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Behaviour of Normal Reinforced Concrete Slab Under Fire

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Abstract: The deterioration of reinforced concrete structures due to exposure to fire and high temperatures remains a major challenge in structural engineering. High temperatures negatively affect the mechanical properties of concrete, particularly its load-bearing capacity, which can lead to premature structural failure before the designed service life. In this experimental study, five reinforced concrete slab specimens, each measuring 1000 × 400 mm, were prepared and tested. The concrete was poured with varying reinforcement ratios ranging from 0.0037, 0.009, 0.012, 0.0075, and 0.007, while the slab thicknesses ranged from 50 mm to 80 mm. The specimens were subjected to various thermal exposure conditions to evaluate the effects of fire-induced deterioration on their structural behavior. All specimens were then teste d under a single-point central load at mid-span until structural failure occurred. The results indicated a significant decrease in the compressive strength and load-bearing capacity of concrete between (25-75%) at elevated temperatures.

Keywords: Reinforcement steel ratio; Exposure duration; Slab Thickness; Load -Deflection.

1. Introduction

Concrete remains the most extensively used construction material worldwide, primarily due to its affordability, availability, and ease of application in various structural systems. One of its most notable advantages is its high compressive strength, which makes it particularly suitable for bearing substantial loads in structural elements. However, the continued use of conventional materials and heavy construction techniques can impose several limitations on modern buildings, including reduced adaptability, inefficiencies in design flexibility, and compromised long-term performance.

The need to strengthen and rehabilitate existing concrete structures often arises due to changes in design requirements, increased service loads, or deterioration over time caused by environmental and mechanical factors. Among the critical challenges to the durability and integrity of concrete is its behavior under elevated temperatures, particularly during fire exposure. High temperatures can significantly degrade the mechanical and physical properties of concrete, posing a serious threat to structural stability and occupant safety. Several variables influence the performance of concrete under fire conditions, including the type and composition of the concrete mix, the amount and configuration of reinforcement, and the intensity and duration of the thermal exposure. This research aims to explore the key physical and structural transformations that occur in concrete when subjected to high temperatures and to identify practical methods for enhancing its fire resistance.

Concrete can sustain damage from intense heat even though it is naturally non-flammable and has a large mass, both of which help to slow heat transfer.

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Under such conditions, concrete may experience a reduction in compressive strength, which often serves as an early indicator of thermal degradation. Internal and external cracking may occur due to the differential thermal expansion between cement paste, aggregates, and moisture content. In addition, surface spalling can result from rapid moisture evaporation and pressure buildup, especially when poor bonding exists between internal components. The modulus of elasticity tends to deteriorate more rapidly than compressive strength, diminishing the material's ability to resist dynamic and shock loads. Thermal incompatibility between the matrix and aggregates may lead to significant cracking, threatening overall structural integrity. Furthermore, variations in permeability and density particularly in dense, low-permeability concrete can exacerbate damage due to vapor entrapment and explosive spalling.
While concrete demonstrates relatively good resistance to heat compared to other construction materials, prolonged or severe thermal exposure can lead to irreversible loss of mechanical performance and, in extreme cases, structural failure. Therefore, in fire-prone or high-temperature environments, it is essential to adopt concrete design strategies that incorporate materials and technologies specifically aimed at improving fire resistance, thereby ensuring both structural safety and durability over the building's service life.

2. Literature Overview

Understanding the behavior of reinforced concrete under fire conditions has become a critical research area in structural and civil engineering. Research efforts focus on evaluating the thermal properties of concrete, the performance of reinforcing steel, and the overall safety of structures exposed to high temperatures. By developing improved predictive models and fire-resistant design techniques, engineers aim to enhance the safety and durability of concrete structures under extreme conditions. Since fire accidents continue to pose a significant threat to buildings and infrastructure, numerous studies have focused on assessing how high temperatures affect the mechanical and physical properties of concrete and embedded reinforcing steel. Studies indicate that although concrete is inherently non-combustible and provides a certain level of fire resistance, its performance deteriorates significantly when exposed to extreme heat or for extended periods. Key areas of research have included changes in compressive strength, cracking patterns, the effects of thermal expansion, deterioration of the steel-concrete bond, and scaling. This chapter reviews a body of scientific research and experimental studies that have addressed the thermal behavior of reinforced concrete structures [5], Figure 1. represents a concrete structure exposed to high temperatures.

Fig.1 Examples of structures subject to fire

Zhaohui Huang [6] conducted a study on how concrete peeling affects the behavior of concrete slabs under fire conditions. The investigation begins with a detailed analysis of uniformly loaded reinforced concrete slabs subjected to different degrees of concrete peeling under typical fire scenarios. The study highlights that the effect of concrete cracking on the structural behavior of floor slabs during fire is significantly mitigated by the presence of compressive film forces within them. Yong Wang et al. [7] published a study on the effect of modeling reinforced concrete slabs in fire and also presented a numerical approach for analyzing the thermal behavior of reinforced concrete slabs at elevated temperatures to provide a clearer understanding of the mechanical and thermal properties of concrete at high temperatures.

In 2011, said [8] studied the impact of behavior and structural design of concrete structures exposed to fire in When compared to other building materials, concrete exhibits exceptional intrinsic properties when exposed to fire. Its fire resistance is significant, and it is essential to implement a suitable structural fire design.

The foundation of this design lies in understanding the material and the structural behavior of concrete when exposed to fire. When concrete is heated, a variety of complex physicochemical processes occur, which degrade the material's mechanical properties, including strength and stiffness. This reduces the cross-section of the element and may expose the reinforcing steel to high temperatures. Spalling is most commonly found in high-strength concrete and can be quite detrimental. However, the mechanism behind it remains poorly understood.

Consequently, designers often rely on either tabular data or simplified calculation methods in practical design. Unfortunately, these techniques frequently fall short of accurately predicting how concrete structures will behave in real fire scenarios. For example, the wide range of actual fire conditions cannot be adequately represented by the traditional heating curve. Moreover, the design must consider the behavior of the entire structure, including alternate failure modes, whereas member analysis often overlooks issues such as high thermal strains caused by incompatible thermal expansions. This paper summarizes the most important analysis and design information contained in these references to predict the extent of changes that occur in the loads of models.

3 Material Properties

3.1 Cement

For this experiment Portland cement produced at the Cresta factory was used, to ensure its quality the cement was transported and stored in a dry, temperate climate. Laboratory tests conducted to meet Iraqi requirements [9] are detailed in Table 1 and Table 2, The results of these tests, which assess the material's quality, will determine whether the cement is suitable for use in the current study.

Table 1. physical properties of the cement.

Physical Properties	Test result	Limit of IQS NO.5:1984
Fineness using Blaine air permeability apparatus (m2/kg)	312	>230
Setting time using Vicat's instruments Initial (hrs: min.) Final (hrs: min)	130 min 4:00 hrs	>45 min <10 hrs

Table 2. Chemical composition of cement

Compound Composite	Weight	Limits of No.5/1984
Limes	63%	N-A
Silicas	20%	N-A
Alumina's	4.3%	N-A
Iron oxidizes	3.1%	N-A
Magnesians	2.7%	≤5%
Sulphates	2.3%	≤2.8%
ignitions	3.6%	≤4%
Insoluble residuals	1.35%	≤1.5%
Limes fullness issue	0.751%	(0.66-1.02) %
T. silicates	51%	N-A

3.2 Fine aggregate (Sand)

All concrete mixtures have included natural sand. It was brought from Basra in southern Iraq. The maximum grain size is 4.75 mm and the modulus of fineness is 2.81. Laboratory tests for sand have been carried out according to the Iraqi specifications [10] and [11]. The results of these tests have been listed in Table 3. and Table 4.

Table 3. Grading of the fine aggregate

Sieves of size	% Passing percentages	
	Fine aggregates	No.5/1984Limits
10	100	100
4.75	99	90-100
2.36	89	75-100
1.18	75.5	55-90
0.60	56	35-59
0.30	20	8-30
0.15	3.2	0-10
Materials passing through a sieve 75 micron %	4.3	≤5%

Table 4. physical properties of the fine aggregate.

Physical Properties	Test result	Limit of IQS NO.5:1984 [11]
Specific gravity	2.56	----
Fineness modulus	2.81	----
Sulphate content %	0.33%	≤0.5%
Absorption %	1.5	----

3.3 Coarse aggregate (Gravel)

The coarse aggregate employed in this study has rounded particles that measure 19 mm, it is from Chilat region of north eastern Amarah. Note that various aggregate qualities are shown in Table 5.and. which show that the grading was compared with the specifications of Iraqi standards No.45/1984 [12].

Table 5. Properties of the coarse aggregate.

Physical properties	Test results	Limits to IQS 45/1984
Specific gravity	2.67	---
Sulfate content (SO3)	0.077%	≤ 0.1 %
Chloride content (Cl)	0.094%	≤ 0.1 %
Absorption	0.80%	---
Loose bulk density kg/m^3	1500	---

3.4 Water

Reverse osmosis (RO) water was utilized for both the production and curing of concrete [13].

3.5 Superplasticizer

Concrete's mechanical properties, along with its workability and other characteristics, are primarily influenced by additives. one of the most important types of additives is water reducers, which enhance the workability of the concrete mixture while minimizing the amount of water required. Among these additives, superplasticizers, also known as high-range waterreducing agents, are experiencing the fastest growth in the cement and concrete additives market. Superplasticizers are used in the production of flowing concrete to adjust the water-to-cement ratio, resulting in improved workability, excellent slump characteristics, and high-strength concrete. In this work, superplasticizers that comply with ASTM C494-99 [14] were utilized as shown in figure.2.

Fig. 2. Superplasticizer PC180.

3.6 Steel Reinforcement

Steel rebar measuring Ø6 mm and Ø8 mm was used for both longitudinal and transverse reinforcement. The tensile test was conducted under ASTM A615 specifications [15].

4. Test Variables

The investigation primarily focused on the behavior of concrete slabs with varying thicknesses and reinforcement ratios under the effects of heat and temperature changes. Table 6. summarizes the key parameters considered in the study. The main purpose behind this project was to study the flexure behavior of the normal concrete slabs shown figure 3. So that the experimental program examined the effect of the following variables on the concrete slabs.

Table 6. The key parameters considered in the study

Variables	Details
Thickness	Different Thickness
Reinforcement	Different Reinforcement Ratio
Time at Fire	Different Time to Fire for The Specimen

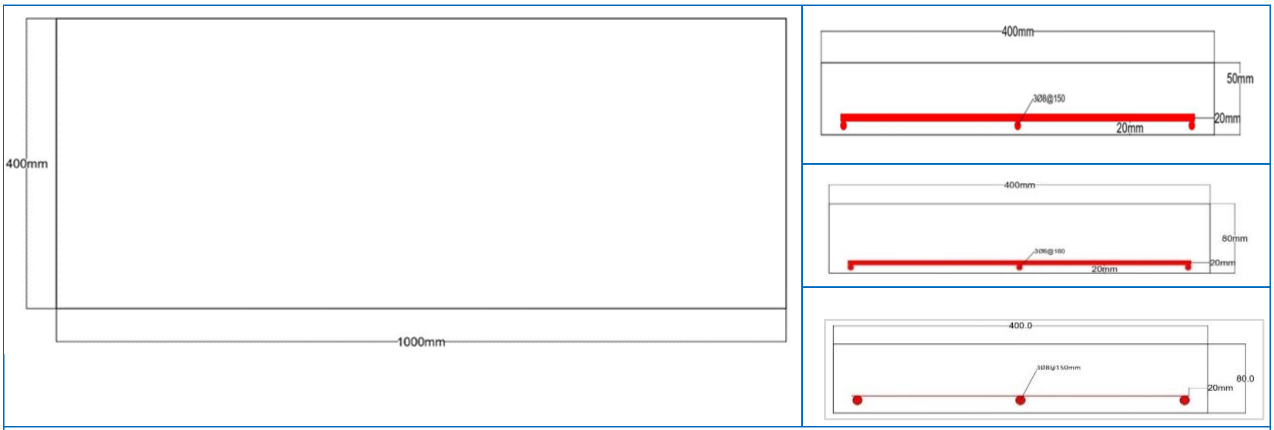


Fig.3 Details to the Specimen .

5. Mix design and mixing procedure.

All materials and equipment must be prepared to complete the casting process as follows: According to Table No.7, which includes the proportions of the concrete mix, as well as the figure.4 details of the casting operations and their stages.

1. Prepare the wood molds (molds made from plywood). The molds must be clean and oiled to prevent the adhesive from sticking to the concrete, as shown in Figure 4(b). The dimensions of the molds are (length = 1000 mm, width = 400 mm, and depth = 50 mm) and (length = 1000 mm, width = 400 mm, and depth = 80 mm).
2. Prepare steel cube molds (150 x 150 x 150 mm), six cylinders (150 x 300 mm), and six prism molds (100 x 100 x 500 mm), as shown in figure 4(a), and the cone to measure concrete slump. The molds must be oiled to prevent adhesive concrete.
3. Prepare the steel reinforcement.
4. Preparing the superplasticizer additive.
5. Prepare the construction materials (cement, gravel, sand, RO water).

Table7. concrete mix container

Type of Concrete	NRC
Cement (kg/m^3)	370
Sand (kg/m^3)	640
Gravel (kg/m3)	1015
W/C	%40
Superplasticizer %	1
fc (MPa)	30

a-cast specimen | b-cubs and prism model | c- wood molds

Fig 4. Stages of preparing and casting samples and cubes

6. Curing of The Specimens.

In order to reach the required compressive strength of concrete, all specimens underwent a 28-day curing process following casting. The slabs were set down in a shady location and covered with Canvas cloth, as shown in figure 5. For 28 days, the samples received two daily sprinkles of water. Before the test day, all specimens were maintained in a shaded place.

Fig 5. curing of the specimen

7. Hardening Test

7.1 Compressive Strength Test

Compressive strength test was conducted on normal concrete [15] using cube measuring 150 mm × 150 mm, testing as Table 8.

7.2 Splitting Tensile Strength Test

The splitting tensile strength test was conducted according to ASTM C496/C496M-04[16] cylinders measuring 150×300 mm, testing as Table 8.

7.3 Flexural Strength Test

Testing concrete cannot be conducted without assessing its flexural strength. This test can be performed using a prism with dimensions of 100 x 100 x 500 mm, by ASTM C78-02[17] testing as Table 8.

Table 8. Hardening Test

Compressive strength fcu (N/mm^2) 28 Day				
Cube 1	Cube 2	Cube 3	Average	Density Kg/m^3
34.4	30	31	31.8	2450
Splitting Tensile Strength (N/mm^2) 28-Day				
Cylinder 1	Cylinder 2	Cylinder 3	Average	
2.8	2.7	2.65	2.71	
Average Flexural Strength (N/mm^2) 28 Day				
prismatic 1	prismatic 2	prismatic 3	Average	
4.6	4.51	4.4	4.5	

8 The process of exposing the models to heat (burning the models).

After curing for 28 days, the panels were tested by applying a heat source to them. The heat source was connected from three heat distribution points using a gaseous fuel source, taking all safety and pr otection measures. Heat was applied to the model gradually until the required temperatures were rea ched in an oven prepared in advance for this requirement with dimensions of
(1 * 1.5 * 2.5) m, as shown in Figure.6 on the website of the graduate laboratories at the University of Masin.

a- Exposing the models. | b-Tools measure fire. | c- Oven burning the models

Fig.6 The process of exposing the models to heat

9 Displacement and Load Measurement.

All slabs were tested under single point bending loading at mid-span over span of (1000) mm and equipped to measure the deflections at mid-span, using a stepwise loading approach, all slabs were tested. A linear variable displacement transducer (LVTD) was used to measure the mid-span deflection of the slab. Deflection readings were taken using a portable electronic data logger. The loading system was assembled, and the initial values of the measuring device for deflections and loads were set to zero.

10 Results and discussions

The comparison and analysis of the experimental results are based on the data presented in Figures 7 and 8 and summarized in Table 9, which includes key parameters such as maximum load, first crack load, burning time, deflection, slab thickness, and reinforcement ratios for each specimen.
This section focuses on evaluating the structural behavior of reinforced concrete (RC) slabs subjected to short-term fire exposure, ranging from 20 to 40 minutes. Despite the relatively brief duration, the thermal exposure had a noticeable impact on the mechanical performance of the slabs particularly in terms of first crack load and ultimate load capacity. Elevated temperatures, even over short periods, can degrade the concrete matrix and weaken the bond between the steel reinforcement and the surrounding concrete, which in turn reduces the

overall load-bearing capacity.

To provide a baseline for comparison, specimen SN2 (unexposed control) recorded a first crack load of 70 kN, an ultimate load of 145 kN, and a reinforcement ratio of 0.009. In contrast, all fire-exposed specimens exhibited varying degrees of performance degradation, primarily influenced by their respective thicknesses and reinforcement levels.

For example, specimen SN1, with a slab thickness of 80 mm and a low reinforcement ratio of 0.007, exhibited substantial reductions, with a cracking load of 36 kN and an ultimate load of 60 kN corresponding to reductions of 58%, when compared to the control. Similarly, specimen SN5, reinforced at a ratio of 0.012, withstood an ultimate load of 40 kN, showing a comparable level of performance reduction 72%.

This trend illustrates the vulnerability of thinner slabs to thermal effects, as heat penetrates more rapidly, accelerating the degradation of both the concrete cohesion and the steel–concrete bond.

Conversely, increasing the reinforcement ratio was found to significantly enhance thermal resistance. Higher steel content improves the tensile capacity and facilitates more effective stress redistribution after fire exposure, thus partially compensating for the strength loss in concrete.

The experimental findings support this conclusion. For instance, under a 40-minute fire exposure, specimen SN3, with a reinforcement ratio of 0.0037, achieved an ultimate load of 65 kN, which is only 55% lower than that of the control specimen. Likewise, specimen SN4, with a reinforcement ratio of 0.0075, recorded an ultimate load of 108 kN, showing a similar percentage reduction. This pattern reinforces the understanding that the observed reductions in capacity are largely influenced by the reinforcement content.

In summary, the results demonstrate that increasing the reinforcement ratio can effectively mitigate the adverse structural effects of fire exposure, particularly in thin concrete slabs, by preserving a greater proportion of their load-bearing capacity.

The control specimen SN2, which remained unexposed to elevated temperatures, was utilized as a reference for evaluating the structural response of the tested slabs. According to visual observations and recorded data, the initial crack was observed at approximately 70 kN, designated as the cracking threshold. Beyond this point, the specimen maintained its load-bearing capacity until reaching a peak resistance of 145 kN, signifying its maximum structural efficiency prior to evident failure. At this ultimate point, the corresponding vertical displacement measured 9 mm. The associated load–deflection profile, illustrated in Figure 7, demonstrates a characteristic nonlinear trend. An initial steep linear segment reflects elastic performance, which gradually transitions into a flattened curvature due to microcrack development and progressive material degradation. This response underscores the ductile behavior and sound mechanical integrity of the unheated reinforced concrete slab, establishing a clear baseline for evaluating fire-induced deterioration.

Upon exposure to thermal conditions, slab SN1 (80 mm thickness, ρ = 0.007) exhibited a marked decline in capacity, with an ultimate strength limited to 40 kN a reduction of 58% relative to the reference. The associated deflection surpassed 11 mm, reflecting compromised rigidity and enhanced susceptibility to deformation as a result of thermal distress.

Similarly, SN5 (80 mm thickness, ρ = 0.012) reached a maximum capacity of 60 kN, equating to a 72% loss compared to the control, accompanied by a deflection exceeding 10 mm. This behavior highlights a substantial degradation in mechanical properties, consistent with fire-induced damage mechanisms.

In the case of SN3 (80 mm thickness, ρ = 0.0037), structural performance declined to 64 kN, indicating a 55% reduction in strength, with vertical displacement beyond 12 mm. The limited reinforcement and minimal section depth accelerated heat penetration, resulting in the deterioration of both the concrete matrix and reinforcement interface.

SN4, with the thinnest cross-section (50 mm) and a reinforcement ratio of ρ = 0.0075, sustained a capacity of 108 kN — representing a 25% reduction. Despite maintaining higher residual strength than other fire-exposed specimens, its deflection also exceeded 10 mm, evidencing diminished stiffness and heightened thermal vulnerability. The slender profile and low reinforcement volume likely facilitated rapid temperature ingress, intensifying material degradation.

Table.9 The Time Burn and Ultimate Load And Deflection

Model	Thickness mm	Stell Reinforcement Ratio (ρ)	Load at First Crack KN	Time Burn min.	Ultimate load kN	Deflection mm
SN2	80	0.009	70	---	145	9
SN1	80	0.007	36	20	40	11
SN5	50	0.012	15	20	60	10
SN3	80	0.0037	48	40	65	12
SN4	50	0.0075	58	40	108	10

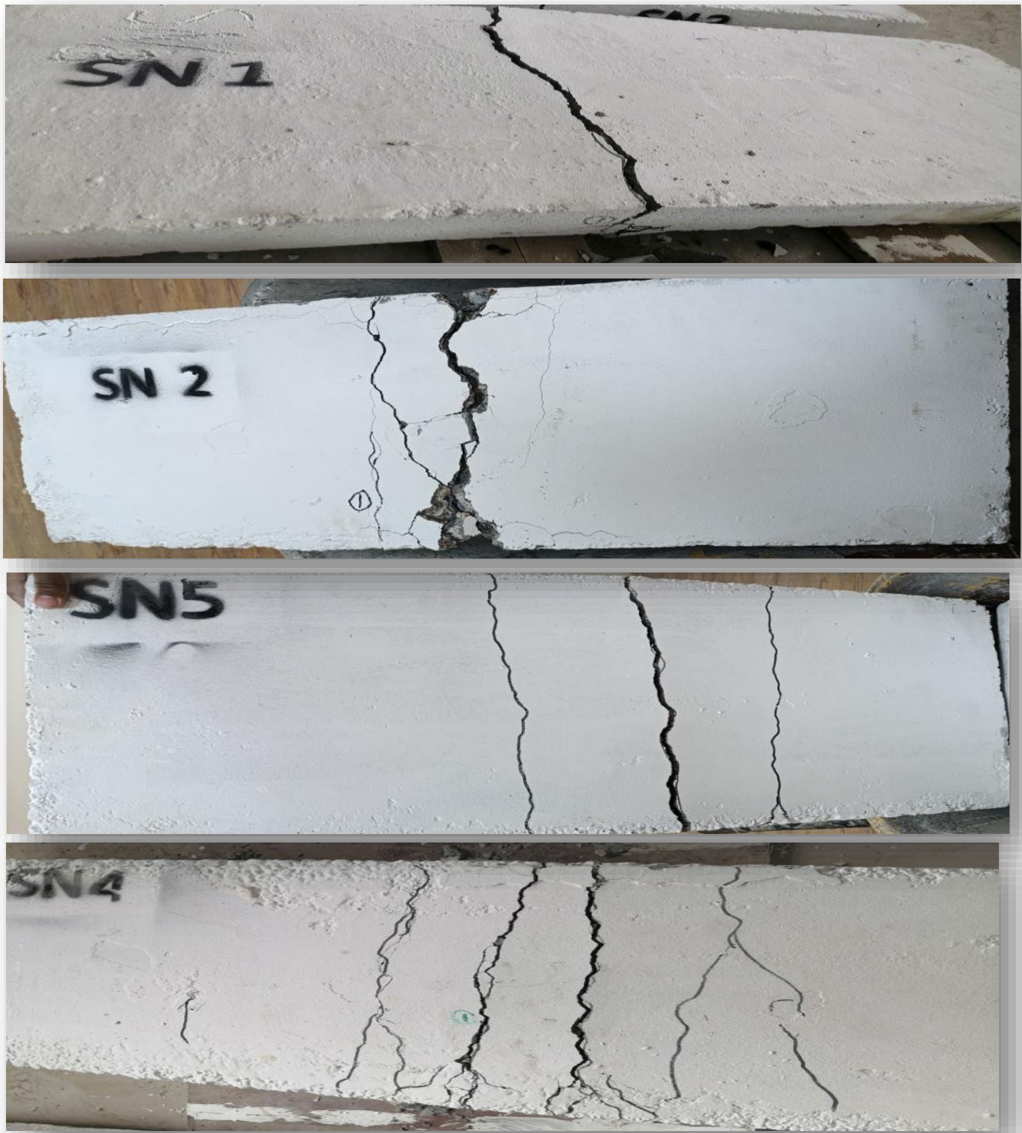
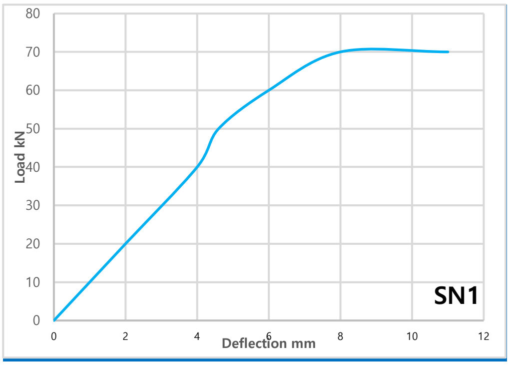
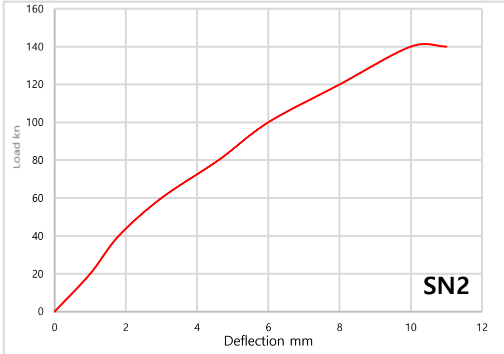


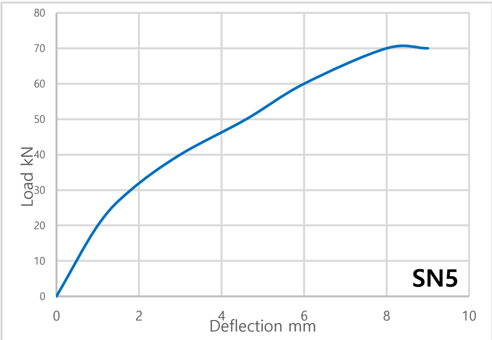
Fig.7 The specimen Slabs after test loading



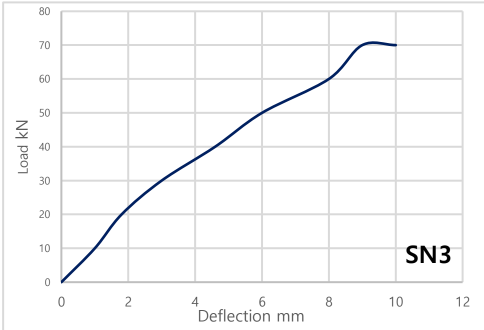
a-Load -Deflection curve SN1



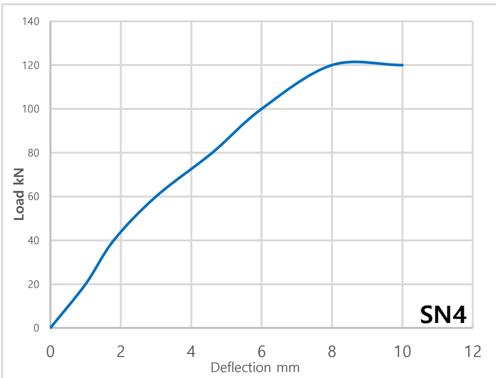
b-Load -Deflection curve SN2



c-Load -Deflection curve SN5



d-Load -Deflection curve SN3



a-Load -Deflection curve SN4

Fig.8 Load –Deflection curve for all specimen.

12 Conclusions

This study evaluated the structural performance of four reinforced concrete slabs subjected to post-fire conditions. The experimental program considered key variables including reinforcement ratios, slab thicknesses, and fire exposure durations. The main conclusions are as follows:

1. The application of fire protection measures, coupled with the use of optimal slab thickness, effectively prevents localized beam-type failures in specimens exposed to fire for 20 to 40 minutes.
2. Increasing the proportion of replacement reinforcing steel significantly enhances fire resistance, highlighting its critical role in improving structural performance under elevated temperatures.
3. Ultimate load tests revealed notable reductions in load-carrying capacity under high-temperature conditions, ranging from 25% to 72% compared to the control specimen.
4. Specimens with a thickness of 80 mm experienced a 57% decrease in load capacity under varying temperature conditions and reinforcement ratios.
5. Specimens with a thickness of 50 mm recorded a 42% reduction in load capacity under similar conditions.
6. Most cracks and failures were concentrated in the middle third of the slabs, while no significant cracking was observed near the supports, indicating a clear flexural failure pattern.

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References

[1] Wang, Y., & Lee, S. (2007). "Fire Resistance of Concrete Structures." Fire Safety Journal, 42(6), 459–469.

[2] Pacheco-Tor gal, F., & Jalali, S. (2011). "Fire Performance of Concrete." Construction and Building Materials,25(5), 1666–1673. Buchanan, A. H. (2002). "Structural Design for Fire Safety." Wiley-Blackwell.

[3] Cavill, R., & Rodd, R. (2004). "Effects of Fire on Concrete in Building Structures.
" Journal of Fire Protection "Engineering, 14(4), 235-249.

[4] Zhang, M., & Fu, J. (2015). "Fire Resistance of Reinforced Concrete: The Impact of Fire on Concrete Strength and Performance." Fire Science Reviews, 4(1), 23–35

[5] Khoury, G. A. (2000). *Effect of fire on concrete and concrete structures*. Progress in structural engineering and materials, 2(4), 429-447.

[6] Huang, Z., Burgess, I. W., & Plank, R. J. (2000). *Effective stiffness modelling of composite concrete slabs in fire*. Engineering Structures, 22(9), 1133-1144.

[7] Duan, M. Z. (1996). *Design guidelines for safe construction of concrete buildings*. Purdue University.

[8] Allam, S. M., Elbakry, H. M., & Rabeai, A. G. (2013). *Behavior of one-way reinforced concrete slabs subjected to fire*. Alexandria Engineering Journal, 52(4), 749-761

[9] IQS 5/1984 Portland cement in IQS 5/1984 "*Portland cement Central Organization for Standardization and Quality Control Iraq*" (in Arabic)

[10] IQS 45/1980 Aggregates, in IQS 45/1980 "*Aggregates from Natural Sources for Concrete and Building Construction*. Central Organization for Standardization and Quality Control". Iraq (in Arabic)

[11] ASTM C33, P. ASTM C33. *Standard Specification for Concrete Aggregates*.

[12] ASTM C494/C494M-1999a, "*Standard Specification for Chemical Admixtures for Concrete*", Vol. 4.2, 1999, 9p.

[13] ASTM A615/A615M-13, "*Standard Specification of Deformed and Plain Carbon Steel Bars for Concrete Reinforcement*", (ASTM A615M-13), ASTM International West Conshohocken. (2013). London: British Standard Institution; 1999.

[15] British Standard1881- 116, in BSI 1983. Testing concrete: Method for determination of compressive strength of concrete. British Standard Institution, London, UK., BS 1881- 116.

[16] ASTM C496/C496M-18, in ASTM C496/C496M-18. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. Vol. 4.2, PP. 1-5,2018.

[17] ASTM C78/C78M, in ASTM C78/C78M. Standard Test Method for Flexural Strength of Concrete. (Using Simple Beam with Third-Point Loading), USA: ASTM International, pp.1-4,2015.