in three layers for the cylinder and two layers for the cube, prism, and the beams. After placing each layer, table vibrator was used to compact the layer and to minimize the air voids to ensure the exit of the bubble. After 24 hours, the specimens were removed from the molds and enter in the hot water curing tanks for period (48±1hour). finally, the all specimens will take out from the accelerated curing tank and then they were placed in normal water tank at (20±2 C°) until the day of the test.

2.5. Details of Beams

In this study seven of RPC and three NSC rectangular beams were used to measures the influence of some variables on flexural behavior these variables are:

1. Types of concrete (RPC and NSC).
2. Types of fibers (PPF and SF).
3. Percentage of fibers. Table (3) show the detail of the beams

Table 3 Detail of beams

Concrete type	Beam Designations	SF%	PPF%	Bottom Reinforcement	Top Reinforcement	Stirrups
RPC	B1-RPC0	0	0	2Ø8	2Ø6	Ø6@50mm
	B2-RPC1	1				
	B3-RPC1.5	1.5				
	B4-RPC2	2				
	B5-RPC0.25		0.25			
	B6-RPC0.5		0.5			
	B7-RPC0.75		0.75			
NSC	B8-NSC0	0	0			
	B9-NSC1	1				
	B10-NSC0.25		0.25			

2.6. Testing of Beams

At the age of 28 days, the all beams are removed from the normal curing tank and left until the test day at 56 age. before the day of the test, the beams were clean and then painted with white color to facilitate crack vision and also the demec points were fixed to measure the longitudinal strain at five equal distance at mid span for the section depth Figure (4). Each beam was placed on simply supported with two-point load at universal testing machine of capacity (3000 kN) and adjust the clear span between the simply supports of (1200)mm and between the two-point load of (400)mm as shown in Figure (3) and Figure (5).To avoid local failure and to distribute the load evenly on the supports, a small plate with a thickness of (15)mm was placed between the support and the face of beam. To measure the maximum deflection of the beam under load, a dial gage with accuracy of (0.025) mm was placed in the mid span so that the head of dial gage touch the bottom face of the beam .The value of deflection is recorded by recording the motion of the dial gage indicator by a small camera connected to a computer and also recording the load by another camera to return to the video through which it can be take many point to draw the load – deflection curve. After the completion of the preparation of the test, the load was applied at rate 0.1 kN/sec until failure occur and the longitudinal strain reading was taken every 10 kN load by the extensometer device accuracy of (0.001)mm.

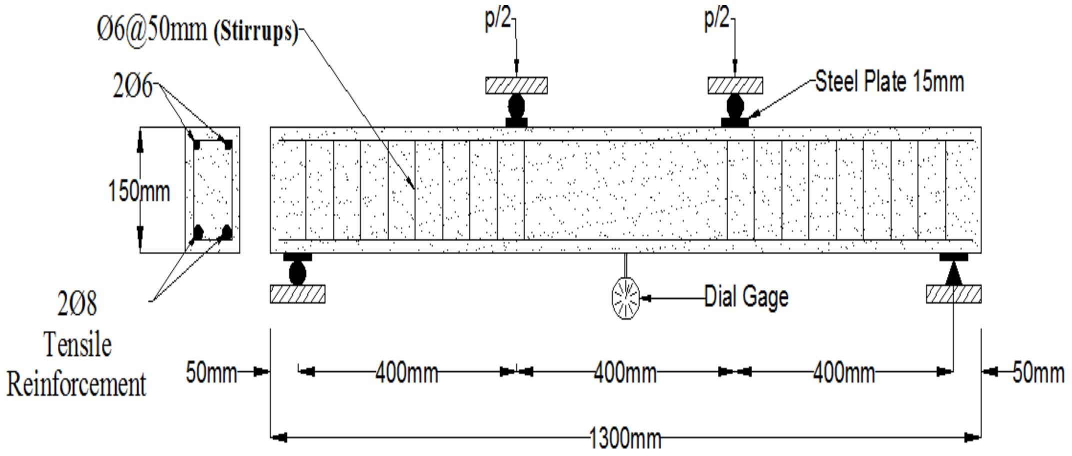


Figure 3 Schematic of RPC R-beam.

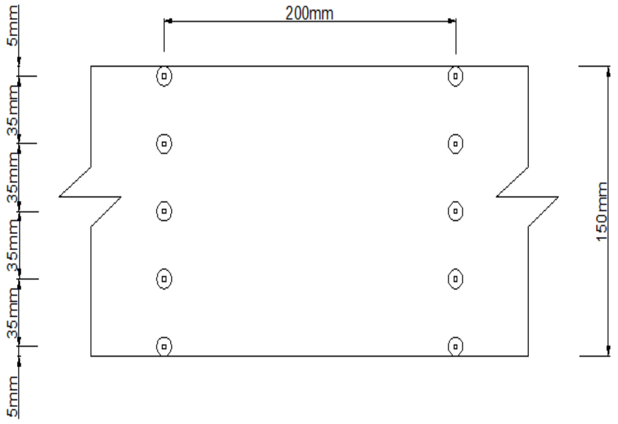


Figure 4 Beam side view showing locations of demec points

Figure 5 One of the beams on the testing.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties of RPC and NSC

Standard cube specimens with dimension of (50×50×50)mm were used to test the compressive strength (f_{cu}) of RPC and standard cylinders specimens with dimension of (100×200)mm were used to test the splitting tensile strength. The test results of RPC are shown in Table (4) and Figure (6) and (7). It can be seen from results that PPF have less effect than SF and this can be explained as PPF is a weak material which produces a concrete with poorer workability, more bleeding and segregation, with relatively higher entrapped air **(Ibrahem, 2008; Selvaraj and Priyanka, 2015)**[1][11]. In contrast to the compressive strength, the results of the splitting tensile strength tests, indicated in Figure (5) clearly showed the benefit of fibers. Where the presence of fibers in concrete restrains the development of internal microcracks and thus contributes to an increase in tensile strength.

Table 4 Compressive and splitting tensile strength of RPC

Mix Type	Compressive Strength (MPa) at 28 days	%Increasing with respect to RPC0	Splitting Tensile Strength (MPa) at 28 days	%Increasing with respect to RPC0
RPC0	108.4	-	8.52	-
RPC0.25	111.2	2.6	9.21	8.1
RPC0.5	115.2	6.3	9.71	14.0
RPC0.75	119.9	10.6	10.84	27.2
RPC1	130.3	20.2	13.27	55.8
RPC1.5	137.6	26.9	15.68	84.0
RPC2	146.9	35.5	16.26	90.8

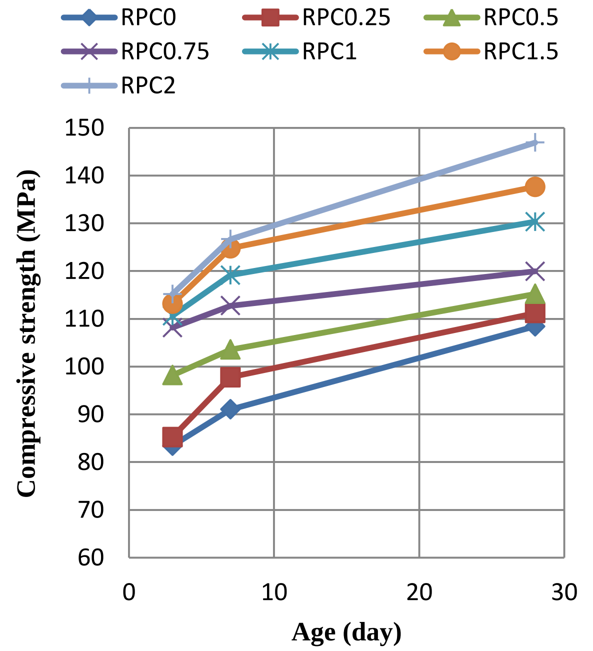


Figure 6 Compressive strength of RPC mixes

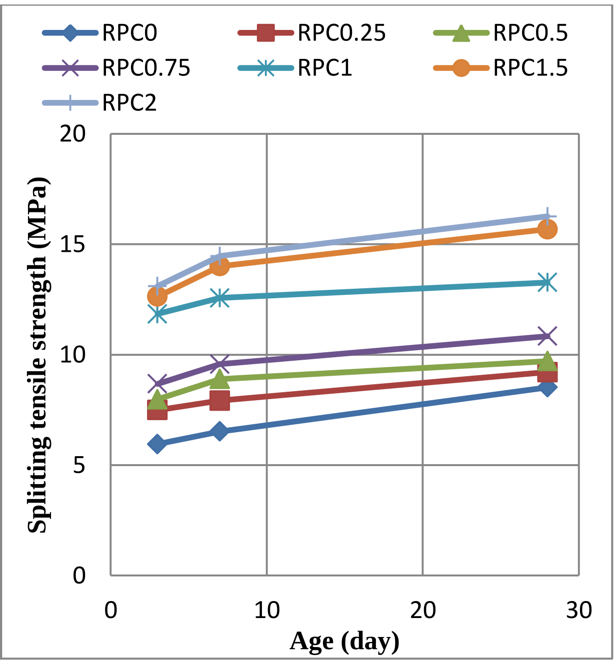


Figure 7 Splitting tensile strength of RPC mixes.

3.2. Flexural Beams Results

The beams were tested under two point loading. Table 5 shows the experimental test results of RPC and NSC beams.

Table 5 Experimental test results of RPC and NSC beams.

Beam Designation	First Crack Load Fcr (kN)	Ultimate Crack Load Fu (kN)	Reserve Strength	Deflection at First Crack Load Δc(mm)	Deflection at Ultimate Crack Load Δu(mm)	Ductility	Stiffness	Mode of Failure
B1-RPC0	8.00	41.52	419	1.60	26.78	16.74	1.550	Yielding of Tension Steel followed by secondary compression failure
B2-RPC0.25	9.40	45.28	382	1.37	30.21	22.05	1.499	
B3-RPC0.5	9.88	47.16	377	1.55	34.87	22.50	1.353	
B4-RPC0.75	10.83	50.86	370	1.63	37.80	23.19	1.346	
B5-RPC1	13.56	60.78	348	0.91	17.93	19.70	3.390	Yielding of Tension Steel
B6-RPC1.5	20.24	66.16	227	1.37	17.78	12.98	3.720	
B7-RPC2	23.18	72.34	212	1.52	16.98	11.17	4.260	
B8-NSC0	7.84	39.12	399	0.64	24.89	38.89	1.572	Yielding of Tension Steel followed by secondary compression failure
B9-NSC0.25	8.84	42.10	376	0.79	27.43	34.72	1.535	
B10-NSC1	11.05	44.90	306	0.84	23.11	27.51	1.943	

3.2.1. Effect of Volume Ratio of Fibers (V_f)

It can be seen from Table (5) that the first cracks of nonfibrous beam B1 appeared when the load reached 8kN and the failure occurred when the load reached 41.52kN. Hence the cracking load actually represented at about 19.27 % of ultimate flexural failure load. With addition of SF or PPF both the first cracking load and ultimate load increase. For PPF, Table (5) shows that when the fiber volumetric ratio increased from 0% in beam B1 to 0.25% in beam B2 to 0.5% in beam B3 and 0.75% in beam B4, the first cracking load increases to 9.4kN to 9.88kN and 10.83kN which represents an increase of 17.5% to 23.5% and 35.38% respectively as compared with the control nonfibrous RPC beam B1 (Fcr=8kN). Also for the same increase in the volumetric ratio of fibers, the ultimate flexural strength increases to 45.28kN to 47.16 and 50.86kN which represent an increase of 9.06% to 13.58% and 22.50% respectively as compared with the control nonfibrous RPC. The same conclusion was reported by (Ibrahem, 2008 and Rathi et al., 2013)[1][12].For SF, Table (5) shows that when the fiber volumetric ratio increased from 0% in beam B1 to 1% in beam B5 to 1.5% in beam B6 and 2% in beam B7, the first cracking load increases to 13.56kN to 20.24kN and 23.18kN which represents an increase of 69.50% to 153.0% and 189.75% respectively as compared with the control nonfibrous RPC beam B1 (Fcr =8kN). Also for the same increase in the volumetric ratio of fibers, the ultimate flexural strength increases to 60.78kN to 66.16kN and 72.34kN which represent an increase of 46.39% to 59.34% and 74.23% respectively as compared with the control nonfibrous RPC. The same conclusion was reported by (Ibrahem, 2008; Ismael, 2013; Ma'roof, 2013 and Mohammed, 2016)[1][5][13][14]. These increases in first and ultimate load with increase SF volumetric ratio belong to the reason that fibers across the initiating flexural cracks restricted growth and extension of the cracks and transmit the tensile stresses uniformly to the concrete surrounding the cracks resulting in more bearing capacity, also SF improves the bond between the matrix and the reinforcing bars by inhabiting the growth of cracks. Also it was found that the reserve strength for all RPC beams decrease with increase of volume fraction of fibers. It can be noticed from Table (5) at the same content of fibers, the effect of fibers on the percentage increase of the ultimate load of RPC beams is greater than that corresponding of NSC beams.

3.2.2. Load–Deflection Relationship

Typical load-deflection curves for RPC and NSC beams reinforced with either SF or PPF are shown in Figures (8) and (9) respectively. It can be seen from these Figures that the all beams which reinforced with PPF have higher deflection than which reinforced with SF. It can also be seen from Table (5) that B7-RPC2 (RPC beam with 2% SF) has a higher failure load of 72.34kN, with a mid-span deflection of 16.98mm, while B4-RPC0.75 (RPC beam with 0.75% of PPF) has a failure load of 50.86kN with a higher mid span deflection of 37.80mm. For polypropylene fibers, it was found that the ductility of beams show in Table (5) increased with the increase in volume fraction of fibers but for steel fibers it was found that the ductility decreased with the increase in volume fraction of fibers. This is due to the higher ultimate deflection for beams reinforced with PPF at the moment of failure compared to beams reinforced with SF which the ultimate deflection at the moment of failure is less. From Figures (8) and (9), it can be seen for all RPC and NSC beams that the deflection with the same load before failure was decreased with increase of volume fraction of fibers for both PPF and SF this due to the increasing of stiffness of the beam for resisting the deflection. At failure for RPC and NSC beams, it can be seen that from Figure (9) where the SF content increase the deflection value decrease through the beam B5 into B7. The results leads to saying that increasing the stiffness of the beam for resisting the deflection. The same conclusion was reported by (**Mohammed, 2014)**[15]and **(Yoo and Yoon, 2015)**[3]. Also at failure for RPC beams, it can be seen that from Figure (8), where the PPF content increased the deflection value increase through the beam B2 into B4. The results leads to saying that decreasing the stiffness of the beam for more ductility and deflection.

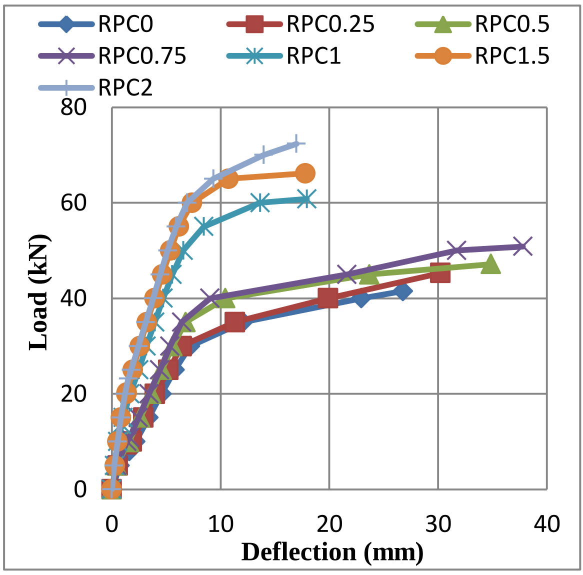


Figure 8 Load Deflection Curves of RPC beams

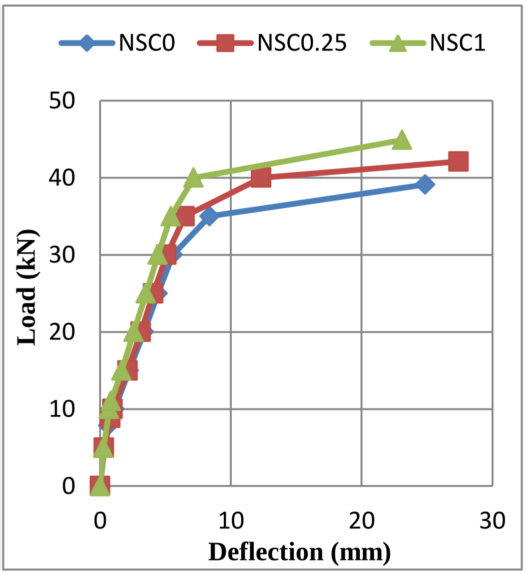
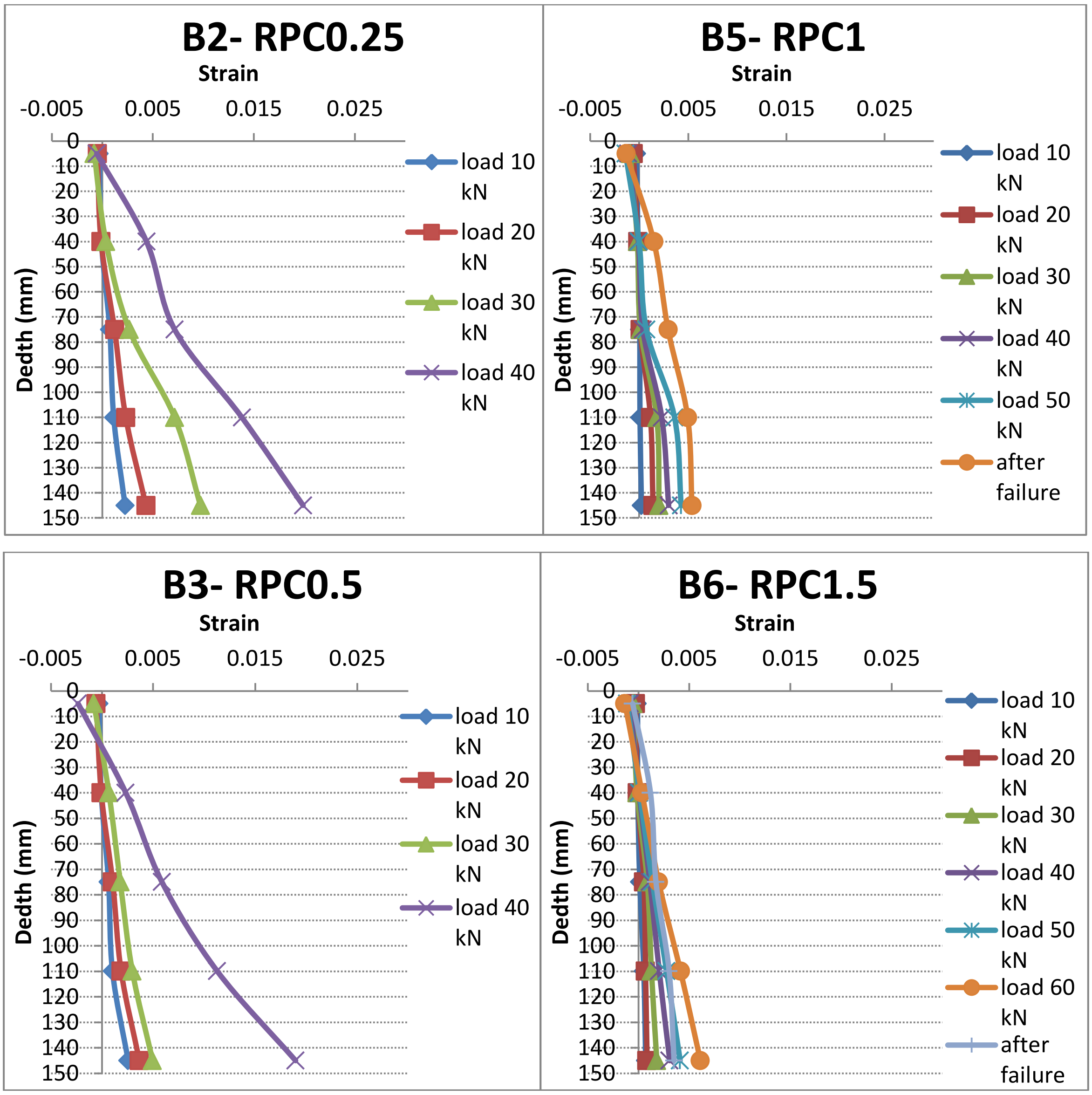
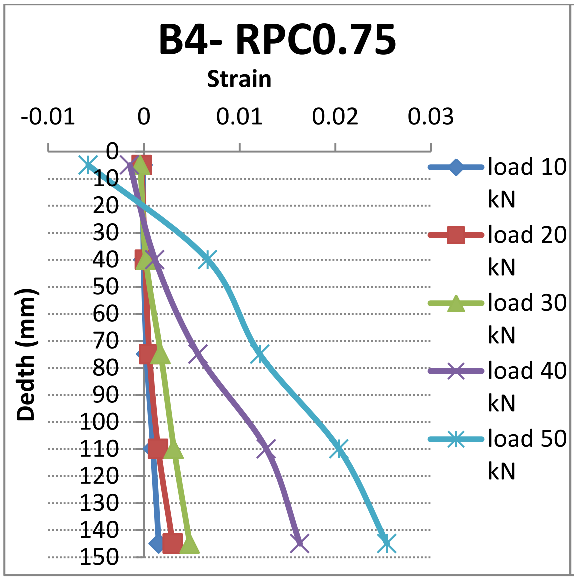


Figure 9 Load Deflection Curves of NSC beams

3.2.3. Strain Distribution

The strains in the concrete at midspan section of the tested beams were measured using demic point with 200mm gage length at five various levels across the depth of every beam as shown in Figures (10) and (11). These Figures reveal that the strain concentration settled relatively straight in the compression region through the loading stage. Whilst in the tension region, the strain concentration was relatively straight at lowering loads and become nonlinear at larger loads due to cracking. It can be noted that the presence of fibers (especially polypropylene fiber) leads to increase ultimate concrete strain at both tension and compression zones but the influence is more significant in the tension zone, this can be attributed to the better activity of fibers in the tension rather than in compression. Also it can be seen from these Figures that the increase of percentage of fibers led to decrease the concrete strain during loading before failure but the ultimate concrete strain increased. Moreover, Figures of beams strain distribution record that as the load rises, neutral axis position drives up across the compression region of the cross-section because of the development of tension cracks and through increasing load, tension cracks increase in width and number.





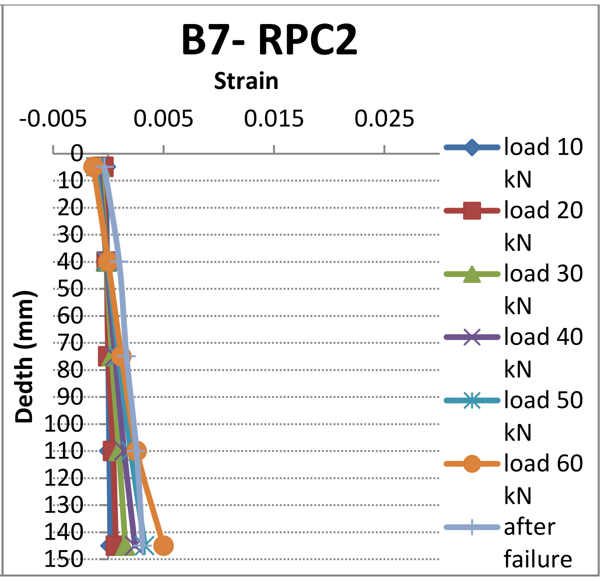


Figure 10 Strain distribution of RPC with PPF **Figure 11** Strain distribution of RPC with SF

3.2.4. Crack Patterns and Mode of Failure

It can be noticed for beams with the same type of fibers, it was found that the mode of failure was not highly effect with increasing volume fraction of fibers (Vf) (Hannawayya, 2010)[15] while (fibers type) played a major role, by observing the mode of failure for RPC beams container with PPF and without fibers, it is noted that the mode of failure in these beams is (Yielding of Tension Steel followed by secondary compression failure)compared with mode of failure for RPC beams contain SF which be only (Yielding of Tension Steel) this is due to:

1. Increasing of ultimate deflection for beams containing polypropylene fibers with comparison of beams containing steel fibers which leads to increase the strain of concrete at compression zone and exceeded the ultimate strain of concrete (ε_{cu}) at moment of failure.
2. Decreasing of compressive strength of RPC specimens with polypropylene fibers and without fibers with comparison of specimens of RPC with steel fiber which is higher compressive strength.

It can be seen that the mode of failure at compression zone (crushing) for B1-RPC0 is more visible this is due to lack of fibers which bonds the components and decrease the brittleness. Figure (12) show the mode of failures of RPC beams.

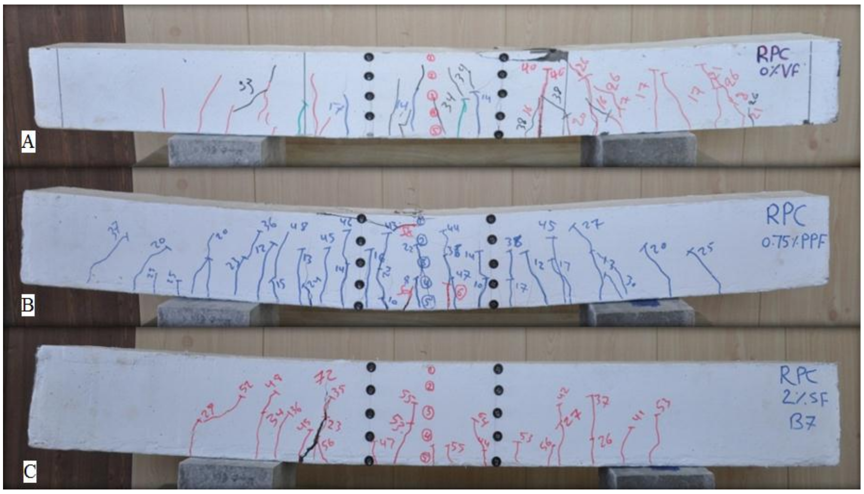


Figure 12 Mode of failures of RPC (A)0%V_f ,(B)0.75%PPF and (C)2%SF.

4. CONCLUSIONS

1. RPC mixes with steel fibers exhibit higher value of (compressive strength and splitting tensile strength)(146.92 and 16.26)MPa respectively at 28 days age.
2. For RPC mixes with steel fibers, the results show that the (compressive strength and splitting tensile strength) will be increased by (12.70 and 22.5)when the percentage of fibers increased from 1 to 2% respectively at 28 days age.
3. For RPC mixes with polypropylene fibers, the results show that the (compressive strength and splitting tensile strength) will be increased by (7.8 and 17.70)% when the percentage of fibers increased from 0.25 to 0.75% respectively at 28 days age.
4. For RPC and NSC beams, increasing the fibers content in the sections, increase the first crack load and ultimate carrying capacity of beam and this increase is higher for beams with steel fibers compared to beams with polypropylene fibers.
5. The use of fibers in RPC reinforced beams is better than in NSC beams due to more significant increase in first crack load and ultimate carrying capacity.
6. For both RPC & NSC reinforced beams, the use of steel fiber will be increased the compressive strength of the section and increase the stiffness of beam to decrease the deflection in contrast of polypropylene fiber which decrease the stiffness of beam to increase the deflection.
7. Before cracking stage for all beams, as fiber content increase for both (SF and PPF) the deflection will be reduced compared with non-fibrous RPC beams.
8. At ultimate load stage, as fibers content increase the deflection will be reduced for beam with steel fibers and it will be increased significantly for beams with polypropylene fibers compared with non-fibrous RPC beams.
9. for polypropylene fibers, as fibers content increase the ductility of the beam will be increase gradually but for steel fibers, the optimum of fibers content to increase the ductility is 1% and then the ductility decreases when fibers content increase from 1% to 2%.

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