International Journal of Mechanical Engineering

Punching Shear Response of Hybrid Reinforcement Concrete Slab under High Temperature Loading

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Abstract: Under the influence of punching shear force, the behavior and strength of reinforced concrete slabs were examined. The primary goal of this study is to examine the punching shear behaviour of reinforced concrete slabs in an experimental setting which were exposed to high temperature up to 400 c° by using an electric oven. Six models were cast and using high strength concrete mixture with normal concrete, all slabs have dimensions of (400x400x60) mm, with steel reinforcement mesh of (Ø6mm) diameter. Laboratory tests show that there is an increase in the value of First Crack Loading (FCL) and Ultimate Load (UL) by (80, and 118.9) % and a decrease in deflection by (56.85) % due using a fully high strength concrete mixture. The use of the (HSC) mixture in layers gave results close to the slab which consists of full (HSC) this gives the benefit of more than the use of a slab that contains full high strength in terms of cost, the increase was in FCL and UL by (30, 60 and 43.24, 73) % and a decrease in the value of deflection by (18.19, 30.28) %. The use of a partial area of high strength mixture also showed good results and by increasing the dimensions of the HSC area the results were better, Where the increase in FCL and UL by (0,30, 50) % and (27.02, 35.13, 59.5) % and a decrease in value of deflection by (0.91, 10, and 27.73) % from reference slab.

Keywords: *High temperature, Punching Shear, High strength Concrete, Flat slab (two way).*

1. Introduction

A flat plate is a slab resting directly on columns. A flat plate is a slab that rests directly on the columns of a building. In order to be capable of passing the loads directly and securely to the supporting columns, the slab is strengthened without the need of using column capitals or drop panels. Flat plate construction does not necessarily mean the absence of beams, since beams are often used in areas such as around stairs and large openings in the slab, among other locations [1]. Load sensitivity varies from structural component to structural member, with concrete slabs being the most sensitive structural parts during the building period or construction phases. The punching shear failure type is the most common kind of failure in flat slabs. As a consequence of a concentrated stress due to load on the columns, causing this type of failure around the columns.

Figuer-1 Flat plate concrete construction [2].

Figure-2 Typical punching shear failure [3].

Mikael,1996 [4] the impact of high strength concrete (HSC) with compressive strengths. The comprehensive strength was ranging from 60 to 120 MPa on the punching shear of flat slabs he investigated. Ten identical high strength concrete flat slabs with a circular shape were tested. Shear reinforcement was taken as a variable. While some samples were reinforced against shear stresses, others were not. A flat slab made out of normal strength concrete was made as a reference sample for comparison. It has been found that HSC can boost the punching resistance, and a supplementary effective utilization of the flexural reinforcement than the sample made out of normal concrete.

Ghannoum, 1998 [5] in their study investigated impact of high-strength concrete on the slab-column specimens performance. Evidence suggests that raising the compressive strength of slabs in concrete leads in an improvement in their performance, as seen by an enhancement in the punched shear strength and an enhancement in the post-cracking stiffness.

Sarcasm et.al, 2005 [6] in their study examined the resistance of punching shear slab with normal and high strength concrete test results of (47) reinforced concrete slabs including seventeen in NSC and thirty slabs in HSC. These 47 tests covered a very wide range of concrete compressive strength (f'c). This shows that the usage of (HSC) has been proven to enhance punching shear resistance while also enabling larger forces to be delivered via the slab-column connection.

Ahmed,2005 [7] reported the outcomes of 27 HSC and NC slab samples, and indicated that an increase in shear strength can be achieved by increasing the compressive strength. This enhancement was (47%) in rectangular loaded areas with respect to improving the compressive strength from (33 MPa) to (94.2 MPa). However, around 50% of the upper enhancement was attained in square loaded upon raising the compressive strength of concrete from (36.1 MPa) to (39.1 MPa) (75.4 MPa).

Ozden et al, 2006 [8] in their study investigated flat plates' punching shear performance. A total of twenty-four circular specimens slab of conventional and elevated potency concrete were used in the study. They explored and utilization of steel fiber reinforcement and the effects of flexural reinforcement. They discovered that following the first punching failure, increasing the ratio of plate flexural reinforcement resulted in a rise in strengths of punching and residual in reinforced concrete slabs, indicating that the strength residual of reinforced concrete slabs is relatively consistent and stable.

Inácio et al., 2013 [9] conducted an experiment in order to investigate the behavior of elevated strength concrete (HSC) flat slabs punching with compressive strengths up to 130MPa and identical dimensions of 1650 mm square and 125 mm, resulted and adjusted the longitudinal reinforcement with different ratios. It is noted that the capacity high strength concrete slabs punching increased by up to 43% compared to a standard strength concrete reference specimen.

2. The aim of this study

The main purpose behind this experimental program is to explicate the consequence of high temperature on concrete strength in the presence of high strength concrete and to know punching shear behavior of seven specimens of two-way flat plate slabs.

3. Description of the Tested Slabs

Slabs of (400x400x60) mm were used in the current experiment, each of which was simply supported on its four sides, loaded by a (40x40) mm dimesion central steel column. Slabs designation were as following:

1st symbol (R) for reference slab.

2nd symbol (O) for no addition.

3^{ed} symbol (F) for high temperature up to 400c°

4th symbol (HS.) for a concrete type (HSC)
5th symbol (L) for layers.
6th symbol (10, 16, 22) cm dimensions of the partial high strength concrete (HSC). **See Fig.3 to more details.**
7th symbol (1.5, 3) cm dimensions for layers of (HSC). **Fig.4 to more details.**
8th symbol (S) from a square shape.
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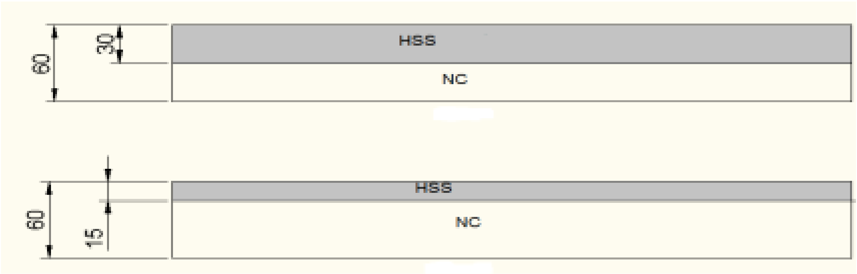


Figure 3. Use (H.S.C) in layer with different dimensions

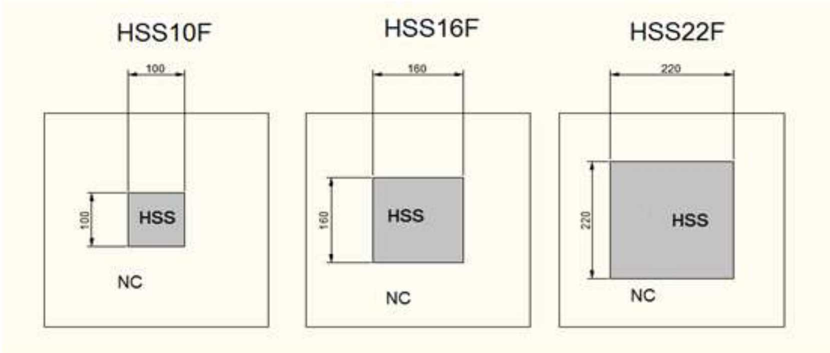


Figure 4. Use (H.S.C) in in a square shape

Table 1. The table shows the symbols used in the search

Group name	specimens	Dimension in (cm) L	B	T	Description
H.S.C	R1STO2ndOF3ed	40	40	6	This model consists of N.C with reinforcing steel
	HS4thOOF	40	40	6	It contains a complete mix of high strength concrete
	HSL5th157thF	40	40	6	Contains high strength concrete on the form of a layer in dimensions 1.5cm and the rest is N.C in dimensions 4.5cm. **see fig.3**

HSL30^{7th}F	40	40	6	Contains high strength concrete on the form of a layer in dimensions 3cm and the rest is N.C in dimensions 3cm.**see fig.3**
HSS^{8th}10^{6th}F	40	40	6	Contains high strength concrete on the form of a super in dimensions (10*10)cm at the center of the slab and the rest is N.C **see fig.4**
HSS16^{6th}F	40	40	6	Contains high strength concrete on the form of a super in dimensions (16*16)cm at the center of the slab and the rest is N.C **see fig.4**
HSS22^{6th}F	40	40	6	Contains high strength concrete on the form of a super in dimensions (22*22)cm at the center of the slab and the rest is N.C **see fig.4**

4. Methodology

All the samples were designed according to (ACI-318-14) [10], used normal concrete and reactive powder concrete. Table (2) and (3) gives mix proportions of (NSC) and (H.S.C) used in this research.

Table 3.Properties of Concrete Mix (NC)

Cement kg/m^3	Sand kg/m^3	Gravel kg/`	w/c
400	600	1200	0.45

Table 3.Properties of Concrete Mix (HSC)

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	w/c	Super plasticizer (L/m^3)
510	590	1000	0.32	5

The molds used, as indicated in fig.5, the study samples were cast from ply-wood that had been greased with specific moisture-resistant oil.

Figure 5. Some molds are used

After the casting process and curing the models put them in water for 28 days as shown in the fig.6.

Figure 6. Slabs during curing.

The slabs were removed out of the curing container and cured in open air for one day prior to the testing day. The slab specimens were cleaned and coated with white paint on both sides throughout the drying process to provide clear sight of cracks during testing. The placements of the supports, the centrally applied load, and the dial gauge were all noted and market before the specimens were tested. A dial gauge with a sensitivity of 30mm and a resolution of 0.01mm (ELE type were used for measurement of the central deflection of the slab specimen. A 5 kN increase is added to the load. An accurate image of the slab's structural behavior was obtained by applying this load. In order to give the necessary room for the board, the testing machine was equipped with a customized supporting frame with a clear distance of support of (400x400) mm. To create the square shape of this supporting structure, four steel beams are welded together. Four steel beams, one on each side, are covered with 25-millimeter-wide welded steel tape, which serves as a simple support for the board's edge. A solid square steel cube (40X40mm) is put over the slab's centre to give a focused load as shown in Fig. 7 shows the details of slab testing.

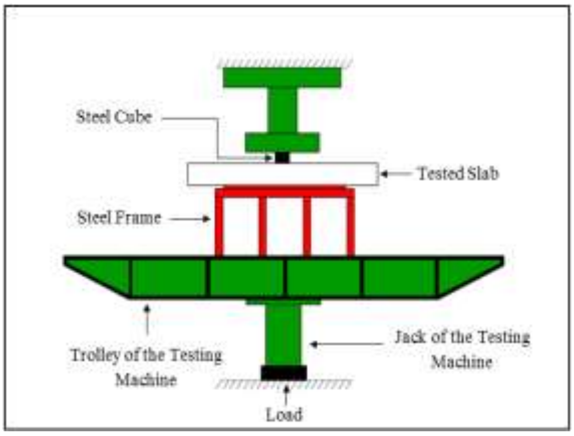


Figure 7. The hydraulic Universal testing machine.

5. Result and discussion

The Table 4 below shows the standard of the material properties has been used for (N.C), for (R.P.C) use three cylinders (100*200) mm ASTM C 39/C39M-01 and standard cubes (100) mm (B.S: 1881: part 116).

Specimen	Number of specimen	Test	Standards of test
Cube 100*100*100 mm	3	Cube compression strength	B:S: 1881: part 116 [11]
Cylindrieal R:100 mm H:200mm	3	Cylindrieal Compression Strength	ASTM C39/C39M-05 [12]
Cylindrieal R:100mm H:200mm	3	Splitting Tensile Strength	ASTM C496-04 [13]
Prism B:100mm L:500mm	3	Modulus of Rupture	ASTM C78-02 [14]

Table 4. stander used in the test

This tables 5 and 6 shows the results of the properties of the materials used at the age of 28 days. All results obtained are the average of three models.

Table 5. Mechanical properties for (NC) Mixes

Cylinders Compressive Strength f'_c (MPa)	Cubes Compressive Strength f_{cu} (MPa)	Modulus of Elasticity E_C (GPa)	Splitting Tensile Strength f_{sp} (MPa)	Modulus of Rupture f_r (MPa)
32	39	27.132	4.81	4

Table 6. Mechanical properties for (HSC) Mixes

Cylinders Compressive Strength f'_c (MPa)	Cubes Compressive Strength f_{cu} (MPa)	Modulus of Elasticity E_C (GPa)	Splitting Tensile Strength f_{sp} (MPa)	Modulus of Rupture f_r (MPa)
51.66	62.24	34.81	4.2	7.3

Figure-8 the cubes, prisms, and cylinder

6. Models during burning process

The electric furnace was used in the laboratory of the University of Mustansiriyah, where the models were exposed to a high temperature up to 400 c˚. As shown in the figure below.

Figure-9 Slabs specimens inside the electric oven

7. The first crack and ultimate load

The initial crakes and ultimate load values for each model are shown in Table (7).

Table-7 Initial crakes and ultimate load values

Group name	Specimens	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	$\frac{F.C.L}{(F.C.L)R}$ (%)	$\%\frac{U.L}{(U.L)R}$
HSC	R000F	5	18.5	-	-
	HS00F	9	40.5	180	219
	HSL15F	6.5	26.5	130	143.24
	HSL30F	8	32	160	173
	HSS10F	5	23.5	100	127.03
	HSS16F	6.5	25	130	135.13
	HSS22F	7.5	29.5	150	159.46

The table above shows the following:

1- In Form HSOO shows an increase in value F.C.L and U.L, where the ratio (80, 119) % about reference slab (ROOOF), due to the fully high strength concrete mixture used.

2- In slabs (HSS16F, HSS22F) Showed an increase in the value of the F.C.L and U.L where the ratio was (30, 50) % and (35.13, 59.46) % for the reference slab.

3-In slab (HSS10F) when compared to the reference slab where there was no increase in the value of the first crack, but the increase in the ultimate load was small where the ratio was (27.03) %.

4-In slabs (HSL15F, HSL30F) Showed an increase in the value of the F.C.L and U.L where the ratio was (30, 60) % and (43.24, 73) % for the reference slab.

8. Load Deflection

Explain the following Figures to show the overall behavior of these specimens, the centre load-deflection curve for all tested slabs of each group, and shows the relation between central deflections with the all tested slab specimens. These figures were illustrated the different in the stiffness value among the tested specimens through the observed values of the deflection.

Table 8. Central Deflection of R.P.C

Group Name.	Specimens	Ultimate Load (U.L)kN	Deflection at Ultimate Load (mm)
H.S.C	ROOOF	18.5	11
	HSOOF	40.5	7
	HSL15F	26.5	9
	HSL30F	32	6.9
	HSS10F	23.5	10.9
	HSS16F	25	9.9
	HSS22F	29.5	7.95

1- A decrease in the value of deflection at the ultimate load is shown by the slab, although it is exposed to a high temperature up to 400 C°, due to the use of high strength concrete mixture.
2-In slab (HSOOF) It was observed a decrease in the value of deflection by (36.37) %, due to the fully mixture of high strength concrete used.
3-In slabs (HSL15F, HSL30F) a decrease in the deflection value was observed and the ratio was (18.18, 37.27) %, due to the use of a concrete mixture of high strength in layers and the more the thickness of the layer increases the resistance of the model.
4-In slabs (HSS16F, HSS22F) a decrease in the deflection value was observed and the ratio was (10, 27.73) %, due to the use of a high strength concrete mixture in partial area (square shape) in the center of the slab, the larger the dimensions of the square (partial area), the greater the resistance of the model.

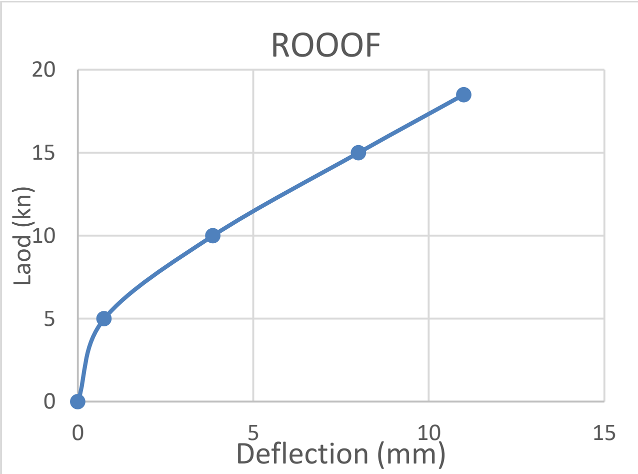


Figure 10. Load – Deflection Curve of Specimen (ROOOF)

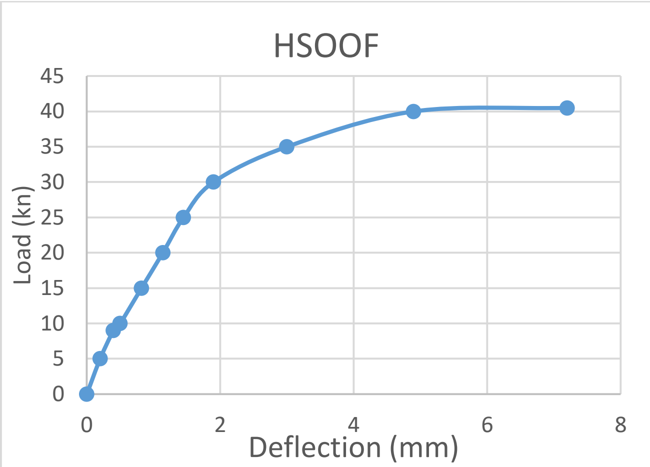


Figure 11. Load – Deflection Curve of Specimen (HSOOF)

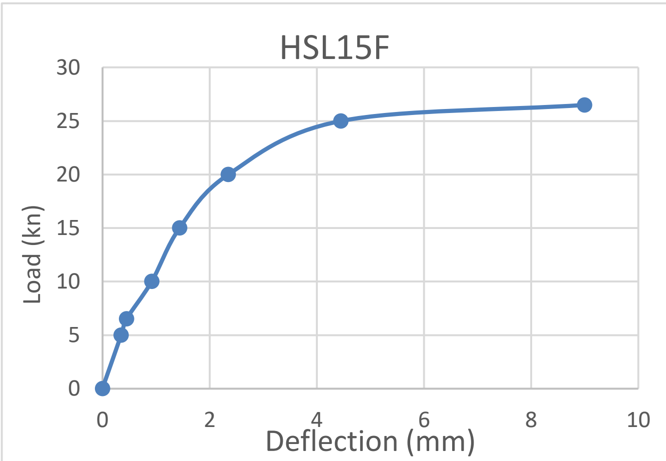


Figure 13. Load – Deflection Curve of Specimen (HSL15F)

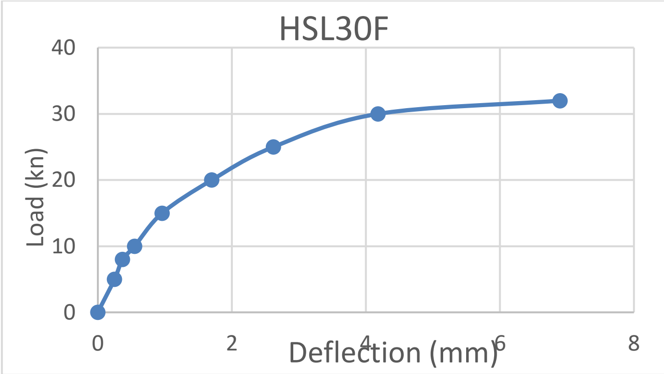


Figure 14. Load – Deflection Curve of Specimen (HSL30F)

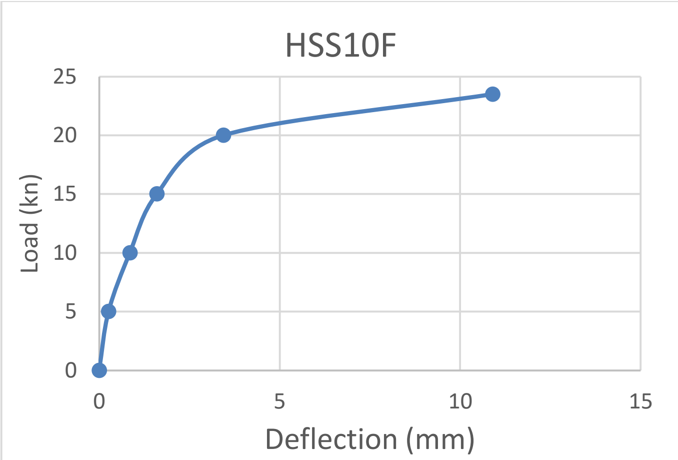


Figure-15 Load – Deflection Curve of Specimen (HSS10F)

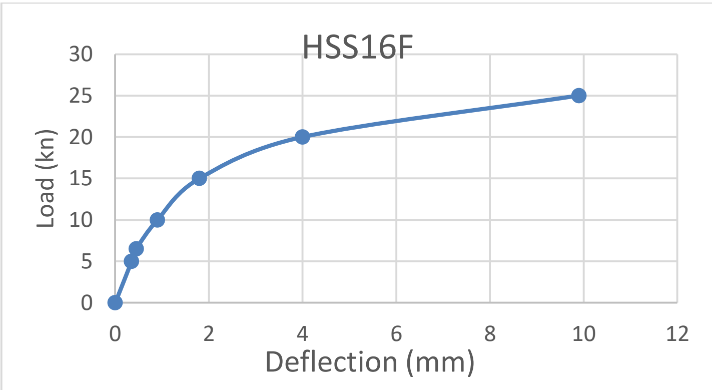


Figure-16 Load – Deflection Curve of Specimen (HSS16F)

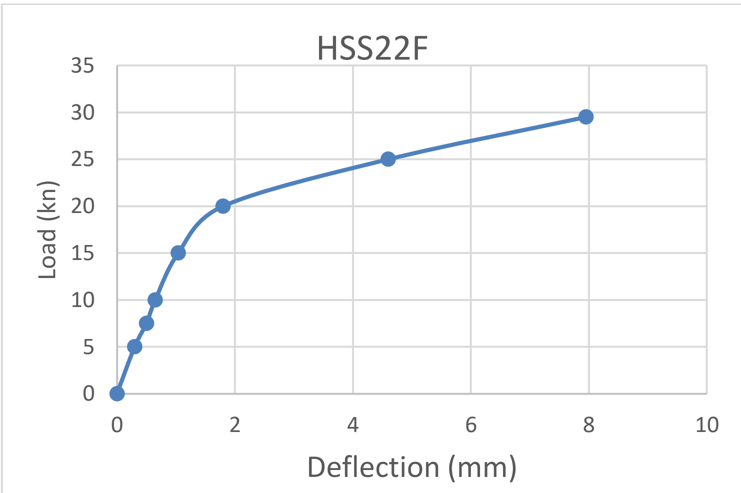


Figure-17 Load – Deflection Curve of Specimen (HSS22F)

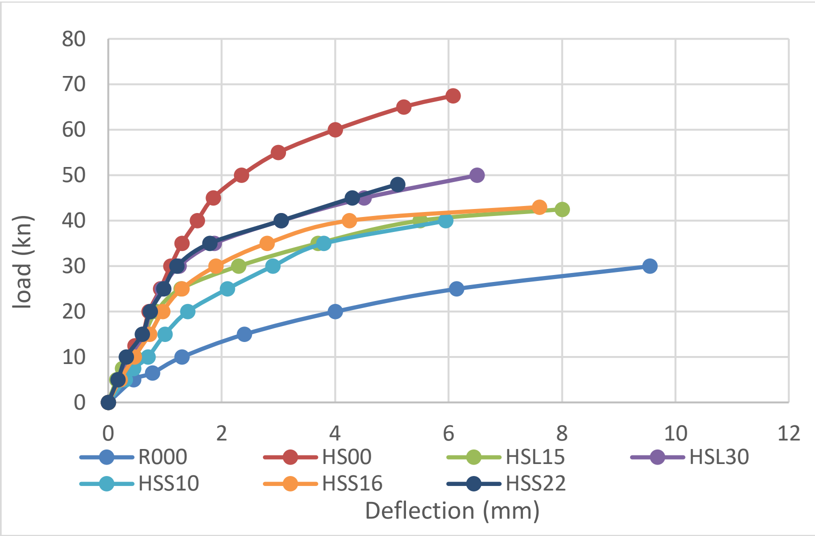
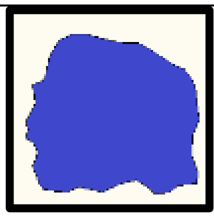
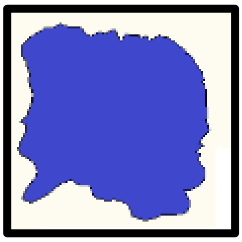
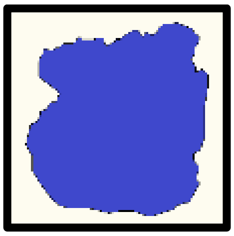


Figure-18 Load – Deflection Curve of H.S.C group (Not exposed to high temperature

9. Size of the Failure Zone and Perimeters

The areas and perimeters of the punching failure zones are measured by method by Auto Cad, the values of area and perimeter of these methods are illustrated in table 9

Table-9 Area and Perimeter of the Failure Zone of the Tested

Slab	Measured Area (mm^2) by Auto Cad	Measured Perimeter (mm) by Auto Cad	Zone of Failure
ROOOF	61257.14	1140.87	
HSOOF	77648.4761	1270.347	
HSL15F	82846.87	1237.79	

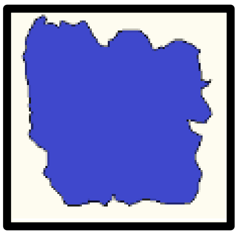
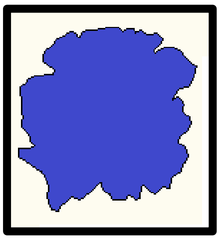
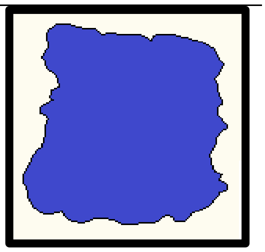
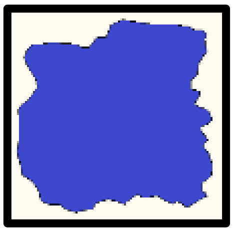
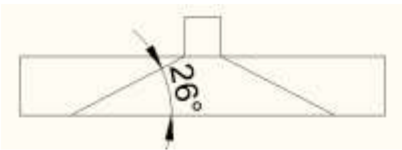
HSL30F	70518.76	1246.84	
HSS10F	82598.07	1406.29	

Table-9 Continued

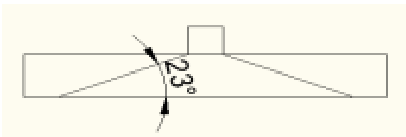
Slab	Measured Area (mm^2) by Auto Cad	Measured Perimeter (mm) by Auto Cad	Zone of Failure
HSS16F	78313	1206.967	
HSS22F	76255.3	1216.787	

10. Failure Angles

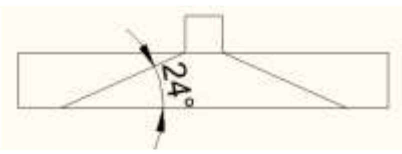
Angles will be calculated for all slabs by using a program Auto CAD**.**



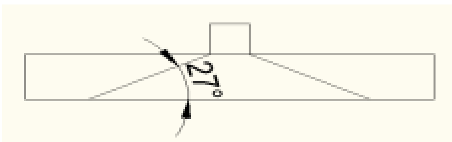
Failure angle of slab HSOOF



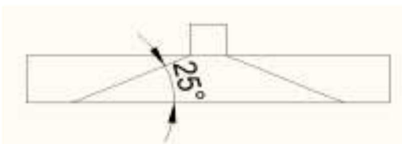
Failure angle of slab HSS10F



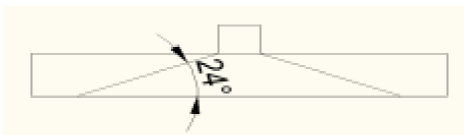
Failure angle of slab HS15F



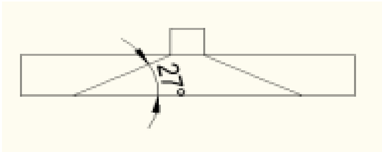
Failure angle of slab HSS16F



Failure angle of slab HSL30F



Failure angle of slabHSS22F



Failure angle of slab ROOOF

Figure-18 Failure Angles of all Slabs

11. Conclusions

1- Through the results obtained show that the use of a mixture of fully high strength gave better results than other models, where the increase in U.L in the rate of (119%) and a decrease in a deflection in the rate of (36.37%) from the reference model.
2- Use H.S.C with different layer was showed good results, where the specimen was optimum (U.L and P.L) with increase thickness layer of R.P.C.
3- The models exposed to a high temperature of up to 400 c° were found to have lost about 0.6 percent of their final resistance.
4- The use of a high strength concrete mixture in layers gave better results than use partial area (square shape) in the center of the specimen.

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