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Effect Of Light-Weight Concrete On The Behavior Of Reinforced Concrete One-Way Ribbed Slabs Under Fire

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Abstract
The globe is currently working towards sustainability by reducing the amount of concrete, thereby reducing the total unit weight. Additionally, materials with a higher strength-to-weight ratio are needed for design construction. Leading sustainability amenities include lightweight concrete (LWC) and ribbed slabs. In order to assess how concrete type and slab type affect the structural behavior of one-way ribbed slabs, this research created an experimental study. Lightweight concrete (LECA and LAVA) was used to build eight one-way slabs, and three slabs was constructed using gravel. These slabs were burned in accordance with the standard fire curve (ASTM-E119). The slabs were exposed to fire for about time (60) minutes and cooled by (water and air), these slabs were tested under two-point load and simply supported until failure. The results showed that using light weight (LECA and LAVA) instead of gravel led to lightweight concrete (LWC), with a cylinder compressive strength of (38 to 42.2) MPa and a density of (1786to 1985) kg/m^3. Using LWC instead of normal-weight concrete (NWC) decreased the unit weight by (32.7 and 19.4) %.
Keyword: *one-way ribbed Slab, lightweight Concrete, Standard Fire Curve.*

1. Introduction

Light weight aggregate concrete (LWC) has long been used for structural applications due to its favorable properties **[1]**. In structural contexts, the density of lightweight concrete (LWC) can be just as important as its strength. Reducing the density without sacrificing strength decreases the dead load, thus enhancing the efficiency of structural design. To explore various forms of lightweight slabs under such parameters, numerous studies and experimental investigations have been conducted. One prominent form is the ribbed slab. The use of reinforced concrete ribbed slabs is increasingly common in modern construction as a substitute for solid slabs, primarily for their cost-effectiveness. An advantage of ribbed slabs is their role in sustainable construction, as they require less concrete, thereby reducing overall environmental impact **[2].**

Numerous writers have examined how lightweight aggregate (LWA) affects the behavior of one-way slabs; Abdul Rahman et al. (2017) [3] assessed ribbed slabs reinforced with steel fibers under four-point bending. Thicker topping correlated with greater load-bearing capacity. Steel fibers improved crack behaviors and energy absorption. Adil and Abdul Razzaq (2017) [4], Adheem et al. (2018) [5], Jomaa'h et al. (2018) [6], and Babu and Rex (2019) [7]. However, normal-strength concrete (NSC) and one-way solid slabs have frequently been the subject of these research. Coz-Díaz et al. (2020) [8] conducted an experimental study on composite slabs of lightweight and normal-weight concrete under standard time-temperature curve. Both slab types-maintained fire resistance for about 30 minutes without spalling. Mohammed and Kadhim (2022) [9] conducted tests on ribbed slabs with high-strength lightweight concrete (HSLWC) using sugar molasses (SM) and pumice stone. HSLWC met performance standards but had 17.70% lower ultimate strength than conventional slabs.

The majority of research on lightweight aggregate concrete (LWAC) focuses on several types of aggregates, such as recycled, natural, and industrial wastes. Not much is known about using natural lightweight aggregates

(LECA, LAVA) in place of gravel. Actions under fire to analyze the performance of solid slabs under fire. Research on one-way ribbed slabs of LWC exposed to fire is lacking. Examine how LWC one-way ribbed slabs react to fire and the effects of the extinguishing procedure.

2. Experimental Program

The following experimental program was used in this study:

1- Raw material preparation and testing.

2- To determine the ideal mix proportion for lightweight concrete, numerous trial mixes of the material are being conducted.

3- Mold preparation for slab specimens.

4-Casting of specimens:

a-Control specimens [cubes (150 * 150) mm, cylinders (150 × 300) mm.

b-Slab specimens (8 one way ribbed slab and 3 solid slabs)

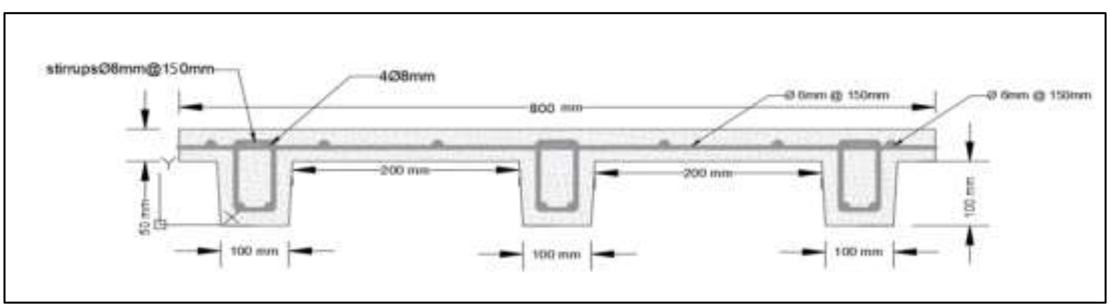
5- The specimens are cured for 28 days.

6-Exposed the specimens to the fire according to the ASTM **[10]**

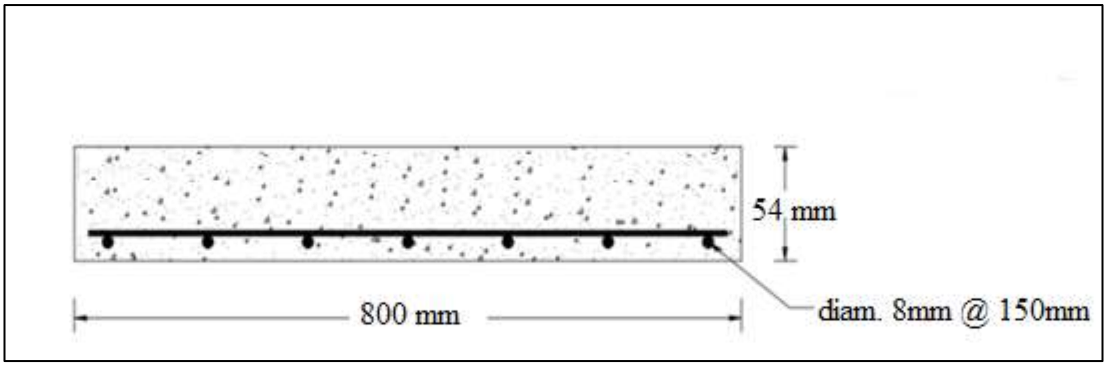
7- Examining each specimen.

2.1. Details of Specimens and Materials

One aspect of the experimental program was examining the impact of the concrete type, slab type and type of cooling. Table 1 shows the examples of eleven slabs. Eight reinforced concrete one-way ribbed slabs with dimensions were cast and tested as part of the program. (1000 mm length,800 mm width, and 150 mm rib depth) and three solid slabs have the same overall dimensions as above but with slab thickness equal 54mm. These slab specimens was casted with lightweight concrete (LWC) and others with normal weight concrete (NWC). The ultimate technique to fail by flexure mode under the two-point load was used in the design of the one-way reinforced concrete 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). To avoid the occurrence of shear failure, (7-Ø8@150mm c/c) mm diameter stirrups were provided in each rib.For solid slabs the reinforcement of (h=54mm, Ø8@150mm c/c bottom). The clear cover at the bottom was 25mm for all slabs. The geometry and steel reinforcement details of the solid and one-way ribbed slabs sections are shown in Figure 1.



(a) Typical adopted one-way ribbed slab (RLEC, RLEA1, RLEW1, RLAC, RLAA1, RLAW1, RNC and RNB)



(b) Typical adopted one-way solid slab (NCS, LES and LAS)

Figure (1): Steel reinforcement and geometric sections details of specimens

Table 1: Designation and details of the tested slabs

Slab symbol	Details of slab **Ribbed slabs**
RLEC	Ribbed slab LECA control no fire
RLEA1	Ribbed slab LECA under fire one hour cooled by air
RLEW1	Ribbed slab LECA under fire one hour cooled by water
RLAC	Ribbed slab LAVA control no fire
RLAA1	Ribbed slab LAVA under fire one hour cooled by air
RLAW1	Ribbed slab LAVA under fire one hour cooled by water
RNC	Ribbed slab normal concrete no fire
RNB	Ribbed slab normal concrete under fire one hour
Solid slabs	
NCS	Normal weight concrete solid slab no fire
LES	LECA solid slab no fire
LAS	LAVA solid slab no fire

2.2 Properties of Materials

Portland cement (Karasta) is sourced from the local market. Conducted at the Materials Laboratory, Kufa University. Standards Compliance Verified according to EN 197-1[11] and IQS No. 5/2019 **[12].** Fine Aggregate (Sand) Natural fine aggregate. Grading: Zone 2 specifications according to IQS No. 45/1984 **[13]**. Analysis: Sieve analysis results are presented in Figure (2).

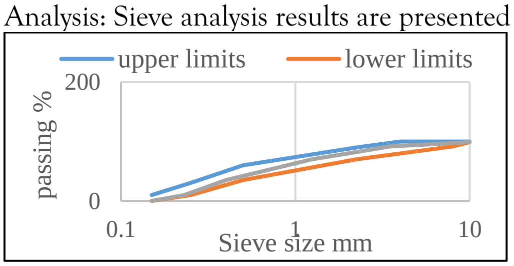
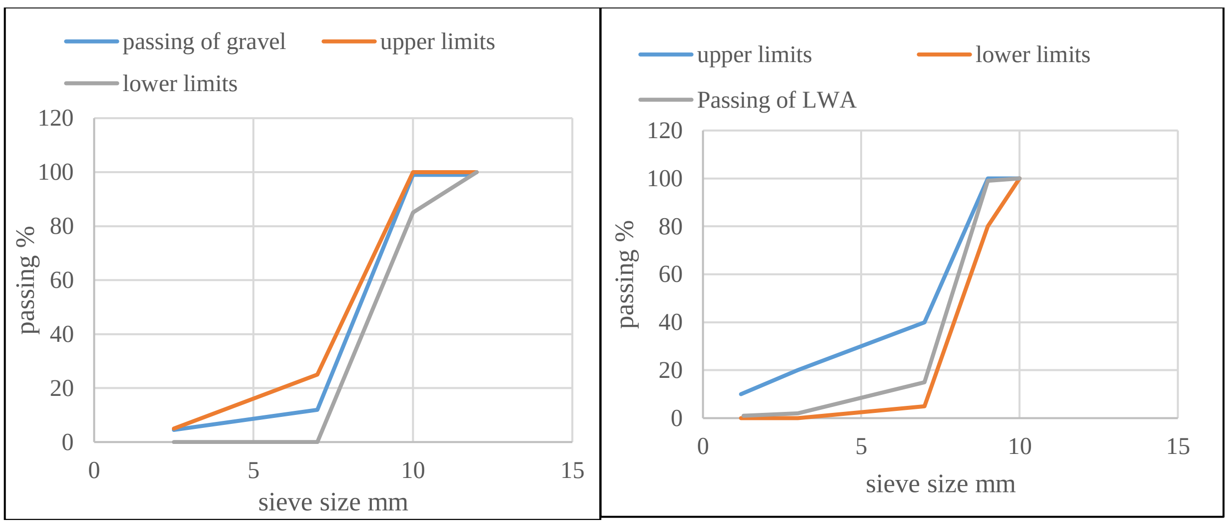


Figure (2): Sieve Analysis of Fine Aggregate (sand)

Two types of coarse aggregate were employed: Normal-Weight Coarse Aggregate (Gravel) Locally sourced gravel. Maximum Size 10 mm. Conforming to IQS No. 45/1984 **[13].** Lightweight coarse aggregate natural volcanic rock sourced from the Iraq-Iran-Turkey border region, including LAVA and LECA. LAVA (Pumice rocks): Formed by volcanic activity. Low specific gravity, lightweight, high porosity, and high rate of water absorption. LECA (Lightweight Expanded Clay Aggregate) is made from fine organic matter-containing expandable clays. Processed in a rotary kiln at temperatures above 1200 °C. Resulting product is highly porous with a sintered shell on the surface. Maximum Size 10 mm. Characteristics Low density, high porosity, and high silica content (SiO_2). Grading curves shown in Figure (3). Tap water was used for both the mixing and curing processes. The superplasticizer used in this study was HM 50x, classified as a high-range water reducer and compliant with ASTM C494/C494M-15a **[14]**. One wood and two steel molds of various geometries were fabricated for casting. The mechanical characteristics of every deformed steel bar utilized to reinforce every slab specimen that complies with ASTM A496**[15]** are displayed in Table 2. Plate (1) plywood and steel formworks.



(a) Sieve analysis curve of gravel

(b) Sieve analysis curve of LWA for both types (LECA and LAVA)

Figure (3): Adopted Grading of (NWA and LWC)

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

a. for ribbed slab b. for solid slab

Plate (1): Plywood and steel formworks

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

Table 3: Concrete Mix Proportions

Concrete Type	Cement Kg	Sand Kg	Aggregate Kg	Water Litter	Superplasticizer Litter	Compressive strength
LWC LECA	475	675	500	100	4.5	38.8
LWC LAVA	475	520	695	128	5.4	40.2
NWC	420	780	1050	110	5	40

2.3 Burning Procedures

A railway was used to gently hold the slab specimen, positioning it horizontally inside the oven above iron supports. The methane burner network was placed beneath the slab specimen with a 15 cm gap between the slab's exposed surface and the burner nozzles. The aperture was sealed with a plate cover. The burners were ignited with an ignition tool, and the burning temperature increased progressively every five minutes, following the standard fire curve (ASTM E119) **[25].** The electrical gas regulator controlled the gas flow to maintain the desired temperature. A thermocouple measured the temperature at the slab specimen's exposed surface. The concrete temperature at the unexposed surface of the slab specimens was measured every five minutes using a thermometer. The gas valve was shut off after the burning process was complete. The slab specimens were removed from the oven and allowed them to cool gradually in the open. The burning and cooling procedure. (either by air or by water) as illustrated in plate (2):

a.

Burning **b. cooled by air (c)** **c. cooled by water**

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

2.4 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 (3).one (LVDTs) were 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 (3): the instrumentations used in the test of the specimens

2.4.2 Method of Testing

As indicated in plate (4), the tested slabs were positioned above the test machine base and adjusted to set the one LVDT, the line-loading positions, and the support centerlines in their appropriate and chosen locations. In order to capture all of the data that comes from them using a computer program, load cell, and LVDT were linked to the data logger, which was connected to a desktop computer (LAP-View 2018). At first, the test started with the initial loading of (10) kN to seat supports, loading increments of 5 kN were then applied. Following the emergence of the initial fracture, the cracking breadth was measured. Additionally, cracks appeared between the mid-span and the supports as the stresses increased. Loading was applied gradually until the slab specimens failed when they reached advanced loading stages. Deflection rapidly increased when the load indicator ceased recording new loading values or turned back on. A magic pencil was used to mark the patterns of cracks at each load increase.

Plate (4): the load application mechanism

3.Results and Discussion

3.1 Temperature Progression of specimens

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 (4). 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.

More carrying capacity is carried out by the LWC (LAVA) than by the LWC (LECA) in that regard. More porosity in the LWC (LAVA) because it increases voids, which causes water to be absorbed. A series of complex physical and chemical variables cause strength to decline. Where voids inside the aggregate form, the material volcanic coarse aggregate fails. Consequently, the compressive strength decreases as the pumice amount increases. When the behavior of LWC LECA and LWC LAVA is compared, it can be seen that both forms of concrete affected by temperature increases similarly.

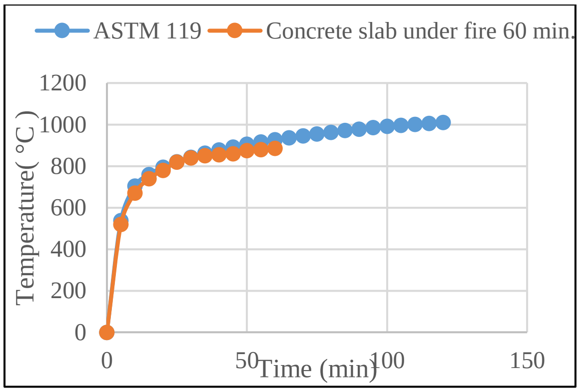


Figure (4): Time-Temperature curve of specimen (60 minutes)

3.2 Concrete Properties Results

The mechanical property data for both LWC and NWC mixes are summarized in Table 4. These findings demonstrate that employing LWC rather than NWC reduced fcu, fc`, fr, and ft by ((13.6 and 4), (14.77 and 3.4), (34) for both types of LWC and (34.2 to 31.8)) %, compared (LECA and LAVA) with NWC respectively, because of the porous nature of LWA that weakens the aggregate. Moreover, using LWA decreased the values of density w_c by about (24.6 and16.2) % for LECA and LAVA concrete respectively.

Table 4. Mechanical properties of concrete mixes

Concrete Mix at 20C°	fcu (MPa)	fc` (MPa)	fr (MPa)	ft (MPa)	w_c (kg/m^3)
LWC LECA	38	29	2.5	2.25	1786
LWC LAVA	42.2	34	2.5	2.33	1985
NWC	44	36	3.8	3.42	2370

3.3 General Cracking Behavior

All studied slab specimens exposed to the impacts of two-point loading showed three unique stages of deformation, which is used to evaluate and discuss the cracking performance of the slabs. In the early phases of testing, prior to the initiation of the first crack, the deformations might be classified as elastic deformations. As indicated in Table 5, the fracture developed in the tension face of the tested slabs when the applied load reached the first cracking load, which varied between (14 and 36) % of the ultimate loads. As the load rose, more flexural cracks started to form at the tension face of the tested slab specimens and extended horizontally from the mid-span to the support.

The elastic-plastic stage is represented by this stage. The number and width of cracks thereafter grew and traveled upward to the flange of the one-way ribbed slab specimens and to the compression zone in the one-way solid slab specimens. Ultimately, when the load magnitude increased, the slab specimens' stiffness decreased further (plastic stage), which was followed by failure. One could describe the slab specimen's collapse as a flexural failure.

plate 5. summarizes the cracking outlines of all specimens. From this figure, in summary, converting the slab type from solid (NCS, LES, LAS) to ribbed (RNC, RLEC, RLAC) resulted in a decrease in the first crack loading capacity by (57, 60 and 66) % respectively. This reduction is attributed to the high moment of inertia present in one-way ribbed slabs compared to one-way solid slabs with the same depth.

The effect of concrete types of concrete with NWA and LWA on the first crack load of one–way ribbed slabs will be discussed. The slabs were not exposed to fire, using lightweight concrete (LWC) RLEC and RLAC led to reduction in the first crack load compared to slabs with normal weight Concrete (NWC) RNC by a (28.5 and 14.3) % respectively. compared with slab RNC. When the slabs were exposed to fire for 60 minutes and then air-cooled, which was presented by RLEA1 and RLAA1 led to a (50) % for both slabs reduction in the first crack load compared to ribbed slab NWC (RNB) under the same conditions. Using NWC increased the cracking loading capacity more than LWC because of the concrete's enhanced mechanical qualities, such as its tensile strength and elastic modulus. due to the aggregate's mechanical characteristics and composition.

For cooling the lightweight concrete (LECA and LAVA) with two distinct kinds, two cooling techniques were applied: air cooling and water cooling. When comparing slab specimens that were burned and immediately cooled by sprinkler water to those that were burned and cooled gradually in the air (RLEA1 with RLEW1) and (RLAA1 with RLAW1)), the first crack load increased by (25 and 15.3) % respectively. These results significantly influenced the durability of lightweight concrete cooled by sprinkler water.

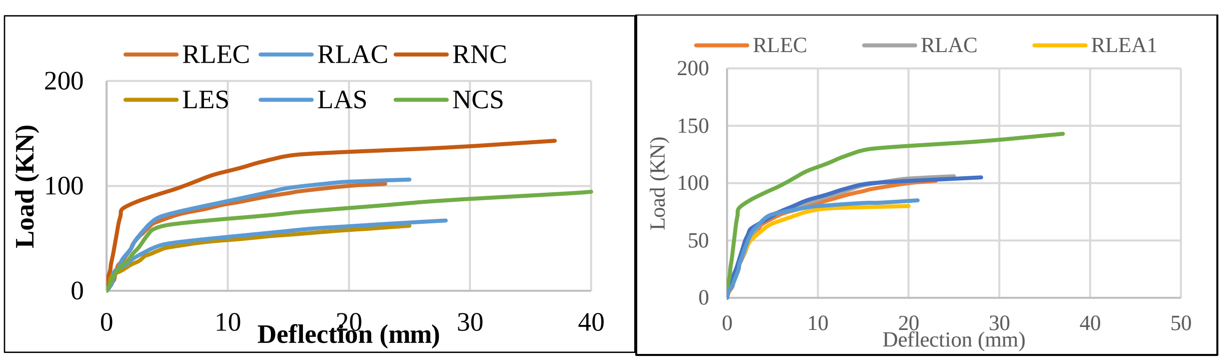
Table 5: Ultimate and cracking capacity for test specimens

Slab specimen	**P_{cr} (KN)**	**P_u (KN)**	**Ultimate vertical mid-slab deflection-δu (mm)**
RLEC	25	102	23
RLEA1	15	80	20
RLEW1	12	70	14
RLAC	30	106	25
RLAA1	15	85	21
RLAW1	35	76	15
RNC	35	143	37
RNB	30	105	28
NCS	15	94.4	40
LES	10	62	25
LAS	10	67	28

Plate (5): Cracking patterns for all tested slab specimens

3.4 Load–Deflection Curve

Figure 5 displays the load-deflection curves for each tested slab specimen.



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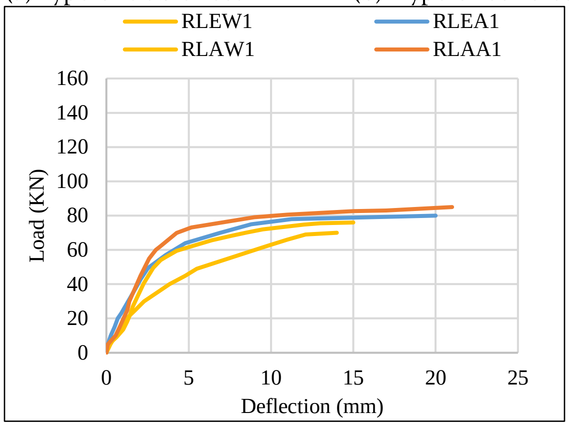
(a)Type of slab effect (b) Type of concrete



(c) cooling type

Figure (5): Load–deflection curve for tested slab specimens

Using one–way ribbed slab (RNC, RLEC and RLAC) instead of solid slab (NCS, LES and LAS) led to increase the ultimate capacity by (51.4, 64.5 and 58) % in comparison to solid slabs (NCS, LES and LAS) respectively. On the other hand, when comparing the type of lightweight concrete (RLAC with RLEC) it led to an increase in the ultimate load capacity and deflection by (4 and 8.7) %. Also, the amount of steel reinforcement ratio played in changing the deflection of solid slab specimens. This behavior is because of the reduction of the moment of inertia and internal moment capacity

Using one-way ribbed slabs with lightweight concrete (RLEC and RLAC) resulted in a (28.6 and 25.8) % decrease in ultimate load and a (37.8 and 32.4) % decrease in deflection compared to RNC ribbed slab (NWC) respectively. For slabs using lightweight concrete (RLEA1 and RLAA1) burned at 60 minutes and cooled by air, the load capacity decreased by (23.8 and 19) % and deflection by (28.5 and 25) % compared to RNB burned and cooled by the same conditions respectively.
Using lightweight concrete (LECA and LAVA) with two different cooling methods—air cooling and water cooling—produced notable differences in slab performance. For slabs burned and gradually cooled in the air (RLEA1 and RLAA1) compared to those immediately cooled by sprinkler water (RLEW1 and RLAW1), the ultimate load increased by approximately (14.3 and 11.8) %, respectively, and the deflection increased by (43 and 28.5) %, respectively. These effects are attributed to thermal shock, which causes internal fractures due to differing surface and internal temperatures of the specimens. The durability of lightweight concrete that was cooled by sprinkler water was greatly impacted by these findings.

4.Conclusions

Through the experimental results of this study, it can be concluded that:

1- Comparing the two lightweight concrete varieties, LECA and LAVA, it was discovered that the latter provides a higher density of about 11% and a higher strength of about 11 %.
2- When lightweight concrete types RLAC and RLEC were compared, the ultimate load increased by 1.3% and the deflection increased by 5%. The modulus of elasticity varies throughout concrete kinds, which is the reason for these discrepancies. LAVA lightweight concrete's denser and more durable matrix allowed it to perform better and support more weight than LECA.
3- The ultimate capacity is generally increased by using a one-way ribbed rather than solid slabs by (51.4, 64.5 and 58) %.

4- The ultimate load and deflection were decreased by (28.6, 25.8) % and (37.8 and 32.4) % respectively, when using lightweight concrete (LWC) instead of normal weight concrete (NWC) slabs, in one-way ribbed slabs. On the other hand, the ultimate load and deflection were decreased by (23.8 and 25) % and (28.5 and 19) % respectively, when comparison ribbed slab normal weight burning with slabs that were air-cooled and burnt for 60 minutes.
5- The ultimate load and deflection increased by roughly (14.3 and 11.8) % and (28.5 and 43) % respectively, when slabs that were burned and cooled gradually in the air and those that were cooled instantly by sprinkler water

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