Flexural Behavior of Reinforced Concrete Beams Covered by Gypsum Layers and Exposed to Elevated Temperatures

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Abstract. The paper presents results of exposure of normal concrete to elevated temperatures (400 and 700) °C covered by layers (gypsum and plaster) with different thicknesses (10 and 20) mm. The casted specimens for each type of test were divided into three groups. The first was without covering the concrete surface with gypsum, while the second and third groups were covered with gypsum of the outer surface with a thickness of 10 and 20 mm, respectively. The experimental results found that the ultimate load capacity and the first crack load of RC beams were improved by using gypsum layers through 400°C. At thickness 10 and 20 mm, the (P_{cr} and P_u) loss was about (8 and 6) % and (1 and 7) % respectively, compared to the concrete not covered with gypsum, the loss rate is about (25 and 13) %, and this is clear evidence of the benefit of gypsum in reducing the Elevated Temperatures directly to concrete. As for the temperature of 700, the reduction in (P_{cr} and P_u) was about (57 and 22) % and (31 and 16) % and (10 and 15) % at 0, 10, 20 mm gypsum thickness, respectively. Through the figures shown in the paper, which were obtained from the experimental side of the research, the load-deflection curves improved when the gypsum thickness increased during the specimens' exposure to fire. Where the relationship between them at a temperature of 400°C in a thickness of 20 mm was better than 10 mm when exposed to fire, so by increasing the thickness of the gypsum, the occurrence of deflection is less because it protects the surface of the concrete from direct exposure to heat and thus prevents the occurrence of cracks in the outer surface of the concrete.

Keywords: Beams; temperature; gypsum; plaster; fire flame; load-deflection.

Introduction

When designing concrete structures, thermal insulation and fire resistance are taken into account during the design. Therefore, gypsum is considered one of the construction materials used in fire resistance because it contains the percentage of water in it, which reduces the effects of fire in the structure, which contributes as a heat-resistant barrier. When the gypsum is exposed to fire, the water slowly dilutes as vapor, which dampens the heat production. The gypsum is affected by several factors: extreme weather conditions, poor or no ventilation, thermal shake, unusual framing or body loading, etc. Precautions shall be taken to prevent these and other adverse provisions. Essa et al. [1] Investigate the structural behavior of reinforced concrete beams. Two types of concrete were used: normal concrete, the second high-strength concrete (30 and 78) MPa. Where it investigated the residual bending resistance after the process of exposing the models to the fire. Use two types of temperatures, 400ºC and 700ºC, and for an hour and an hour and a half, and there are two types of cooling, the first with air and the second with water. At 400°C, it was found that the residual bending strength is (84-88) %, (70-72) % for high strength concrete, while (86-91) %, (84-88) % For normal concrete with an hour and an hour and a half respectively. At fire temperature (700 ºC) is (50-55) %, (40-45) % for high strength concrete, and (54-57) %, (38-46) % for normal concrete with an hour and an hour and a half respectively.

Kadhum [2] investigated reinforced concrete beams exposed to fire flame using an imposed load. In this research, load-deflection behavior of beam specimens subjected to fire flame. The samples of concrete and beams were exposed to elevated temperatures in the range of 25-800°C. This study's parameters were the fire temperature of (400, 600, and 800°C), the burning period of (1.0 and 2.0 hours), and various ages of 28, 60, and 90 days. The load-deflection curves show different behavior with the heating temperature. As well, it was observed that the increasing temperature lead to increase shrinkage ratios. Outcomes show a significant decrease in flexural strength after burning, the deflection increased when the temperature increased, and the percentages of the residual yield and ultimate tensile stress slightly decreased with temperature increase. Izzet and AL-Dulffy [3] studied the resistance of post-tensioned concrete beams when exposed to high temperatures, where he investigated the effect of residual bending strength when burning. It was used three types of temperature and two types of air cooling, the second with water, and the burning time is one hour. The practical results showed that the resistance of load capacity decreases with the increase of the fire temperature. At a burning temperature of 300, 500, and 700°C of the maximum residual load for gradually cooled beams was 84, 72, and 60%, respectively.

In order to understand and predict the behavior of plaster and gypsum during a fire, it is necessary to know the properties of the materials that determine the behavior of the member at different temperatures. Plaster and gypsum were used to cover the concrete's outer surface to slow down the heat directly to the surface of the concrete during firing. Load-deflection curve, first crack load, Ultimate load capacity of RC beams were tested to denote the true values after firing and examination and to be able to predict the fire resistance of the structural member.

Structural Members of RC Beams

The experimental program includes casting and testing nine RC Beams, where the models were divided into three groups. The first group did not put gypsum on the outer surfaces of the beam. The second group was the thickness of the gypsum 10 mm, while the third group, the thickness of the gypsum was 20 mm. The three groups were exposed for temperatures (400 and 700) °C. Figure 1 and Table 1 show the flowchart and designation of tested models.

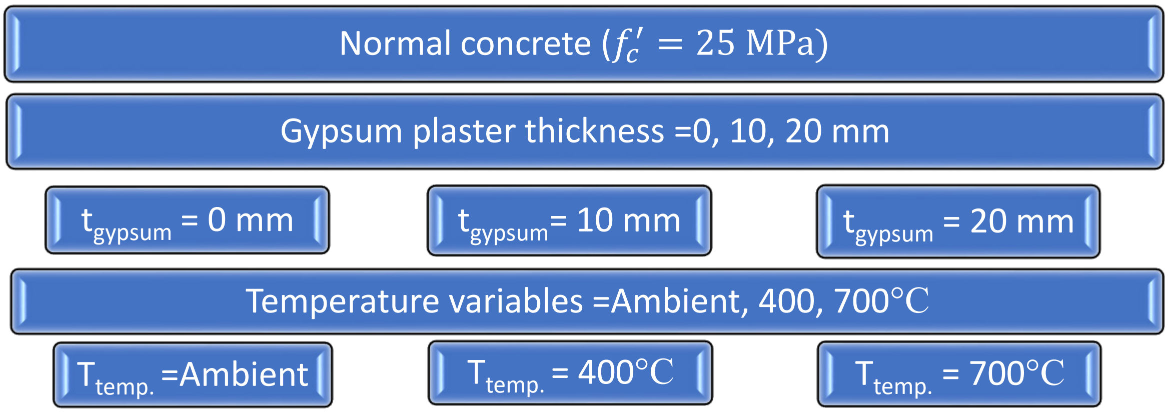


Figure 1. The flowchart of studied variables.

Table 1. The designation of models according to the tested groups.

No. of group	No. of specimens	Temperature (°C)
First group	BG0TA*	Ambient
	BG0T400	400
	BG0T700	700
Second group	BG10TA	Ambient
	BG10T400	400
	BG10T700	700
Third group	BG20TA	Ambient
	BG20T400	400
	BG20T700	700

*BG0TA (Beam, gypsum thickness = 0, Temperature = Ambient)

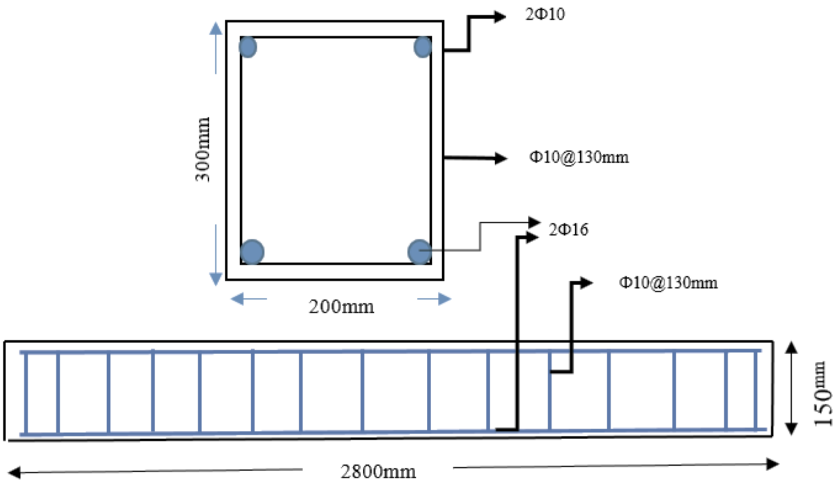
Steel Reinforcement. The steel reinforcement in this study of the minimal organ in all the specimen's beams (Ø10 and Ø16) mm was used as main steel with a 0.00767 steel reinforcement ratio to confirm the minimum reinforcement requirement ACI-318. The ties of beams were fabricated using (Ø10 mm) diameter for steel. Table 2 and Figure 2 show the properties and details of steel bars. The tensile test was performed using the testing machine SANS (1000 kN). Table 2 shows the properties of steel bars.

Table 2. Properties of steel bars*.

Diameter (mm)	Yield stress, fy (MPa)	Ultimate strength, fu (MPa)
10	420	600
16	550	750

* Each value is an average of three specimens.

(A)



(B)

Figure 2. A) Tensile machine for steel bars testing and B) Details for reinforcement models.

Material Properties: Mix Proportions

The ordinary Portland cement was used in the concrete mix of a proposition by weight of (1:1.5:3) for normal strength concrete (cement: sand: gravel). Table 3 shows the details of mix proportions used in this study, depending on the trial mixes and previous research [4, 5, 6].

Table 3. Mix proportions of normal strength concrete.

Cement (C) (kg/m^3)	Sand (S) (kg/m^3)	Gravel (G) (kg/m^3)	Water (W) (kg/m^3)	W/C ratio	Mix proportion by weight
400	600	1200	180	0.45	1:1.5:3

Cement. Ordinary Portland cement (Type I) is used in this work. Many tests indicate that; the used cement conforms to the Iraqi Specification No. 5/1984 [7].

Fine Aggregate. Natural sand is selected and used for NSC mix. Results indicate it is within the requirement of the Iraqi Standard Specification No. 45/1984 [8].

Coarse Aggregate. Crushed river gravel with a maximum particle size of 14mm is prepared and used as coarse aggregate for NSC mix. The coarse aggregate grading excepts the Iraqi Standard Specification No.45/21984 [8].

Mixing Procedure. The casting of NSC Specimen molds was cleaned thoroughly, tightened well, and the internal surfaces were oiled with thin engine oil to prevent the hardened concrete adhesion with molds. Steel wires were fixed at their correct position inside the molds. Each layer is compacted by an external vibrator to minimize the air voids and to get well-compacted concrete. Then, the top surface of the specimen was well finished by using a steel trowel so that the upper surface of the steel block was kept level with the concrete surface. After this stage, all the specimens are covered with nylon sheets to prevent loss of moisture. After 24 hours, the specimens are taken out of the molds, marked, and then cured. Figure 3 shows all stages of work.

Gypsum and Plaster Procedure. Local Iraqi gypsum (Juiss) was used in this study. The consistency and the setting time were measured following the IQS NO. 27 [9] and IQS NO.28 [10] standard. In this study, gypsum was used to make finishes of cubes, cylinders, and prisms, simulating the practical reality with thicknesses of (10 and 20) mm and the use of plaster material for the same purpose above. Also, gypsum and plaster finishes were applied to the mechanical properties of concrete. Below are the stages of using gypsum and plaster in Figure 4.

Figure 3. Stages of work.

Figure 4. The specimens are covering with gypsum and plaster.

Exposure to Fire Flam Test. The furnace was manufactured by using a 3 mm thick steel plate just like a rectangular shape to burn one specimen each time, as shown in Figure 5. The clear inner space was 1500 mm height by 2500 mm width and 3000 mm length. Two of each group were subjected to burning, one of them at 400°C temperature and the second at 700°C. This talk applies to burning RC Beams according to the gypsum's thickness, the plaster, and the temperature. The firing stage was carried out in steps that are placing in the oven the specimens that are burned at 400°C temperature with the beams was placed and then subjected to burning for an hour with the oven covered to ensure that the firing uniformity was distributed evenly over the whole specimen where it was not exposed. The samples are transferred directly to the flame. After that, a temperature is measured every 10 minutes to achieve specification ASTM-E-119 [11]. Note that the temperature was measured with a thermometer and a thermocouple.

Figure 5. Furnace of burning test stage.

Instrumentation, deflection of RC Beams, Strain measurements

Three types of measurements were adopted: temperature, deflection, and strain, to describe RC Beams' behavior through and after the exposure to Elevated Temperatures and to find out the residual ultimate load capacity. Mid and Quarter span deflection was measured by using a dial gauge of 0.01mm/div. Figure 6 illustrates the dial gauges' positions at the loading test stage. Uniaxial electrical resistance foil strain gauge was the method used to measure the strains in concrete. Various sizes of pre-wired strain gauges of (120 Ω) resistance were used, made in Japan by TML. PL-60-11 was used to measure the longitudinal strain at the top, two lateral surfaces, and bottom concrete surfaces during as well as at the loading stage. The CN-E adhesive materials were used to install the strain gauges on the specified surfaces. After preparing the contact surfaces properly, all types of strain gauges commonly used by adhesive material are installed. There was also a coating process for all the embedded strain gauges using W-1 and epoxy resin coating material as recommended by the manufacturer, TML. Tables 4 and 5 show the details of the used strain gauges and the details of adhesive materials, respectively. All strain gauges were fixed in the mid-height of specimens and connected to a laptop computer through a multichannel data logger (4 channels) types Koywa Company/Japan model PCD-300B-F.

Table 4. Details of the strain gauges.

No.	Model	Length (mm)	Setting location
1	PL-60-11	60	Concrete

Table 5. Details of the adhesive materials.

No.	Model	Component	Applicable specimen	Operational temperature	Curing temperature and time
1	CN-E	Cyanoacrylate	Porous, Concrete, Mortar,	−30〜+120 ℃	Room temp. 40sec. -2 min. (thumb pressure)

Temperature Measurements. At the first test stage (burning stag), a thermometer K-type was available with dual inputs was used to measured temperature with respect to time. It also offers a wide range of K-type probes and data logging features across the range. A K-type device appropriate with different kinds of the thermocouple. A thermocouple is a temperature measuring instrument made up of non-identical metals. The metals are welded on the tip to form what is known as the thermocouple junction. The most common thermocouple junction is type K, providing the widest operating temperature range of 1400^{o}C. There is a selection of other probe kinds appropriate for various applications.

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Test of Beam. The test rig was installed at a structural laboratory in the Civil Engineering Department/College of Engineer/University of Baghdad on a strong floor, the test rig frame dimensions were 4.5 m in width and 3m in height, the test rig has a supporting two steel girders of length equal to (3.5 m) elevated at 0.2m above the base plate of the frame steel column. The test rig was used, as shown in Figure 6. A manual mechanical, hydraulic jack of 50-ton maximum capacity was used to apply load on the beam through the loading test stage. The applied load was controlled by using a 100-ton load cell with a digital load reader. Applying the load test stage was carried out using the instrumentations and all requirements as described in previous sections. The monotonic load was applied downward through the mid-point of the stiffened double steel beam (IPE260) spreader. The spreader beams parallel to the specimen and rested on two shaft rods of 30mm diameter (two-point load).

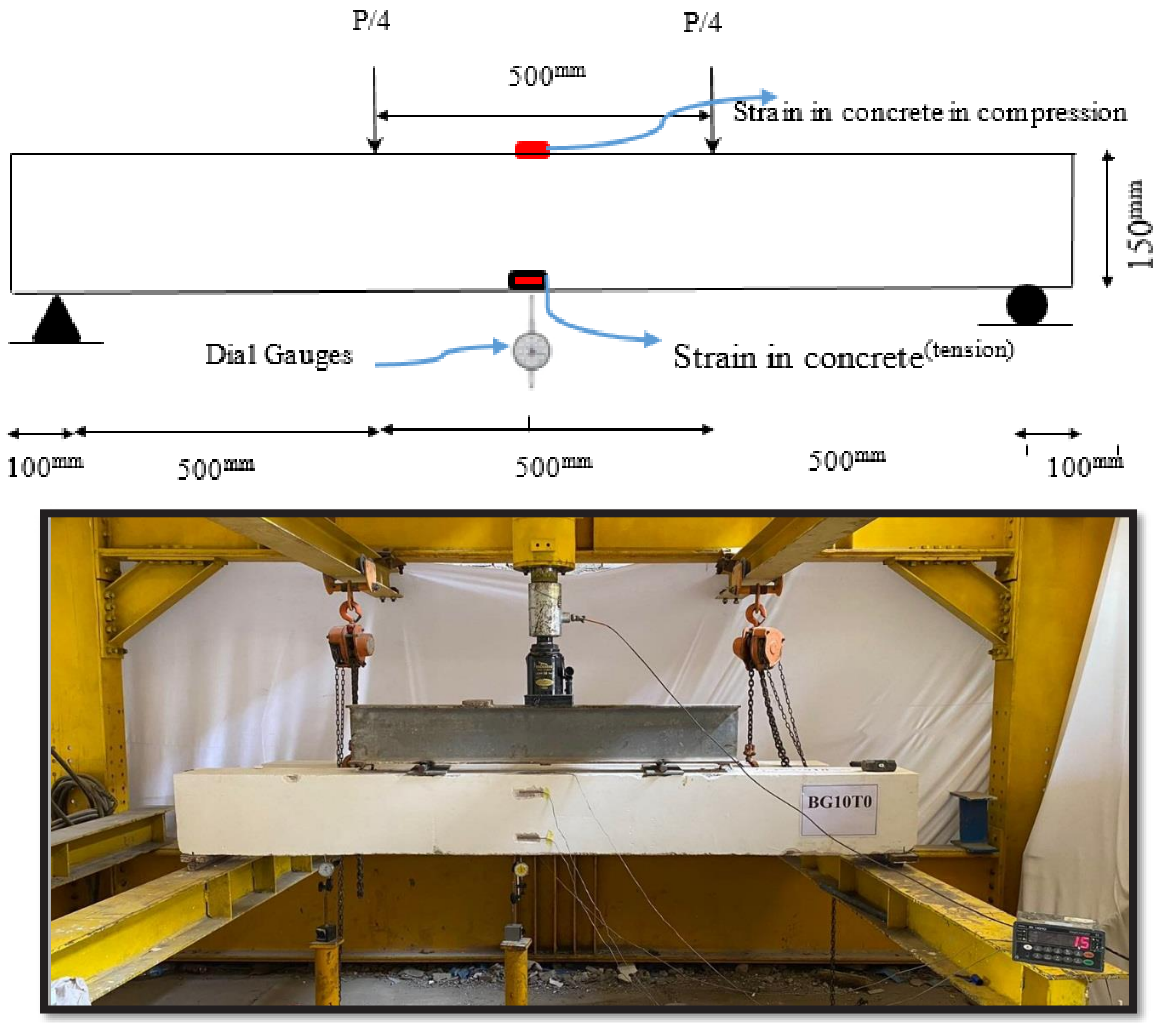

Figure 6. Testing RC beam setup.

The vertical deflection was recorded at each stage of loading at the mid-span of the beam, and the load and corresponding deflection were recorded for all beams, as shown in Table 6. Figures 7, 8, and 9 show the load-deflection curves for the beams of Groups I, II, and III with and without covering of gypsum, respectively, throughout the applied load after the burning process. Through these figures, it can be seen that the increase in fire temperature reduces the load-carrying capacity in beams. This can be referring to the reality that heating leads to a decrease in beam stiffness, mainly due to a decrease in the elastic modulus for concrete and a decrease in the effective section caused by cracking. At a temperature of 400°C, the results at 400°C showed little difference in load and deflection for the gypsum and plaster-covered models compared to the non-covered models. While at temperature 700°C, the covered and non-covered models of gypsum and plaster are affected a lot, so it notices a decrease in the load to a small level, as well as an increase in deflections due to the inability of the gypsum and plaster to resist the Elevated Temperature, as well as the occurrence of cracks in the outer surface of the concrete due to the heat, which helped it in the speed of failure.

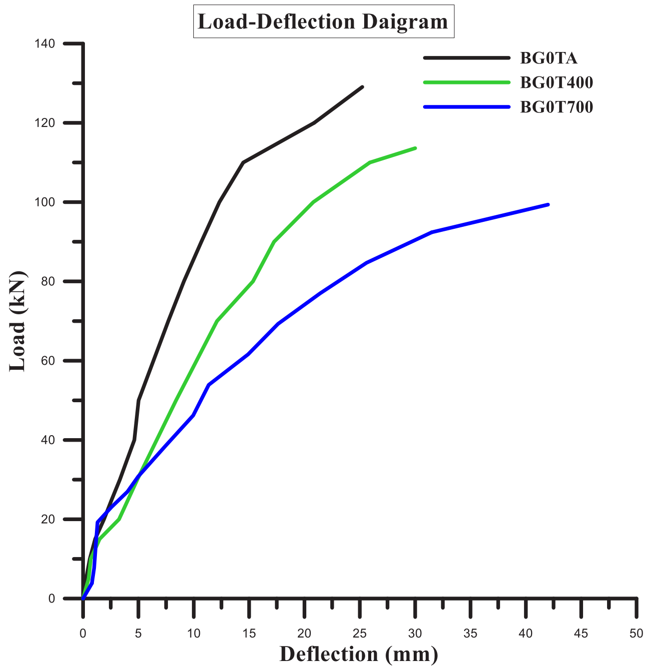

Figure 7. Load-deflection curve of group I.

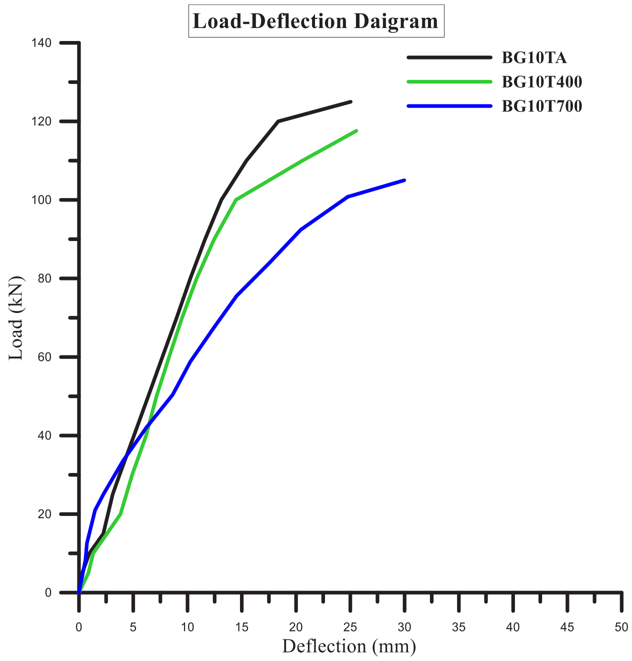

Figure 8. Load-deflection curve of group II.

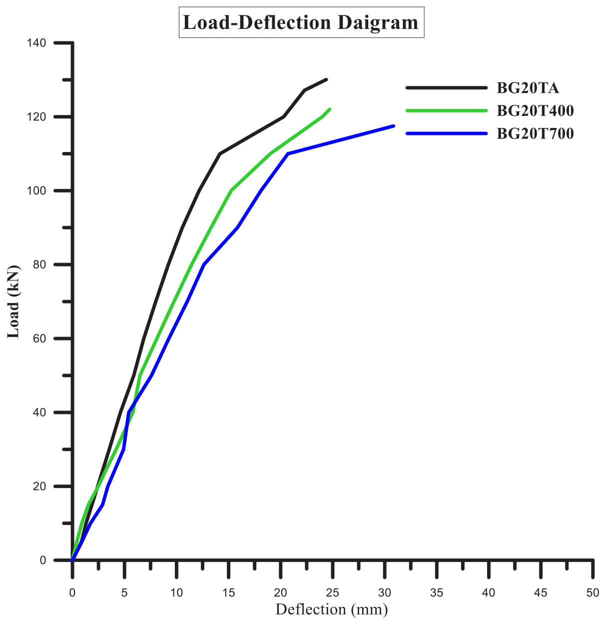

Figure 9. Load-deflection curve of group III.

Table 5 shows the value of load and corresponding deflection at the first visible crack and failure for all beams. For each gypsum thickness compared to its unburned specimen, it can be observed that increasing temperature led to a decrease in the ratio of residual value of loading. The residual results after exposure to 400 and 700°C temperatures noticed a clear difference in the results when the concrete was exposed at a temperature of 400 after covering the concrete using layers of gypsum of different thicknesses. At thickness 10 and 20 mm, the (P_{cr} and P_u) loss was about (8 and 6) % and (1 and 7) % respectively, compared to the concrete not covered with gypsum, The loss rate is about (25 and 13) %, and this is clear evidence of the benefit of gypsum in reducing the temperature directly to concrete. As for the temperature of 700, the reduction in (P_{cr} and P_u) was about (57 and 22) % and

(31 and 16) % and (10 and 15) % at 0, 10, and 20 mm gypsum thickness due to the gypsum's inability to withstand high temperatures. The low loading of concrete can be referred to as the increase in the quantity of micro cracks formation caused by exposure to fire, and the physical-chemical changes in concrete components during burning will result in loss of yield strength.

The comparisons are shown in Figures 10 to 12 exhibit the effect of the gypsum thickness on the load-deflection curves for the burned beams during the static load test. From these figures, as the thickness of the gypsum in the covering of the outer surface of the concrete decreases, the damage to the burden is reduced as it becomes a barrier to the arrival of heat directly to the concrete. In Figures 11 and 12, they notice an improvement in failure profile and ultimate load at thicknesses of 20 and 10 mm compared to the reference specimens not covered with gypsum and plaster.

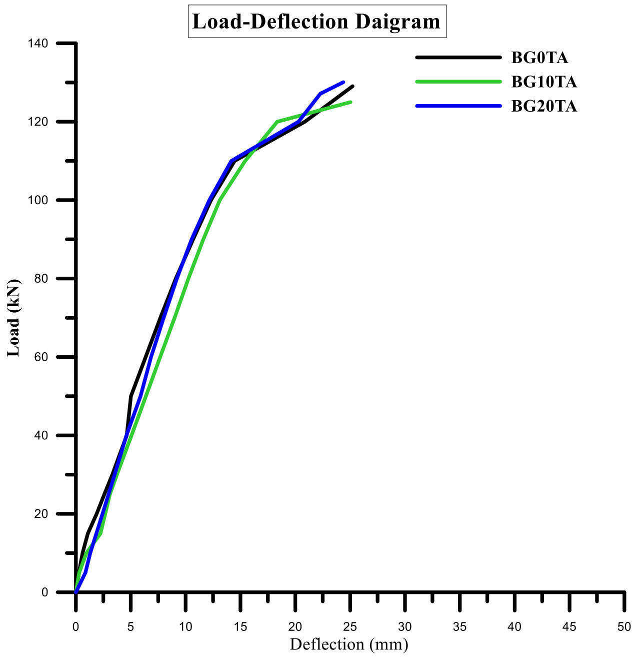

Figure 10. Load-deflection curve of group I.

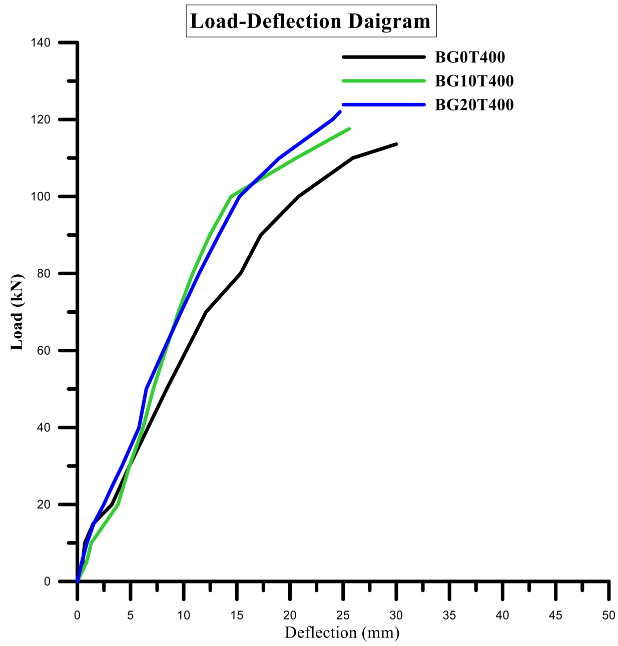

Figure 11. Load-deflection curve of group II.

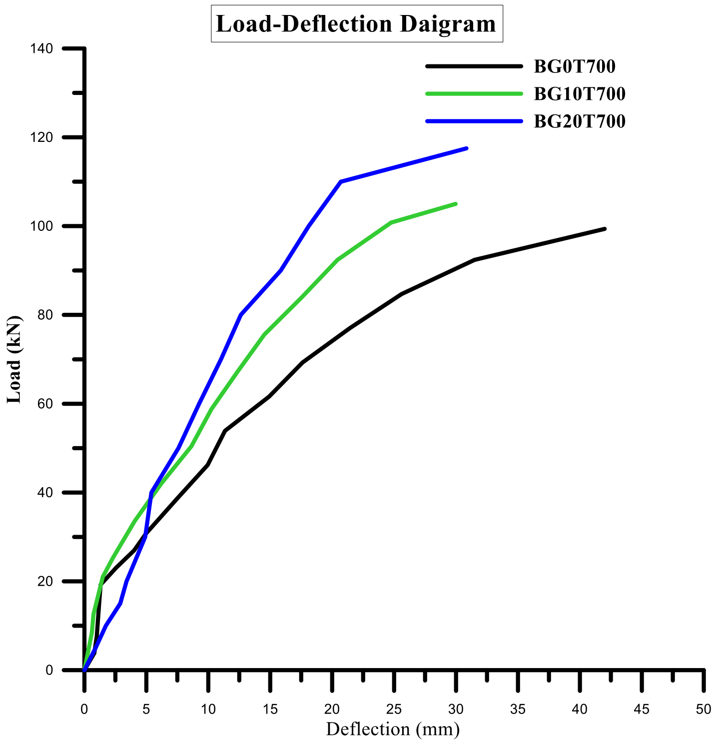

Figure 12. Load-deflection curve of group III.

Table 6. Cracking, ultimate load and the corresponding deflections for tested RC beams.

Group No.	Name of specimens	First crack loading (kN)	Residual of First crack loading (%)	Deflection at first crack loading (mm)	Ultimate loading (kN)	Residual Ultimate loading (%)	Deflection at ultimate loading (mm)
I	BG0TA	14.3	100	1.1	129.05	100	25.23
	BG0T400	10.8	75	0.7	113	87	30
	BG0T700	6.3	43	0.9	99.36	78	42
II	BG10TA	13.9	100	2.24	125	100	25.03
	BG10T400	12.8	92	1.4	117.6	94	25.56
	BG10T700	9.68	69	0.8	105	84	29.96
III	BG20TA	14.1	100	2.1	130.09	100	24.38
	BG20T400	14	99	1.53	122	93	24.7
	BG0T700	12	85	2.31	117.5	90	30.84

Conclusion

Through experimental results and comparison with previous studies, it is concluded:

- Increasing the thickness of the concrete surface with gypsum reduces the direct heat transfer to the concrete and reduces the loss of load capacity for the specimen. Through 400°C, at thickness 10 and 20 mm, the (P_{cr} and P_u) loss was about (8 and 6) % and (1 and 7) %, respectively, compared to the concrete not covered with gypsum. The loss rate is about (25 and 13) %. As for the temperature of 700, the reduction in (P_{cr} and P_u) was about (57 and 22) % and (31 and 16) % and (10 and 15) % at 0, 10, and 20 mm gypsum thickness.
- The figures showing the relationship between load and deflection noticed an increase in the deflections when increasing the temperature of the models. Through 400 °C, there is a difference between burned and unburned plaster and gypsum, and this difference decreases when the outer surface of the models is covered, as this difference decreases at 20 mm thickness of gypsum. As for at a temperature of 700°C, the deflections increase greatly due to the inability of plaster and gypsum to resist such a degree, but the gypsum remains important in protecting the outer surface of the models compared to those not covered with plaster and gypsum, so through the figures, it notices the improvement in the behavior of the drawing when covered with gypsum of the models.

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