



PUNCHING SHEAR STRENGTHS OF HYBRID REINFORCED CONCRETE FLAT PLATE SLABS

Suha Rasheed Abass¹, Haitham Jameel Abd²

1) Asst. Lect. Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq

2) Asst. Lect. Engineering affairs, Baghdad University, Baghdad, Iraq

Abstract: This study is conducted to test experimentally the punching shear of reinforced concrete flat plate slabs made with hybrid concrete (two types of concrete in two layers in specimens. Twelve test slab with (450×450×50) mm dimension The tested slabs have been. divided into four groups, each of which consisted of three slab specimens identical in size and shape but different in concrete type and steel bar reinforcement. All slabs are simply supported along the all edges and subjected to single point load applied at the center of gravity of each slab. Experimental results show that the use of hybrid concrete and high strength concrete improves the punching shear resistance and allows higher forces to be transferred through the slab-column connection. For slab specimen which fully cast using high strength concrete, the ultimate shear capacity increased by (40%) in comparison with the normal concrete slabs. While, for slab specimens cast using with hybrid concrete the ultimate shear capacity increased by (5%-45%) in comparison with the normal concrete slabs. This experimental results revealed that the ultimate load capacity increase with the addition of super plasticizers to the mix of concrete.

Keywords: *Punching Shear, Flexural, RC Slabs, Hybrid Concrete, High Strength Concrete.*

مقاومة القص الثاقب للبلاطات الخرسانية المسلحة ذات الكونكريت الهجين

الخلاصة: يتناول هذا البحث دراسة عملية لتقييم مقاومة القص الثاقب للبلاطات الخرسانية المسلحة الهجين باستخدام نوعين من السمنت على شكل طبقتين. تم صب 12 نموذج من البلاطات ذات الأبعاد (450 x 450 x 50) مم قسمت الى اربع مجاميع كل منها تحتوي على ثلاثة نماذج، لها نفس الشكل والحجم ولكنها تختلف بنوعية الكونكريت وحديد التسليح، جميع النماذج ثبتت على مساند بسيطة في الاطراف وتعرضت الى الاحمال في نقطة واحدة في مركز ثقل البلاطة. اظهرت النتائج ان استخدام الخرسانة الهجين عالية القوة تحسن من مقاومة القص الثاقب في نقطة التقاء البلاطة بالعمود. نماذج البلاطات ذات الاداء العالي للمقاومة، مقاومة القص ازدادت بنسبة 40% عن الخرسانة العادية، اما البلاطات التي تصنع بشكل هجين مقاومة القص ازدادت بنسبة من (5%-45%) مع الخرسانة العادية، وقد اظهرت النتائج ان زيادة قدرة التحميل النهائي تزداد مع اضافة الملدنات على الخلطات.

1. Introduction

A flat plate structure consists of a slab with uniform thickness supported on the columns with no beams and drop panels or column capitals.

Flat-plates have been widely used due to the reduced construction cost associated with the simple formwork and simple arrangement of flexural reinforcement.

An additional advantage of a flat-plate is reduced building story heights that result in more usable space in a building for a given or limited height ⁽¹⁾. Since the depth (thickness) of a typical slab is relatively small, its capacity to transfer load into the columns by shear is often low.

As a result, most failure of flat plates is initiated by overstress in shear at the columns. These failures are termed Punching shear failures.

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 conditions. To increase the load carrying requirement of steel sections, a hybrid section is used.

The Concept of hybrid section in steel structures is not a new idea. Salmon and Johnson⁽⁴⁾ defined a hybrid girder as one that has either the tension flange or both flanges of steel section made with a higher strength grade of steel than used for the web. Conventional shear reinforcement can be used to increase the punching shear strength of slabs, but, when the thin slabs are constructed, a very large amounts of steel reinforcement are required to increase the load capacity.

The newest construction material (technique) which can be used in such cases are moderate or high strength self compacting concrete rather than using conventional shear reinforcement to increase capacity of flat slab. Some times, and for architectural purposes, the flat slabs made with non uniform or irregular shaped, such as circular, triangular, trapezoidal, ...ect. The main objective of this study is to investigate experimentally punching shear of hybrid and high strength concrete. .

2. Experimental Work

2.1. Experimental Program

Test slab were divided into Four groups, each of which consisted of three slab specimens identical in size but different in concrete type and steel bar reinforcement. Slabs which made with normal concrete and high strength concrete (100%) (first (A) and third (C) group), another slabs (second(B) and fourth(D) group) which made with hybrid concrete (50% normal concrete & 50% high strength concrete(additives GL51 ,SP 100)).

All slabs having a width of (450mm), height of (450mm) and thickness of (50mm) , see Table (1) and Figure (1). Each slab was designated in a way to refer to concrete type and steel bar reinforcement.

All slabs are simply supported along all edges and subjected to single point load applied at the center of gravity of each slab.

The applied load is transformed from testing machine through a central column of dimensions (40x40mm). It may be noted that, each group consists of three (slab specimens) based on expected mode of failure.

Table (1) Properties and Description of Tested Slabs

Group	Slab Designation	Concrete type	Reinforcement
Group-A	A1	Normal concrete 100%	ϕ 8mm@ 75 c/c
	A1	High strength concrete (GL51) 100%	
	A3	High strength concrete (SP100) 100%	
Group-B	B1	Normal concrete 100%	ϕ 8mm@75 c/c
	B2	HSC (GL51) 50% & NC 50%	
	B3	HSC (SP100) 50% & NC 50%	
Group-C	C1	Normal concrete 100%	ϕ 10mm@75 c/c
	C2	High strength concrete (GL51) 100%	
	C3	High strength concrete (SP100) 100%	
Group-D	D1	Normal concrete 100%	ϕ 10mm@75 c/c
	D2	HSC (GL51) 50% & NC 50%	
	D3	HSC (SP100) 50% & NC 50%	

2.2. Materials

The following materials are used: ordinary Portland cement (type I) produced at Northern cement factory (Tasluja-Bazian) was used throughout this investigation, properties of this material comply with the Iraqi standard specification No.5/1984 requirements; AL.ukhaider natural sand of 4.75 mm maxim size was used as fine aggregates.

The grading of The fine aggregate complies with the Iraqi Standard specification No.45/1984, Crushed gravel with maximum size of(10 mm) from AL.nibae area. The grading of the coarse aggregate complies with the Iraqi standard specification No.45/1984 ; high water reducer super plasticizer (GL51) (SP100) ; clean tap water was used for both, mixing and curing.

The concrete mix proportions are reported and presented in Table (2). The steel reinforcement mesh of (8 & 10 mm) in diameter at (75 mm) c/c spacing in each way for all groups. A clear cover of (5mm) was provided below the mesh. It may be noted that, for all slabs, the steel reinforcement were designed to ensure the tested specimens to fail either by punching shear or flexural.

Table (2) Concrete Mixes

mix proportions	water(l/m ³)	cement(kg/m ³)	sand(kg/m ³)	Gravel(kg/m ³)	Superplasticizers (l/m ³)
Normal conc.	180	450	610	1220	0
HSC	181.16	500	640	1280	5 (Gl)
HSC	181.16	500	640	1280	5(Sp 100)

2.3. Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) was used to test the slabs specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauge (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face at the center. All tests were made in the

laboratory of structures in Al-Mustansiriya University , college of Engineering, Baghdad, Iraq .

2.4. Test Results of Specimens

Test results of mechanical properties of hardened concrete specimens are summarized in Table (4). Compressive strength was carried out on (100x100x100mm) cubes and (150 x 300) mm cylinders.

Table (3) Mechanical Properties of Concrete

Mix Designation	Property (MPa)	
	Cube Compressive strength (f_{cu})*	Cylinder Compressive strength (f_c)*
A1	38	33
A2	39	34
A3	39	32
B1	40	33
B2	42	34
B3	41	33
C1	38	31
C2	39	32
C3	41	33
D1	38	32
D2	40	31
D3	41	33

*Average of three samples (per mix) by using (100x100x100mm) cubes.

** Average of three samples (per mix) by using (150x300mm) cylinder.

2.5. Test Procedure

Setup of tested specimens is shown in Figure (1). All slab specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states. The tested slabs were simply supported and loaded with a single-point load. The slabs have been tested at ages of (28) days.

The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations. Loading was applied slowly in successive increments; the applied load is transformed from testing machine through a central column of dimensions (40x40mm).

At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the slab surface. When the slab reached advanced stage of loading, smaller increments were applied until failure, where the load indicator stopped recording any more and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.



Figure (1) Setup of Tested Specimens

3. Results and Discussions

3.1. General Behavior

The test results of all (12) slabs included first crack and ultimate load and failure mode are listed in Table (4) and photographs (1-12).

Table (4) Ultimate, Cracked load and type of Failure of Tested Slabs

<i>Group</i>	<i>Slab Designation</i>	<i>First crack load (kN)</i>	<i>Ultimate Load(kN)</i>	<i>Mid-span deflection at first crack (mm)</i>	<i>Mid-span deflection at ultimate load (mm)</i>	<i>Failure mode</i>
Group-A	A1	15	27	300	600	Flexure
	A2	15	40	70	500	Punching + Flexure
	A3	15	45	165	1060	Punching Shear
Group-B	B1	15	24	35	170	Flexure
	B2	17.5	47.5	57	1020	Punching + Flexure
	B3	15	32.5	140	725	Punching Shear
Group-C	C1	15	41	35	550	Flexure
	C2	15	30	220	1200	Punching + Flexure
	C3	15	47.5	20	800	Punching Shear
Group-D	D1	12.5	50	28	710	Punching + Flexure
	D2	15	27.5	27	750	Punching Shear
	D3	12.5	62.5	40	450	Punching Shear

3.2. Crack Pattern and Failure Mode

The elementary cracking of all the tested slabs has been spotted first in the tension zone of

the specimens near the column stump in the shape of flexural cracks towards the specimens edges.

At increasing loading arrival at ultimate load the punching shear failure occurs suddenly. Figure (2) show the crack patterns of specimens of all the tested slabs. The first tested specimens of groups (A1, B1, & C1) were failed in flexure except of slab D1 which showed compound failure (Flexure and Punching).

The second tested specimens of groups (A2, B2, & C2) were failed in flexure except of slab D2 failed in Punching shear and the third tested specimens of groups (A3, B3, C3 & D3) were failed in Punching shear .

GROUP A

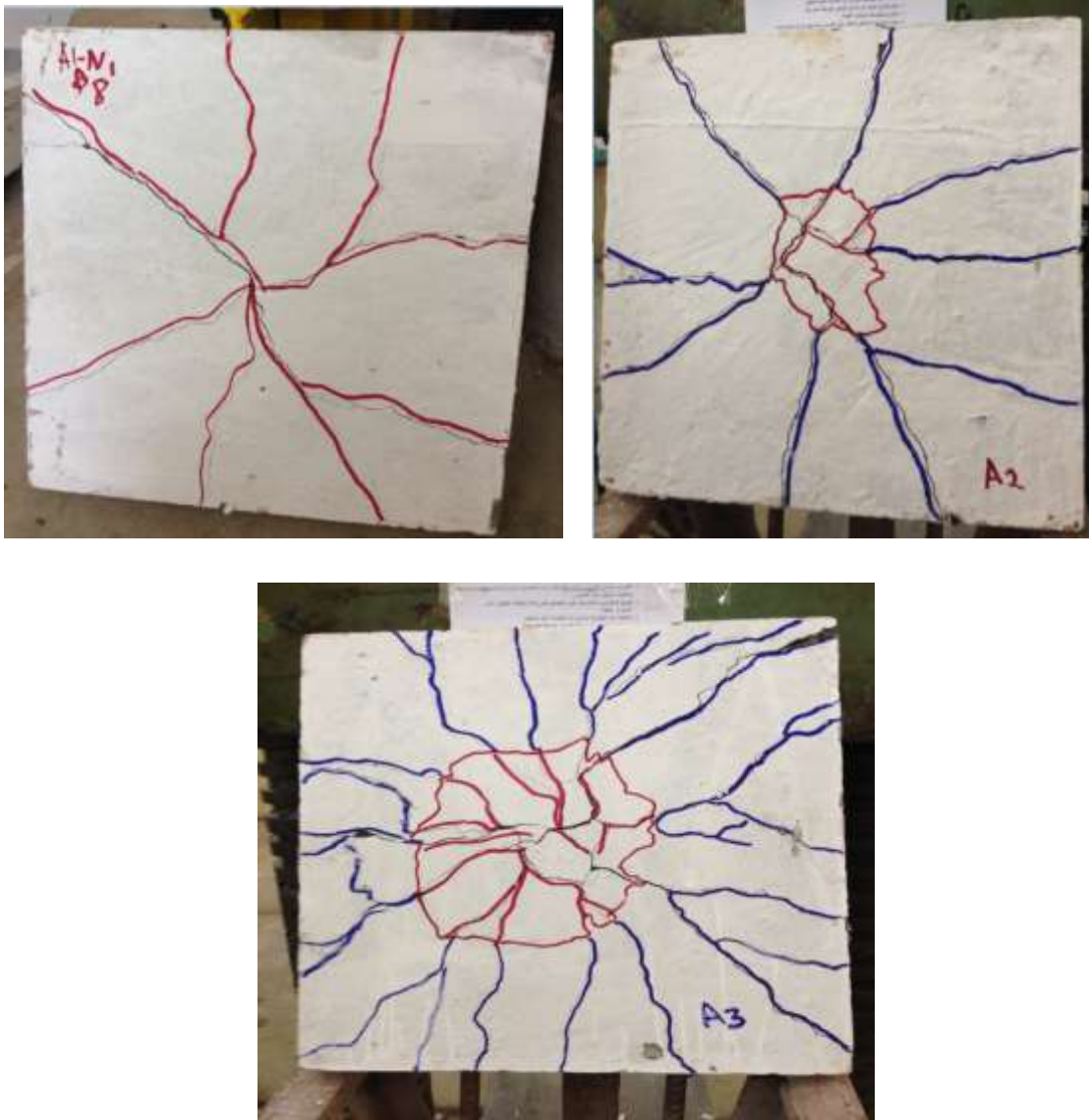
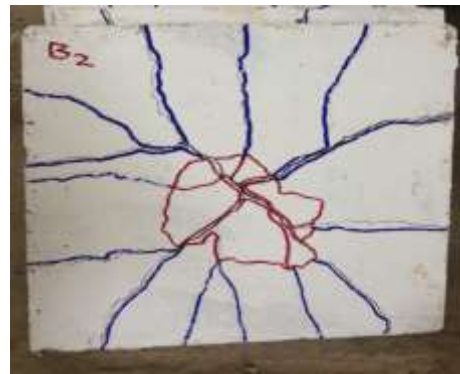
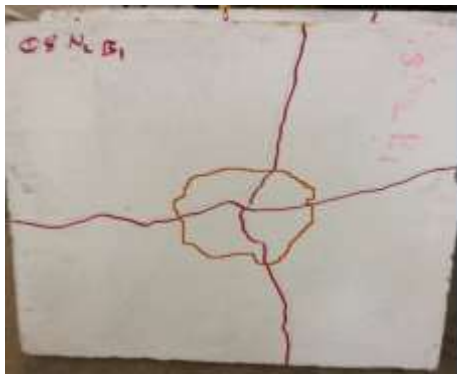


Figure (2) Crack Pattern of Specimens at Failure; Punching Shear and Flexural

GROUP B



GROUP C

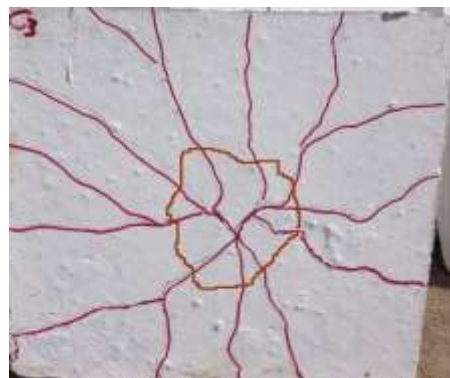
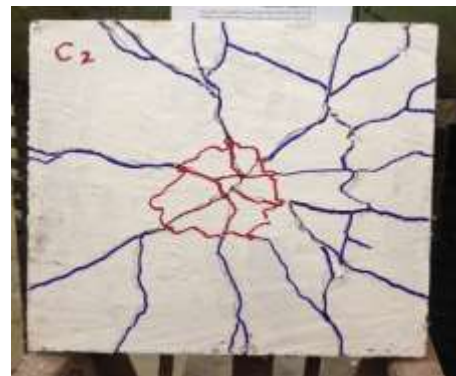


Figure (2): Continued

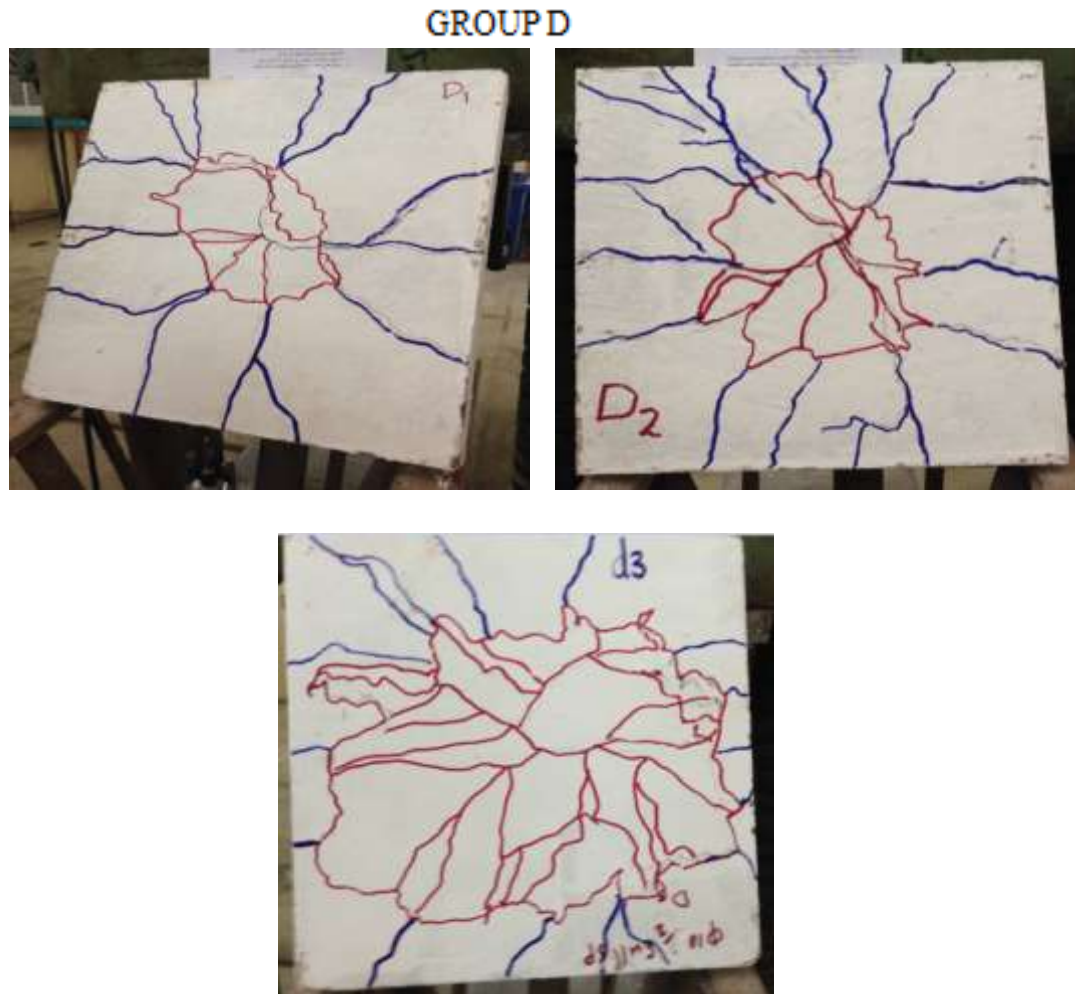


Figure (2) Continued

3.3. Ultimate Loads

This section is to find a difference in ultimate load capacity when using two types of concrete, Slabs cast with normal concrete and high strength concrete (100%) (first and third group), another slabs (second and fourth group) which cast with hybrid concrete (50% normal concrete & 50% high strength concrete(additives GL51 ,SP 100)).

For group (A&B) there is an increasing in ultimate load capacity about (A2 (48%) & A3(66%) with regard to A1) ((B2 (95%) & B3(35%)) with regard to B1 .

This experimental revealed that the ultimate load capacity increase with the addition of super plasticizers to the mix of concrete.

For group (C&D) there is an increasing and decreasing in ultimate load capacity about (C2 (27%) decreasing & C3(15%) increasing with regard to C1), (D2 (45%) decreasing & D3(25%) increasing with regard to D1). Figure (3) show Percentage Increase in Ultimate Load for Slabs.

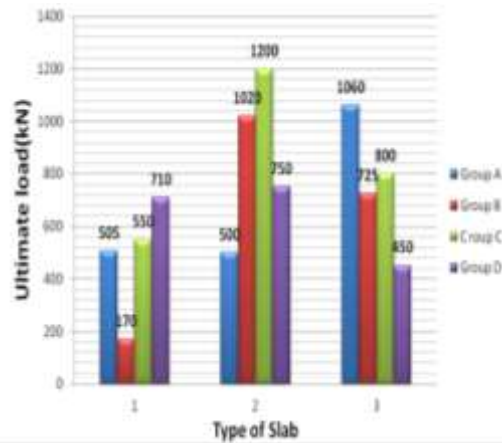


Figure (3): Percentage Increase in Ultimate Load for Slabs

3.4. Cracking Loads

Results presented in Table (5) show that the cracking loading has been decreased with the addition of super plasticizers to the mix of concrete for the same strength of concrete (40 MPa). For slab specimen (A1, A2, A3, B1, B2, & B3) the crack has been occurred at shear force of sacrificial (55% , 38% , 33% , 63% , 37% & 46%). For slab specimen (C1, C2, C3, D1, D2, & D3) the crack has been occurred at (37% , 50% , 32% , 25% , 54% & 20%). These results of group (A&B) are dissimilar to results of group (C&D) because of difference in reinforcement.

3.5. Area of the Failure Zone

The failure perimeters and identification maximum diameter of the punching failure zone are measured and showed in Table (5). The failure perimeter increased with the addition of super plasticizers to the mix of concrete. The crack angle of punching shear was located to be sacrificial between (15) to (25) degrees. The crack angle of specimens which made with high strength concrete was less dropped.

Table (5) Failure Characteristics of Tested Slabs

Group	Slab Designation	Failure Perimeter (mm)	Maximum Diameter (mm)
Group-A	A1	-	-
	A2	495	158
	A3	932	297
Group-B	B1	-	-
	B2	690	220
	B3	1410	449
Group-C	C1	-	-
	C2	550	175
	C3	1520	484
Group-D	D1	733	234
	D2	1065	339
	D3	1550	494

3.6. Load – Deflection Behavior

Load-Deflection curves under the center of loaded area for all tested slabs were set and showed in Figure (4).

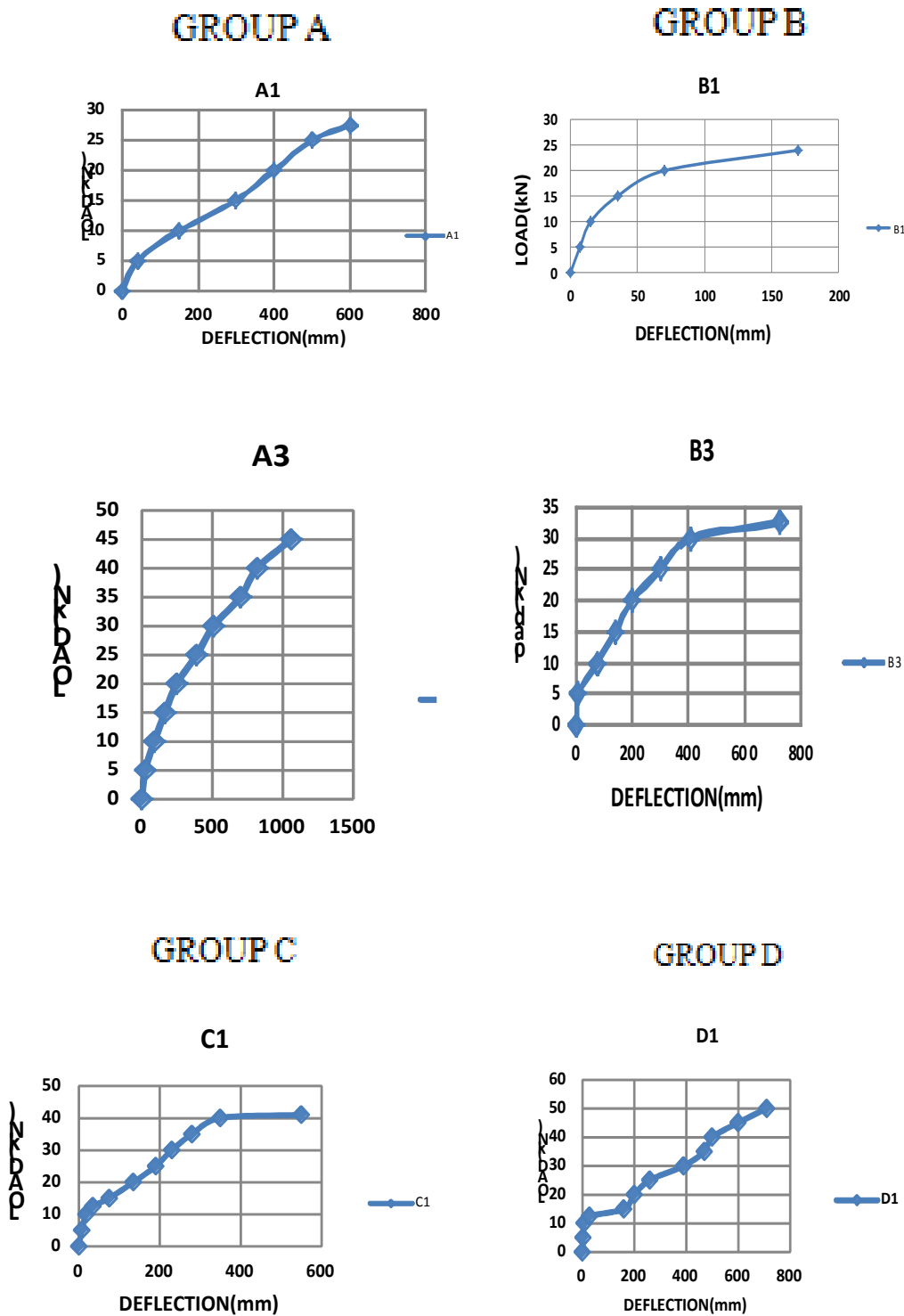


Figure (4) Load-Deflection Curves.. GROUP (A.B.C.D) slabs.

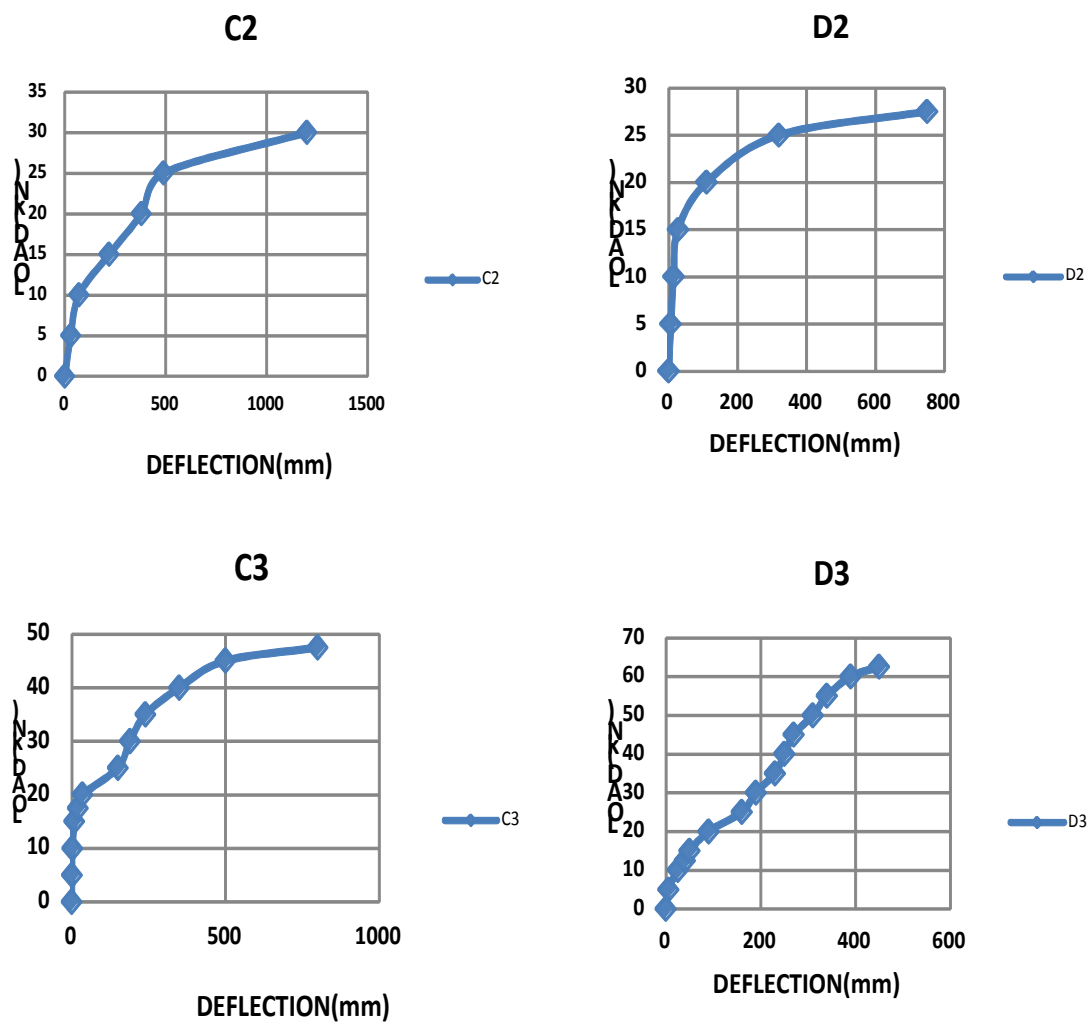


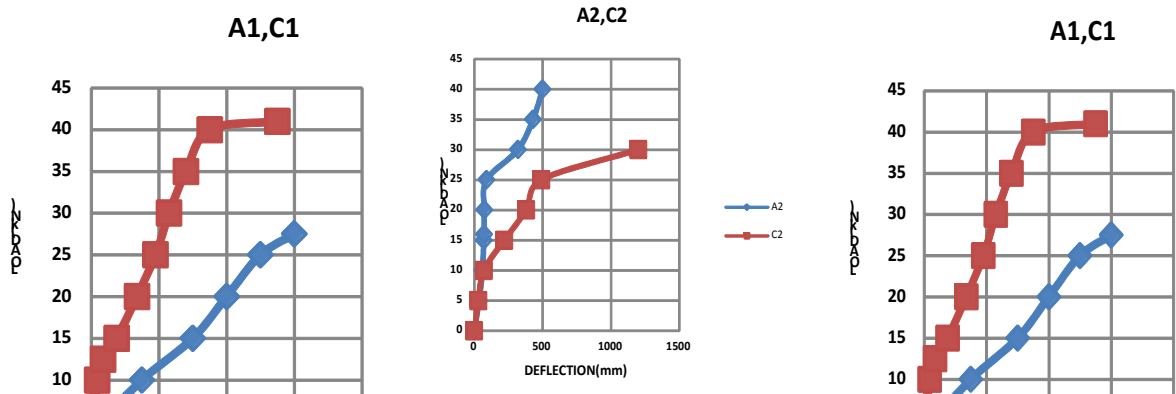
Figure (4) Continued

3.7. Effect of Bar Daimeter in Ultimate Capacity

According to the experimental results, the ultimate load capacity of tested specimens reinforced by 10 mm C1 increased by (34%) in comparison with slab A1 reinforced by 8 mm , for the slab specimen C2 decreased by about (25%) in comparison with slab A2, C3 increased by about (5%) in comparison with slab A3.

But the ultimate load capacity of tested specimens reinforced by 10 mm D1 increased by (52%) in comparison with slab B1, for the slab specimen D2 decreased by about (42%) in comparison with slab B2, D3 increased by about (52%) in comparison with slab B3As shown in Fig. (5).

GROUP A GROUP C



GROUP B GROUP D

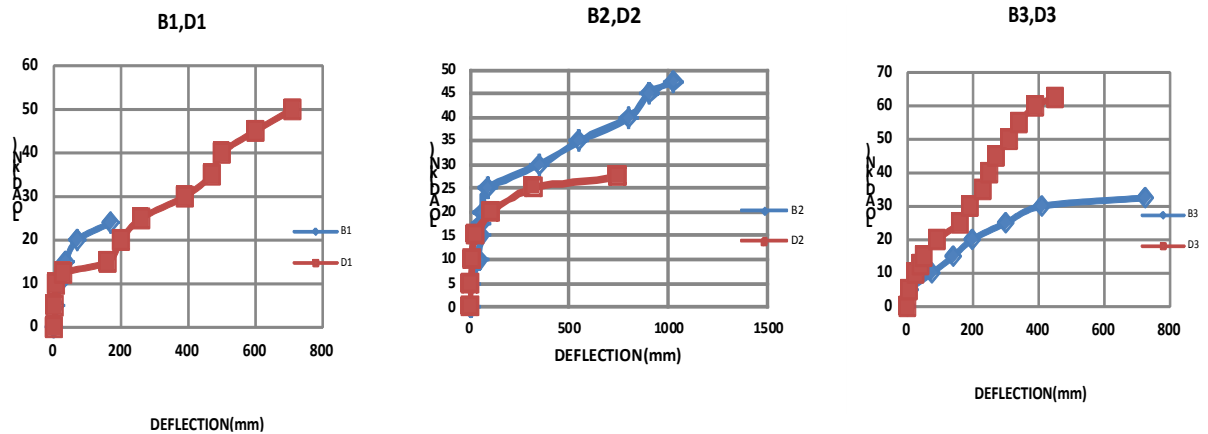
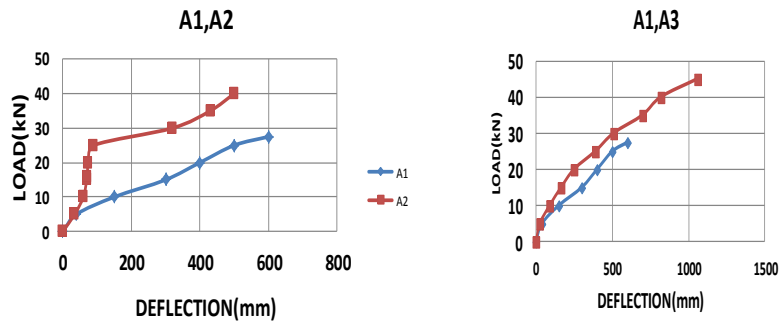


Figure (5) Effect of bar diameter in Ultimate Capacity

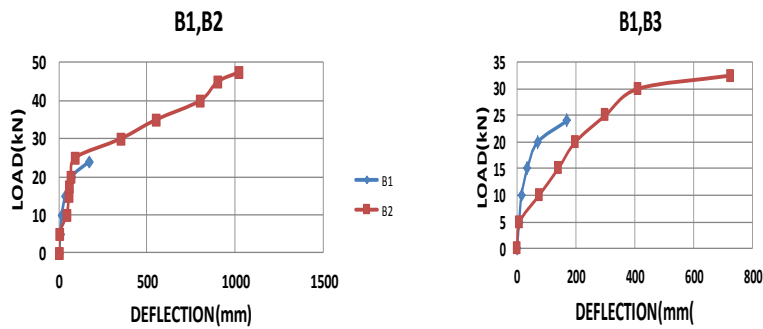
3.8. Effect of Concrete Type in Ultimate Capacity

The experimental results of ultimate load capacity of tested specimens are shown in Fig. (6). For the steel bar reinforcement ($\varnothing 8$ & $\varnothing 10$ mm) with different concrete type (CC & HSC) (HSC with GL51 & HSC with Ssp100). The results showed that the ultimate load capacity of tested specimens A2, A3 increased by (33% & 40%) in comparison with slab A1. B2, B3 increased by (50% & 26%) in comparison with slab B1. In group C & D with steel bar diameter 10 mm, the results showed decreasing in ultimate load capacity of tested specimens for the slab specimen C2 decreased by about (27%) in comparison with slab C1, D2 decreased by about (45%) in comparison with slab D1, but increasing in ultimate load capacity of tested specimens for the slab specimen C3 increased by about (14%) in comparison with slab C1, D3 increased by about (20%) in comparison with slab D1.

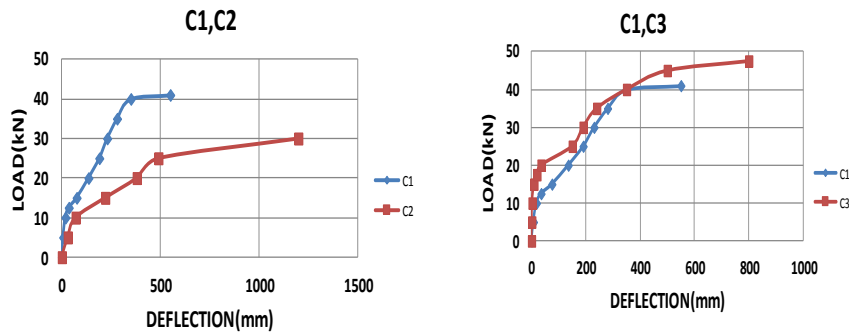
GROUP A



GROUP B



GROUP C



GROUP D

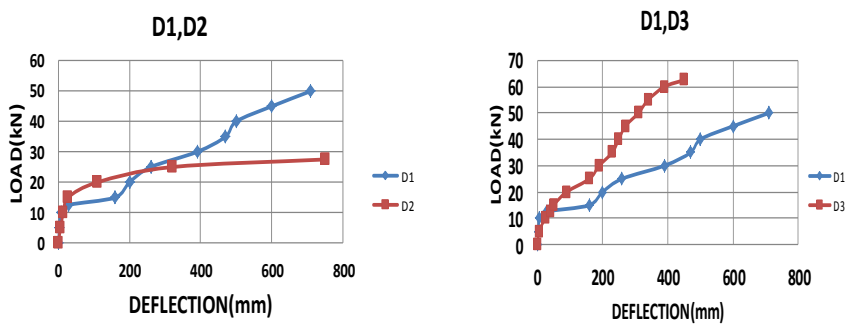


Figure (6) Effect of concrete type in Ultimate Capacity : Group(A,B,C,D)

4. Conclusions

- 1- For specimens which made with hybrid high strength concrete the ultimate capacity of tested specimens increased by about (20% - 50%) in comparison with normal concrete .
- 2- For slabs which made with HSC, the ultimate capacity of tested specimens increased by about (14% - 40%) in comparison with normal concrete .
- 3- For specimens reinforced with steel bar \varnothing 8mm , the results of ultimate load capacity showed increasing for specimens made with hybrid and high strength concrete in comparison with normal concrete. But for specimens reinforced with steel bar \varnothing 10 mm, the results of ultimate load capacity showed increasing for specimens made with hybrid concrete (normal & SP100) but decreasing for specimens made with hybrid concrete (normal & GL51).
- 4- the failure perimeter increased significantly with specimens which made with high strength concrete and hybrid concrete in comparison with normal concrete .
- 5- The amount of steel reinforced slabs does not have a significant effect on the value of the first cracking load but it has effectiveness on the value of the ultimate load.

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