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Rehabilitation of light-weight reinforced concrete ribbed slab exposed to fire using basalt textile reinforced mortar

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Abstract

By utilizing less concrete, the globe is currently heading toward sustainability, which reduces the weight of each unit. Furthermore, for design building, materials with a higher strength-to-weight ratio are required. Leading sustainability amenities include lightweight concrete (LWC) and ribbed slabs. To evaluate how Repairing a lightweight reinforced concrete ribbed slab that was exposed to fire and repaired by basalt textile-reinforced mortar (BTRM). This research created an experimental study. Five of the one-way ribbed slabs were made of light-weight concrete using (LAVA) aggregate. The usual fire curve (ASTM-E119) was followed when burning these slabs. After being exposed to fire for roughly (60 and 30) minutes. The slabs cooled using water and air and strengthened by basalt textile-reinforced mortar (BTRM) and again exposed to fire. After that, these slabs were tested under two-point loads. The results demonstrated that the use of light weight (LAVA) produced lightweight concrete (LWC), which had a density of (1985) kg/m3 and a cylinder compressive strength of (42.2) MPa.Slabs were burning then strengthened by basalt textile-reinforced mortar (BTRM) show a notable increase in load capacity and enhanced repaired slab performance.

Keyword: one-way ribbed Slab, lightweight Concrete, Basalt textile-reinforced mortar (BTRM), Standard Fire Curve.

1. INTRODUCTION

Because of its advantageous qualities, lightweight aggregate concrete (LWC) has been utilized for structural purposes for a long time. [1] The density of lightweight concrete (LWC) can be equally as significant in structural situations as its strength. The efficiency of structural design is increased when density is decreased without compromising strength because this lowers the dead load. Many studies and experimental examinations have been carried out to investigate different types of lightweight slabs under such conditions. The ribbed slab is one notable shape. Because they are more affordable than solid slabs, reinforced concrete ribbed slabs are becoming more and more popular in contemporary buildings. Ribbed slabs are suitable in sustainable building because they use less concrete, which lessens the environmental effect overall **[2].**

Numerous writers have examined the impact of lightweight aggregate (LWA) on the behavior of light weight concrete

Souza and colleagues (2014) **[3]** evaluated the contribution of shear stress by comparing slabs with and without ribs. It was discovered that flange depth has a major impact on ductility and shear resistance. **Abdul Rahman et al.** (2017) **[4]** evaluated steel-fiber reinforced ribbed slabs subjected to four-point bending. Greater load-bearing capacity was associated with thicker topping. Steel fibers enhanced energy absorption and crack behavior. **Du et al.** (2017) **[5]** studies on the tensile behavior of Basalt Textile Reinforced Concrete (TRC), focusing on textile layers, prestress levels, and short steel fibers found that the number of textile layers significantly influenced tensile properties. **Al-Rousan (2020) [6]** investigated the fire resistance of reinforced concrete one-way slabs using ANSYS. The fire endurance period could be doubled by using LWC instead of regular concrete. Experimental research on composite slabs of lightweight and normal-weight concrete under a standard time-temperature curve was carried out by **Coz-Díaz et al.** (2020) **[7].** For around half an hour, both slab types remained fire resistant without spalling.

Alzara et al. (2020) **[8]** examined reinforced foam concrete slabs in harsh environments using ANSYS. High temperatures resulted in a 25% decrease in load-bearing capacity, according to finite element research. **Kadhim and Mohammed (2022) [9]** tested high-strength lightweight concrete (HSLWC) ribbed slabs using pumice stone and sugar molasses (SM). Despite meeting performance requirements, HSLWC's ultimate strength was 17.70% less than that of traditional slabs. **Shamseldein (2022) [10]** implemented an experimental program to validate retrofitting reinforced concrete slabs using BTRM. Flexural strength improvements ranged from 177% to 266%, depending on the textile reinforcement used**. Shamseldein et al.** (2022) **[11]** investigated the tensile properties of BTRM, focusing on textile mesh size, plies number, and mortar type. Increasing the number of plies enhanced both ductility and ultimate tensile load.

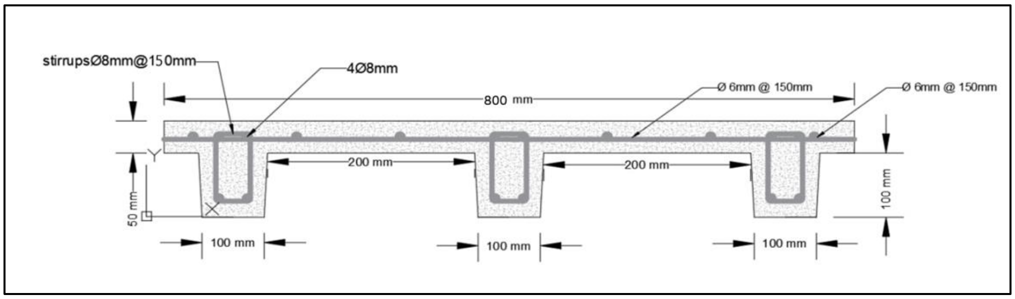
Despite the fact that various studies on the subject of lightweight concrete's fire resistance have been conducted. there are only a few studies available about rehabilitation with strengthening using the bssalt textile reinforced mortar ((BTRM) bssalt textiles were used in this work to creat a composite known as a basalt textile renforced mortar (BTRM), which has qualties similar to those of alkali-resistant glass fibers while being significantly less expensive than carbon or aramid fibers) **[12]** to enhanced the load capacity also,investigated the behavior the strengthened after exposed fire.

EXPERIMENTAL PROGRAM

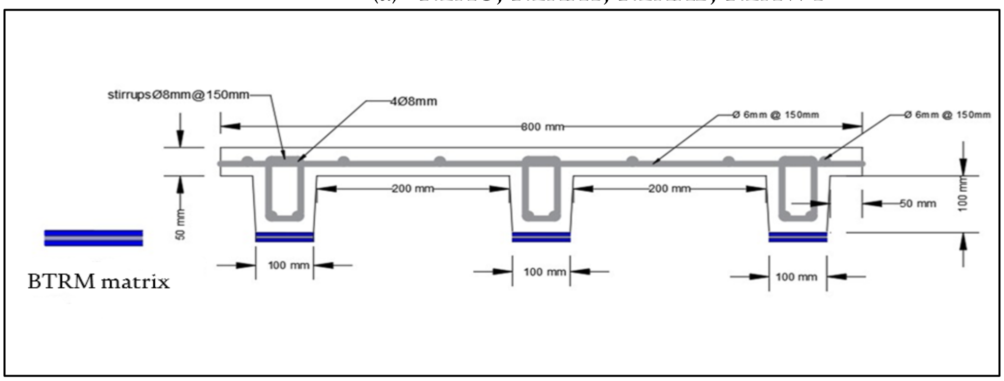
The experimental program methodology used in this investigation was as follows:
1-Preparing raw ingredients and testing them.
2. Performing numerous lightweight concrete trial mixes in order to determine the ideal mix proportion for lightweight concrete.
3. Getting the slab specimen molds ready.
4.Specimen casting: a-Control specimens: 150 x 150 mm cubes and 150 x 300 mm cylinders. b-Slab specimens (5 slabs with one way ribs)
5. The specimens are cured for 28 days.
6. In accordance with ASTM, the specimens were exposed to fire **[13].**
7. BTRM strengthened the sample of the two slabs.
8. Examining every specimen.

2.1. Details of Specimens and Materials

Studying the impacts of cooling time, ribbed slab repair by strengthening (BTRM), and behavior of the strengthened after burning were all part of the experimental program. Table 1 shows five specimens of slabs. The initiative involved casting and testing one-way ribbed slabs of reinforced concrete that were 1000 mm long, 800 mm wide, and 150 mm deep. Lightweight concrete (LWC) was used to cast these slab specimens. The ultimate technique to fail by flexure mode under the two-point load was used in the design of the one-way ribbed slab. All one-way ribbed slab specimens had the same amount of minimum shear reinforcement and minimum steel reinforcement in the flange. To satisfy the shrinkage and temperature reinforcement requirements, the flange was reinforced with square mesh (Ø6@150mm c/c in topping). Stirrups with a diameter of 7-Ø8@150mm c/c were incorporated into each rib to prevent shear failure. All slabs had a 25mm transparent cover at the bottom. Figure 1 displays the one-way ribbed slab sections' shape and steel reinforcing features.



(a) RLAC, RLAA1, RLAA2, RLAW1



(b) RLABT1, RLABT22(externally bonded)

Figure 1: Steel reinforcement and geometric sections details of one-way ribbed slabs

Table 1. Designation and details of the tested slabs

Slab symbol	Details of slab
RLAC	Ribbed slab LAVA control no fire
RLAW1	Ribbed slab LAVA under fire one hour cooled by water
RLAW2	Ribbed slab LAVA under fire half an hour cooled by water
RLABT1	Ribbed slab LAVA under fire one hour cooled by water and strengthening by basalt Textile reinforced mortar BTRM
RLABT22	Ribbed slab LAVA under fire for half an hour cooled by air and strengthened by BTRM and exposed to fire half an hour after strengthening cooled by water

*R:ribbed slab *LA: light weight aggregate (LAVA) *C:control slab without burning
*W:water (cooling by water) *1: one hour *2:half an hour
*B: basalt *T: textile reinforced mortar (TRM)

2.2 Properties of Materials

It was made using regular Portland cement (Karasta), which complies with EN179-1:2011[14]. All mixes contained a fine aggregate (sand), whose grading curve, as seen in Figure 2, complies with the restrictions of Iraqi specification No.45/1984 [15] zone 2. LWC was created using LWA (pumice stone LAVA), which has a dry density of 770 kg/m3. The pumice stone grading, which complies with ASTM C 330, is shown in Figure 3b [16]. HM 50x was utilized in this work as High Range Water Reducer /Superplasticizer Concrete Admixtures. It meets the requirement for SP according to ASTM C494/C494M-15a **[17]**. Lastly, all of the combinations used tap water.

The mechanical characteristics of all deformed steel bars utilized to reinforce all slab specimens that meet ASTM A496 [18] standards are displayed in Table 2. As seen in plate (1), formworks for all slab specimens were fabricated using steel molds that were 15 cm thick.

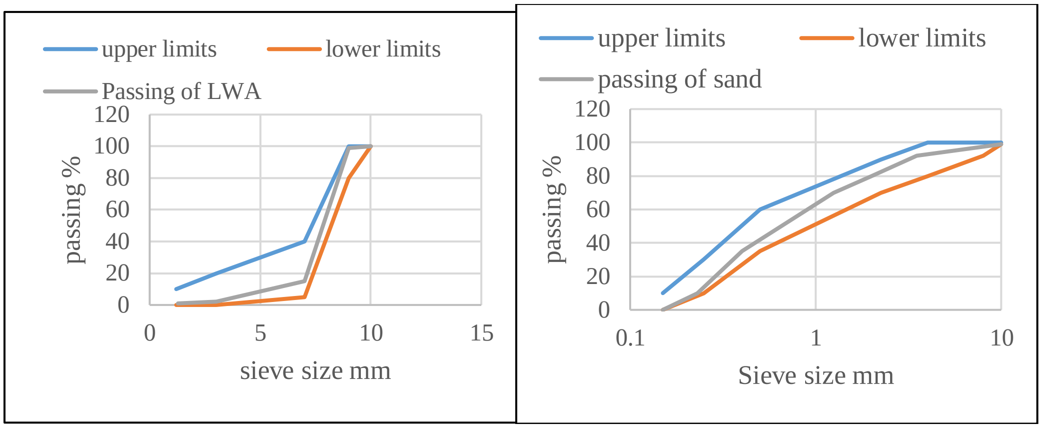


Figure (2): Grading curves for fine and LW aggregate

Plate (1): Steel mold formworks

Table 2. Mechanical properties of steel reinforcing bars

Bar Dia.	fy (MPa)	fu (MPa)
ϕ 6 mm	415	633
ϕ 8 mm	509	656

*fy: tensile yield
*fu: tensile ultimate

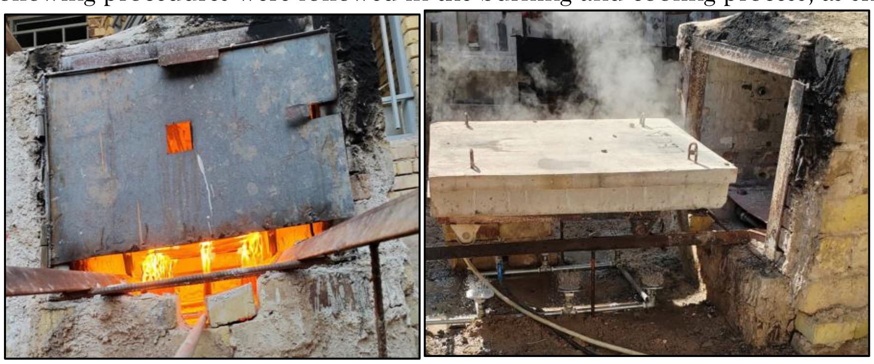
Multiple trial mixes were conducted to ensure the appropriate strength. the mix (light weight concrete), as shown in Table 3.

Table 3: Concrete Mix Proportions

Concrete Type	**Cement Kg**	**Sand Kg**	**Light aggregate Kg**	**Water Litter**	**Superplasticizer Litter**	**Compressive strength MPa**
LWC LAVA	475	520	695	128	5.4	42.2

1.3 Burning Procedures

The slab specimen was placed horizontally into the oven above iron supports using a railway to hold it gently. The slab specimen was positioned underneath the methane burner network, with a 15 cm space between the burner nozzles and the exposed slab surface. A plate cover was used to seal the opening. In accordance with the standard fire curve (ASTM E119), the burners started using an ignition tool, and the burning temperature was raised gradually every five minutes. To keep the gas flow at the appropriate temperature, an electrical gas regulator was used. The exposed surface of the slab specimen was used to detect the temperature using a thermocouple. Every five minutes, a thermometer was used to detect the concrete temperature at the slab specimens' unexposed surface. After being taken out of the oven, the slab specimens were left outside to cool gradually. The following procedures were followed in the burning and cooling process, as shown in plate (2):



a. Burning **b. cooled by water**

Plate (2): Burning and cooling in the air and water the slab specimens.

2.4 Strengthening by basalt textile reinforced mortar BTRM

Two specimens were strengthened with the basalt textile reinforced mortar (BTRM),

Basalt sheets with a mesh size of (5 × 5) mm (Plate 3) were used as additional longitudinal reinforcement (strengthening) of the slab ribs (Plate 4). The manufacturer's certificate for the physical properties of the basalt sheets includes Tensile Strength 810 (MPa) and Tensile Modulus of Elasticity 89 (GPa).

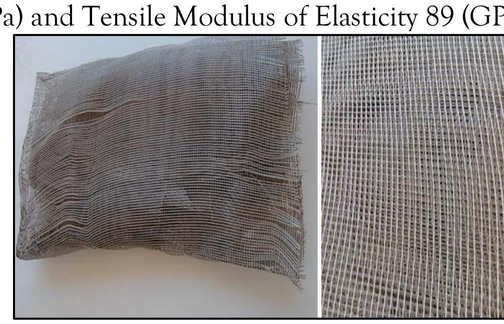


Plate (3): Basalt sheet Used in Current Study

The work steps were as follows: After grinding proses for the slabs scratching to make good bonding and put one layer of grout (TRM) and putting the one layer of sheet basalt mesh size
(5x5) mm and covered by the second layer of the grout (TRM) Plate (4) details the steps of installing sheet basalt on concrete slabs in one direction along the rib. It is cured by soaking it in water and leaving it for 28 days before undergoing examination. One of these specimens was exposed to burning again after strengthening for another 30 minutes.

a. scratching the surface   b. mortar layer applied over the mesh   c. specimens after cured

Plate (4): details the steps of installing external bond sheet basalt

2.5 Testing of Specimens

2.4.1 Instrumentation

The instrumentations used in the testing of specimens consisted of a desktop computer, the data logger, one LVDT (linear variable displacement transducer), load cell, and crack meter as shown in the plate (5). One (LVDTs) was installed under the slab to record the progression of mid-span during the test. The maximum load capacity of the load cell used in the tested specimens is (2000) kN.

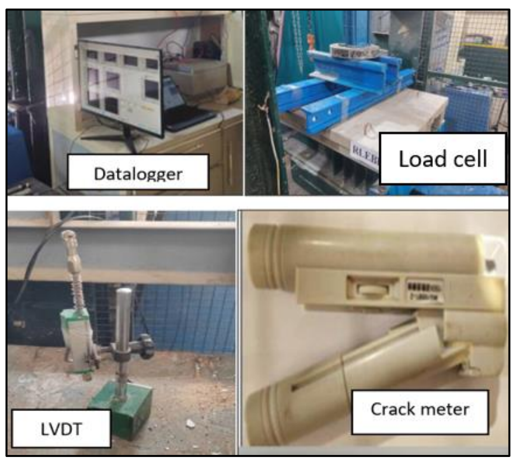


Plate (5): the instrumentations used in the test of the specimens

2.4.2 Method of Testing

The test slabs were placed on the test machine base and adjusted to place the support centerlines, the line-loading positions, and the single LVDT in the proper and selected places, as shown in plate (6). Load cells and LVDTs were connected to the data logger, which was connected to a desktop computer, in order to record all of the data that comes from them using a computer program (LAP-View 2018). The test began by applying an initial loading of 10 kN to the seat supports. Subsequently, loading increments of 5 kN were applied. Additionally, the appropriate measures were specified. The cracking breadth was measured after the first fracture appeared. Furthermore, when the loads grew, cracks developed between the mid-span and the supports. Until the slab specimens reached advanced loading stages and failed, loading was applied progressively. At each increase in load, the crack patterns were marked with a magic pencil.

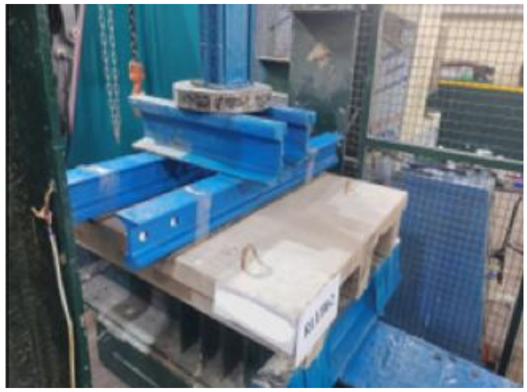
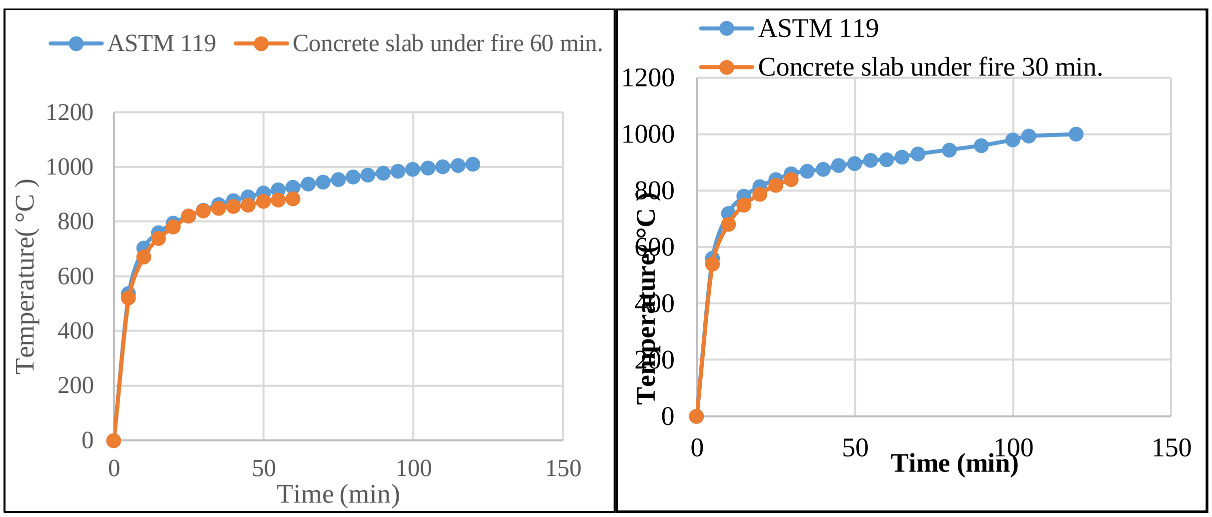


Plate (6): the load application mechanism

3. RESULTS AND DISCUSSION

The specimens' fire resistance was tested after a 28-day curing period. The temperature under the slab specimens increased quickly in the first five minutes shown in figure (3). Subsequently, the temperature was progressively raised to approximate the current standard (ASTM 119) fire curve temperature. An electronic thermometer was used to assess the temperature for cross-sectional structures. The sample (RLABT22) was burned for half an hour and cooled with air and was strengthened with the BTRM method and then exposed to burning again after strengthening for a second 30 minutes to know its maximum capacity and to study this behavior represented by the structure being exposed to fire that previously repaired and then exposed to burning again.



a. Burned 60 min. b. Burned 30min.

Figure (3): Time-Temperature curve of specimen (60 and 30 minutes)

3.1 Concrete Properties Results

Table 4 summarizes the results of mechanical properties for LWC LAVA.

Table 4. Mechanical properties of LWC concrete

Concrete Mix at 20C°	fcu (MPa)	fc` (MPa)	fr (MPa)	ft (MPa)	Density (kg/m^3)
LWC LAVA	42.2	34	2.5	2.33	1985

3.2 General Cracking Behavior

The following is an evaluation and discussion of the tested slabs' cracking performance: Three different stages of deformation were seen in all examined slab specimens that were exposed to the impacts of two-point stress. In the early phases of testing, prior to the initiation of the first crack, the deformations might be classified as elastic deformations. As shown in Table 5, a fracture formed in the tension face of the tested slabs when the applied force reached the first cracking load, which ranged from (0.17 to 0.35) of the ultimate loads. More flexural cracks began to show up at the tested slab specimens' tension face as the load rose, and they expanded horizontally from the mid-span to the support.

plate 7. summarizes the cracking outlines of all specimens. From this figure, in summary, lightweight concrete (LAVA) with two times (60 and 30) minutes were used to burn the specimens. When compared (RLAW1 with RLAW2) the first crack load decreased by (35) % respectively. Extended exposure to high temperatures for 60 minutes reduces the first crack load of concrete specimens compared to those burned for 30 minutes. This can be attributed to thermal degradation, internal stress, loss of moisture, and chemical changes within the concrete, which collectively weaken its load-bearing capacity. The lightweight concrete LAVA (RLABT1 and RLAC) were compared with (RLAW1) the percentage of load-first crack increased by (207 and 130) % respectively. According to experimental results, the BTRM approach significantly affected the ribbed slabs' structural capacity and improved the cracking load. Lightweight LAVA specimens were burned for half an hour. The specimens were reinforced with BTRM following burning. After then, it was left to burn for an additional half hour. Comparing the RLABT22 to the RLAW1, the load-first crack increased by (92) %. This behavior shows that although the BTRM reinforcement was burned, it improved the cracking load.

Table 5: Ultimate and cracking capacity for test specimens

Slab specimen	P_{cr} (KN)	P_u (KN)	Ultimate vertical mid-slab deflection-δu (mm)
RLAC	30	106	25
RLAW1	13	76	15
RLAW2	20	90	20
RLABT1	40	113	35
RLABT22	25	94.5	30

Plate 7: Cracking patterns for all tested slab specimens

3.3. Load–Deflection Curve

Figure 4 displays the load-deflection curves for every slab specimen that was evaluated.

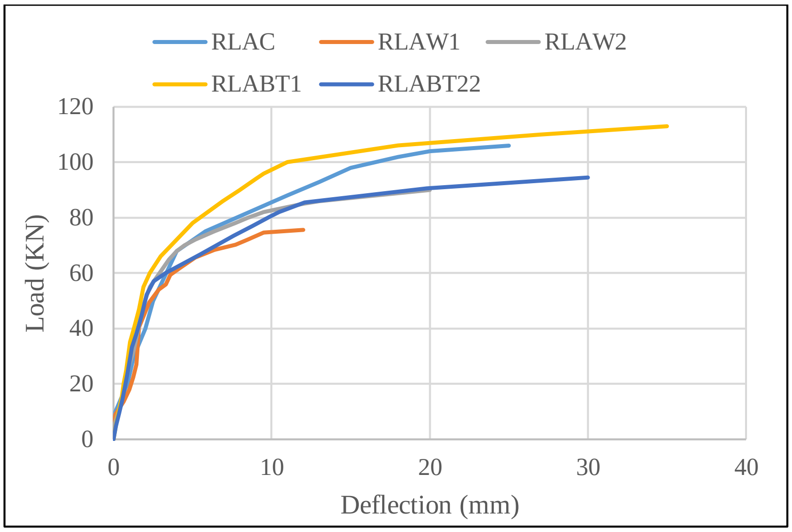


Figure 4: Load–deflection curve for tested slab specimens

This figure revealed that the load-deflection response in all slabs manifested in three distinct stages: the plastic stage behavior, the elastic-plastic stage, and the elastic stage.

For lightweight concrete types (LAVA), the slabs were burned at two different times (60 and 30 minutes). The highest load decreased by (15.5) %, while the deflection dropped by (33) % compared (RLAW1 with RLAW2), results showed that the Concrete specimens exposed to high temperatures for 60 minutes had a lower load and max deflection than those burned for 30 minutes.

The lightweight concrete LAVA (RLABT1 and RLAC) were compared with (RLAW1) the percentage of ultimate load (48.6 and 39.5) % and deflection increased by (133 and 67) % respectively. Experimental results showed that the BTRM technique improved the cracking load and had a substantial impact on the structural capacity of the ribbed slabs.

For 30 minutes, lightweight LAVA specimens were burnt. After burning, BTRM was used to strengthen the specimens. It was then allowed to burn for another half hour. The RLABT22 ultimate load and deflection increased by (24.3 and 100) % when compared to the RLAW1. This behavior demonstrates that the BTRM reinforcement increased the ultimate load despite being burned.

4.CONCLUSIONS

Based on this study's experimental findings, it can be said that:

1- Lightweight concrete (LAVA aggregate) has a reduced density of 1985 m^3/kg and a compressive strength of 42.2 MPa.

2- According to the study, for lightweight concrete type (LAVA), the slabs were burned at two different times (60 and 30 minutes). The highest load decreased by (15.5) %, while the deflection dropped by (33) %. Concrete loses cohesiveness and strength after 60 minutes of burning because of internal fissures caused by unequal expansion and contraction. As a result, longer burning times result in a greater decrease in ultimate load and deflection than shorter ones.

3- Lightweight concretes slab exposure to fire and strengthened by BTRM and light weight concrete slab without exposure to fire exhibited greater deflection (133% and 67%) and maximum load percentages (48.6% and 39.5%) compared with light weight concrete slab were burned at 60 minutes and cooled by water. The ribbed slabs' structural load capacity was greatly increased by BTRM technology.

4- increased the ultimate load by 24.3% and the deflection increased by 100% when comparing the lightweight concrete slab that was burned at 60 minutes and cooled by water with the slab was burned for 30 minutes, strengthened with BTRM, and then burned for another 30 minutes. These findings show that even after extended heat exposure, BTRM considerably improved the concrete's flexibility and load-bearing capacity. This emphasizes how crucial it is to strength concrete structures in order to improve their performance under heat stress. Also, heat transport via basalt fibers decreases due to their low thermal conductivity. Thus, BTRM-reinforced concrete structures are less prone to undergo thermal deformation, preserving the structure's integrity both during and after exposure to high temperatures.

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