High-Temperature Effects on Punching Shear Performance of Hybrid Reinforced Concrete Slabs

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Abstract

Scientists tested reinforced concrete slabs for their behavior and strength under punching shear stress. An electric oven was used to experimentally heat reinforced concrete slabs to high temperatures (up to 400 °C), and the punching shear behavior of these slabs is the primary focus of this research. A steel reinforcing mesh with a diameter of (Î6mm) and slab dimensions of (400x400x60) mm was used to construct each of the six models. The concrete used in their construction combined regular and high strength. Using an entirely high-strength concrete mixture results in a 56.65% reduction in deflection, an 80% rise in First Crack Loading (FCL), and a 118.9% increase in Ultimate Load (UL), according to laboratory tests. As a result of layering, the (HSC) mixture was comparable to that of a slab composed completely of (HSC). This provides extra cost advantages compared to utilising a slab with complete high strength. Deflection dropped by 18.19%, whereas FCL and UL increased by 30.0%, 60.0%, and 43.24%, respectively, for a 73% increase. A partial region of a high-strength mixture performed better when the findings were enhanced by expanding the dimensions of the HSC area. Deflection values from the reference slab decreased by 0.91 percent, 10%, and 27.73 percent, respectively, whereas FCL and UL increased by 0% and %, respectively, according to the data. These findings promote cost-effective, fire-resistant construction by optimising material use, enhancing punching shear resistance, and improving structural durability under high temperatures.

Keywords- Elevated Temperature, Punching Shear Resistance, High Strength Concrete, Two Way Flat Slab.

I. INTRODUCTION

The term "flat plate" refers to a slab held up by columns, as shown in Figure 1. In buildings, this means that the columns themselves support the slab. In the absence of column capitals or drop panels, the slab is reinforced to transfer weights directly to the supporting columns. Beams have widespread application, including in the vicinity of staircases and expansive spaces between slabs, so it's not always the case that they are not present in flat plate construction [1]. Concrete slabs are commonly thought of as the most load-sensitive structural components in a building, although this is not necessarily the case. Most flat slab failures are of the punching shear type, which happens near the columns due to the concentrated tension that results from loads applied to the impact of compressive strengths on HSC [2]. The punching shear of the flat slabs had examined had a comprehensive strength ranging from sixty to one hundred and twenty MPa is illustrated in Figure-2: common punching shear failure. They tested ten spherical, comparable slabs of high-strength concrete. Shear reinforcement was one of the variables considered [4]. Shear stress reinforcements were present in some samples but not in others. An equal-strength concrete flat slab was constructed as a benchmark. Findings demonstrate that HSC enhances punching resistance and makes better use of flexural reinforcement when compared to the conventional concrete sample.

Figure 1. Flat plate concrete system [3]

Figure-2 Common punching shear failure [4].

Ghannoum studied the effects of high-strength concrete on slab-column specimen behavior [5]. Under high temperatures, steel fiber-reinforced concrete (SFRC) maintains its residual compressive and tensile strength while exhibiting pseudo-ductile behavior, indicating better mechanical qualities. Fiber integration improves energy absorption, fire resistance, and crack control in structural applications subjected to harsh environments [6]. Under low-velocity impact loading, fiber-reinforced concrete (FRC) improves tensile strength and energy absorption. Steel and polyvinyl alcohol (PVA) fibers greatly increase dissipated energy and lessen damage. FRP retrofitting further enhances impact resistance and structural performance [7].
According to the research, a higher compressive strength improves the performance of concrete slabs. Supporting this, there is a rise in both punch shear strength and post-cracking stiffness. In [8] tested 47 reinforced concrete slabs for punching shear resistance; 17 of these slabs were NSCs, and 30 were HSCs. From the 47 experiments, we can see that the concrete compressive strengths (f'c) vary greatly. This proves that HSC increases the slab-column connection's capacity to apply larger pressures by enhancing punching shear resistance. According to [9], who examined 27 samples of HSC and NC slabs, increasing the compressive strength improves the shear strength. Rectangular loaded areas showed the greatest increase in compressive strength (47%), going from 33 MPa to 94.2 MPa. However, square-laden concrete achieved approximately half of the maximum boost upon which the concrete's compressive strength was raised from 36.1 MPa to 39.1 MPa (equivalent of 75.4 MPa).The punching shear performance of flat plates was examined in the study of [9]. This study used twenty-four round specimen slabs of both standard and high-potency concrete. They investigated steel fiber reinforcement and flexural reinforcement, as well as their effects. The reinforced concrete slabs' consistent and stable residual strength was demonstrated by higher punching and residual strengths following the initial punching failure, which was caused by a larger ratio of plate flexural reinforcement to total reinforcement. With compressive strengths reaching 130MPa, in [10] set out to study the effects of various longitudinal reinforcement ratios on the performance of 1650 mm square, identically 125 mm high-strength concrete (HSC) flat slabs. There was a 43% increase in the punching capacity of high-strength concrete slabs as compared to a reference specimen constructed of ordinary-strength concrete. The details of reinforced concrete slab studies are summarised in Table 1.

Table 1. Details of Reinforced Concrete Slab Studies

Study Reference	**Sample Dimensions (mm)**	**Number of Samples**	**Mix Proportion Details**	**Compressive Strength (MPa)**
Current Study	400 × 400 × 60	7 slabs	NC (Normal Concrete) and HSC (High-Strength Concrete) layers	NC: 32 MPa, HSC: 51.66 MPa
[6]	Varied; Not specified	47 (17 NSC, 30 HSC)	Varied	NSC: 33 MPa, HSC: 94.2 MPa
[7]	Not specified	27 (NC and HSC)	Varied	NC: 36.1 MPa, HSC: 75.4 MPa
[8]	Round specimens; varied	24	Reinforced with steel fibers	Up to 130 MPa
[9]	1650 × 1650 × 125	Not specified	Longitudinal reinforcement ratios studied	Up to 130 MPa

Novel strategies for improving concrete structures' durability and mechanical performance have been investigated in recent research. In order to improve the flexural performance of concrete beams, Yuan et al. [11] looked into the IHB-CFRP anchorage scheme and found that it significantly improved the structural behavior under flexural loads. The advantages of lightweight materials in lowering overall structural weight while preserving strength were highlighted by Yahya and Galeb [12], who analysed important parameters influencing the structural behavior of fiber-reinforced lightweight concrete ribbed slabs. Experimental studies on rubberised concrete slabs with recycled tire steel fibers were carried out by Tahwia et al. [13], who found improvements in slab-on-grade systems' performance, especially under load circumstances. In their investigation of the effects of macro synthetic fibers on reinforced concrete slabs with holes, Umapathi and K. G. M. [14] demonstrated their beneficial influence on flexural behavior. In their evaluation of the incorporation of nanoparticles with ultra-high-performance fiber-reinforced concrete, Anish and Logeshwari [15] pointed out the possible uses for attaining better structural performance. In their investigation of the static and fatigue behavior of concrete bridge deck slabs reinforced with steel bars and basalt fiber-reinforced polymer (BFRP), Ali et al. [16] showed enhanced static strength and fatigue resistance. Excellent post-temperature performance was found in Zhang et al.'s [17] evaluation of the dynamic impact mechanical properties of high-temperature-resistant ultra-high-performance concrete (HTRUHPC) following exposure to extreme temperatures. Lastly, Khadim and Abdulridha [18] reported experimental results on carbon fiber-reinforced polymer (CFRP)-enhanced lightweight concrete slabs that showed a considerable increase in flexural capacity.

II. THE OBJECTIVE OF THE STUDY

These experimental techniques primarily seek to do two things: 1) to study how high temperature affects the strength of concrete and 2) to examine how seven two-way flat plate slab specimens behave under punching shear.

III. DESCRIPTION OF THE TESTED SLABS

We used four-sided supports and a central 40x40 mm steel column to keep the (400x400x60) mm slabs in place for this experiment, as illustrated in Table 2. The following was the designation of the slabs:
1st the reference slab's sign (R).
2nd symbol (O) points out no addition should be made.
3rd F for temperatures up to 40
4th Code for a concrete type (HSC)
5th Layer sign is an (L).
6th Half-high concrete (HSC) dimensions, (10, 16, 22 cm). Get more details by looking at **Figure 3**.
7th Symbol indicates the dimensions of HSC layers (1.5, 3 cm). Additional details can be seen in **Figure 4**.
8th Square-shaped sign denoted as (S)
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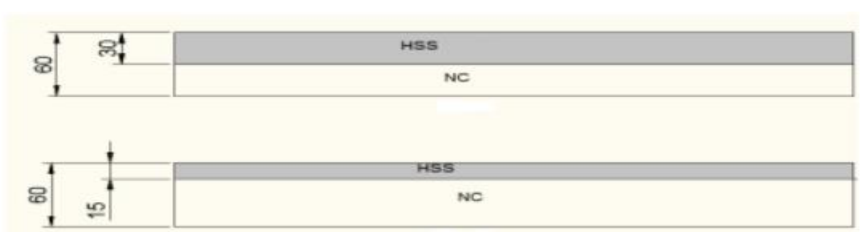

Figure 3. Apply (H.S.C.) to a multi-dimensional layer

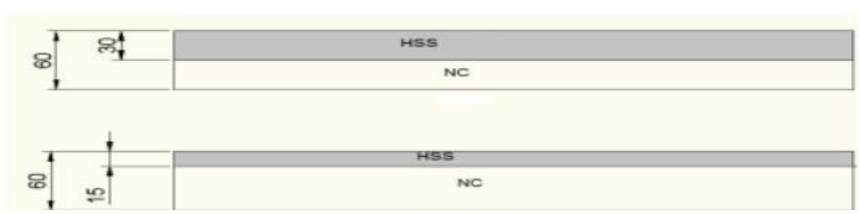

Figure 4. For a square design, use (H.S.C.)

Table 2. The search symbols are displayed in the table.

Dimensions in (cm)					
Group Name	**Specimens**	**L**	**B**	**T**	**Explanation**
H.S.C	R1STO2ndOF3ed	40	40	6	The model is built from N.C. with reinforcing made of steel.
	HS4thOOF	40	40	6	The product includes an all-inclusive blend of high strength concrete.
	HSL5th157thF	40	40	6	Include 1.5cm thick layer of high strength concrete dimensions and the remainder is 4.5cm in size and is marked as N.C. **regard figure 3**.
	HSL307thF	40	40	6	Layered with 3cm of high-strength concrete and the remainder 3cm of non-concrete. **peruse Figure 3**.
	HSS8th106thF	40	40	6	A section of the base is constructed using 10*10 cm super-shaped high-strength concrete, while the remainder is N.C. **(refer to figure 4)**.
	HSS166thF	40	40	6	Details may be found in **figure 4**; the slab is composed of N.C. on the outside and high-strength concrete on the inside, arranged in a superstructure with dimensions of (16*16) cm.
	HSS226thF	40	40	6	The middle section of the slab is 22*22 cm of super-strength concrete, and the remaining is N.C. **(see figure 4).**

IV. METHOD

All tests were conducted in accordance with ACI 318-14 [19] for both ordinary concrete and reactive powder concrete. For a breakdown of the NSC and HSC percentages utilised in this research, see Tables 3 and 4.

Table 3. Classification of Concrete Mixture (NC)

Cement g/cm3	**Sand g/cm3**	**Gravel g/cm3**	**w/c**
0.40	0.6	1.2	0.45

Table 4. Features of High-Strength Concrete (HSC)

Cement g/cm3	**Sand g/cm3**	**Gravel g/cm3**	**w/c**	**Super plasticiser (L/m3)**
0.51	0.590	1	0.32	5

As shown in Figure 5, The research samples were made using moulds made of plywood that were treated with an oil that prevents moisture.

Figure 5. Some molds are used

Figure 6. Slabs during curing.

After opening the curing container, the slabs were taken out and let to cure for another day before testing. Before testing, the cleaned slab specimens were painted white on one side, given time to dry, and then utilised to detect any fissures. Prior to testing, precise notes were taken regarding the locations of the supports, dial gauge, and centrally applied force. A 30 mm sensitive and 0.01 mm resolution ELE dial gauge was used to measure the slab specimens' central deflection. There was a 5 kN increase in load that could be measured as the stress on the slab. A unique testing apparatus with a special structure offered a 400 x 400 mm clearance for the board. Four welded steel beams were utilised to build this square framework. The edges of the boards were fastened to the beams using 25 mm wide welded steel tape. As shown in Figure 7, the slab testing technique involves positioning a solid square steel cube (40 x 40 mm) in the middle of the slab.

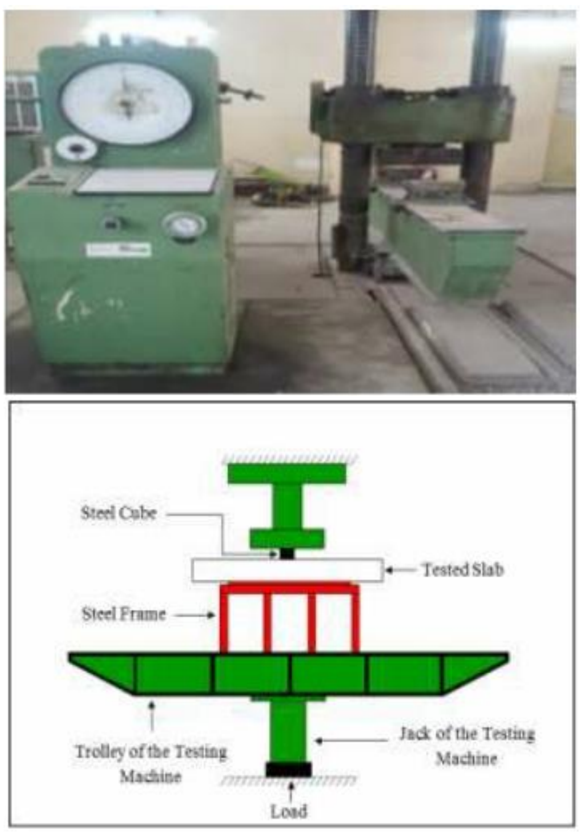

Figure 7. The universal testing machine with hydraulic motion.

V. RESULTS AND DISCUSSION

In order to determine the standard for (R.P.C), we used three 10*20 cm ASTM C 39/C39M-01 cylinders and one 10 cm standard cube (B.S: 1881: part 116), as shown in Table 5 below.

Table 5. Standardised Samples

Specimen	**Number of specimens**	**Test**	**Standards of test**
Cube 10*10*10 cm	three	Strength of Cube compression strength	B:S: 1881: part 116 [22]
Cylindrical Specimens Radius:10cm Height:20cm	three	Strength of Cylindrical Compression	ASTM Standard C39/C39M-05 [21]
Cylindrical Specimens Radius:10cm Height:20cm	three	Strength of Splitting Tensile	ASTM Standard C496-04 [20]
Prism Standard Base:10 cm Length: 50cm	three	Rupture Modulus	ASTM Standard C78-02 [23]

At 28 days of age, the results of the material properties are shown in table 5. The results represent the average of three individual models.

Table 5. Structural properties for (NC) Mixer

Type of mixer	Cylinders of Compressive Strength f'c (**kN/m3**)	Cubes of Compressive fcu (kN/m3)	Elasticity Modulus EC (kN/m3)	Tensile Strength of Splitting fsp (kN/m3)	Rupture Modulus fr (kN/m3)
(NC) Mixer	32000	39000	27132000	4810	4000
(HSC) Mixes	51660	62240	34810	4200	7300

Figure 8. Cylindrical, Prismatic, and Cube-shaped

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VI. MODELS DURING BURNING PROCESS

In the University of Mustansiriyah lab, an electric furnace was used to heat the models up to 400 °C. The supplied figure makes this point clear.

Figure 9. Slab specimens within the electric furnace

VII. OBSERVATION OF INITIAL AND ULTIMATE LOAD

Table 6 represents the starting cracks and final load values for all the models

Table 6. The values of initial crakes and final loads

Group name	Specimens	Initial crack load (FCL) (N)	Ultimate load (UL) (N)	*FCL* (*F.C.L*) *R* (%)	. % (.)
HSC	R000F	5000	18500	-	-
	HS00F	9000	40500	180	219
	HSL150F	6500	26500	130	143.24
	HSL300F	8000	32000	160	173
	HSS100F	5000	23500	100	127.03
	HSS160F	6500	23000	130	135.13
	HSS220F	7500	29500	150	159.46

The following are displayed in the table above:

1- Form HSOO demonstrates a rise in FCL and UL values, with a ratio of 80:19% relative to the reference slab (ROOOOF), as a result of utilising a fully high-strength concrete mixture.

2– With a ratio of 30% to 50% in slabs (HSS160F, HSS220F) and 35.13% to 59.46% in the control slab, the FCL and UL values increased.

3-The reference slab's initial crack value was unaltered in slab (HSS100F), but the final load was up by a hair's breadth (27.03 percentage points).

4-The FCL and UL values increased in slabs (HSL150F, HSL300F) compared to the reference slab, which had a ratio of (30, 60%) and (43.24%, 73%).

VIII. LOAD DEFLECTION

An account of the relationship between central deflections and all tested slab specimens, as well as the general behaviour of the specimens, is illustrated in the figures. Each group also includes a centre load-deflection curve. The observed deflection values highlighted the differences in the stiffness values among the tested specimens.

Table 7. Central Deflection of Reactive Powder Concrete (RPC)

Group Name	Specimens	Ultimate Load N	Deflection (cm)
HSC	R000F	18500	1.1
	HS00F	40500	0.7
	HSL150F	26500	0.9
	HSL300F	32000	0.69
	HSS100F	23500	1.09
	HSS160F	23000	0.99
	HSS220F	29500	0.795

1. The slab can show less deflection at the ultimate load, even when exposed to temperatures up to 400 C° because it is made of a high-strength concrete mixture.
2. The value of deflection in the 2-inch slab (HSOOOF) was reduced by 36.37 percent when fully mixed high-strength concrete was used.
3. By layering a high strength concrete mixture, the deflection values of slabs (HSL150F) were reduced by 18.18% and those of slabs (HSL300F) by 37.27%. This enhancement, which makes the model more robust, is attributed to the increased layer thickness.
4. A reduction of 10% and 27.73% in deflection values was achieved by applying a high-performance concrete mixture to the slab's central partial region (square shaped). Model resistance improved linearly with increasing partial region dimensions.

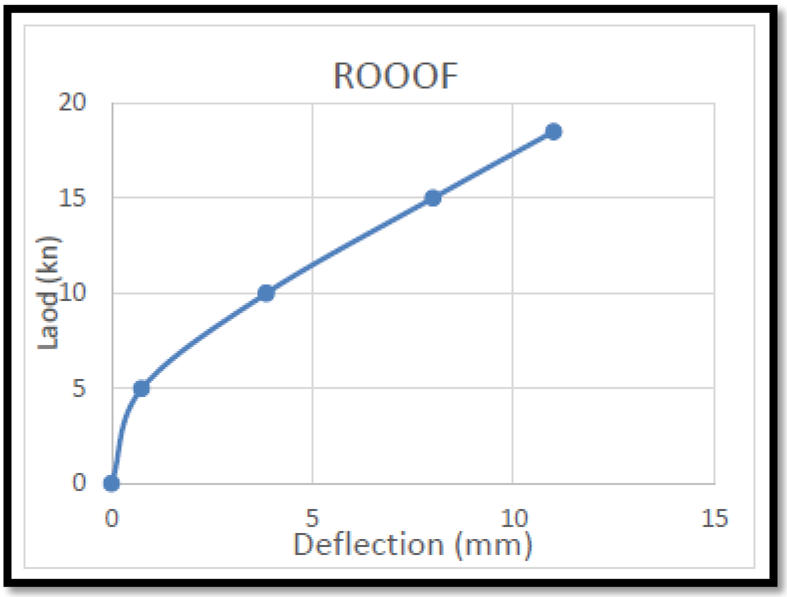

Figure 10. Deformation Curve of the Specimen under Load (ROOOOF)

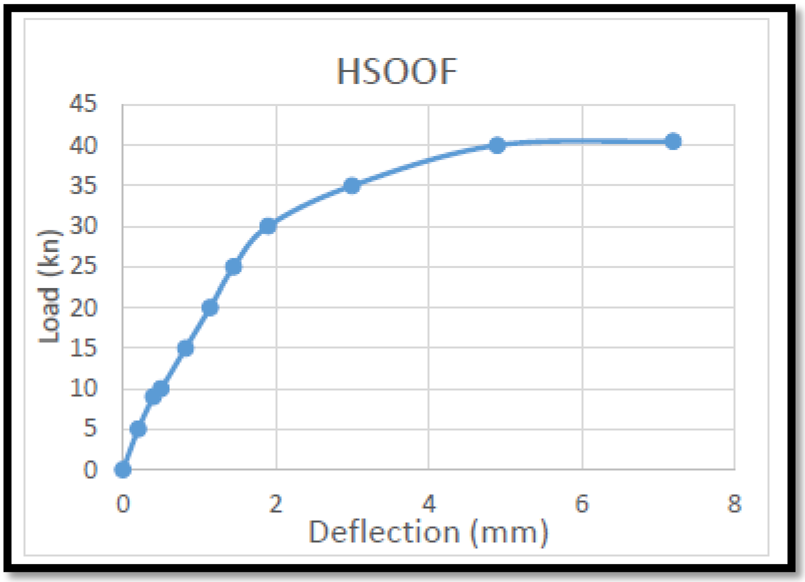

Figure 11. Measurement of Specimen Load Deflection (HSOOOF)

During the studies, cracks began to form at particular stress levels for every slab. Due to their higher tensile strength and stiffness, slabs with high-strength concrete layers or partial portions showed delayed crack initiation, whereas the reference slab (R000F) showed the first crack at a load of 5000 N. For instance, slab HSL300F showed early cracking at 8000 N, suggesting that the layered high-strength concrete (HSC) significantly improved cracking resistance. The exact crack patterns seen on each slab upon collapse are depicted in Figure 11. Near the center load application point, radial cracks predominated; diagonal and shear cracks took over as one moved toward the slab edges. The cracking patterns were more dispersed in slabs containing partial HSC areas (e.g., HSS220F) than in slabs composed wholly of conventional concrete (NC). Table 7 and Figures 10–16 summarise the load-deflection behaviour of the tested slabs. The ductility, strength, and stiffness of the slabs under applied loads are shown in each picture. Due to the full utilisation of HSC, slab HS00F showed the lowest deflection (0.7 cm) at the ultimate load, while the reference slab (R000F) showed the largest deflection (1.1 cm).
Table 8 and Figure 18 provide specifics on each slab's failure method. While slabs with homogeneous HSC mixtures mainly failed in punching shear because of their higher stiffness and decreased ductility, slabs with layered or partial HSC areas (such as HSL150F and HSS220F) showed a combination of flexural and punching shear failure.

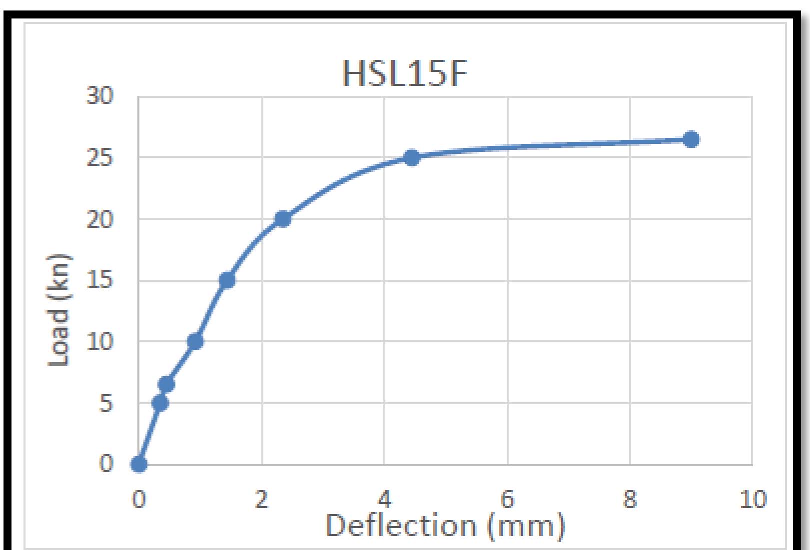

Figure 12. Load – Deflection Curve of Specimen (HSL150F)

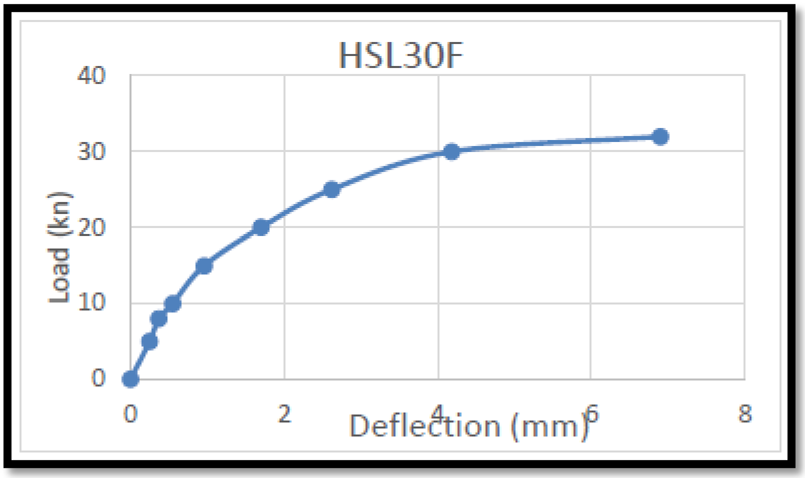

Figure 13. Load – Deflection Curve of Specimen (HSL300F)

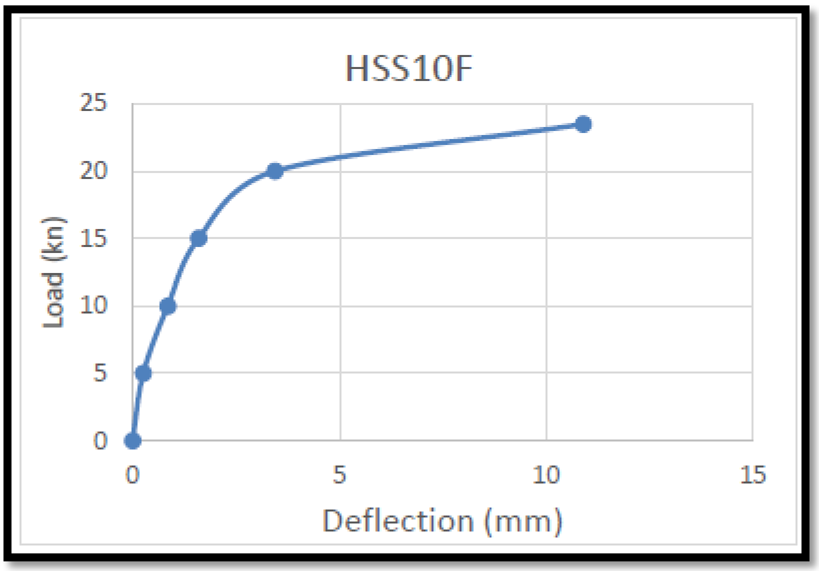

Figure14. Load – Deflection Curve of Specimen (HSS100F)

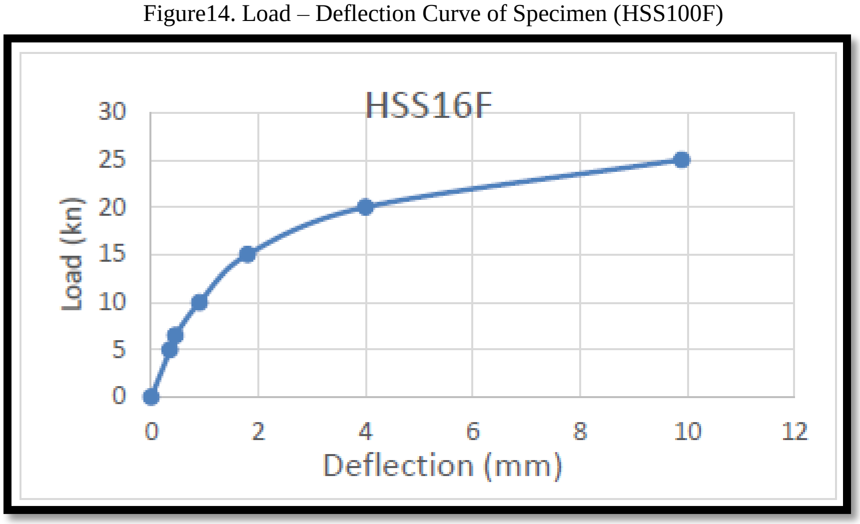

Figure15. Load – Deflection Curve of Specimen (HSS160F)

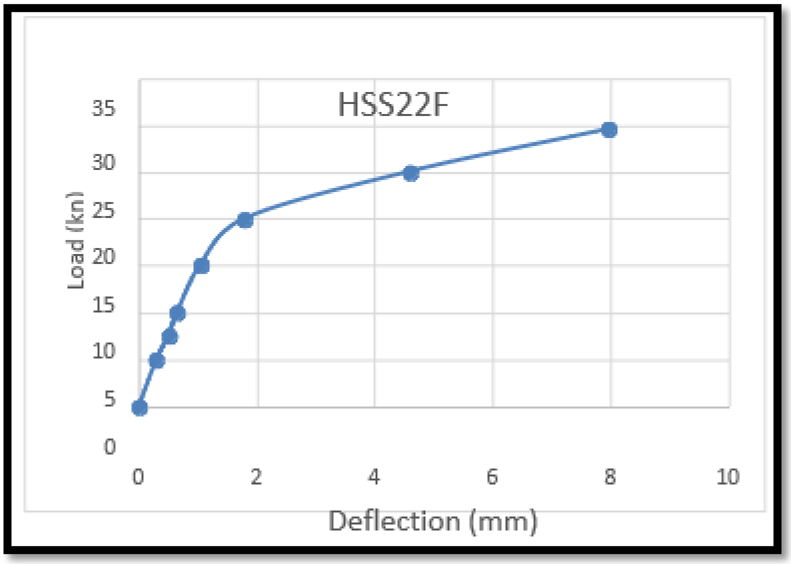

Figure16. Load – Deflection Curve of Specimen (HSS220F)

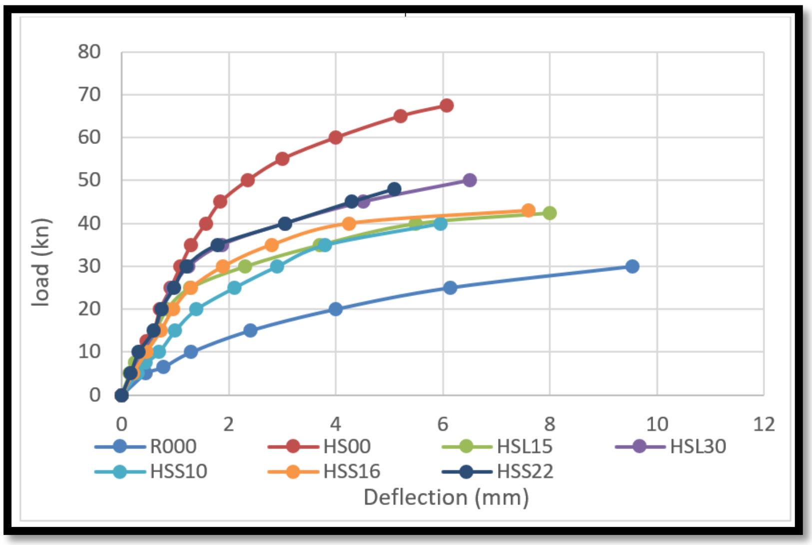

Figure17. Deflection under load H.S.C. group curve (i.e., not subjected to high temperatures)

Figure 17 shows the combined load-deflection curves for every slab. The stiffness and ductility of each specimen can be directly compared thanks to the grouping of these curves. It is clear that slabs having partial HSC regions (such HSS220F) have better load-bearing capacity and less deflection, which makes them appropriate for high-performance and reasonably priced applications.

IX. FAILURE REGION AND PERIMETERS DESIGN

The quantity and kind of damage, including failure angles, spalling zones, and crack propagation, are depicted in Figure 18. For example, slabs with incomplete HSC areas exhibited more localised failure patterns, whereas slab HS00F showed a homogeneous failure zone with less spalling. The variations in failure behaviour among the tested slabs are visually confirmed by these pictures. The important stress points and regions of high deformation are further highlighted in annotated pictures, which are in good agreement with load-deflection data and theoretical projections.

The increases in ultimate load and deflection that were seen are in good agreement with earlier studies on high-strength concrete (HSC), demonstrating how well it works to increase punching shear resistance. Deviations in several parameters, however, call for more investigation to confirm these findings in comparison to earlier research. The ACI 318-14 standards must be taken into consideration while evaluating the trial results, especially when it comes to safety considerations and design guidelines for high-strength concrete in hot environments. Furthermore, the examined slabs' small-scale dimensions (400x400x60 mm) are a drawback because they might not accurately represent real-world situations. Future studies should consider how increasing the slab's dimensions may affect the structure's deflection and load capacity. Notwithstanding these drawbacks, the work shows how HSC layering can be

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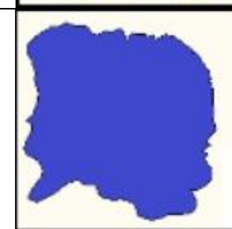
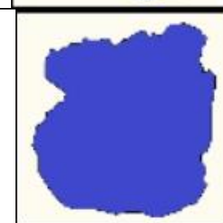
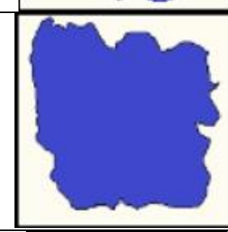
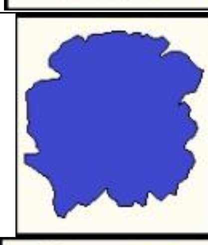
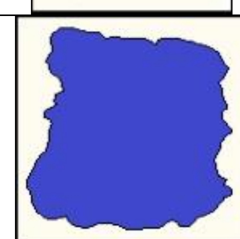
an affordable way to increase structural durability and fire resistance, with useful ramifications for engineers looking to maximise material utilisation while maintaining safety regulations.
Table 8 displays the results of the area and perimeter measurements taken by Auto Cad for the punching failure zones.

Slab	Measured Area (mm2) by Auto Cad	Measured Perimeter (mm) by Auto Cad	Zone of Failure
ROOOOF	61257.14	1140.87	
HSOOOF	77648.4761	1270.347	
HSL150F	82846.87	1237.79	
HSL300F	70518.76	1246.84	
HSS100F	82598.07	1406.29	
HSS160F	78313	1206.967	
HSS220F	76255.3	1216.787	

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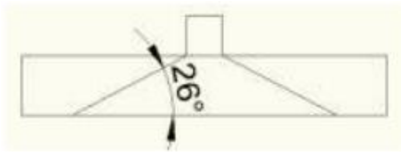
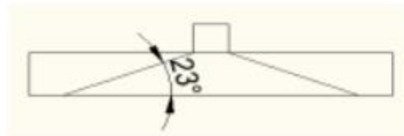
X. ANGLES OF FAILURES

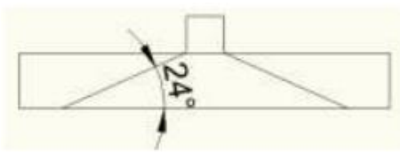
Using the Auto CAD tool, we will determine the angles for every slab**.**



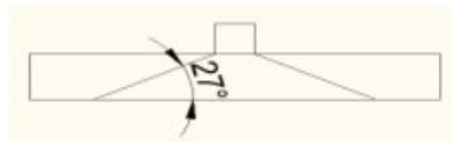
Angle at which slab HSOOOF fails



An angle at which slab HSS100F fails



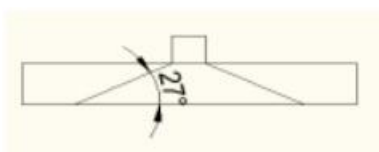
Angle at which slab HS15F fails



Angle at which slab HSS160F fails

Angle at which slab HSL300F fails

Angle at which slab HSS220F fails



Angle which at slab ROOOOF fails

Figure 18. Angels of Failure of all Slabs

The quantity and kind of damage, including failure angles, spalling zones, and crack propagation, are depicted in Figure 18. For example, slabs with incomplete HSC areas exhibited more localised failure patterns, whereas slab HS00F showed a homogeneous failure zone with less spalling. The variations in failure behaviour among the tested slabs are visually confirmed by these pictures. The important stress points and regions of high deformation are further highlighted in annotated pictures, which are in good agreement with load-deflection data and theoretical projections.

The increases in ultimate load and deflection that were seen are in good agreement with earlier studies on high-strength concrete (HSC), demonstrating how well it works to increase punching shear resistance. Deviations in several parameters, however, call for more investigation to confirm these findings in comparison to earlier research. The ACI 318-14 standards must be considered while evaluating the trial results, especially regarding safety considerations and design guidelines for high-strength concrete in hot environments. Furthermore, the examined slabs' small-scale dimensions (400x400x60 mm) are a drawback because they might not accurately represent real-world situations. Future studies should consider how increasing the slab's dimensions may affect the structure's deflection and load capacity. Notwithstanding these drawbacks, the work shows how HSC layering can be an affordable way to increase structural durability and fire resistance, with useful ramifications for engineers looking to maximise material utilisation while maintaining safety regulations.

XI. CONCLUSION

1- Compared to other models, the results show that using a completely high-strength mixture is the best option. The reference model showed a deflection decrease of 36.37% and a rise of 199% in UL.
2-The specimen performed well (UL and P.L.) when the R.P.C. layer thickness was increased, and the use of H.S.C. with various layers yielded positive results.
3-It was found that models heated to 400 °C gradually lost about 0.6% of their total resistance.
4-A central square on the specimen was not as durable as a partially covered area when a high-strength concrete mixture was placed in layers.
Future work could expand on these findings by exploring the long-term durability of HSC slabs under cyclical heating and cooling conditions and integrating these design principles into modern building codes and standards.

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