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IMPROVING SHEAR STRENGTH OF THICK HOLLOW CORE SLABS BY USING LIGHTWEIGHT HIGH STRENGTH CONCRETE PRODUCED FROM RECYCLED CRUSHED CLAY BRICK AND IRON POWDER WASTE

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Abstract: This investigation provides an experimental study about structural behavior of reinforced hollow core slab (HCS) by using recycled lightweight material. Six hollow core slab specimens were casted with dimensions 1200mm length, 450mm width and different thickness (200mm, 250mm and 325mm). The shear reinforcement was used for each thickness to resist the shear failure that occur in thick hollow core slab. The Recycled materials were crushed clay brick and iron powder waste. The crushed clay brick was used as a coarse aggregate instead of gravel to a get lightweight concrete. The hollow core slab specimens were tested with age 28-day. The test was done by applied two line load up to failure. The experimental results showed an increase in the shear strength up to 50% and decrease in the maximum deflection up to 50% with increasing thickness specimen. Also the experimental results showed an increase in the shear strength up to 50% and increase in the maximum deflection up to 50% with using shear reinforcement compare with hollow core slab specimens without shear reinforcement. From the experimental results of this investigation can be avoid the shear failure and change the mode of failure from the shear to flexural failure.

Keywords: *Hollow Core Slab, Lightweight Concrete, Different Thickness, Shear Reinforcement, Shear Strength, Crushed Clay Brick, Iron Powder Waste*

تحسين قوة القص للسقوف المجوفة السميكة بأستخدام خرسانة خفيفة الوزن عالية المقاومة مصنوعة من مكسر الطابوق الطيني و نفايات مسحوق الحديد المعاد تدويرها

الخلاصة: يقدم هذا البحث دراسة عملية حول السلوك الانشائي للسقوف المجوفة المسلحة بأستخدام مواد معاد تدويرها خفيفة الوزن. تم صب ست نماذج من السقوف المجوفة بأبعاد 1200ملم طول، 450ملم عرض و بأسماك مختلفة (200ملم، 250ملم و 325ملم). تم أستخدام تسليح القص لكل سمك لمقاومة فشل القص الذي يحصل في السقف المجوفة السميكة. المواد المعاد تدويرها كانت مكسر الطابوق الطيني و نفايات مسحوق الحديد. تم استخدام مكسر الطابوق الطيني كركام خشن بدلاً من الحصى للحصول على خرسانة خفيفة الوزن. نماذج السقوف المجوفة تم فحصها بعمر 28 يوم. تم الفحص بواسطة تسليط حمليين خطيين لحد الفشل.النتائج العملية اظهرت زيادة في مقاومة القص لغاية 50% و نقصان في الهطول الاقصى لغاية 50% مع زيادة سمك النماذج. كذلك النتائج العملية أظهرت زيادة في مقاومة القص لغاية 50% و زيادة في الحمل الاقصى لغاية 50% مع استخدام تسليح القص بالمقارنة مع نماذج السقوف المجوفة الخالية من تسليح القص. من النتائج العملية لهذا البحث يمكن تجنب فشل القص و تحويل نمط الفشل من فشل القص الى الانثناء.

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1. Introduction

Hollow core slab (HCS) system is commonly used at the present time. This system content voids through the longitudinal axis. These voids have more advantage from the term of the structure are reduce in unit weight thus reduce the cost and become more economy where it used in the roof and floor of buildings, parking, wall panels, and deck slab for the bridge. While from term services, it used for electrical purposes, water drainage purposes, and air ducts for heating and cooling [1].

The use steel fiber in mix for cast hollow core slab (HCS) specimens increase in the shear strength up to 30% and become more ductility compare with HCS specimens without steel fiber [2].

The engineering property that makes lightweight concrete (LWC) a viable alternative to normal weight concrete (NWC) is its lower density. The density of LWC is approximately 80 percent that of NWC. This lower density creates opportunities for cost savings in both the design and construction phases. The lower dead loads may allow larger beam spacing and smaller loads being transmitted to the substructure and the foundation with a resultant saving in support costs. Also construction, the lower density may result in cost saving due to easier handling and the potential for a reduction in shipping costs. Another advantage during construction is that the lower density may allow lifting of members that would otherwise be too heavy for the crane capacity. Hence, LWC offers more than cost savings [3].

This type of concrete LWC is considered as having a density not exceeding 1920 kg/m^3, while normal density concrete is considered to have a usual density ranging between 2240 kg/m^3 and 2480 kg/m^3, and the minimum compressive strength (f 'c) at 28 days is 17 MPa. LWC with cylinder compressive strength (f 'c) greater than 41 MPa, it is characterized as high strength concrete (HSC) [4].

Celal (2011) [5] studied the shear behaivor of precast prestress HCS, where the length of bearing, voide shap (circular anf non-circlar) and different thickness were investigated. The load applied was one line load in one side of the specimens. Three types of thickness were used (200mm, 250mm, and 325mm). The dimensions of HCS specimens were 4000mm for thickness 200mm and 250mm and 4575mm for thickness 300mm and the width was 1216mm. Two type of length of bearing was used (63mm and 38mm). The expremental results showed the reduace bearing length from (63mm to 38mm) reduease in the shear capacity about (9% to 35%). The voide shape occure on the shear capacity, where the non-circular shap improve the shear capacity about 4% for thickness 200mm and 49% for thickness 250mm compare with HCS specimens with circular voide. The effect of different thickness showed variance in values, where the thickness 300mm was more efficient for shear resistance but thickness 250mm was less efficient shear resistance compare with thickness 200mm.

Abed (2016) [6] tested eight specimens of HCS slab. The different type of diameter of the hollow core was use (75mm, 100mm, and 150mm), the different (a/d) was used (2, 2.5, and 3), and cooperation between the solid slab and HCS system. The dimensions of all specimens were 2050mm length, 600mm width, and 250mm thickness. The test was done by applying two line load up to failure. The results showed the ultimate load decrease with increase the hollow core dimater about (5.49%, 15.7%, and 20.6%) with using circular dimeter (75mm, 100mm, and 150mm) respectively. When the increase (a/d) from (2 to 2.5 and 3) the ultimate decrease about (31% and 45%) respectivelly and the deflection increase about (19.9% and 23.4%) respectivety.

The improving of shear strength of thick HCS were not addressed in the previous research studies. In the present research paper, different techniques were suggested to improve the shear strength of HCS made from lightweight recycled materials (crushed clay brick (CCB) and iron powder waste (IPW)) and tested by using an experimental program.

2. Experimental Program

The experimental work was included cast six HCS specimens with dimensions of (1200mm length, 450mm width and different thickness 200mm, 250mm and 325mm). Each HCS specimen content three voids, thickness 200mm content three circular voids with diameter 75mm while in thickness 250mm and 325mm the three hollow increase in the high with increase thickness to keep the distance 62.5mm from the outer radius to the faces of slab. The dimensions details of HCS specimens shown in the Table (1). The HCS specimens were designed according to ACI-318M-14 [7]. For HCS specimens without shear reinforcement content main steel reinforcement 4Ø10mm and secondary reinforcement Ø8@80mm, while the HCS specimens with shear reinforcement content main reinforcement 4Ø10mm and shear reinforcement Ø8@80mm from end span to points load without secondary reinforcement as shown in the Fig. (1) through Fig. (6). The Top view of all HCS specimens shown in the Fig. (7). The HCS specimens were selected to ensure thick plat, the thickness to clear length ratio $\frac{h}{l_n} < \frac{1}{5}$ where h is thickness of slab and l_n is clear span [8].

Table (1) The Details Dimensions of HCS Specimens

HCS specimens*	Length (mm)	Width (mm)	Thickness (mm)	Shear Reinforcement
HCS-200-A	1200	450	200	Without
HCS-250-A	1200	450	250	Without
HCS-325-A	1200	450	325	Without
HCS-200-B	1200	450	200	With
HCS-250-B	1200	450	250	With
HCS-325-B	1200	450	325	With

*A=HCS specimens contain three hollows along entire length of HCS (1200mm) and without shear reinforcement.
B=HCS specimens contain three hollows along entire length of HCS (1200mm) and with shear reinforcement.

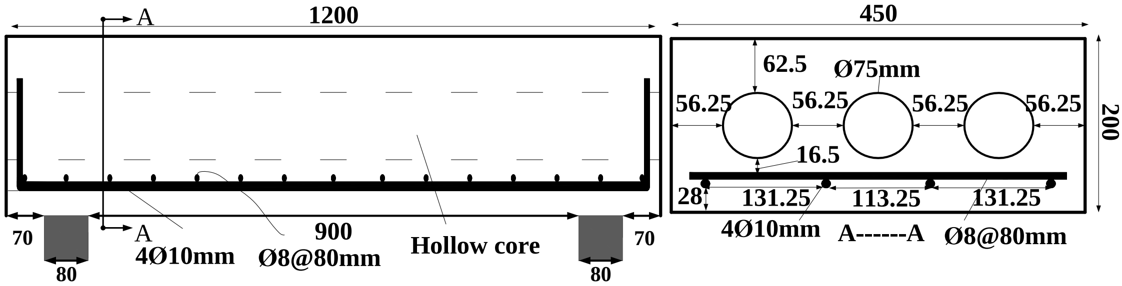
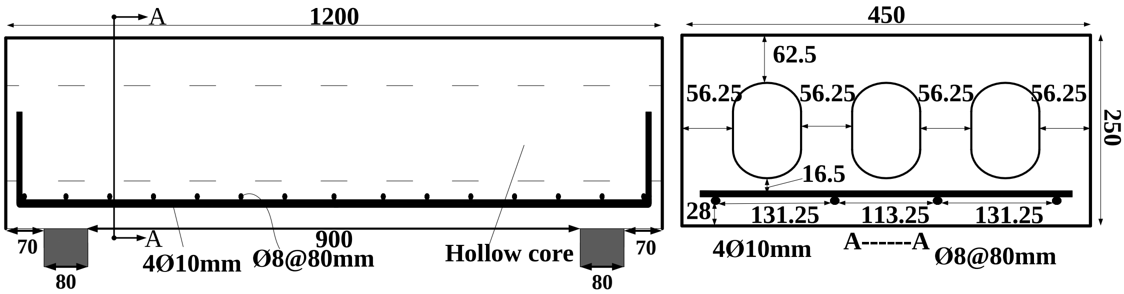
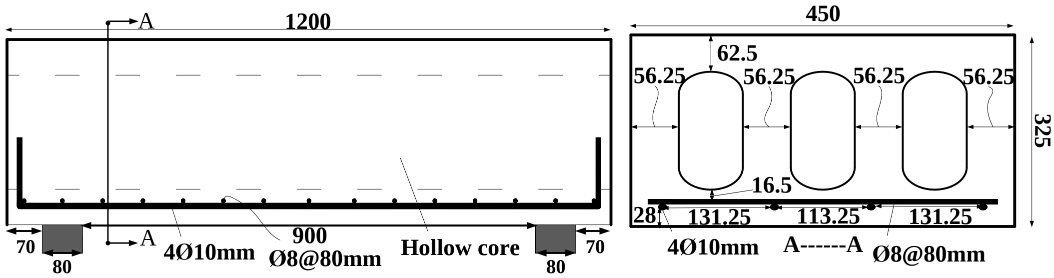


Figure (1). The Details of Section and Side View of HCS Specimen (HCS-200-A) (all dimensions in mm)



Figure(2). The Details of Section and Side View of HCS Specimen (HCS-250-A) (all dimensions in mm)



Figure(3). The Details of Section and Side View of HCS Specimen (HCS-325-A) (all dimensions in mm)

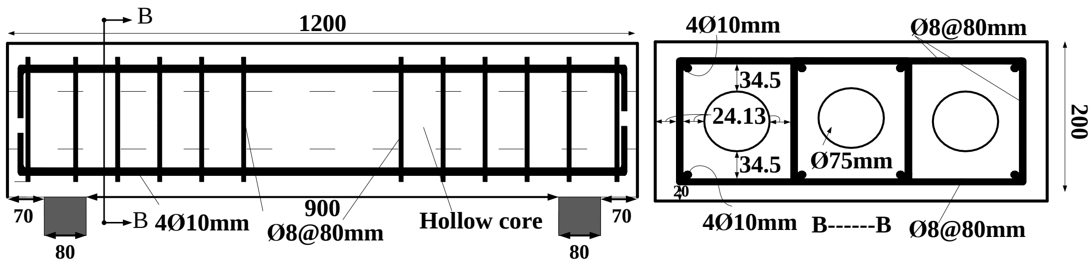


Figure (4). The Details of Section and Side View of HCS Specimen (HCS-200-B) (all dimensions in mm)

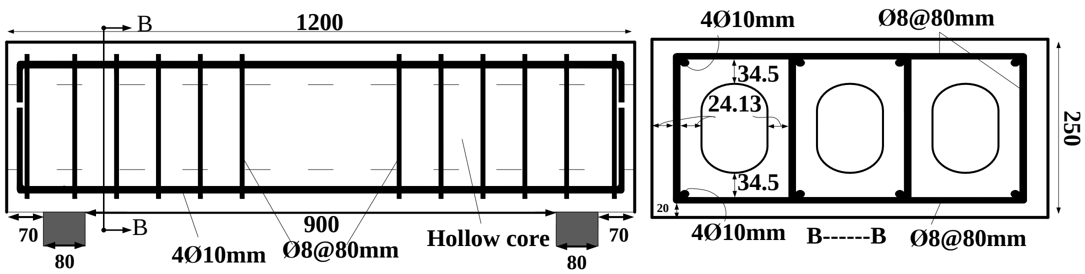
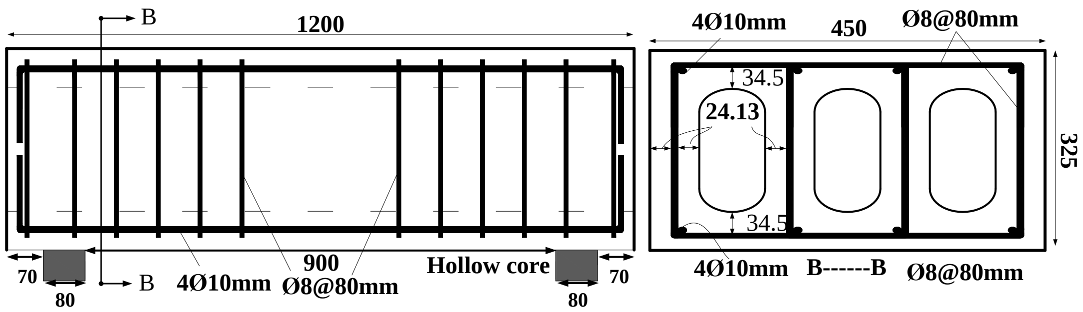


Figure (5) The Details of Section and Side View of HCS Specimen (HCS-250-B) (all dimensions in mm)



Figure(6) The Details of Section and Side View of HCS Specimen (HCS-325-B) (all dimensions in mm)

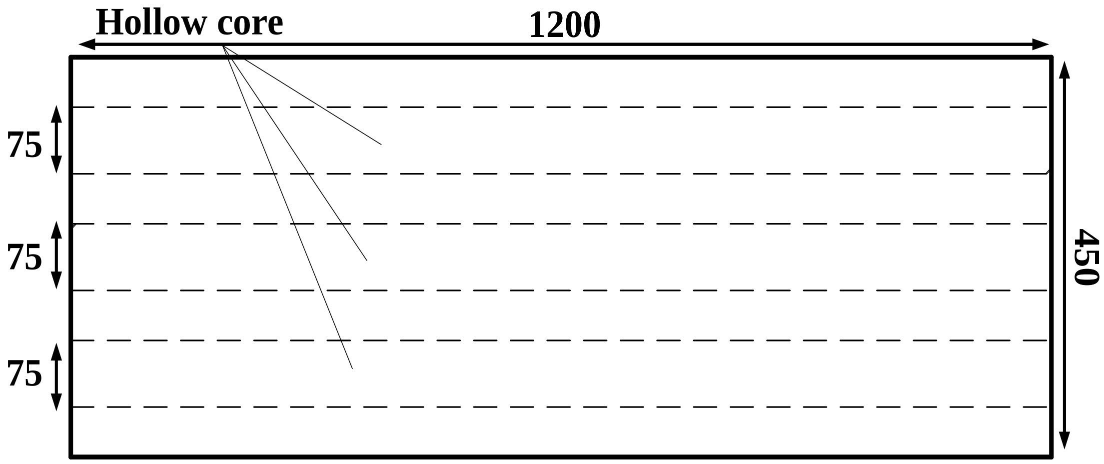


Figure (7) The Details of Top View of all HCS Specimens (all dimensions in mm)

3. Materials

The recycle LWC was used in this investigation. The crushed clay brick (CCB) was used as a coarse aggregate to reach LWC and used silica fume (SF) with iron powder waste (IPW) to reach high strength LWC. Also, superplasticizer (Glenium 51) was used to increase the workability. The details of the mix shown in the Table (2). The properties of steel reinforcement according to ASTM A615-05 [9] shown in the Table (3).

Table (2) Details of Concrete Mix

Parameter	Cement kg/m^3	Sand kg/m^3	CCB kg/m^3	SF kg/m^3	IPW kg/m^3	Superplasticizer L/m^3	W/C
Content	485	500	712	48.5	4.85	4.85	0.31

Table (3) Properties of Deformed Steel Reinforcement

Bar Nominal Diameter (mm)	Bar Measure Diameter (mm)	Yield Stress (f_y) (MPa)	Ultimate Strength (f_u) (MPa)	Elongation (%)
8	7.83	582	696	12.5
10	10.05	524	650	13

4. Molds and Preparation for Cast

The mold was used in this investigation made of plywood with thickness (15mm). The dimensions of the mold were length 1200mm, width 450mm and different thickness 200mm, 250mm and 325mm as shown in the Plate (1). The voids were made by PVC pipe with diameter 75mm in HCS specimens with thickness 200mm and increase in the high by using polystyrene block as shown in the Plate (2).

The molds cleaned and oiled to avoid adhesion concrete with it and the net of steel reinforcement placed inside the mold then the PVC pipes instilled inside the mold to get voids in specimens as shown in the Plates (3) and (4).

Thickness 200mm

Thickness 250mm

Thickness 325mm

Plate (1) The Molds

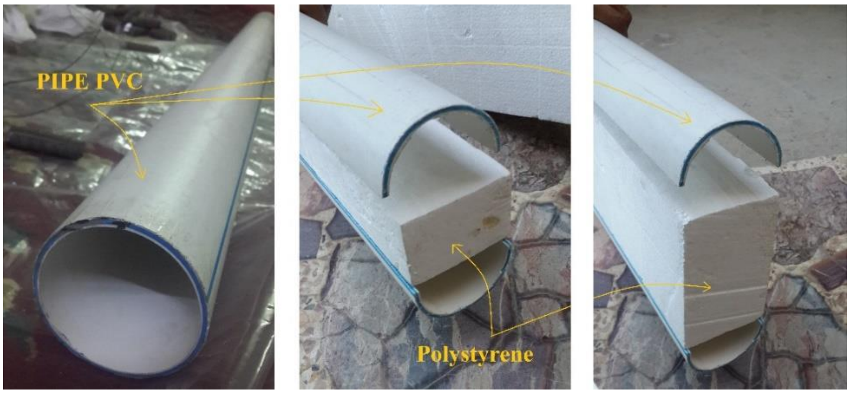


Plate (2) PVC Pipes for Voids

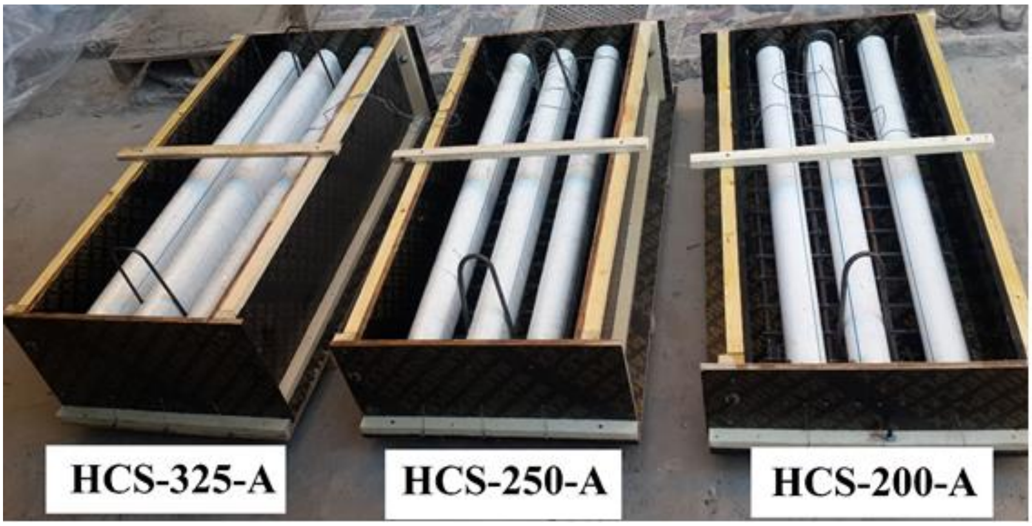


Plate (3) Install pipe and steel reinforcement in the molds for HCS Specimens without Shear Reinforcement

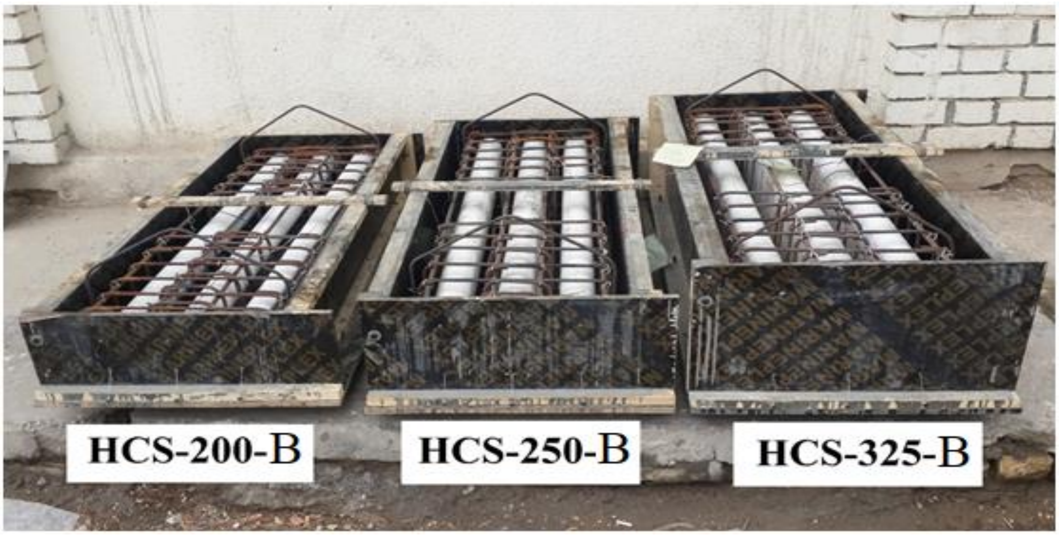


Plate (4) Install pipe and steel reinforcement in the molds for HCS Specimens with Shear Reinforcement

5. Test Process of HCS Specimens

The HCS specimens were tested under two line loads up to failure with step loading 5kN. The dial gauge was installed in the mid span to measure the deflection with step load. The machine test shown in the Plate (5). The strain gauge was used in different locations to measure the strains that occur due to applied load.

The strain gauge for concrete installed in the top fiber at mid span to measure the strains in the compression zone (S.G.1) and in the side of specimens to measure the shear stress (S.G.2) as shown in the Fig. (8). The strain gauge for steel installed in the mid of steel reinforcement at mid span to measure the strains in the tension zone (S.G.3) and in the shear reinforcement to measure the strains that occur it (S.G.4) as shown in the Fig. (9).

Plate (5) The Test Machine

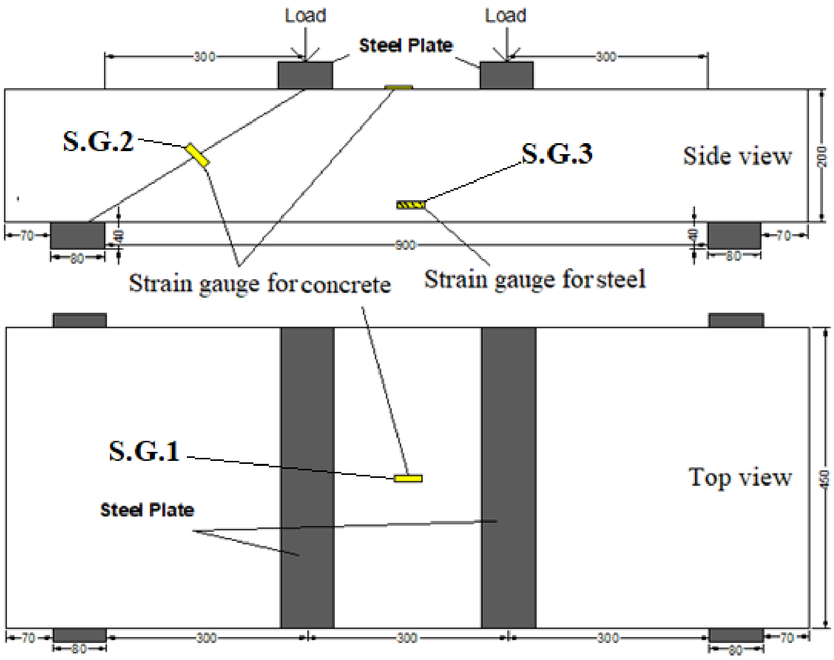
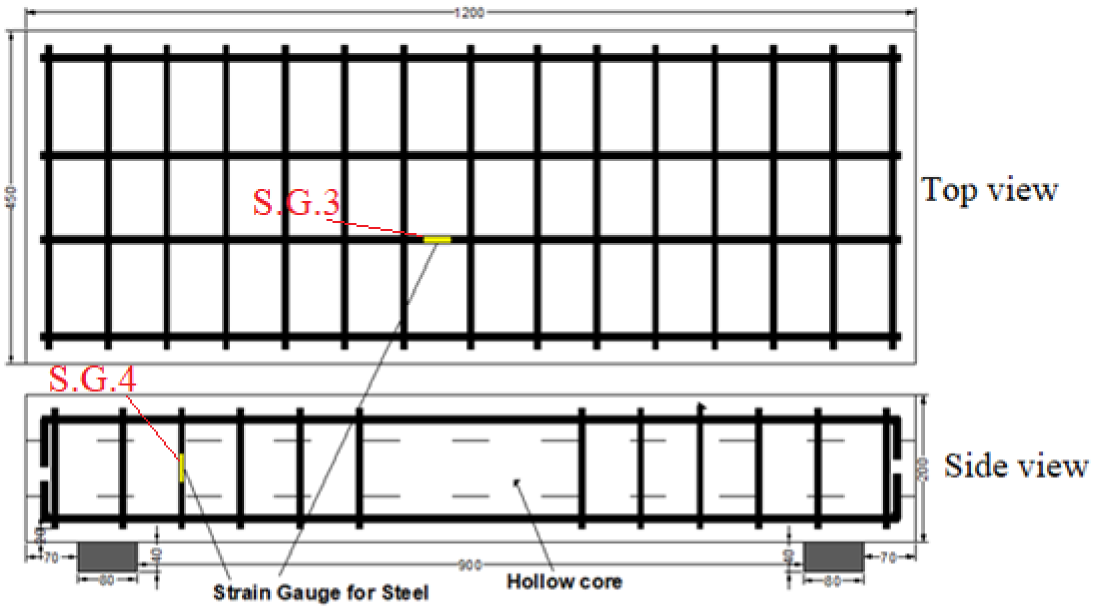


Figure (8) Locations Strain Gauge for Concrete and Steel



Figure(9) Locations Strain Gauge for Steel Reinforcement

6. Results and Discussion

6.1 Testing of Fresh Concrete

The workability of mix concrete was tested by slump test according to ASTM C 143 [10] as shown in the Plate (6). The results of the test was 110mm.

Plate (6) Slump Test

6.2 Testing of Hardened Concrete

The mechanical properties of LWC shown in the Table (4). The cube compressive strength (f_{cu}) tested according to BS 1881-part 116-2000 [11], the cylinder compressive strength ($f_c^{'}$) according to ASTM C39/C39M-05 [12], the splitting tensile strength (f_{ct}) according to ASTM C496-04 [13], the modulus of rupture (f_r) according to ASTMC78-02 [14] and the modulus of elasticity (E_c) according to ASTMC469-02 [15]. The density of the LWC was calculated from weight of average three cubes with dimensions (150x150x150)mm.

Table (4) Mechanical Properties of Concrete Mix

f_{cu} (MPa)	f_c' (MPa)	f'_{ct} (MPa)	f_r (MPa)	E_c (MPa)	Density (kg/m^3)
51	42.3	3.1	3.33	24147	1910

6.3 Test of HCS Specimens

The HCS specimen placed in the machine test. The dial gauge installed in the mid span to measure the deflection with load step. The load was done by applied two line load. The read strain gauge and deflection recorded with step load 5kN. At the first stage of loading the HCS specimen free of apparent cracks.

After increase the load, the first crack (P_{cr}) can be seen at the mid span in the tension zone. Then with increasing the load, more several cracks can be seen and the cracks became faster and spacious. The load applied continues up to failure HCS specimen then record the ultimate load (P_u) and maximum deflection (Δ_u). The cracks were marked for clarifying. The results of test HCS specimens shown in the Table (5) and the crack pattern shown in the Plate (7) through Plate (12).

The experimental results showed change in the mode failure, where change from shear failure to flexural failure by using shear reinforcement near the support. This change due to the specimen became more stiffness where resist the shear failure and convert the main cracks from the shear region to flexural region.

Table (5) Experimental Results of Test HCS Specimens

HCS Specimens	P_{cr} (kN)	P_u (kN)	R*(%)	V_u (kN)	Δ_u (mm)	Mode of Failure**
HCS-200-A	12.3	73.5	16.74	36.75	3.9	S
HCS-250-A	16.1	92.5	17.41	46.25	3.5	S
HCS-325-A	18.9	137.5	13.75	68.75	3.3	S
HCS-200-B	23.4	167.5	14	83.75	4.6	F
HCS-250-B	25.8	198	13	99	4.3	F
HCS-325-B	28.8	247.5	11.64	123.75	4	F

* $R = \frac{P_{cr}}{P_u} * 100$

** S=shear failure, F = Flexural failure

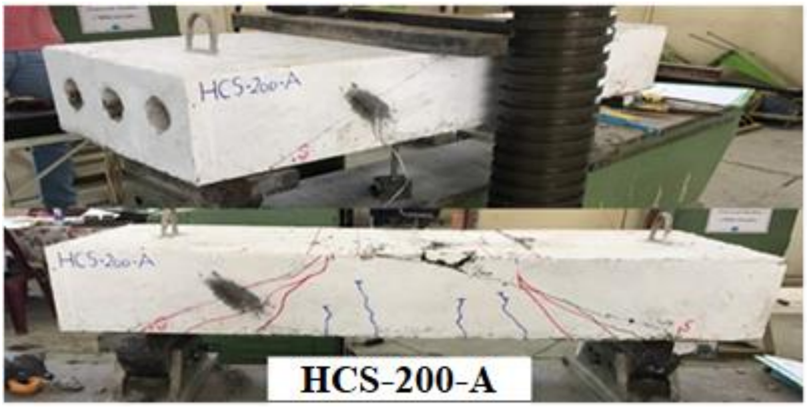


Plate (7) Crack Pattern for HCS-200-A

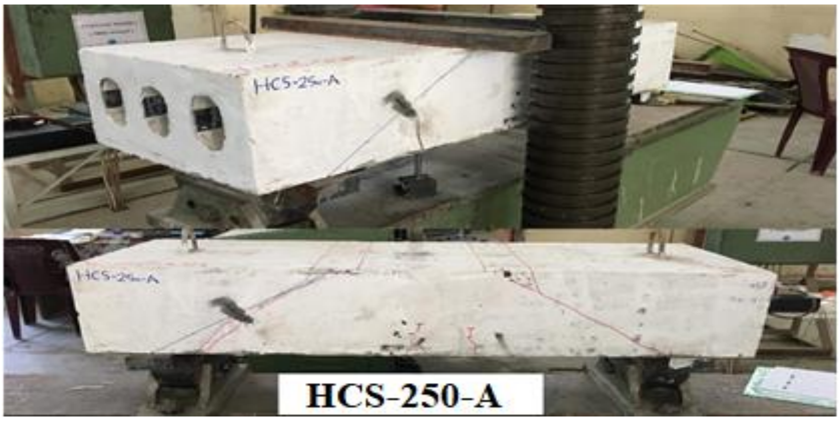


Plate (8) Crack Pattern for HCS-250-A

Plate (9) Crack Pattern for HCS-325-A

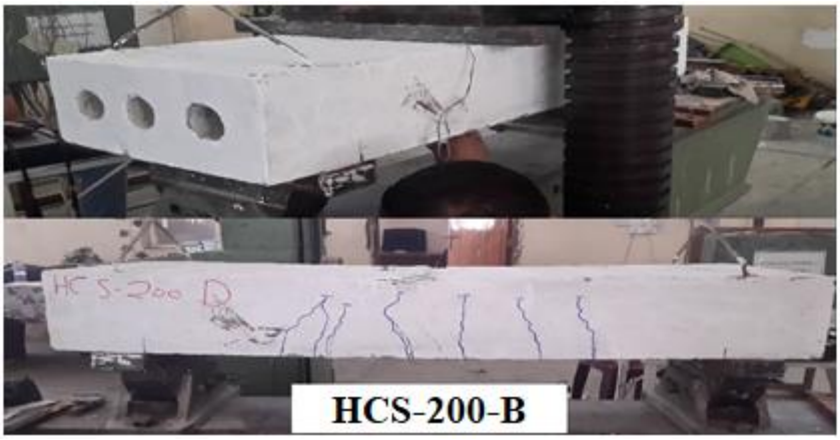


Plate (10) Crack Pattern for HCS-200-B

Plate (11) Crack Pattern for HCS-250-B

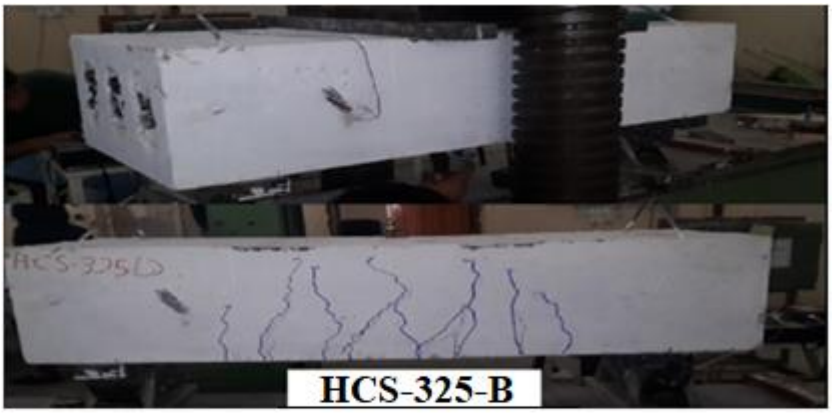


Plate (12) Crack Pattern for HCS-325-B

6.4 Ultimate and First Crack Loads

6.4.1 Effect of Shear Reinforcement

The experimental results shown in the Table (6). The results showed increase in the ultimate load up to 127.89% and increase in the first crack load up to 90.24% with use shear reinforcement. This increase due to the use shear reinforcement increase the stiffness of the specimen to resist the shear failure and convert the failure to flexural mode.

Table (6) Effect Shear Reinforcement on the Ultimate and First Crack Loads

HCS Specimens	P_{cr} (kN)	Ratio of P_{cr} (%)	P_u (kN)	Ratio of P_u (%)
HCS-200-A*	12.3	-	73.5	-
HCS-200-B	23.4	+90.24	167.5	+127.89
HCS-250-A*	16.1	-	92.5	-
HCS-250-B	25.8	+60.25	198	+114
HCS-325-A*	18.9	-	137.5	-
HCS-325-B	28.8	+52.38	247.5	+80

*Reference HCS specimens

6.4.2 Effect of HCS Thickness

The experimental results shown in the Table (7). The results showed increase in the ultimate load up to 87.07% and increase in the first crack load up to 53.66% with increasing the thickness of HCS specimens. This increase due to increase in the moment of inertia with increase the thickness thus the specimen become more stiffness. As well as, increasing the thickness of specimens was increased the effective depth (d), thereby, increasing the moment capacity of slabs.

Table (7) Effect of HCS Thickness

HCS Specimens	P_{cr} (kN)	Ratio of P_{cr} (%)	P_u (kN)	Ratio of P_u (%)
HCS-200-A*	12.3	-	73.5	-
HCS-250-A	16.1	+30.9	92.5	+25.85
HCS-325-A	18.9	+53.66	137.5	+87.07
HCS-200-B*	23.4	-	167.5	-
HCS-250-B	25.8	+10.26	198	+18.2
HCS-325-B	28.8	+23.1	247.5	+47.76

*Reference HCS specimens

6.5 Deflection

6.5.1 Effect of Shear Reinforcement on the Maximum Deflection

The experimental results shown in the Table (8) and Fig. (10) through Fig. (12). The Results showed increase in the maximum deflection up to 22.86% with use shear reinforcement. This is due to that shear reinforcement was resist the shear failure and convert the cracks from the shear region to flexural region thus lead to increase in the ultimate load, thereby, deflection at mid span was increased, also.

Table (8) Effect of Shear Reinforcement on the Maximum Deflection

HCS Specimens	Δ_u (mm)	Ratio of Δ_u (%)
HCS-200-A*	3.9	-
HCS-200-B	4.6	+17.95
HCS-250-A*	3.5	-
HCS-250-B	4.3	+22.86
HCS-325-A*	3.3	-
HCS-325-B	4	+21.21

*Reference HCS specimens

6.5.2 Effect of HCS Thickness on the Maximum Deflection

The experimental results shown in the Table (9) and Fig. (10) through Fig. (12). The results showed decrease in the maximum deflection up to 15.4% with increasing thickness of specimens. This is due to increase in the moment of inertia with increasing thickness specimens and become more stiffness thus decrease in the maximum deflection.

Table (9) Effect of HCS Thickness on the Maximum Deflection

HCS Specimens	Δ_u (mm)	Ratio of Δ_u (%)
HCS-200-A*	3.9	-
HCS-250-A	3.5	-10.26
HCS-325-A	3.3	-15.4
HCS-200-B*	4.6	-
HCS-250-B	4.3	-6.52
HCS-325-B	4	-13

*Reference HCS specimens

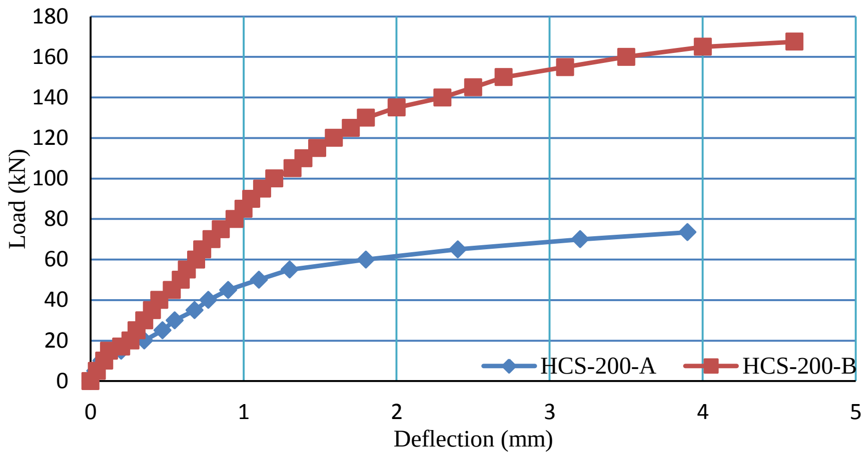


Figure (10) Load-Deflection Curve for HCS-200-A and HCS-200-B

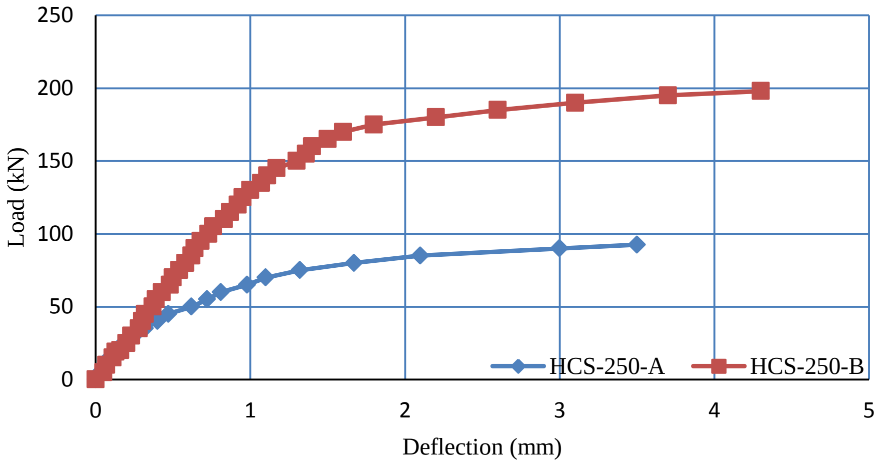


Figure (11) Load-Deflection Curve for HCS-250-A and HCS-250-B

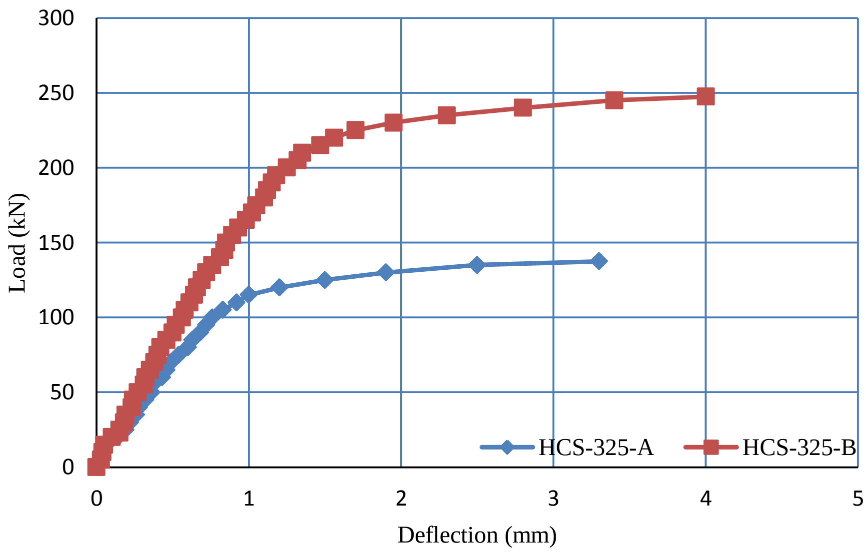


Figure (12) Load-Deflection Curve for HCS-325-A and HCS-325-B.

6.6 Strain Profile

6.6.1 Effect of Shear Reinforcement on the Strain-Load Curve

The strain load curve in this investigation was determine from reading record from (S.G.1) in the compression zone and (S.G.3) in the tension zone of concrete. The results of strain gauge shown in the Fig. (13). The reading of strain gauge was recorded with step load 5kN. The results showed increasing in the strains in the compression and tension zone at mid span with using shear reinforcement. This is due to the shear reinforcement convert the failure from the support region to flexural region, which lead to increase the strains that occur due to applied load at mid span.

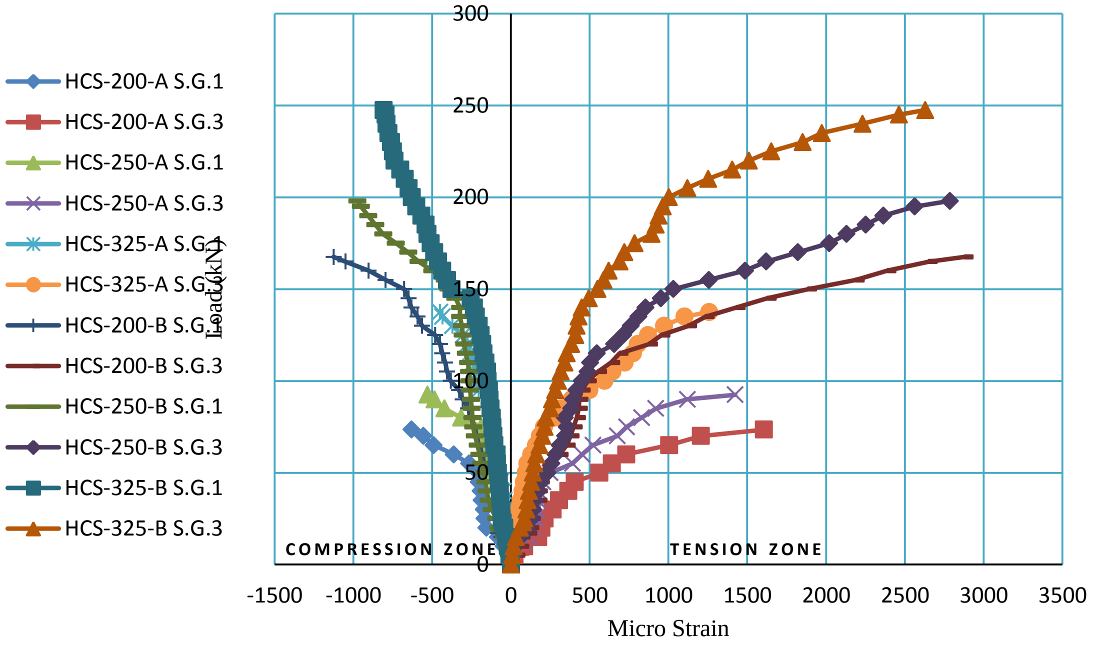


Figure (13) Strain-Load Curve for Strain Gauge S.G.1 and S.G.3

6.6.2 Effect of HCS Thickness on the Strain-Load Curve

From the experimental results of stain gauge as shown in the Fig. (13), increasing the thickness of HCS specimens was decreased the strains in the compression and tension zone at mid span. This is due to increase moment of inertia of the section HCS specimens thus became more stiffness which lead to resist the stresses in the compression and tension zone at mid span.

6.6.3 Shear Stress in HCS

6.6.3.1 Effect of Shear Reinforcement on the Shear Stress in Concrete

The shear stress in concrete was measured from reading record by strain gauge (S.G.2) as show in the Fig. (14). The maximum shear stress was determine by using Mohr's circle as shown in the Table (10).

The experimental results showed, shear reinforcement was decreased the shear stress up to 77%. This decreasing due to the shear reinforcement resist the shear failure and work to convert the cracks from the shear region to flexural region. The equations were used to calculate the shear stress as shown in (1) through (3).

$$\varepsilon = \frac{\gamma_{max}}{2} \quad (1)$$

$$G = \frac{E_c}{2*(1+\nu)} \quad (2)$$

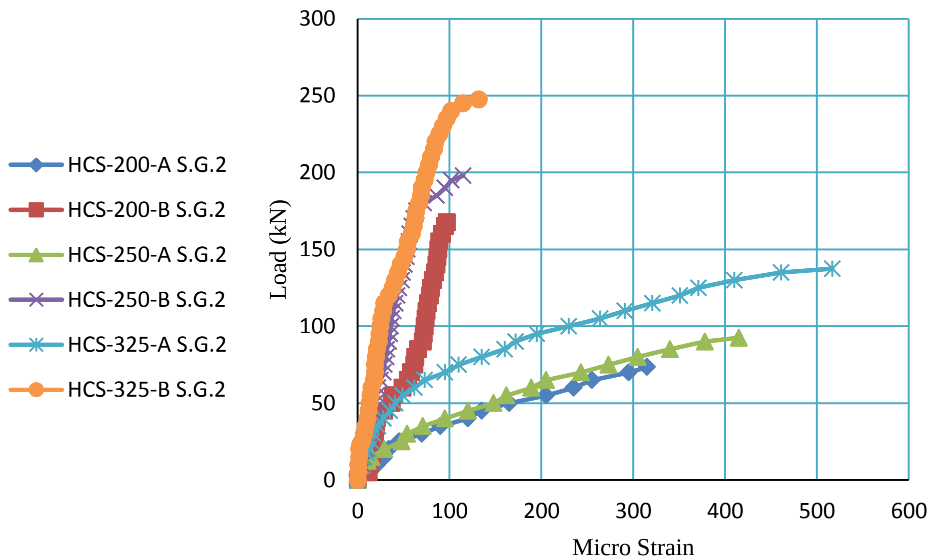
$$\gamma_{\max} = \frac{\tau_{\max}}{G} \quad (3)$$

Where ε is strain record, γ_{max} is maximum shear strain due to strain occur, ν is Poisson's ratio, G is shear modulus (MPa) (Poisson's ratio was 0.23) and τ_{max} is shear stress (MPa).

Table (10) Effect of Shear Reinforcement on the Shear Stress in Concrete

HCS Specimens	Shear Stress (τ_{Max}) (MPa)	Retio of τ_{Max} (%)
HCS-200-A*	6.18	-
HCS-200-B	1.9	-69.26
HCS-250-A	8.15	-
HCS-250-B	2.26	-72.27
HCS-325-A	11.29	-
HCS-325-B	2.59	-77

*Reference HCS specimens



Figure(14) Strain Load Curve for Strain Gauge S.G.2

6.6.3.2 Effect of HCS Thickness on the Shear Stress in Concrete

From the experimental results shown in the Table (11). It can be seen, increasing thickness of HCS specimens was increased the shear stress. This is due to increase the moment of inertia with increase thickness of spacemen where the failure was convert to the support region thus increase the stresses in this region.

Table (11) Effect of Shear Reinforcement on the Shear Stress in Concrete.

HCS Specimens	Shear Stress (τ_{Max}) (MPa)	Ratio of τ_{Max} (%)
HCS-200-A*	6.18	-
HCS-250-A	8.15	+31.88
HCS-325-A	11.29	+82.69
HCS-200-B*	1.9	-
HCS-250-B	2.26	+18.95
HCS-325-B	2.59	+36.32

*Reference HCS specimens

6.6.4 Stress in the Shear Reinforcement

The stress in the shear reinforcement was determine from the reading record of (S.G.4) as shown in the Fig. (15). The stress was calculated by using Hook's low as shown in (4) because of the shear reinforcement in the linear stage as shown in the Table (12). The results showed decreasing in the stresses and convert the failure form the shear region to flexural region with increasing thickness of HCS specimens.

$$E = \frac{\sigma}{\varepsilon} \quad (4)$$

Where E is modulus of elasticity (MPa), σ is stress (MPa) and ε is strain record.

Table (12) Stress in the Shear Reinforcement

HCS Specimens	Stress (σ_{Max}) (MPa)	Ratio of τ_{Max} (%)
HCS-200-B	61	-
HCS-250-B	40	-34.43
HCS-325-B	23	-62.3

*Reference HCS specimens

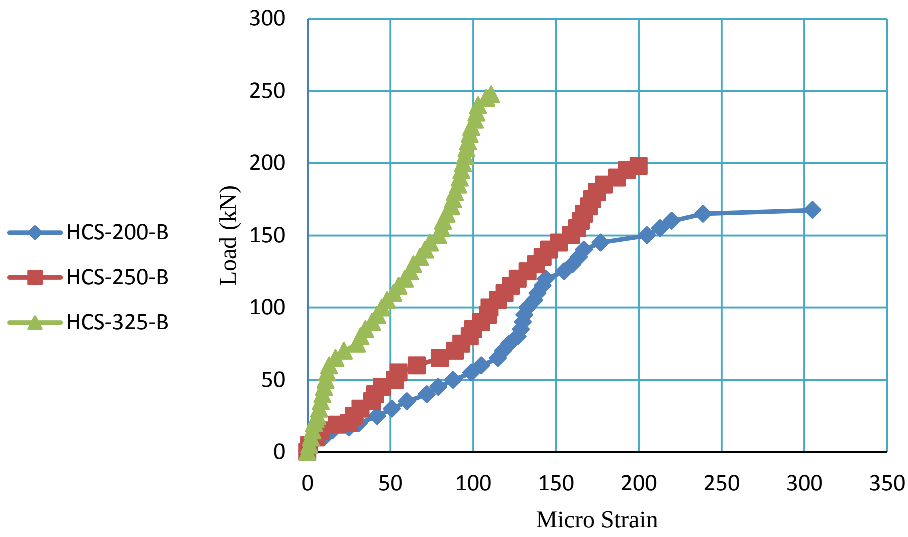


Figure (15) Strain Load Curve for S.G.4

7. Conclusions

The conclusions according to the experimental results are presented:

1.The technique of using shear reinforcement in HCS specimens was resisted the shear failure and showed increasing the ultimate load up to (127.89%), increasing the first crack load up to (90.24%) and increasing the maximum deflection up to (22.86%).

2.Increasing thickness of HCS specimens about (25% and 62.5%) was showed increasing the ultimate load up to (87.07%), increasing the first crack load up to (53.66%) while the maximum deflection was decreased up to (15.4%).

3.Using shear reinforcement to improve the shear strength of HCS specimens was showed change in the mode failure from the shear failure to flexural failure.

4.Reading record from the strain gauge was showed that shear reinforcement was caused increasing in the stresses in the compression and tension zone of concrete at mid span where the failure convert from the support region to mid span region.

5.The shear stress of HCS specimens was decreased up to (77%) with using shear reinforcement compare with HCS specimens without shear reinforcement.

6.With increase thickness HCS specimens about (25% and 62.5%) was caused increasing shear stress up to (82.69%).

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