The Iraqi Journal For Mechanical And Material Engineering, Special Issue (B)

Flexural Behavior of Reinforced Concrete Partially Restrained Slab Specimens Subjected to Fire Flame

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ABSTRACT:

This research deals with the flexural behavior of partially end restrained slabs subjected to burning by fire flame. The investigation is based on casting and testing 16 reduced scale (600×600×40mm) reinforced concrete slab specimens. Two concrete mixes with design 28 days compressive strengths of (30 and 38 MPa) were adopted. Two steel ratios of (0.005, 0.009) were used. The specimens were exposed to fire flame temperature levels of (400,500 and 600°C) at the lower surface of the slab specimens with exposure duration of one hour, then after 24 hours; they were tested in flexure to failure under uniformly distributed load while they are partially edge restrained against lateral and rotational movements.

It was found from the results that the values of ultimate load capacity, decreased for all specimens after exposing to fire flame. The residual ultimate load capacity for specimens burnt at temperatures of (400 and 500°C) was higher than that for specimens burnt at 600°C. At temperature around 600°C and for steel ratios of (0.005 and 0.009), the percentages of residual ultimate load ranged between (85 and 87%) respectively. The residual compressive strength at 600°C was about (63 %). However the residual modulus of rupture was in the range of (47 and 51 %) and the residual modulus of elasticity ranged between (29 and 26%) at 600ºC.

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الخلاصة:

هذا البحث يعالج سلوك الانثناء للبلاطات الخرسانية المسلحة المقيدة جزئيا من النهايات والمعرضة للحرق بلهب النار. الدراسة اعتمدت على صب وفحص ١٦ نموذج مصغر بأبعاد (٦٠٠*٦٠٠*٤٠)ملم من البلاطات الخرسانية المسلحة. تم اختيار خلطتين خرسانيه ذات مقاومة انضغاط تصميمية بعمر ٢٨ يوم مقدارها ٣٠ و ٣٨ نيوتن ملم٢ وتم اختيار نسبتين لحديد التسليح(٠,٠٠٥-٠,٠٠٩).عرضت النماذج إلى حرارة لهب النار

بثلاث مديات (٦٠٠،٥٠٠،٤٠٠)درجه سليزيه على الوجه السفلي للبلاطة وبزمن تعرض مقداره ١ ساعة،فحصت النماذج لحين الفشل بعد ٢٤ ساعة تحت ثقل موزع منتظم اثناء تقييدها جزئيا ضد الحركة العرضية والدورانية.

أظهرت النتائج أن مقاومة التحمل الحدية للبلاطات قلت لجميع النماذج المعرضة للهب النار. كانت المقاومة الحدية المتبقية بعد الحرق في درجة حرارة (٤٠٠و٥٠٠) أعلى منها في درجة ٦٠٠ سليزيه. فلقد وجد انه بعد الحرق بدرجة حرارة ٦٠٠ سيليزية ولنسبة حديد التسليح (٠,٠٠٥ و٠,٠٠٩)كانت ألنسبه المتبقية من ألمقاومه ألحديه تتراوح بين (٨٥- ٨٧%). وكانت مقاومة الانضغاط المتبقيه عند ٦٠٠ سيليزية حوالي (٦٣%). بينما كانت نسبة معاير التصدع المتبقي يتراوح بين (٤٧-٥١%) اما المتبقي من معاير المرونه فكان يتراوح بين (٢٦-٢٩%).

Introduction

The concrete buildings could be exposed to the effect of fire. Human safety is one of the considerations in the design of residential, public and industrial buildings. Unlike wood and plastics, concrete is incombustible and does not emit toxics fumes on exposure to fire .On the contrary of steel, when subjected to temperature between (700-800)ºC , concrete is able to retain an adequate strength for reasonably long periods, thus permitting rescue operations by reducing the risk of structural collapse **(Mehta 1986)**.

There are many instances of exposing concrete structural members to elevated temperatures. One of the most common instances of exposure is by accidental fire in buildings. Another instance of heat exposure may be found in some industrial equipment when concrete is used in places exposed to sustained elevated temperatures. Long exposure to elevated temperatures is imposed on foundations for blast furnace and coke batteries, furnaces wall and dampers, industrial chimneys and flues, floors below boilers and kilns and nuclear- reactor pressure vessels **(Neville 2000)**.

Effect of Fire on Concrete

Many researchers since 1972 investigated the effect of high temperatures on the compressive strength of concrete.

***Noriaki et al* (1972)** investigated the effect of temperature on the properties of concrete (compressive strength, modulus of elasticity and Poisson's ratio). Cylinders (150 x300 mm) were used. After 28 days of curing the specimens were stored in sealed containers at (40, 70, 90oC) for a period of (1 – 13 Weeks). The test results showed that the compressive strength for sealed specimens decreased with rising temperature. They found that the modulus of elasticity for sealed specimens at exposure to high temperatures depends on the compressive strength. Poisson's ratio was not affected under the storage temperature but stayed in the range of (0.15 -0.20).

***Nuri* (1983)** investigated the effect of high temperatures on some properties of concrete. The specimens were exposed to temperatures in the range of (20-600 °C) and the periods of exposure of heating were (30, 60 and 90 minutes) at different ages of concrete (3, 7, 28, and 60 days). Concrete cylinders (102*203) mm were used for compressive and splitting tensile strengths. He found that:

1. After 300 °C exposure, concrete retained about (59-102%) and (44 – 100%) from original compressive and tensile strength respectively.
2. After 600 °C, concrete retained (28 – 64%),and (20 –62 %) from original compressive and splitting tensile strengths respectively .

***Valiasis and Papayianni* (1991)** studied the effect of high temperatures on the mechanical properties of concrete in which Portland cement concrete cylinder specimens (150 x300 mm) were used. After 28 days of moist curing and six months of drying , the specimens were exposed to four temperature levels (200 ,400 ,600 and 800 °C) without any imposed load .Groups of three specimens each were crushed at 1 day ,7 days and 3 months after heating .The included variables were compressive strength ,splitting tensile strength and modulus of elasticity .The test results showed that the concrete with Portland cement only had a reduction in strength about 25 % .While the concrete with pozzolanic material showed a reduction from 38 % to 50 % at 200°C . They observed that at a temperature over 400 °C all the tested concrete suffered deterioration and lost (70 – 80 %) of their initial strength.

Effect of Fire on Reinforced Concrete

***Kadhum* (2003)** studied reinforced concrete slabs which were subjected to a drying period of two months. Then, they were exposed to direct fire flame temperature of 600°C for 1.5 hour period of exposure without any imposed loads during burning. Then, the slabs were cooled to the laboratory temperature. The author concluded that the maximum crack width before burning was (0.24, 0.255 and 0.275mm) for two, three and four end- restrained slabs respectively. The maximum crack width for free, two end, three end and four end restrained slabs after burning was (0.25, 0.75, 0.725 and 0.71mm) and (0.07, 0.675, 0.7 and 0.75mm) respectively.

Experimental Work

Materials

Cement

The cement used in this study**(Hussen 2007)** is ordinary Portland cement (OPC). The cement complies with the Iraqi standard specification **(IQS No.5:1984)**

Fine Aggregate

Natural sand from **AL-Akaidur** region was used. Its specifications conformed to the Iraqi standard specification **(IQS No.45:1984).**

Coarse Aggregate

The gravel used was brought Al-Nibai area with a maximum size of 20 mm. The gravel used conforms to the Iraqi standard specification **(IQS No.45/1984)**.

Mix Proportions

Two concrete mixes were designed according to **(ACI-211.1-91).** These mixes were designed to give target 28 days compressive strength of 30 and 38 MPa.

The proportions of the two concrete mixes are summarized in Table (1)

Table (1): Mix proportions and slump of the concrete mixes.

Mix Proportions						
Mix. Notation	Gravel kg/m^3	Sand kg/m^3	Cement kg/m^3	Water kg/m^3	W/C ratio	Slump (mm)
A	966	686	448	205	0.457	80-100
B	966	596	538	215	0.40	80-100

Testing of Concrete Mechanical Properties:

Compressive strength of concrete was carried out and tested according to **BS 1881**: part **116:1983** specification. Concrete cubes of (150) mm were cast and tested.

For flexural strength test concrete prisms of (100×100×400mm) were cast and tested. This test was performed according to **ASTM C293-94** specification.

The static modulus of elasticity was determined according to **ASTM C469-94)**specification**.**

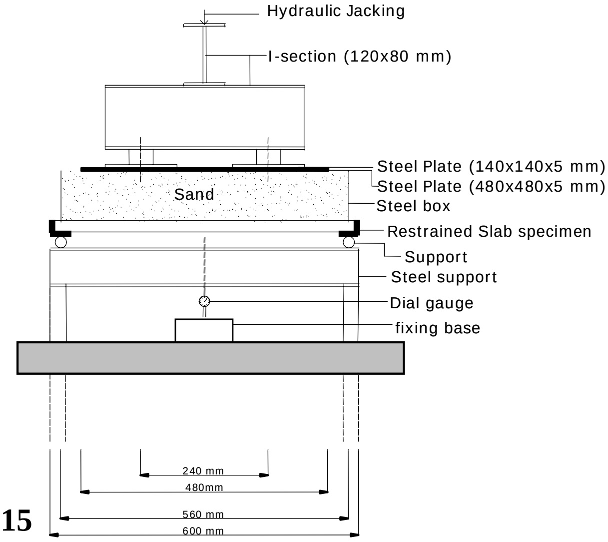
Flexure Testing of Slab Specimens:

The load-deflection behavior of slab specimens was tested in pressing machine. The steel restraining frame was used to represent the end restraint acting at the periphery edges of reinforced concrete slabs.

A load cell with a capacity of (100 tons) was used to record the load which is applied by a hydraulic jack.

A steel loading plate and 100mm layer of sand were used to transmit and distribute the load exerted by a steel loading frame to the slab specimen as uniformly distributed load. The steel loading frame was used to transmit the load exerted by the hydraulic jack to the 100 mm layer of sand used between the loading plate and the slab specimen as shown in Figure (1). The steel loading frame consists of three steel I-section members, two of these members are parallel to each other and the third is welded perpendicularly upon them. The two parallel steel members are connected to four steel legs. These legs are connected by welding to four steel plates, then, these plates are fixed over a steel plate of (480×480×5mm) by welding.

A box of dimensions of (520×520×100mm), made of four welded steel plates of thickness 5mm opened from upper surface, while the lower surface is made of fabric, was used to hold the sand inside. Deflections were measured at load stages using a dial gauge with a capacity of (25.4mm) and accuracy of (0.025mm) at mid span of the slab specimens.



Sec. A-A

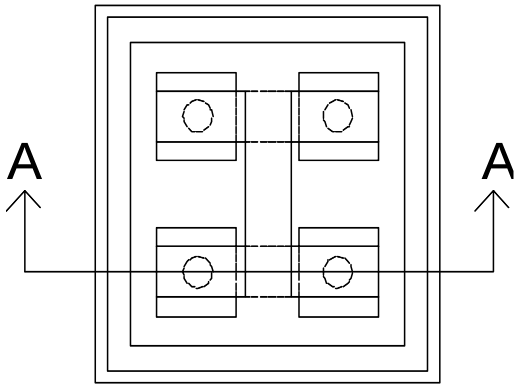


Figure (1): Loading arrangement and test setup for flexure test of the end-restrained reinforced concrete slab specimens.

Edge Restraining Steel Frame

The plate edge restraining steel frame consists of four equal steel angles, each of size (40 *40 *5 mm) welded together at right angles to form a square steel frame (600*600 mm). The plate (slab) concrete specimen was put inside the steel restraining frame. To maintain a good contact between the plate edges and the steel frame the gap was filled with high strength cement paste. Three days later, the whole system (the steel restraining frame with the concrete plate inside) was moved to the testing machine to be tested in flexure. This edge steel frame exerts partial restraining to the axial movement and rotation occurring when loading the concrete plate in flexure. This end restraint is believed to represent the boundary condition at the edges of reinforced concrete slab panels.

Results and Discussion

Compressive Strength

The test results of compressive strength of the cube specimens in the present investigation are shown in Figure (2). It was found that:

1 At 400 °C of fire flame exposure, the percentages of residual compressive strength were (82-84%) and (81-83%) for series A and B respectively.

2- At 500°C of fire flame exposure, the residual compressive strength ranged between (71-73%) and (70 – 72%) for series A and B respectively.

3-The tested specimens show a further loss in compressive strength at temperature of 600 °C where the residual compressive strength ranged between (62%) and (60-63%) for series A and B respectively.

The decrease in compressive strength of concrete is attributed to the break-down of interfacial bond due to incompatible volume change between cement paste and aggregate during heating and cooling and the formation of relatively weak hydration products (dehydration of the calcium –silica hydrate in cement paste).

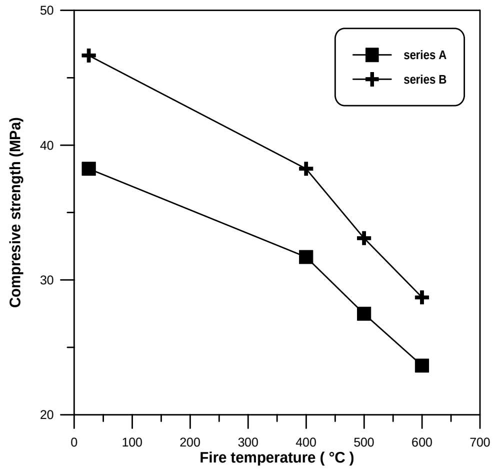


Figure (2): The effect of fire temperature on the concrete compressive strength

Flexural Strength

The modulus of rupture results are summarized in Figure (3)

1 -At 400°C, the percentages of residual flexural strength were in the the range of (77-79%) and (75-76%) for series A and B respectively.

2 -At temperatures around 500°C, the percentages of residual flexural strength were (60-62%) and (59-62%) for series A and B respectively. Hair –cracks and pink color were observed in the prisms.

3 -At 600°C ,the percentage residual flexural strength compared to the original strength before exposure to fire flame are (47-50%) for series A and (48-51%) for series B . From these results, it can be seen that the reduction in values of concrete modulus of rupture were more significant than that of the compressive strength at identical fire flame temperatures.

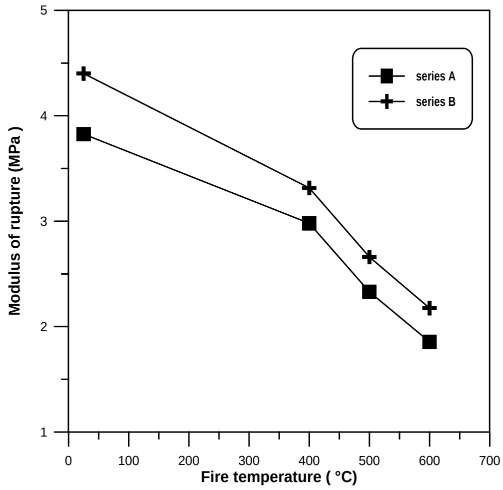


Figure (3): The effect of fire temperature on the concrete modulus of rupture

Modulus of Elasticity

The modulus of elasticity results are summarized in Figure (4) It can be seen that the effect of fire temperature on concrete modulus of elasticity has a similar trend to that on compressive strength and flexural strength, but the reduction percentages are more pronounced than that of compressive and flexural strength at identical fire temperatures.

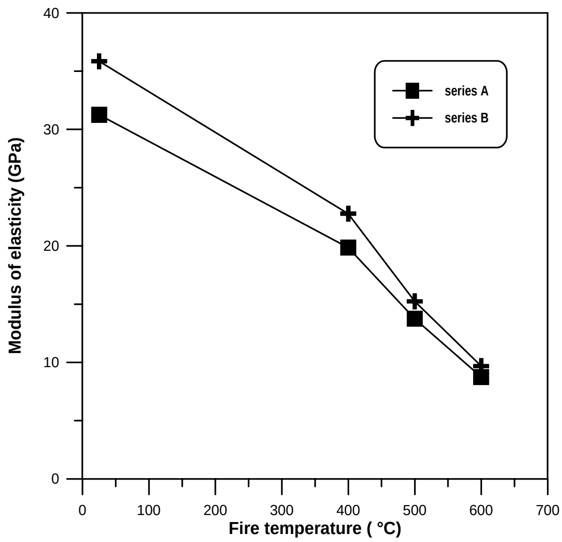


Figure (4): The effect of fire temperature on concrete modulus of elasticity

Flexure Behavior of Slab Specimens

Ultimate Load Carrying Capacity

The ultimate resisted load or *Load Carrying Capacity* is the load which is recognized by excessive increasing in the deflection without any increment in the applied flexural load. The ultimate load results are given in Figure (5) and (6) for series A and B respectively. The residual ultimate load values were calculated for series A and B at fire temperature levels of (400, 500, 600 °C). It was found that:

1-At burning temperature around 400 °C and for steel ratio of (0.005, 0.009) the percentages of residual ultimate load were (95, 95.3%) and (95.3, 96.6%) for series A and B respectively.

2- The tested specimens showed a further loss in ultimate load at fire temperature of 500 °C where the residual ultimate load ranged between (91.8, 93%) and (92.3, 92%) for steel ratio of (0.005, 0.009) for series A and B respectively.

3- At burning temperature around 600°C, the specimens exhibited a further loss of ultimate load. The percentages of residual ultimate load ranged between (86.8, 87.2%) and (86.1, 85.5%) for steel ratio of (0.005, 0.009) and for series A and B respectively.

When fire temperature reaches about (600 °C) the further decrease in ultimate load may be attributed to both burning and subsequent cooling of concrete and the dehydration of the cement gel.

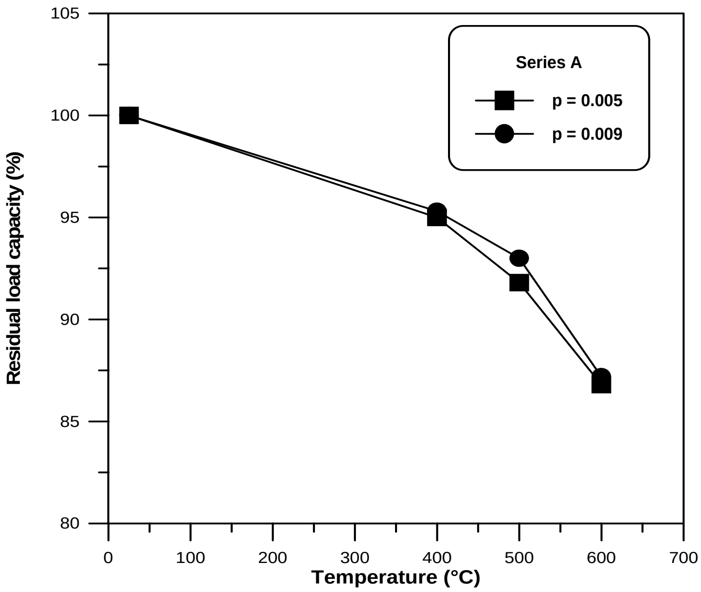


Figure (5): Effect of fire temperature on percentage of residual load carrying capacity of reinforced concrete restrained slab specimens, (series A).

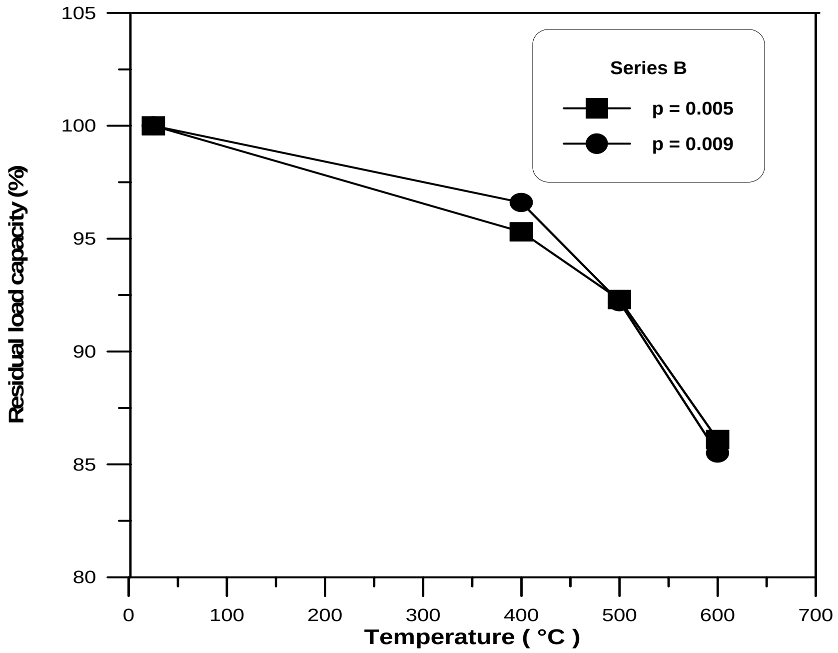


Figure (6): Effect of fire temperature on percentage of residual load carrying capacity of reinforced concrete restrained slab specimens, (series B)

Load –Deflection Relationship

Effect of fire temperature on the load- deflection relationship of partially restrained slab specimens is presented in Figures (7) to (10).

With respect to these curves, it can be seen that the load- deflection curve of unburned specimens (25°**C)** exhibits four stages each with different slope. The first stage is the elastic or uncracked stage, the second stage is the multiple cracking stage; and the third stage is the plastic stage which represents the widening of cracks, and finally the yielding of steel reinforcement stage. At fire temperature of 400°**C** and 500°**C**, the three above stages were less pronounced. At fire temperature of 600°**C,** the load-deflection relations of restrained slab specimens are flatter, representing softer load-deflection behavior than that of the control (unburned) restrained slab specimens. This can be attributed to the reduction in modulus of elasticity of concrete and increase in the amount of cracks formation. It can be seen that for the same steel reinforcement ratio and under a certain load the deflection increases with increasing the burning temperature. This can be attributed to the fact that fire causes a reduction in slab stiffness which is essentially due to the reduction in the ***modulus of elasticity*** and the ***effective moment of inertia*** of the restrained slab specimens.

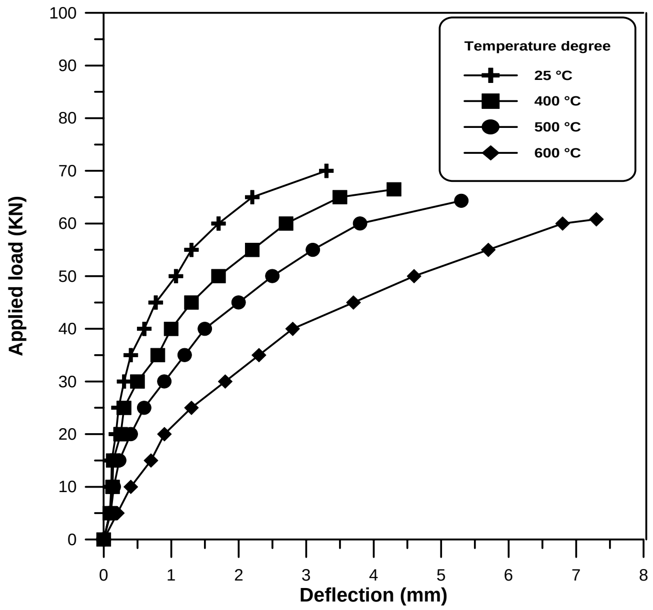


Figure (7): Load – deflection relationship for the reinforced concrete partially restrained slab specimens at different burning temperatures of series A (ρ = 0.005).

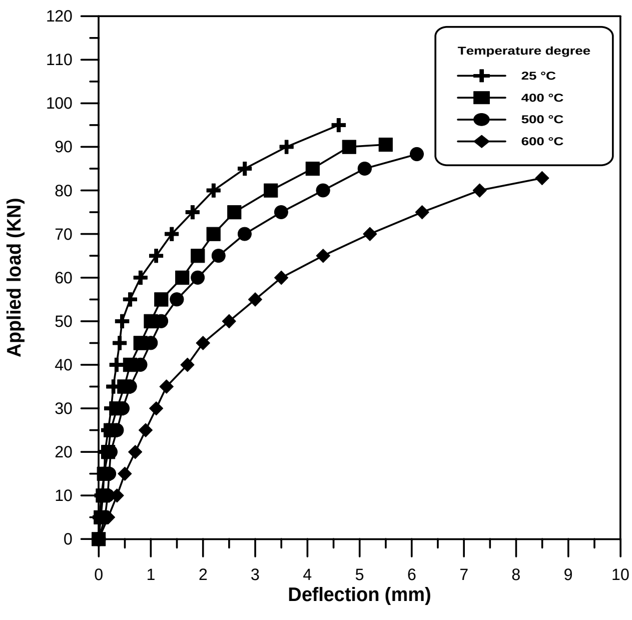


Figure (8): Load – deflection relationship for the reinforced concrete partially restrained slab specimens at different burning temperatures of series A (ρ = 0.009).

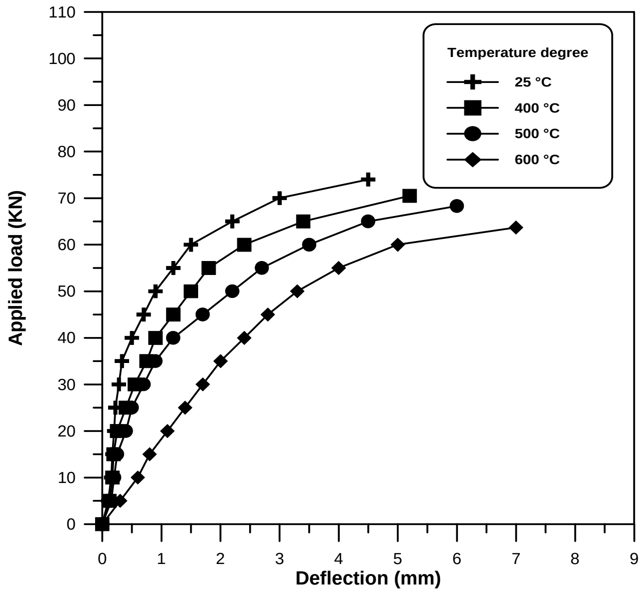


Figure (9): Load – deflection relationship for the reinforced concrete partially restrained slab specimens at different burning temperatures of series B (ρ = 0.005).

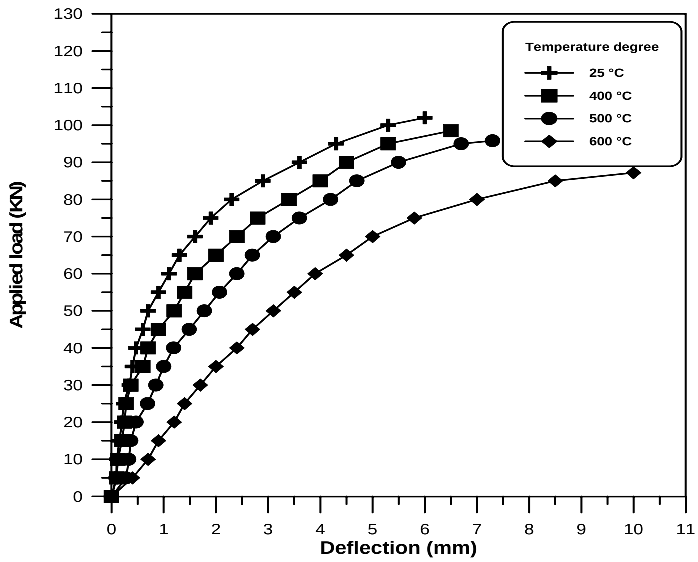


Figure (10): Load – deflection relationship for the reinforced concrete partially restrained slab specimens at different burning temperatures of series B (ρ = 0.009).

Conclusions

Based on the results of the present study, the following conclusions can be drawn:

1 - Concrete compressive strength decreases significantly after exposing to fire. The residual values of compressive strength at fire temperatures around 600 °C were (62% and 63%) for series A and B respectively.

2 – The reduction in concrete flexural strength is more pronounced than that in compressive strength after exposing to fire. The residual values of flexural strength at fire temperatures around 600 °C were (47%, 51%) for series A and B respectively.

3 – The reduction in values of concrete modulus of elasticity was more significant than that of the compressive and flexural strength at identical fire flame temperatures. The residual modulus of elasticity at fire temperatures around 600 °C were (29% , 26%) for series A and B respectively .

4 - The slab specimens reinforced with higher steel ratio show slightly higher unexposed surface temperature than that of slab specimens reinforced with lower steel ratio at the end of 1-hour fire exposure. This may belong to the higher concentration of steel reinforcement of slab specimens.

5 - The percentages of the residual value of ultimate load at temperatures around 600 °C were (86 % , 87 %) for series A and for steel ratios (0.005, 0.009) respectively, and (86 %, 85 %) for series B with the same respective steel ratios.

6 - The load- deflection relations of specimens exposed to fire flame are flatter, representing softer load-deflection behavior than that of the control slab specimens. This behavior can be attributed to the early cracking and lower modulus of elasticity.

7 - Direct fire flame exposure and subsequent cooling decreases residual ultimate resisted load of slabs when compared with slabs stored in furnace.

8 - The partial restraint to both lateral translation and rotation of the slab edges in either direction provides significant enhancement in load carrying capacity if compared with free reinforced concrete plates.

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