Journal of Engineering and Development

www.jead.org
Vol. 20, No.02, March 2016
ISSN 1813-7822

EFFECT OF VOLUME OF STEEL FIBERS ON THE PUNCHING SHEAR BEHAVIOR OFHYBRID REINFORCED CONCRETE FLAT SLAB

Dr. Layth Al-Jaberi[1], Zinah Waleed Abbas[2], *Esraa Kamal Jaffar[3]

1) Lect., Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq.
2) Lect., Civil Engineering Department, Al-Mustansiryiaah University, Baghdad, Iraq.
3) Assist Lect., Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq.

(Received:16/09/2015; Accepted: 03/ 11/2015)

Abstract: The main object of this study is to figure out the effects of the volume of fibers (Vf) on the punching shear behavior of hybrid system of flat slab that made of Lightweight Concrete (LWC) and Reactive Powder Concrete (RPC). Five flat slabs, two of them made fully of Normal Strength Concrete (NSC) (named as S1) and LWC (named as S2), and the rest three made of LWC and RPC (named as S3, S4 and S5). The variable in S3, S4 and S5 is the values of Vf which are (0.5%, 1% and 2%) respectively. The hybrid flat slabs are designed that RPC to fill the critical zone of the punching shear area, and LWC to fill the remaining area. At 28 days age of concrete, the slabs are simply supported along the all edges and single point load applied at the center of slab until the failure is happened. The experimental work indicates that S1, S2 and S3 are failed with punching shear failure. While S4 and S5 are suddenly failed in the region occupied by LWC. The results show that S2 exhibits the weaker behavior, followed by S1. S3 has the best behavior of failure among all. The load deflection curves for all tested slabs behaves first as linear relation followed by nonlinear relation up to failure. The values of (fcu), (Pc) and (Pu) for S1 are higher than those for S2 by about (69%, 29% and 42%) respectively. While the values of the same properties for S3 are higher than those for S2 by about (622%, 128% and 142%) respectively, and about (326%, 78% and 71%) respectively than those for S1

Keywords: *Punching Shear, Hybrid Flat Plate, Reactive Powder Concrete*

تأثير حجم الألياف على تصرف القص الثاقب للبلاطات المستوية المصنعة هجينيا

خلاصة: ان الهدف الأساسي من هذه الدراسة هو لاكتشاف مدى تأثير حجم الالياف (Vf) على طبيعة فشل القص الثاقب للبلاطات المستوية المصنعة هجينيا من الخرسانة الخفيفة (LWC) الوزن وخرسانة المساحيق الفعالة (RPC). تم تصنيع خمس بلاطات ، اثنان منها مصنعة بالكامل من الخرسانة الاعتيادية المقاومة (NSC) (S1) والخرسانة الخفيفة الوزن (S2) ، والثلاثة المتبقية مصنعة هجينيا من الخرسانة خفيفة الوزن وخرسانة المساحيق الفعالة (S3 و S4 و S5). المتغير في (S3 و S4 و S5) هو قيمة نسبة الالياف (Vf) والتي كانت (0.5% و 1% و 2%) على التوالي. تم صب البلاطات المهجنة بحيث يغطي (RPC) المنطقة الحرجة لمنطقة القص الثاقب ، بينما يغطي (LWC) بقية البلاطة. عند (28) يوم من عمر الخرسانة تم تعريض البلاطات الى فحص الحمل المركز على العمود وبالاستناد البسيط من جميع الجهات. أشر الفحص حدوث فشل القص الثاقب لكل من (S1, S2 and S3) ، بينما اشر حدوث فشل فجائي في منطقة (LWC) في البلاطات (S4 and S5). أظهرت النتائج ان (S2) هي ذات الطبيعة الأضعف بين البلاطات ، تليها (S1). كان تصرف الفشل للبلاطة (S3) هو الأمثل والأفضل. أظهرت منحنيات التحميل – الانحراف لجميع البلاطات سلوكا خطيا مرنا عند البداية يليه سلوك لاخطي لدائني لحين حصول الفشل.

*Corresponding Author laithjabri@yahoo.com

1. Introduction

The failure mechanism of structural members like flat slabs or foundation etc. by shear, is called Punching Shear. Consider a part of slab subjected to an increasing concentrated load. Finally, the slab will fail. One possible method of failure is that the load punches through the slab. Punching shear is most common, and is a major design consideration, in flat slab construction.

Hong and Yew-Chang, (2003) [1] stated that the critical design issue of reinforced concrete flat slab is the concentration of shear stresses round the portion which connected the slab with column that can cause sudden punching shear failure at loads far below the slab flexural strength (Plate 1)[2]. The nature of this type of failure is local and brittle, and in the kind of column punching out of the plate over a felled cone that rise by a diagonal cracking round the column.

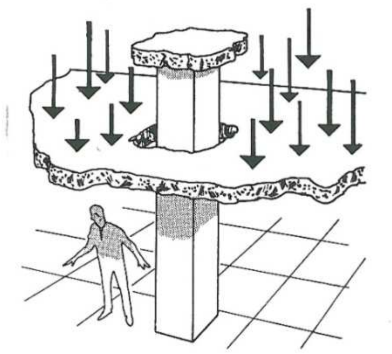


Plate 1: Punching Shear Failure [2]

This critical section of punching shear is located at one-half effective distance from the faces of column (Figure 1) [2]. The punching shear strength of concrete should be larger than factored shear stress at critical section as:

$$\emptyset \boldsymbol{v_c} \geq \boldsymbol{v_u}$$

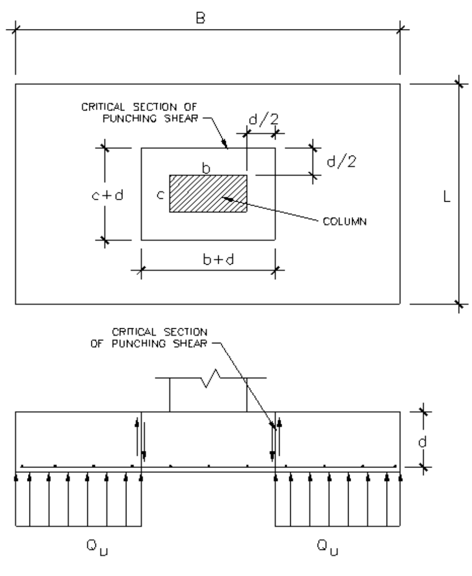


Figure (1): Critical Sections of Punching Shear [2]

Reactive Powder Concrete (RPC), which is one of the newest kinds of Ultra High Performance Concrete (UHPC), is characterized by a very dense matrix thanks to the improvement of the granular packing of the dry fine powders and a firm microstructure. Fibrous articles of different variety that consisted in RPC have a significant role in increasing its strength and cohesion. Through adding fibers, not just the strength, the structural perfection, and the post-crack status will be improved [3]. The function of randomly spread short fibers is to provide some post-cracking “ductility” through bridging across the developed cracks. Fibers that are sufficiently strong and sufficiently bonded to material, allow the matrix to hold considerable stresses over a comparatively large strain capacity in the post-cracking state [4]. These characteristics encourages the use of RPC in such critical section of punching shear. However, some properties of RPC such as density and cost affect its widespread use.

Structural lightweight aggregate concrete (SLWAC) is a significant and versatile concrete in the construction industry. Multistory buildings, bridges, offshore oil platforms, and pre-stressed or pre-cast members of all kinds, are an important examples of the considerable and various uses of this type of concrete [5]. SLWAC resolves the problems conserved with weight in structures and durability in exposed elements. Less self-weight, developed seismic structural restraint, wider spans, improved fire standings, thinner sections, lower height of stories, smaller size structural elements, less rebar, and lower costs of foundation costs, are some of the features that provided by SLWAC and present design flexibility and essential cost savings [6].

Hybrid systems that consisting of two types of concrete can be consider as a good method to achieve better characteristics such as better strength resistance, more ductility, less dead load, thinner sections, lower costs, and others.

2. Previous Researches

Tuan Ngo (2001) [7] stated that the employ of high strength concrete (HSC) improves the punching shear behavior permitting higher stresses to be transmitted through the connection area between slab and column.

Ali et al (2013) [8] investigated experimentally the punching shear behavior of hybrid flat plate containing HSC and Steel Fiber Reinforced Concrete (SFRC). They found that the employment of SFRC develops the punching shear behavior and transfers higher stresses through the connection area between slab and column. They also indicated that for slab sample that casted fully with SFRC, the ultimate shear capacity increased by (25%) in comparison with the slab that casted fully with NSC. While, the ultimate shear capacity of samples that made with hybrid system of concrete, is increased by (5%-13%) in comparison with the NSC sample.

Sarsam and Hassan (2013) [9] studied the punching shear behavior of RPC and MRPC slabs. They study the effect of the volume fraction of steel fiber (Vf) on the punching shear behavior of these slabs. The results of their work showed that increasing (Vf) leads to decreased perimeter of the punching shear section.

3. Experimental Program

3.1 *Materials*

3.1.1 Cement

The cement used in this study is Iraqi ordinary Portland cement (Taslogah) type (I). This cement is evaluated according to IOS 5:1984 [10]. Tables (1) and (2) show the chemical and physical properties of this cement and the criteria of IOS 5:1984 [10] for each one.

Table 1. Chemical Composition of Cement

Chemical Composition		
Oxides	Test Results	IOS 5:1984 Criteria
SiO_2	19.66	-
Fe_2O_3	3.44	-
Al_2O_3	4.66	-
CaO	62.23	-
MgO	2.83	< 5
SO_3	2.61	< 2.8
L.S.F	0.94	0.66 - 1.02
L.O.I	2.95	< 4
I.R	1.27	< 1.5
C_3A	6.53	-

Table 2. Physical Properties of Cement

Physical Properties			
Properties	Test Results		IOS 5:1984
Specific surface area (Blaine Method), m^2/kg	327		> 230
Mortar Compressive strength (MPa) at	3 days	31.5	> 15
	7 days	40.5	> 23
Setting Time(min)	Initial	180 min.	≥ 45 min.
	Final	3.55 hr.	≤10 hours
Soundness: autoclave %	0.19		< 0.8

3.1.2 Fine Aggregate

Natural sand from Al-Ukhaider region is used for NSC and LWC mixes in this work. Table (3) shows the grading of the fine aggregate and the limits of the Iraqi specification No.45/1984 [11]. Table (4) shows the physical properties of the fine aggregate.

Table 3. Grading of Fine Aggregate

Sieve size (mm)	% Passing by weight	Limits of the Iraqi specification No.45/1984 (zone 3)
10	100	100
4.75	97	90-100
2.36	91	85-100
1.18	84	75-100
0.60	71	60-79
0.30	18	12-40
0.15	7	0-10

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	0.17 %	≤ 0.50 %
Absorption	0.75 %	-

3.1.3..Extra Fine Aggregate (Sand)

Extra Fine Sand (EFS), chemically inert, graded, hardwearing aggregate with size (300-600) µm is used for RPC mixes in this study. Don Construction Products produce this extra fine sand. Table (5) shows that the physical properties of this extra fine sand are satisfactory to the requirements of the IOS No.45/1984 [11].

Table 5. Grading of the Extra Fine Sand

Sieve size (mm)	% Passing by weight	Limits of the IOS No.45/1984 (zone 3)
10	100	100
4.75	100	95-100
2.36	100	95-100
1.18	100	90-100
0.60	100	80-100
0.30	42	15-50
0.15	8	0-15

3.1.4 Coarse Aggregate

Rounded gravel of nominal size (5-14) mm is used for NSC mixes. Table (6) show the grading of this aggregate, which conforms to the Iraqi specification No.45/1984 [11]. The specific gravity, sulfate content and absorption of coarse aggregate are illustrated in Table (7).

Table 6. Grading of Coarse Aggregate

Sieve size (mm)	% Passing by weight	Limits of the Iraqi specification No.45/1984
20	100	100
14	98	90-100
10	84.6	85-100
5	10.0	0-10
2.36	0	0-5

Table 7. 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 %	-

3.1.5 Porcelanite Aggregate (PA)

PA is used in this study for LWC mixes. PA has a white color and is characterized by high permeability and low density. The large stones of Porcelanite are crushed to smaller sizes manually with a hammer. The jaw crusher was set up to give a finished product of about 14 mm maximum aggregate size. Then the PA is washed with water to remove the dust.

According to ACI 211.2, 2004 [12], the porcelanite aggregate was saturated through soaking it in water at the laboratory temperature. Tables (8) and (9) show physical and chemical analysis of PA respectively. Table (10) show the grading of PA that meets the requirements of the Iraqi specification No.45/1984 [11].

Table 8. Physical Properties of PA

Property	Test Result
Specific Gravity	1.67
Absorption	44%
Unit Weight (Dry Rodded)	855 kg/m³

Table 9. Chemical Properties of PA

Oxide Composition	%by weight
SiO_2	70.05
CaO	8.21
MgO	2.80
Fe_2O_3	0.97
Al_2O_3	3.32
SO_3	0.1
Loss on ignition	9.4

Table 10. Grading of PA

Sieve size (mm)	% Passing by weight	Limits of the Iraqi specification No.45/1984
20	100	100
14	95	90-100
10	89	85-100
5	7	0-10
2.36	0	0-5

3.1.6 Water

Tap water is used for both mixing and curing of concrete.

3.1.7 Silica Fume (SF)

MEYCO MS 610 is a mineral additive that is used in normal and sprayed concrete, which increases the engineer-ship properties of concrete such as pressure resistance, bending resistance, breaking mechanics and impermeability by improving the interface properties of concrete and the microstructure of the cement paste. It complies with ASTM C 618 and ASTM C 1240/95. Table (11) shows the chemical composition for this product.

Table 11. Chemical Composition of SF

Oxides	Content %	ASTM C 1240-05 Specification	
		Min.%	Max.%
SiO_2	87.00	85	-
Fe_2O_3	2.50	-	-
Al_2O_3	1.00	-	-
CaO	1.00	-	-
SO_3	0.50	-	-
K_2O+Na_2O	3.00	-	-
L.O.I	2.90	-	6
Moisture Content	1.00	-	3

3.1.8 High Range Water Reducing Admixture (HRWRA)

The HRWRA used in this work is a third generation super-plasticizer for concrete and mortar which is known commercially as (Glenium 51). Glenium 51 has been primarily developed for applications where the highest durability and performance are required. Glenium 51 is free from chlorides and complies with ASTM C494-99type G and F.

3.1.9 Ultra-Fine Steel Fibers (UFSF)

Ultra-fine steel fibers are used throughout the experimental program as shown in Plate (2). The properties of this type of fibers are showed in Table (12). UFSF is suitable to use with RPC.

Plate (2). UFSF Used in This Investigation

Table 12. Properties of the Used Steel Fibers

Property	Specifications	Property	Specifications
Type	WSF0213	Form	Straight
Surface	Brass coated	Average length	13 mm
Relative Density	7860 Kg/m^3	Diameter	0.2mm±0.05mm
Tensile Strength	Minimum 2300MPa	Aspect ratio (L_f/D_f)	65

3.2. Mix Proportions

Three types of concrete mixes were used in this investigation NSC, LWC and RPC. The details of these three concrete mixes are shown in Table (13).

Table 13. Mix Proportions

Materials	NSC	LWC	RPC
Cement (kg/m^3)	300	540	933
Water (kg/m^3)	150	216	168
Coarse aggregate (kg/m^3)	1200	-	-
Fine aggregate (kg/m^3)	650	605	-
Extra Fine aggregate (kg/m^3)	-	-	1030
Porcelanite (kg/m^3)	-	454	-
Silica fume (kg/m^3)	-	-	234
HRWRA (%)	-	-	5
w/c ratio	0.5	0.5	0.18

3.3. Test Specimens

Five slab specimens with (900x900x80) mm dimensions were tested. Two specimens were made fully with one type of concrete; NSC and LWC. While, the other three specimens were made as hybrid slabs containing two types of concrete. Except the area of the critical punching shear zone, the whole slab was made of LWC. The variables are concrete type of the critical punching shear zone of the slab and the value Vf in RPC mix.

All slabs were simply supported along the all edges. Single point load applied at the center of slab. The applied load was transformed from testing machine through a central column of dimensions (150x150) mm. Table (14) shows the slabs designation. Plain wires of (6 mm) diameter used as flexural reinforcement placed in the tension face of the slab (at bottom). Each wire have an average yield strength (fy) of (382 N/mm2) determined from tensile test. The wires is uniformly spaced and placed in two perpendicular directions, Figure (2) shows the dimensions and steel reinforcement for the tested slabs.

Five wooden molds were used to cast the slabs, first of all molds were cleaned, assembled and oiled. The reinforcement was placed at their position inside the molds.

For the slabs with two types of concrete, the first layer at the critical zone was RPC with different percentage of steel fiber. While the area around the critical zone was LWC. The hardened slabs were removed from the molds and cured in water containers at temperature of 25 co until testing at age of 28 days. The tested slabs were placed on the testing machine and the load applied until failure. Plate (3) shows the molds, the steel reinforcement and the tested slabs before and after casting.

Table 14: Slabs Designation

Slab Designation	Concrete Type at Critical Zone	Concrete Type Rest of Slab	Vf in RPC mix
S1 (NSC)	NC		-
S2 (LW)	LWC		-
S3 (LW+RPC)	RPC	LWC	0.5
S4 (LW+RPC)	RPC	LWC	1
S5 (LW+RPC)	RPC	LWC	2

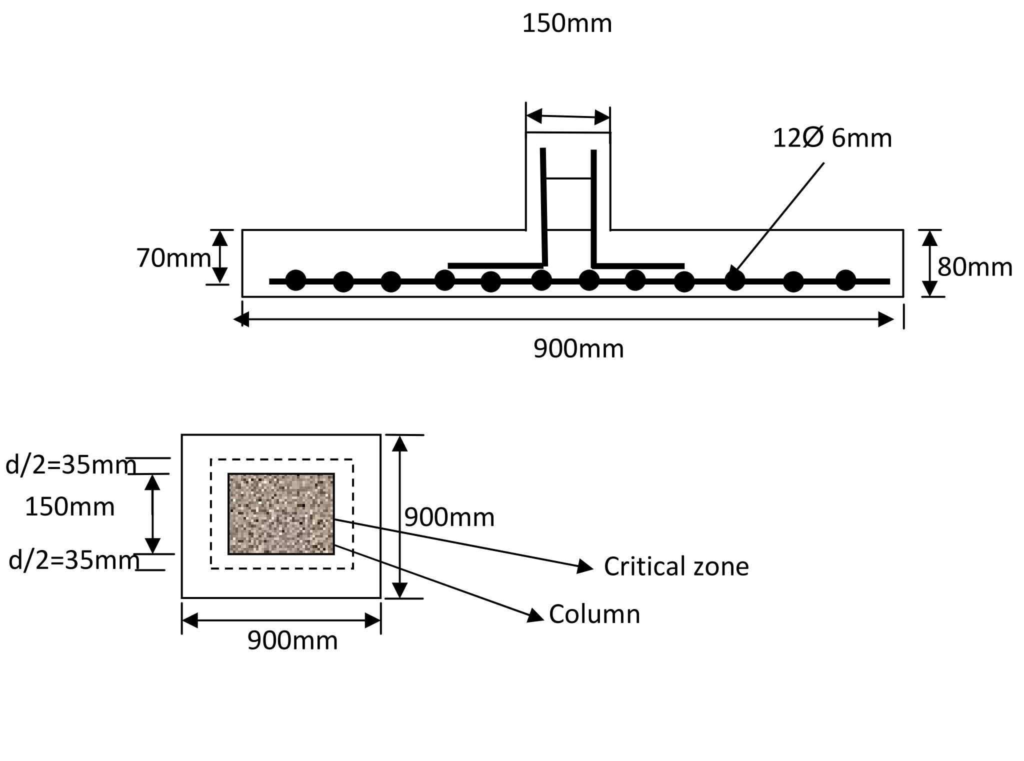


Figure 2: Dimensions of the tested slabs

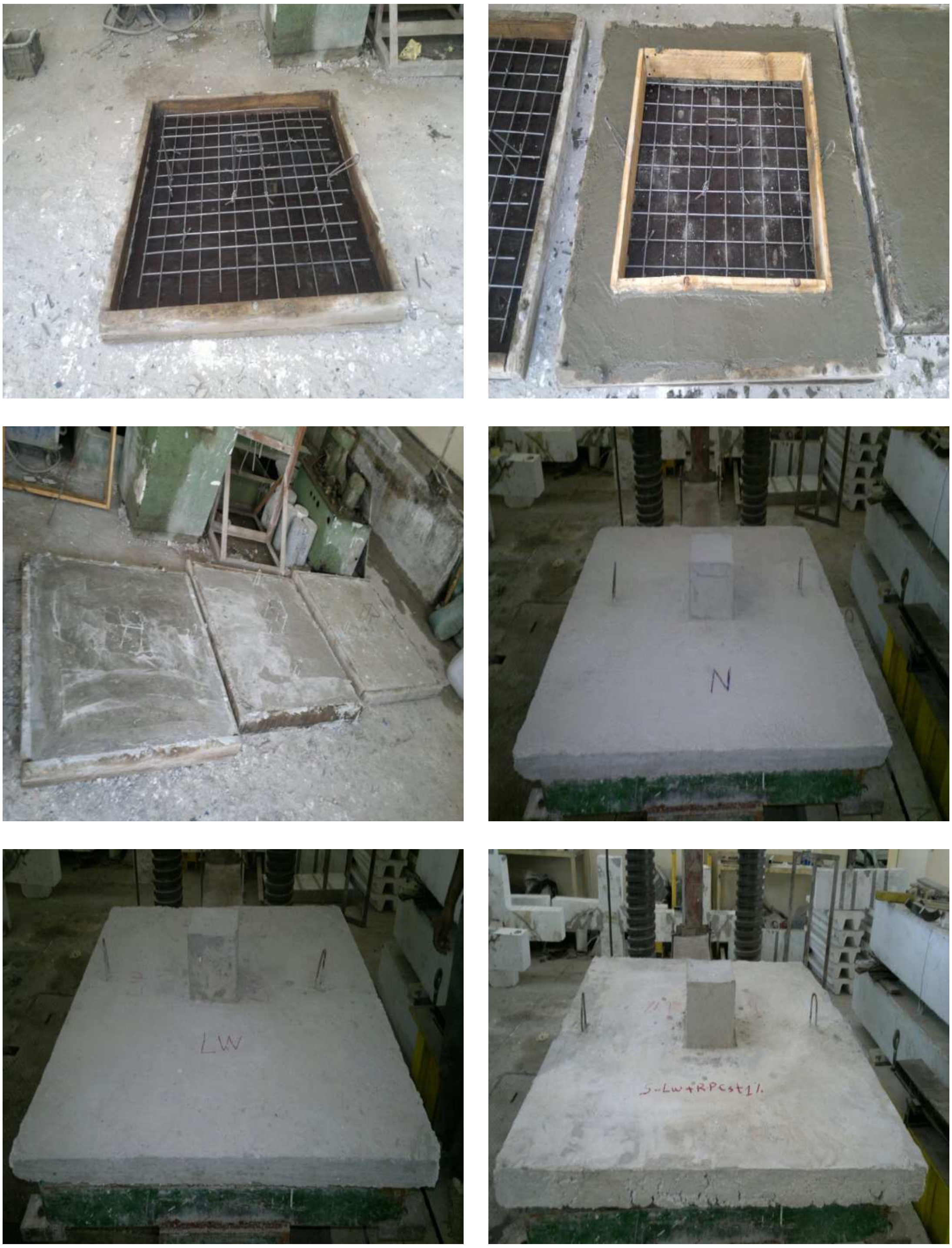


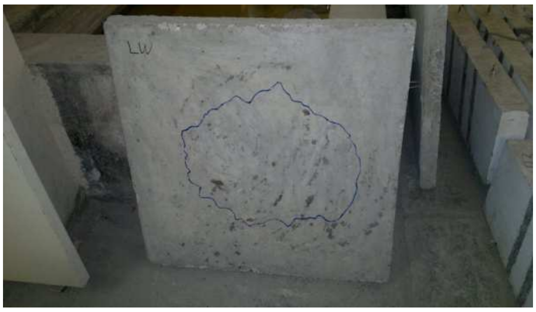
Plate 3: Molds, Reinforcements and Tested Slabs

4. RESULTS AND DISCUSSION:

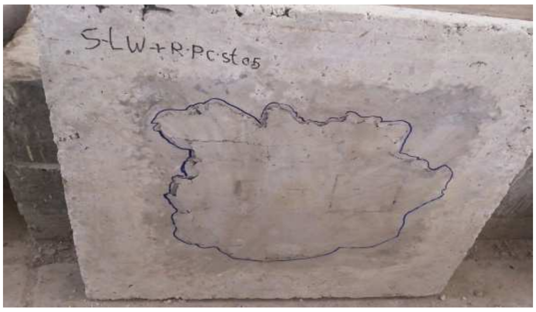
Photos in Plate (4) show the cracks patterns for the slabs (S1, S2, S3, S4 and S5). It can be seen that all slabs were failed due to punching shear and the cracks are observed around the connection area between the column and the slab for S1, S2 and S3, while the failure of S4 and S5 happened in the zone which occupied by LWC away from the face of column. The nature of failure and distance between the face of the column and the cracks are not same and differ from slab to another.

The failure area in S3 was narrower than S1 and S2. Whilst the cracks is much obvious in S3 than in S1 and S2. This can be attributed to the development of strength, the structural integrity and the post-crack state of the RPC in hybrid system of S3. The nature of failure of S4 and S5 confirm this explanation. Higher value of Vf in S4 and S5 lead to improve the properties of RPC matrix and make it more capable to carry significant stresses over a relatively large strain capacity in the post-cracking stage, while the LWC matrix will become the weakest substance and will fail before any crack can be noticed in RPC matrix. It can be said that the nature of failure in S4 and S5 is a sudden failure in the part of the slab made with LWC. This kind of failure is not recommended for the safety purposes. S3 showed the best nature of punching shear failure.

Tested slab with NSC mix (S1)



Tested slab with LWC mix (S2)



Tested slab with RPC (V_f 0.5%) in critical zone (S3)

Tested slab with RPC (V_f 1%) in critical zone S4)

Plate 4: Cracks Patterns and Failure Mode for the Tested Slabs

Tested slab with RPC (V_f 2%) in critical zone (S5)

Plate 4: Continues

Table (15) shows the cracking load and ultimate load for the tested slabs. From this table it can be seen that the values of (fcu), (Pc) and (Pu) for S2 are the lowest among the others. The values of S1 are higher than those for S2 by about (69%, 29% and 42%) respectively. While the values of the same properties for S3 are higher than those for S2 by about (622%, 128% and 142%) respectively, and about (326%, 78% and 71%) respectively than those for S1. The values of the same properties for S4 are higher than those for S2, S1 and S3 by (633%, 186% and 175%), (333%, 122% and 94%), and (1.5%, 25% and 13.8%) respectively. For S5 the values of these percentages are (650%, 229% and 192%), (343%, 156% and 106%), (4%, 44% and 21%), (2%, 15% and 6%) comparing with S2, S1, S3 and S4 respectively. These values agree with the scientific fact, that the RPC matrix has much superior properties comparing with NSC and LWC matrices, and confirm the previous illusion that explain the nature of failure for S4 and S5.

Table 15: Results of Cracking Load, Ultimate Load and Compressive Strength

Slab designation	fcuMpa	Cracking load Pc (kN)	Ultimate load Pu (kN)	Pc/Pu %
S1	30.5	45	85	53
S2	18	35	60	58
S3	130	80	145	55
S4	132	100	165	61
S5	135	115	175	66

Figures (3, 4 and 5) shows the load deflection curves for the tested slabs. All curves show a linear behavior followed by nonlinear behavior up to failure. The deflection for S1 is less than the deflection for S2 by about (86%) under the same applied load. The deflection for S3 is less than the deflection for S1 and S2 by about (56%) and (94%) respectively under the same applied load. This behavior gives another confirmation to the previous explanations. In other words, the hybrid system in S3 exhibited more ductile behavior than un-hybrid systems for S1 and S2. Although the failure of S4 and

S5 is occurred in LWC region, as indicated before, Figure (5) shows that, the deflection of those slabs is less than that for S3.

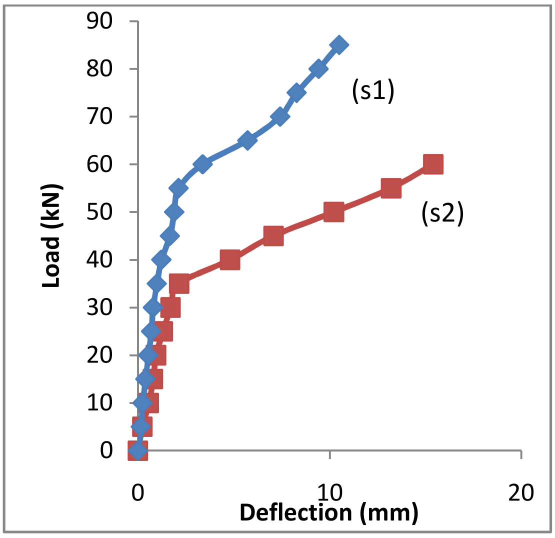


Figure 3: Load Deflection Curves for S1 and S2

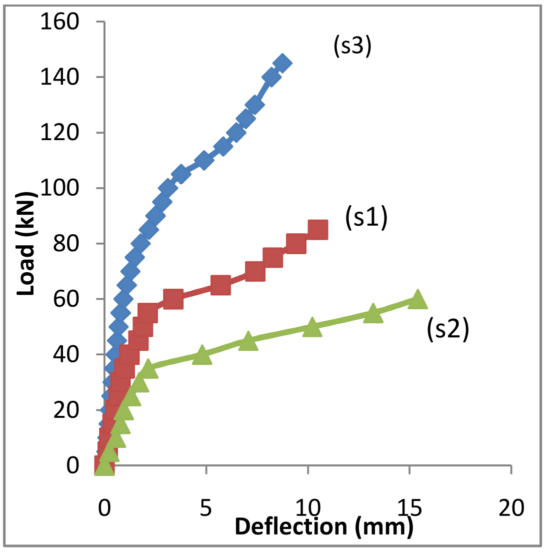


Figure4: Load Deflection Curves for S1, S2 and S3

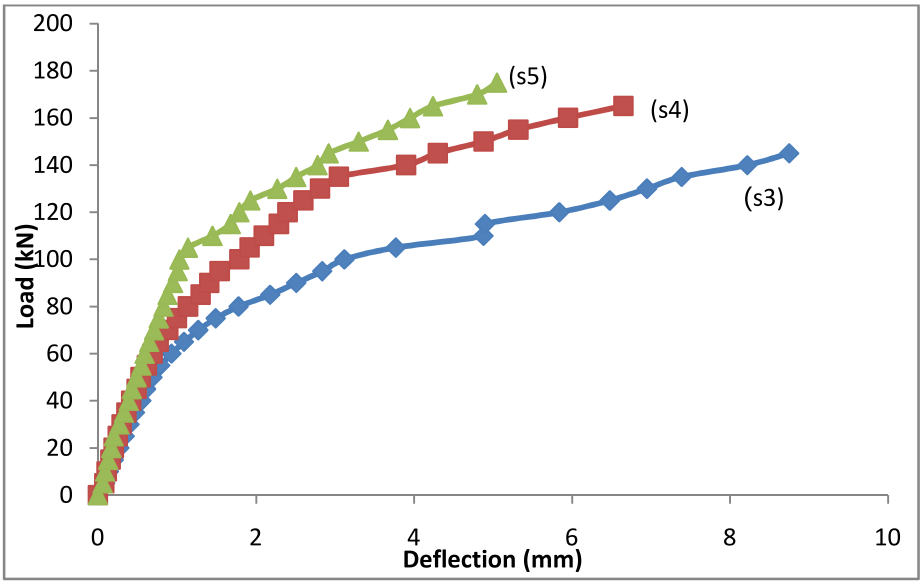


Figure5: Load Deflection Curves for S3, S4 and S5

5. CONCLUSIONS

1. The load deflection curves for all tested slabs behaves first as linear relation followed by nonlinear relation up to failure.
2. The cracks in the slabs that made fully with NSC or LWC are occurred around the column until the failure occurs by punching shear.
3. RPC matrix, which contains fibrous substances, shows high grade of structural strength and ductility, and this in turn improves the capability of hybrid system of flat slab, that contain LWC and RPC, to carry higher levels of the cracking load and ultimate load.
4. Hybrid system of flat slab that contain RPC (with V_f = 0.5) in the critical zone region and LWC outside this region, exhibits less area of cracks around the column, more ductile behavior and recommended punching shear failure.
5. Increasing the amount of fibers (V_f) in the hybrid system of flat slab, that contain LWC and RPC, over (0.5%) leads the slab to sudden failure in the LWC region.
6. The values of of (fcu), (Pc) and (Pu) for S1 are higher than those for S2 by about (69%, 29% and 42%) respectively. While the values of the same properties for S3 are higher than those for S2 by about (622%, 128% and 142%) respectively, and about (326%, 78% and 71%) respectively than those for S1.

6. REFERENCES

1- Hong, G. and Yew-Chang, L.,(2003) "Failure Analysis of Column-slab Connections with Stud Shear Reinforcement", Canadian Journal of Civil Engineering, Vol.30, pp.934-944.

2- McCormac, J.C.,(2001) "Design of Reinforced Concrete", 5th Edition, John Wiley &Sons, Inc., 738 pp.

3- TazalyZ.,(2011),"Punching Shear Capacity of Fibre Reinforced Concrete Slabs with Conventional Reinforcement", Computational analysis of punching models, TRITA-BKN. Master Thesis 334, Structural Design and Bridges, ISSN 1103-4297, ISRN KTH/BKN/EX-334-SE.

4- Nguyen Van CHANH, "STEEL FIBER REINFORCED CONCRETE", Vietnam Joint Seminar, Ho Chi Minh City University of Technology.

5- (1987),“Guide for Structural Lightweight Aggregate Concrete”. ACI 213R-87, American Concrete Institute, Detroit, Michigan.

6- “Advantages of Structural Lightweight Aggregate Concrete”. Expanded Clay, Shale and Slate Institute, www.escsi.org

7- Tuan Ngo, 1 (2001)" Punching shear resistance of high-strength concrete slabs", Electronic Journal of Structural Engineering,.

8- Ali H. Aziz, Shatha S. Kareem and Ban Sahib A., " Experimental Study For Punching Shear Behavior In RC Flat Plate With Hybrid High Strength Concrete", Journal of Engineering and Development, Vol. 17, No.3, August 2013, ISSN 1813-7822.

9- Kaiss F. Sarsam and Hassan F. Hassan, " Punching Shear Failure Characteristics Of Flat Slabs Using Reactive And Modified Powder Concrete With Steel Fibers", Journal of Engineering and Development, Vol. 17, No.5, November 2013 , ISSN 1813- 7822.

10- Iraqi specification No. 5 : 1984, Iraqi Cement Standard for Portland Cement.

11- Iraqi specification No.45/1984, Natural Aggregate for concrete and Buildings.

12- ACI Committee 211-2, 2004, Standard Practice for Selecting Proportions for Structural Lightweight Concrete, ACI Manual of Concrete Practice.