Punching Shear Resistance of Reactive Powder Concrete Flat Slabs

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Abstract

This work is devoted to studying the mechanical properties of reactive powder concrete(RPC) and modified reactive powder concrete (MRPC) as a material as well as studying the punching shear behavior of RPC and MRPC slabs. The experimental program includes investigating the effect of steel fiber volumetric ratio (V_f) and absence of coarse aggregates on some important mechanical properties of RPC and MRPC such as compressive strength, uniaxial stress-strain relationship in compression, splitting tensile strength and modulus of rupture. Additional experimental tests are also conducted to study the effect of V_f, steel reinforcement ratio (ρ) and slab thickness on the punching shear behavior (in terms of load-deflection response, load-strain response and ultimate failure load) of simply supported reinforced RPC slabs having dimensions of 1000×1000× 50 or 70 mm under concentrated load at the center of the slab.

Keywords : MRPC , steel reinforcement ratio (ρ) , steel fiber volumetric ratio (V_f)

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1.Introduction

Reinforced concrete slabs may be carried directly by the columns without using beams, drop panels or column capitals. Such slabs are described as "flat plates". This type of structure has more space in addition to its pleasant appearance. Flat plates have been widely used due to the reduced construction cost. They are also economical in their formwork and lead to simpler arrangement of flexural, reinforcement. An additional advantage of a flat plate is reduced building storey heights that result in more usable space in buildings for a given or limited height. Many other advantages can be achieved by flat plates, such as a reduction in dead loads on the columns and foundations [1].

One of the major problems in such structures is the punching shear failure (also known as two-way action shear) that takes place when a plug of concrete is pushed out from the slab immediately above the columns. The pushed plug takes the from of a frustum cone or a cutoff pyramid with a minimum cross section at least as large as the loaded area[2]. Punching shear failure of slabs is usually sudden and leads to progressive failure of flat plate structures; therefore, caution is needed in the design of slabs and attention should be given to avoid the sudden failure condition.

2. Reactive Powder Concrete

Research over the past decade has yielded a new classification of concrete called Reactive Powder Concrete (RPC) now labeled and classified as Ultra-High Performance Concrete (UHPC). UHPC tends to exhibit superior properties such as advanced strength, durability and long-term stability that make it well suited for use in a wide variety of structural and nonstructural applications.[3]

The RPC concept is used on the principle that a material with a minimum defect, such as microcracks and inside voids, will possess a greater load carrying capacity and greater durability.

This can be possible according to the following concept [4] .

1) Eliminating all the coarse aggregates.
   The homogeneity of the concrete material can be improved by eliminating all the coarse aggregates and making, as much as possible the dry components material of the same particle size. All the dry components used in RPC are less than 0.6 mm in particle size.
2) Very low water- cement ratio.
   The water cement ratio used in RPC ranges approximately from 0.15 to 0.23. This range of w/c ratio produces not only the highest range of strength, but also ensures that all the water in the mixture will be combined in producing calcium silicate hydrate (C-S-H) [5].
3) The microsilica or another suitable pozzolanic material. In RPC materials with high silica content are necessary for optimum performance.
4) Very fine sand
   The largest particles size in RPC are in the aggregate which is the sand (300 – 600 μm), the next largest particle size is cement (100 μm), the smallest particles size is silica fume, which is in the order of (0.1 μm) in diameter.

The volumes of these particles are selected to achieve the greatest particle packing and hence the greatest density of the paste [6].

5) The steel fibers
They are used in order to increase the concrete ductility and improve its splitting tension, and rupture strengths [7].

6) Applying the pressure and heat treatment
They may be helpful to get rid of excess water and to increase the paste density, and can improve chemical process and strength gain.

The above composition and casting lead to the following properties of RPC:

1- Ultra compressive strength (200-800 MPa) combined with higher shear capacity.
2- Static Young's modulus higher than ordinary concrete and can range from 29 – 74 GPa [8].
3- Tensile strength ranging from 20 to 50 MPa, twice as strong as normal concrete in compression [9].
4- Fracture energies ranging from 20000 to 40000 J/m^2 [10].
5- Flexural strength ranging from 30 to 141 MPa[10].
6- Its low and non-interconnected porosity making penetration of liquids, gases or radioactive elements nearly nonexistent.
7- Enhanced abrasion resistance provides extended life for bridge decks and industrial floors [11].
8- Superior corrosion resistance provides protection from de-icing chemicals and continuous exposition to humid environments [12].

3. Experimental Program

In the experimental work, control specimens were cast which were three cylinders and four cubes for compression test, one cylinder for compressive stress-strain diagram, three cylinders for splitting strength and three prisms for modulus of rupture. Details of these control specimens are shown in Table (1) .

Table (1) Details of the control specimens

Type of test	Number and type of specimens	Specimens dimension mm
Compression	3 cylinders	100X200
	4 cubes	100 X 100 X100
Compression stress strain	1 cylinder	150X300
Splitting tensile strength	3 cylinders	100X200
Modulus of rupture	3 prisms	100X100X500

Four variables are investigated in this study to show their effects on the punching shear strength of the RPC slabs. These variables are:

1. Percentage of steel fibers.
2. Flexural steel reinforcement ratio.
3. Thickness of slab.
4. Type of concrete (RPC &MRPC) .

Table (2) illustrates the details of all the test slabs.

Table (2) Details of all the test slabs of the present investigation

Group No.	Slab Designation	Flexural steel reinforcement	Steel reinforcement ratio (ρ)	Steel fibers % by volume	Slab thickness (mm)
Group One (Normal concrete slabs as reference slabs) (CC)	S1	Ø 4mm @ 100mm c/c	0.0033	0	50
	S2	Ø 6mm @ 150mm c/c	0.0033	0	70
	S3	Ø 4mm @ 50mm c/c	0.0066	0	50
	S4	Ø 6mm @ 75mm c/c	0.0066	0	70
Group Two (R0)	S5	Ø 4mm @ 50mm c/c	0.0066	0	50
	S6	Ø 4mm @ 100mm c/c	0.0033	0	50
	S7	Ø 6mm @ 75mm c/c	0.0066	0	70
	S8	Ø 6mm @ 150mm c/c	0.0033	0	70
Group Three (R1)	S9	Ø 6mm @ 150mm c/c	0.0033	1	70
	S10	Ø 6mm @ 75mm c/c	0.0066	1	70
	S11	Ø 4mm @ 50mm c/c	0.0066	1	50
	S12	Ø 4mm @ 100mm c/c	0.0033	1	50

Table (2)

Group Four (R2)	S13	Ø 6mm @ 75mm c/c	0.0066	2	70
	S14	Ø 4mm @ 50mm c/c	0.0066	2	50
	S15	Ø 4mm @ 100mm c/c	0.0033	2	50
	S16	Ø 6mm @ 150mm c/c	0.0033	2	70
Group Five (MR2)	S17	Ø 6mm @ 75mm c/c	0.0066	2	70
	S18	Ø 6mm @ 150mm c/c	0.0033	2	70
	S19	Ø 4mm @ 50mm c/c	0.0066	2	50
	S20	Ø 4mm @ 100mm c/c	0.0033	2	50

4.Mixing Procedure

In this study, mixing was performed by using 0.19 m^3 capacity horizontal rotary mixer. Before using the mixer, any remaining concrete from a previous batch was cleaned off. A damp cloth was used to wipe the pan and the blades of the mixer. The silica fume powder was mixed in dry state with the required quantity of sand for 5 minutes to ensure uniform dispersion of the reactive powder particles throughout the sand particles. Then, cement was loaded into the mixer and mixed for another 5 minutes. The required amount of tap water was added to the rotary mixer within 1 minute. Then all the superplasticizers were added and mixed for an additional 5 minutes . Finally when steel fibers were used, they were introduced, and dispersed uniformly. These were added slowly to the rotary mixer after the rest of the materials had been properly mixed and the concrete had a wet appearance and mixed for an additional 2 minutes. Also hand mixing was done after adding the required quantity of fibers to prevent segregation or balling of fibers during mixing. This procedure is similar to the method used by Wille et al [13] which was used successfully to produce RPC with compressive strength exceeding 150MPa without using heat curing; this is a major factor in the process of production, especially in this country.

5.Results and Discussions

5-1 Concrete Compressive Strength

The test results of RPC and MRPC cube and cylinder compressive strength are shown in Figures (1) and (2) in which it is clear that increasing the steel fiber volume ratio increases the compressive strength. The percentage increase in the cube compressive strength (f_{cu}) is higher for higher ratios of steel fibers reaching up to (176.57%) for the volume ratio of steel fibers that equals 2 %. This is significantly higher for (f'_c), where it is (214.66%) with 2% steel fibers volume ratio.

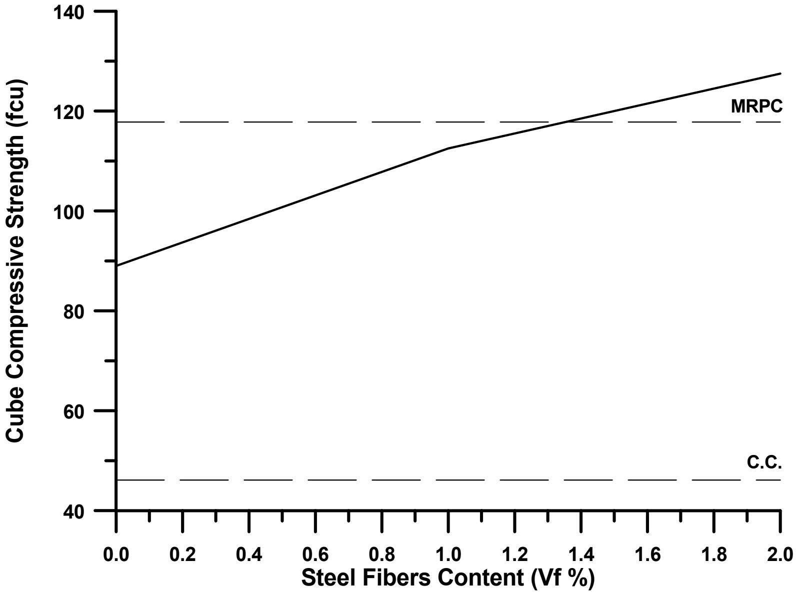

Figure (1): Effect of steel fibers content on (100mm) cube compressive strength

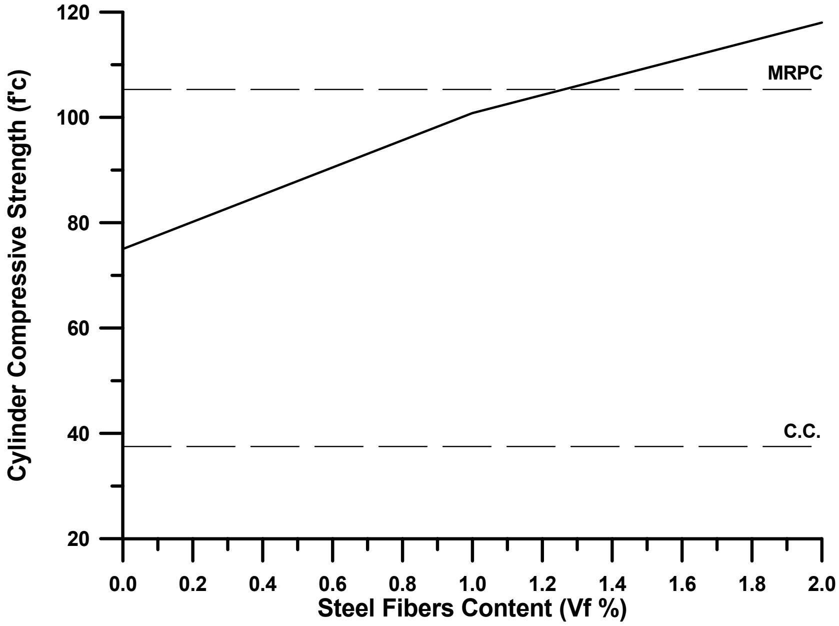

Figure (2): Effect of steel fibers content on (100 X200mm) cylinder compressive strength

5-2 Splitting Tensile Strength

The contribution of steel fibers to the improvement of splitting tensile strength of RPC is significantly higher than its contribution to the improvement of compressive strength. Referring to Figure (3) , the splitting tensile strength of RPC cylinders can be increased up to (308.26%) as steel fibers volume ratio increases from 0 to 2%.

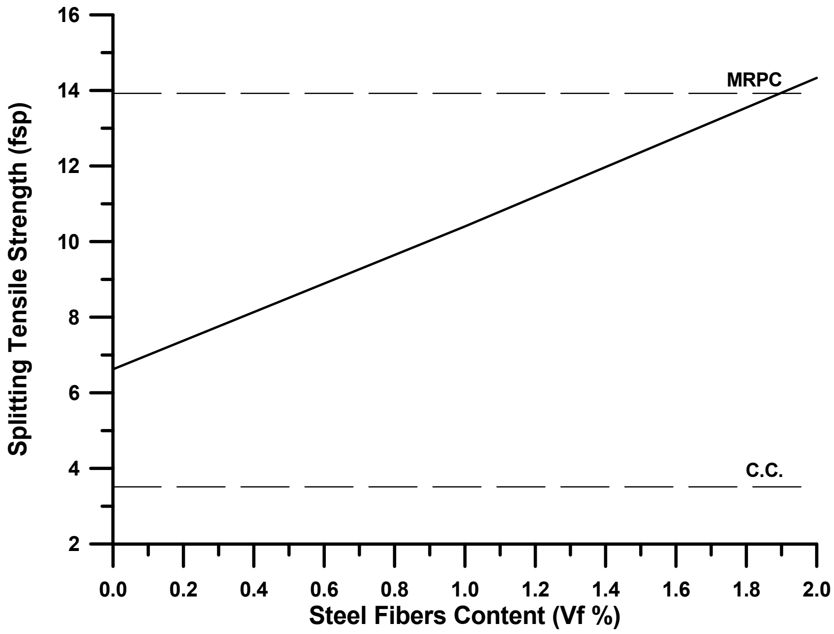

Figure (3): Effect of steel fibers content on splitting tensile strength

5-3 Modulus of Rupture

Figure (4) show the effect of changing the steel fiber volumetric ratio on the modulus of rupture of RPC, where it is clear that changing steel fibers ratio from 0 to 2% increases the modulus of rupture by 405.54% .

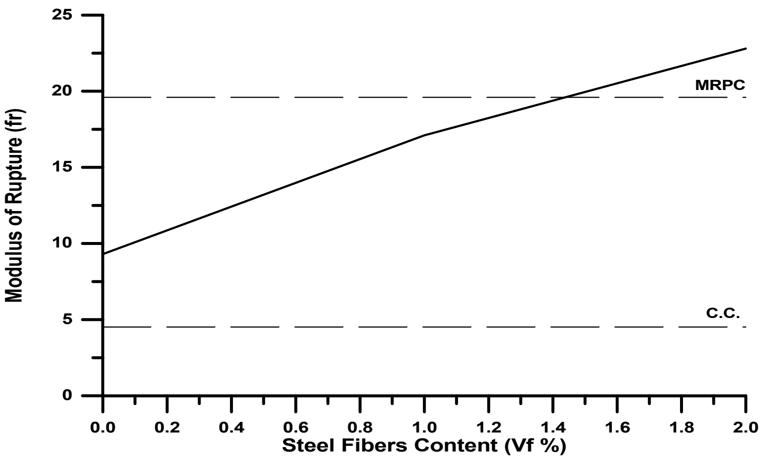

Figure (4): Effect of steel fibers content on modulus of rupture

5-4 Modulus of Elasticity

The effect of increasing steel fiber volumetric ratio on modulus of elasticity is shown in Figure (5). In general increasing steel fiber ratio increases the modulus of elasticity, and this can be attributed to the fact that the ascending part of the stress-strain curve becomes steeper as the steel fiber ratio increases.

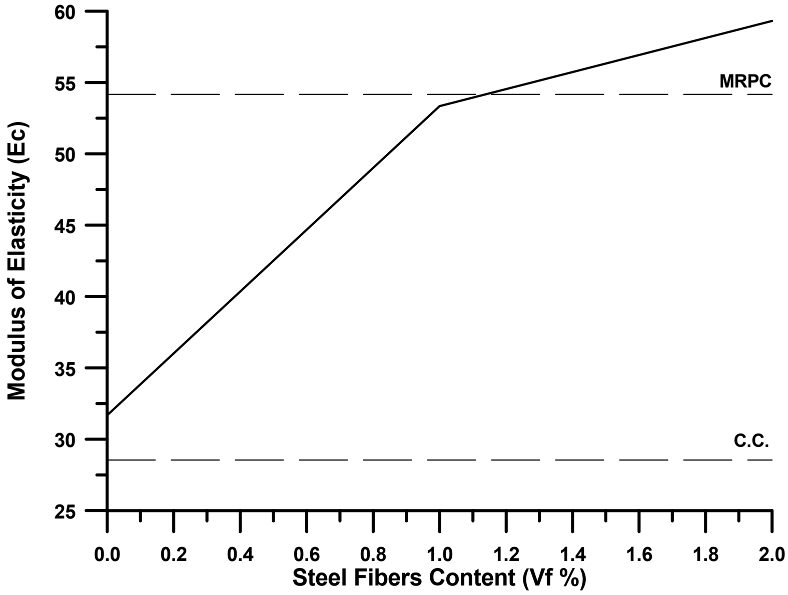

Figure (5): Effect of steel fibers content on modulus of elasticity

5-5 Slab Punching Shear Test Results

5-5-1 Load-Deflection Characteristics

In this study, 20 slabs were tested. These slabs are identical in size, different in concrete type (C.C., RPC and MRPC), fiber volume fraction, flexural steel reinforcement ratio and slab thickness. According to these variables ultimate loads, crack patterns, critical sections, angles of failure as well as modes of failure are different from one another. So, these slabs are divided into five groups. All results are shown in Tables (1), (2), (3), (4) and (5).

Table (1) Load - Deflection Characteristics of Group 1 slabs (C.C.)

Slab NO.	Thickness (mm)	ρ	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection at first crack (mm)	Midspan deflection at ultimate load (mm)	Mode of failure
S1	50	0.0033	0	37.5	9.5	52.5	0.38	5.78	Punching + flexure
S2	70	0.0033	0		11.5	67.5	0.23	7.22	Punching + flexure
S3	50	0.0066	0		12.5	57.5	0.45	4.4	Punchin g
S4	70	0.0066	0		26	108	0.28	6.17	Punchin g

Table (2) Load - Deflection Characteristics of Group2 slabs (R0)

Slab NO.	Thickness (mm)	ρ	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection at first crack (mm)	Midspan deflection at ultimate load (mm)	Mode of failure
S5	50	0.0066	0	75	13	81	0.46	11.15	Punching
S6	50	0.0033	0		10	73	0.15	14.8	Punching+ flexure
S7	70	0.0066	0		24.5	150	0.24	11.95	Punching
S8	70	0.0033	0		12	105	0.18	15.88	Punching+ flexure

Table (3) Load - Deflection Characteristics of Group3 slabs (R1)

Slab NO.	Thickness (mm)	ρ	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection at first crack (mm)	Midspan deflection at ultimate load (mm)	Mode of failure
S9	70	0.0033	1	100.8	15	145	0.43	17.3	Punching
S10	70	0.0066	1		30.5	185	0.6	13.05	Punching
S11	50	0.0066	1		15.5	98	0.85	13.01	Punching
S12	50	0.0033	1		12.5	85	0.6	15.3	Punching + flexure

Table (4) Load - Deflection Characteristics of Group4 slabs (R2)

Slab NO.	Thickness (mm)	ρ	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection at first crack (mm)	Midspan deflection at ultimate load (mm)	Mode of failure
S13	70	0.0066	2	118	27.5	245	0.63	19.92	Punching
S14	50	0.0066	2		18.5	137.5	0.8	16.89	Punching
S15	50	0.0033	2		15	95	0.54	15.7	Punching
S16	70	0.0033	2		17	190	0.34	20.69	Punching

Table (5) Load - Deflection Characteristics of Group5 slabs (MR2)

Slab NO.	Thickness (mm)	ρ	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection at first crack (mm)	Midspan deflection at ultimate load (mm)	Mode of failure
S17	70	0.0066	2	105.3	26	225	0.62	14.02	Punching
S18	70	0.0033	2		19	161	0.51	16.24	Punching
S19	50	0.0066	2		18	130	0.77	15.66	Punching
S20	50	0.0033	2		14	86	0.48	12.92	Punching

5-5-2 Load-Strain Characteristics

Based on measurements of strains at the compression and tension faces of all tested slabs, all the ultimate compressive and tensile strains of all tested slabs are given in Table (6).

Table (6) Load - Strain Characteristics of All Tested Slabs

Slab NO.	Type Of concrete	$f'c$ (MPa)	Steel fiber% by vol.	Thickness (mm)	Ultimate load (U.L) (kN)	Ultimate Compressive Strain $X10^{-6}$	Ultimate Tensile Strain $X10^{-6}$
S1	C.C.	37.5	0	50	52.5	1400	950
S2	C.C.		0	70	67.5	1233	848
S3	C.C.		0	50	57.5	986	900
S4	C.C.		0	70	108	1086	795
S5	RPC	75	0	50	81	1001.4	1035
S6	RPC		0	50	73	1150.6	1188
S7	RPC		0	70	150	915	991
S8	RPC		0	70	105	1108	1190
S9	RPC	100.8	1	70	145	996	1420
S10	RPC		1	70	185	835	1496
S11	RPC		1	50	98	859.8	1192
S12	RPC		1	50	85	1019	1455
S13	RPC	118	2	70	245	770	1723
S14	RPC		2	50	137.5	803	1287
S15	RPC		2	50	95	934	1580
S16	RPC		2	70	190	901	1540
S17	MRPC	105.3	2	70	225	800	1588
S18	MRPC		2	70	161	928	1481
S19	MRPC		2	50	130	909	1244
S20	MRPC		2	50	86	944	1295

5.6 Summary of The Test Results with Further Discussion

5.6.1 Ultimate Failure load

The use of silica fume and steel fibers in RPC and MRPC slabs leads to significant increases in ultimate failure load. Tables (7) to (10) show the percentage increases for slabs with (50 and 70mm) thicknesses and (0.0033 and 0.0066) flexural steel reinforcement ratio, respectively. From these tables one can see that the improvement in compressive strength has far exceeded the results achieved with conventional concretes. This resulted in an increase in the punching shear strength of the reinforced RPC slabs by about (38.88-181.5)% above that of the reference slab.
Such results indicate that both the shear and flexural strengths of the RPC slabs are increased substantially with the use of steel fibers and increased fiber content. The orientation of fibers across the initiating cracks restricted their propagation and transmitted the tensile stresses uniformly to the concrete media surrounding the crack instead of being concentrated at its tip. This would result in a reduced stress intensity at the crack tip so that an additional load could be accommodated by the slab before the initiating cracks transformed into the whole section.

Table (7) Ultimate failure load for slabs with (H=50mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	cf' (MPa)	Pu (kN)	Increasing ratio% (P_u)	
S1	C.C.	50	0.0033	37.5	52.5	0	$\frac{S1-S1}{S1} X100$
S6	RO	50	0.0033	75	73	39.05	$\frac{S6-S1}{S1} X100$
S12	R1	50	0.0033	100.8	85	61.9	$\frac{S12-S1}{S1} X100$
S15	R2	50	0.0033	118	95	80.95	$\frac{S15-S1}{S1} X100$
S20	MR2	50	0.0033	105.3	86	63.81	$\frac{S20-S1}{S1} X100$

Table (8) Ultimate failure load for slabs with (H=70mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	cf' (MPa)	Pu (kN)	Increasing ratio% (P_u)	
S2	C.C.	70	0.0033	37.5	67.5	0	$\frac{S2-S2}{S2} X100$
S8	RO	70	0.0033	75	105	55.55	$\frac{S8-S2}{S2} X100$
S9	R1	70	0.0033	100.8	145	114.81	$\frac{S9-S2}{S2} X100$

Table8

S16	**R2**	**70**	**0.0033**	**118**	**190**	**181.5**	$\frac{S16-S2}{S2}\times100$
S18	**MR2**	**70**	**0.0033**	**105.3**	**161**	**138.5**	$\frac{S18-S2}{S2}\times100$

Table (9) Ultimate failure load for slabs with (H=50mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	cf´ (MPa)	Pu (kN)	Increasing ratio% (P_u)	
S3	C.C.	50	0.0066	37.5	57.5	0	$\frac{S3-S3}{S3}\times100$
S5	RO	50	0.0066	75	81	40.87	$\frac{S5-S3}{S3}\times100$
S11	R1	50	0.0066	100.8	98	70.43	$\frac{S11-S3}{S3}\times100$
S14	R2	50	0.0066	118	137.5	139.13	$\frac{S14-S3}{S3}\times100$
S19	MR2	50	0.0066	105.3	130	126.09	$\frac{S19-S3}{S3}\times100$

Table (10) Ultimate failure load for slabs with (H=70mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	f´c (MPa)	Pu (kN)	Increasing ratio% (P_u)	
S4	**C.C.**	**70**	**0.0066**	**37.5**	**108**	**0**	$\frac{S4-S4}{S4}\times100$
S7	**RO**	**70**	**0.0066**	**75**	**150**	**38.88**	$\frac{S7-S4}{S4}\times100$
S10	**R1**	**70**	**0.0066**	**100.8**	**185**	**71.3**	$\frac{S10-S4}{S4}\times100$
S13	**R2**	**70**	**0.0066**	**118**	**245**	**126.85**	$\frac{S13-S4}{S4}\times100$
S17	**MR2**	**70**	**0.0066**	**105.3**	**225**	**108.33**	$\frac{S17-S4}{S4}\times100$

Fibers content, use of silica fume and the presence of coarse aggregates or not does also affect the load-deflection curve of slabs and this effect is summarized in the Figures (6) to (9). These figures show that RPC and MRPC slabs have less deflection during the loading stages than the reference slabs, but still the ultimate deflection (at failure) in RPC and MRPCis higher than the reference slabs due to the use of steel fibers.

5.6.2 Ultimate Tensile and Compressive Strains

The use of silica fume and steel fibers in RPC and MRPC slabs leads to significant increases in ultimate tensile strain . Tables (11) to (14) show the percentage of increasing for slabs with (50 and 70mm) thicknesses and (0.0033 and 0.0066) flexural steel reinforcement ratio, respectively. From these tables one can see that the improvement in compressive strength and steel fiber content has far exceeded the results achieved with conventional concretes. This resulted in an increase in the ultimate tensile strain of the reinforced RPC slabs by about (15-116.73)% above that of the reference slab.

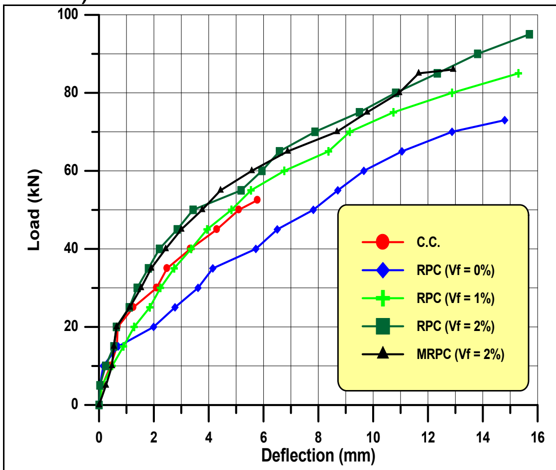

Figure (6): Load – Deflection of slabs with H = 50 mm, and ρ = 0.0033

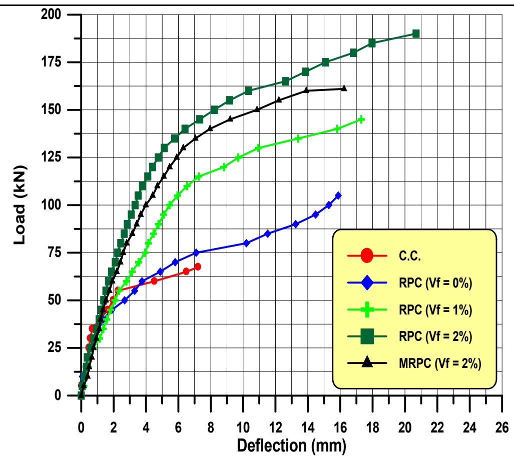

Figure (7): Load – Deflection of slabs with H = 70 mm, and ρ = 0.0033

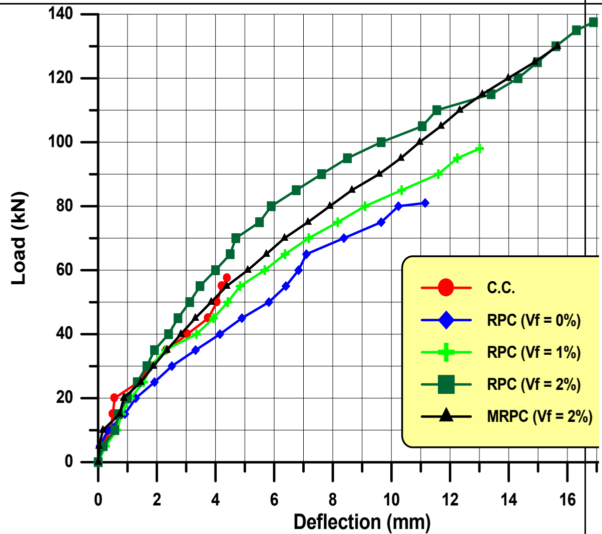

Figure (8): Load – Deflection of slabs with H = 50 mm, and ρ = 0.0066

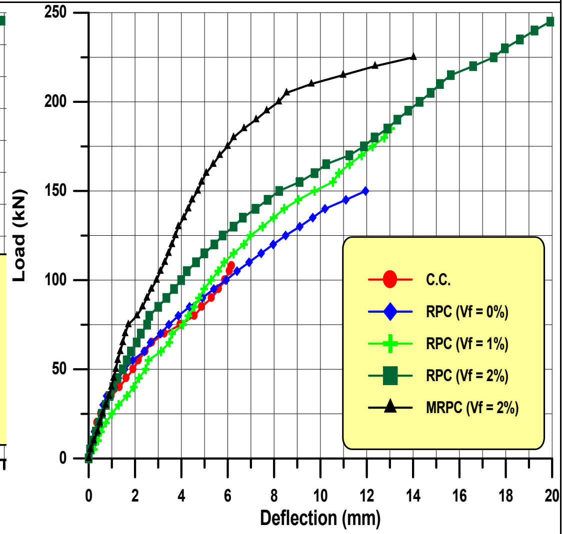

Figure (9): Load – Deflection of slabs with H = 70 mm, and ρ = 0.0066

Table (11) Ultimate tensile strain for slabs with (H=50mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf´ (MPa)	Ultimate Tensile Strain X10^{-6}	Increasing ratio% (ε_T)	
S1	C.C.	50	0.0033	52.5	37.5	950	0	$\frac{S1 - S1}{S1} x100$
S6	RO	50	0.0033	73	75	1188	25.05	$\frac{S6 - S1}{S1} x100$
S12	R1	50	0.0033	85	100.8	1455	53.16	$\frac{S12 - S1}{S1} x100$
S15	R2	50	0.0033	95	118	1580	66.31	$\frac{S15 - S1}{S1} x100$
S20	MR2	50	0.0033	86	105.3	1295	36.31	$\frac{S20 - S1}{S1} x100$

Table (12) Ultimate tensile strain for slabs with (H=70mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf´ (MPa)	Ultimate Tensile Strain X10^{-6}	Increasing ratio% (ε_T)	
S2	C.C.	70	0.0033	67.5	37.5	848	0	$\frac{S2 - S2}{S2} x100$
S8	RO	70	0.0033	105	75	1190	40.33	$\frac{S8 - S2}{S2} x100$
S9	R1	70	0.0033	145	100.8	1420	67.45	$\frac{S9 - S2}{S2} x100$
S16	R2	70	0.0033	190	118	1540	81.6	$\frac{S16 - S2}{S2} x100$
S18	MR2	70	0.0033	161	105.3	1481	74.65	$\frac{S18 - S2}{S2} x100$

Table (13) Ultimate tensile strain for slabs with (H=50mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf´ (MPa)	Ultimate Tensile Strain X10^{-6}	Increasing ratio% (ε_T)	
S3	C.C.	50	0.0066	57.5	37.5	900	0	$\frac{S3 - S3}{S3} x100$
S5	RO	50	0.0066	81	75	1035	15	$\frac{S5 - S3}{S3} x100$
S11	R1	50	0.0066	98	100.8	1192	32.44	$\frac{S11 - S3}{S3} x100$
S14	R2	50	0.0066	137.5	118	1287	43	$\frac{S14 - S3}{S3} x100$
S19	MR2	50	0.0066	130	105.3	1244	38.22	$\frac{S19 - S3}{S3} x100$

Table (14) Ultimate tensile strain for slabs with (H=70mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf´ (MPa)	Ultimate Tensile Strain X10^{-6}	Increasing ratio% (ε_T)	
S4	C.C.	70	0.0066	108	37.5	795	0	
S7	RO	70	0.0066	150	75	991	24.65	
S10	R1	70	0.0066	185	100.8	1496	88.17	
S13	R2	70	0.0066	245	118	1723	116.73	
S17	MR2	70	0.0066	225	105.3	1588	99.75	

Results also show that the use of silica fume and steel fibers in RPC and MRPC slabs leads to small decrease in ultimate compressive strain . Tables (15) to (18) show the percentage increase for slabs with (50 and 70mm) thicknesses and (0.0033 and 0.0066) flexural steel reinforcement ratio, respectively. From these tables one can see that the improvement in compressive strength and steel fiber content has affected the results achieved with conventional concretes. This resulted in a decrease in the ultimate compressive strain of the reinforced RPC slabs by about (1.56-33.28)% below that of the reference slab.

Table (15) Ultimate compressive strain for slabs with (H=50mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf´ (MPa)	Ultimate Compressive Strain X10^{-6}	Decreasing ratio% (ε_c)	
S1	C.C.	50	0.0033	52.5	37.5	1400	0	
S6	RO	50	0.0033	73	75	1150.6	17.81	
S12	R1	50	0.0033	85	100.8	1019	27.21	
S15	R2	50	0.0033	95	118	934	33.28	
S20	MR2	50	0.0033	86	105.3	944	32.57	

Table (16) Ultimate compressive strain for slabs with (H=70mm& ρ=0.0033)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf' (MPa)	Ultimate Compressive Strain X10^{-6}	Decreasing ratio% (ε_c)	
S2	C.C.	70	0.0033	67.5	37.5	1233	0	$\frac{S2-S2}{S2}x100$
S8	RO	70	0.0033	105	75	1108	10.13	$\frac{S8-S2}{S2}x100$
S9	R1	70	0.0033	145	100.8	996	19.22	$\frac{S9-S2}{S2}x100$
S16	R2	70	0.0033	190	118	901	26.92	$\frac{S16-S2}{S2}x100$
S18	MR2	70	0.0033	161	105.3	928	24.73	$\frac{S18-S2}{S2}x100$

Table (17) Ultimate compressive strain for slabs with (H=50mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf' (MPa)	Ultimate Compressive Strain X10^{-6}	Decreasing ratio% (ε_c)	
S3	C.C.	50	0.0066	57.5	37.5	986	0	$\frac{S3-S3}{S3}x100$
S5	RO	50	0.0066	81	75	1001.4	1.56	$\frac{S5-S3}{S3}x100$
S11	R1	50	0.0066	98	100.8	859.8	12.8	$\frac{S11-S3}{S3}x100$
S14	R2	50	0.0066	137.5	118	803	18.56	$\frac{S14-S3}{S3}x100$
S19	MR2	50	0.0066	130	105.3	909	7.81	$\frac{S19-S3}{S3}x100$

Table (18) Ultimate compressive strain for slabs with (H=70mm& ρ=0.0066)

Slab No.	Concrete type	Slab Thickness	ρ	Pu (kN)	cf' (MPa)	Ultimate Compressive Strain $X10^{-6}$	Decreasing ratio%	
S4	C.C.	70	0.0066	108	37.5	1086	0	$\frac{S4-S4}{S4}X100$
S7	RO	70	0.0066	150	75	915	15.75	$\frac{S7-S4}{S4}X100$
S10	R1	70	0.0066	185	100.8	835	23.11	$\frac{S10-S4}{S4}X100$
S13	R2	70	0.0066	245	118	770	29.1	$\frac{S13-S4}{S4}X100$
S17	MR2	70	0.0066	225	105.3	800	26.33	$\frac{S17-S4}{S4}X100$

6. Conclusions

1. The mixing procedure used in this study presents a successful way to produce RPC with a (100 X200mm) cylinder compressive strength exceeding 115 MPa without using the heat curing, as found in previous research.

2. Experimental tests show that increasing the steel fiber volumetric ratio V_f in RPC and MRPC mixes will increase its compressive strength. For example, using V_f as high as 2% increases cube and cylinder compressive strengths for RPC by (176.57 and 214.66)%, respectively, and for MRPC by (155.53 and 180.80)%, respectively. However, an insignificant gain of compressive strength is achieved for low values of V_f. Steel fibers also affect the failure mode of RPC cylinders, where RPC without fibers has an explosive collapse under loading while with steel fibers, these fibers showed an arresting or confining effect in preventing cylinders from exploding even after failure.

3. As expected, the positive effect of using steel fibers was found to be greater on the splitting tensile strength than on the compressive strength. The results showed that when using steel fiber volumetric ratio by 2%, the splitting tensile strength is increased by (308.26 and 296.58)% for RPC and MRPC, respectively.

4. Experimental test results of modulus of rupture of RPC and MRPC prisms showed a significant positive effect of increasing steel fiber volumetric ratio compared with compressive strength and splitting tensile strength. This positive effect reached (405.54 and 334.60)% by using steel fiber volumetric ratio of 2% for RPC and MRPC, respectively.

5. For the case of 50mm slabs the following was found. With ρ=0.0033 the percentage increase in the ultimate failure load of RPC slabs exceeded that of NSC ones by (39.05, 61.90 and 80.95)% when RPC slabs had V_f of (0, 1 and 2)% respectively, and of the order (40.87, 70.43 and 139.31)%, for RPC slabs with ρ=0.0066.
6. For the case of 70mm slabs With ρ=0.0033 the percentage increase in the ultimate failure load of RPC slabs exceeded that of NSC ones by (55.55, 114.81 and 181.50)% when RPC slabs had V_f of (0, 1 and 2)% respectively, and of the order (38.88, 71.30 and 126.85)%, for RPC slabs with ρ=0.0066.
7. The increase in ultimate load was also obtained for MRPC slabs with 2% steel fiber volumetric ratio. The failure load increased by (63.81 and 126.09)% for slabs with 50mm thickness and (ρ=0.0033 and 0.0066), respectively, and increased by (138.50 and 108.33)% for slabs with 70mm thickness and (ρ=0.0033 and 0.0066), respectively.
8. For the 50mm slabs With ρ=0.0033 the midspan deflection at ultimate load is considerably increased by the presence of steel fibers exceeded that of NSC ones by (155.5, 163.8 and 170.7)% when RPC slabs had V_f of (0, 1 and 2)% respectively, and of the order (153.4, 195.7 and 283.8)%, for RPC slabs with ρ=0.0066.
9. For of 70mm slabs With ρ=0.0033 the midspan deflection at ultimate load is considerably increased by the presence of steel fibers and exceeded that of NSC ones by (128.3, 139.6 and 186.6)% when RPC slabs had V_f of (0, 1 and 2)% respectively, and of the order (93.7, 111.5 and 222.9)%, for RPC slabs with ρ=0.0066.
10. The increase in deflection at ultimate load was also obtained for MRPC slabs with 2% steel fiber volumetric ratio. The deflection increased by (122.8 and 255.9)% for slabs with 50mm thickness and (ρ=0.0033 and 0.0066), respectively, and increased by (124.9 and 127.2)% for slabs with 70mm thickness and (ρ=0.0033 and 0.0066), respectively.
11. Measurements of longitudinal strains of RPC and MRPC slabs showed that the increase in V_f increases the ultimate tensile strain between (15-99)%, and decreases the ultimate compressive strain between (1.5-33.3)%.

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مقاومة القص الثاقب للبلاطات المصنوعة من خرسانة المساحيق الفعالة المعدلة

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المستخلص

يهتم البحث الحالي بدراسة الخواص الميكانيكية لخرسانة المساحيق الفعالة (RPC) وخرسانة المساحيق الفعالة المعدلة (MRPC) كمادة إضافة إلى دراسة تصرف القص الثاقب (Punching Shear) للبلاطات المصنعة من هذه الخرسانة. يتركز البرنامج العملي من البحث على دراسة واستقصاء تأثير النسبة الحجمية للألياف الحديدية ووجود الركام الخشن على بعض الخواص الميكانيكية المهمة لخلطة خرسانة المساحيق الفعالة مثل مقاومة الانضغاط للخرسانة ومقاومة شد الانشطار ومنحني الإجهاد-الانفعال تحت تأثير انضغاط أحادي المحور ومعامل الانثناء. يتضمن البحث أيضا دراسة تأثير نسبة حديد التسليح وسمك البلاطات إضافة إلى المتغيرات أعلاه على تصرف القص الثاقب (بدلالة منحنى الحمل-الهطول,منحني الحمل-الانفعال,حمل الفشل الأقصى,خصائص الفشل وانتشار التشققات) لبلاطات مصنعة من خرسانة المساحيق الفعالة بأبعاد(1000X1000 X50أو 70) مم ذات إسناد بسيط تحت تأثير حمل مركز في منتصف البلاطة.

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