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Behavior of One Way Foamed Concrete Slabs Using Different Types of Reinforcement

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Abstract

This research included a study of the behavior of lightweight foam concrete and a study of the effect of adding lightweight aggregate (LECA) to some groups. The program also included an examination of the behavior of foam concrete for one-way slabs with and without adding LECA aggregate in different proportions and with two types of reinforcement (normal and GFRP).

This study aimed to Investigate the behavior of lightweight one-way foam concrete slabs reinforced with two types of reinforcement (Normal reinforcement and GFRP), performing an experimental investigation to produce lightweight foamed concrete and Investigate the effect of additional of LECA to improve the mechanical properties of LWFC.

Light-weight foam concrete was produced with compressive strength 35.2MPa and dry density 1830Kg/m3, and then adding LECA content to the fresh mixture (LWFC).The results were compared between the two mixtures (containing LECA aggregates and without LECA aggregates) to determine the effect of LECA on improving the mechanical properties of LWFC ,where was compressive strength 42MPa and dry density 1885 Kg/m3 at 28 days ,and note that the mechanical properties of LWFC with LECA achieved higher results for mechanical properties such as compressive strength, splitting strength, modulus of elasticity, and modulus of rupture increased by 16.19%,11.8%, 27.93%, and 29.7%, respectively ,and the flowability of the lightweight foamed concrete reduced by 25% compared to lightweight foam concrete without LECA. the results showed that ultimate load increases for the slabs that has the highest reinforcement ratio (ρmax.) and gradually decreases for the slabs that has an average (ρavg.) and minimum (ρmin.) reinforcement ratio, respectively. On the other hand, as the ratio of reinforcement increases, deflection decreases, and vice versa

also, presence of LECA also increased the ultimate load rate more than the slabs that did not contain LECA.

Keywords: *Reinforced concrete slab; Flexural behavior; Lightweight foamed concrete.*

1 Introduction

The foam concrete is the air-void based concrete in the mortar assisted by agent to support sustainability. In addition to its lightweight property, the foam concrete is considered the best concrete type to fire resistance (Ramamurthy et al., 2009). However, the low compressive strength and higher fluidity were observed. The production of lightweight concrete is affected by the material composition and the methods of

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production. The air voids comprise between the range of 10-90% of the total hardened specimen

Meanwhile, the most common properties of foam concrete according to the state of the foam concrete, the fresh condition which is divided into consistency mostly affected by water content and it is measured by Marsh cone, stability which is the spread property and workability which is also the water cement-ratio dependent. On the other hand, the physical properties such as the air-voids ratio which is mainly the air-voids distribution within the concrete, and density which includes fresh and harden foam concrete condition as well as the foaming agent

The lightweight concrete (LWC) could be classified due to its types to lightweight aggregate concrete (LWAC) and foam concrete (FC). Also, it could be classified due to its density and strength to structural lightweight concrete, medium-strength lightweight concrete, low-density lightweight concrete, and ultra-lightweight concrete.

This research focuses on foam concrete. Foamed concrete is a light cellular concrete with random air-voids created by a foam agent mixture in mortar. It is classified as a lightweight concrete (density 400-1850 kg/m3). Foamed concrete has a high flowability, a low cement content, and a low aggregate usage. (K. Ramamurthy et al.2009, P.J. Tikalsky et al.2004), [H. Weigler et al.1980, S. Kolias et al.2005], as well as its excellent thermal insulation.

Foam concrete classified to two major types mechanical foaming and chemical foaming. By using foaming agent and high-pressure foam generator in its construction, it called pre-foaming. Although, it called mix- foaming by using air-entraining agent and high-shear mixing (Neville and Brooks,2010; Slaby, Aziz and Hadeed ,2008; Newman and Choo,2003

2 Experimental methodology

The main goal of this experimental study is to understand how lightweight foamed concrete responds to additives and compare it to foamed concrete with LECA. It also aims to investigate the behavior of lightweight one-way foamed concrete slabs reinforced with two types of reinforcement (Normal reinforcement and Glass fiber) using various values of reinforcement ratios. The experimental work for this study is divided into two parts

2.1 Materials

• Materials used in this experimental work.

• Ordinary Portland Cement (Maas) conforming to Iraq standard specification No. 45-1984[18].

• Silica Sand Fine silica sand is used as fine aggregate provided by BASF company, which is based in the Iraqi province of Baghdad

• The lightweight aggregate manufactured in Tehran was used with gradations 0–8 mm, which conforms to the specifications and standards (ASTM Standards C 330–04) [20].

• Tap water for aggregate washing, concrete mixing, and curing of specimens.

• Silica Fume A powdered micro-silica concrete admixture, BASF company MasterRco MS 610, comprises very small SiO_2 particles.

• Superplasticizers (Mega flow 110) It is a modified superplasticizer made of polycarboxylate ether that significantly increases cement particle dispersion The CON MIX Company in Iraq prepared it

•Foaming Agent Firefighting foam was utilized as the foaming agent (Synthetic foams

•Glass Fiber Reinforced Polymer (GFRP) Bars the GFRP bars were made by Nanjing Fenghui Composite Material Co., Ltd. and had a high level of durability. It is in agreement with (ACI 440.1R, 2006 and ACI 440.1R, 2015) AS shown fig. 1

•Steel Reinforcement To investigate the bond behavior of LWFC, deformed steel bars of diameters 10mm and 12mm were tested using a tensile test apparatus.

Fig. 1: The Geometry of GFRP Bars Used in This Work

Table (1): Dried density and gradations for light-weight aggregate (LECA)

Declared performance: Essential characteristics	Performance		
Particle shape	Semi-Round/cracked		
Aggregate size distribution (Dry Sieving) (ASTM C136-06)	Passing		
	Sieves	Limits	Typical
	8	100-75%	90.2
	6.35	93-75%	82.8
	4.75	70-40%	47.7
	2.8	35-10%	22.33
	2	25-5%	13.7
	1	8-0%	3.3
Aggregate size	8-0%		
Loose bulk density (ASTM C29-97)	Limits:600Kg/m³		
	Typical :700Kg/m³		

Table (2): Steel Reinforcement

Diameters (mm)	Surface texture	Ultimate Surface fu (MPa)	Yield Stress fy (MPa)	ES (GPa)	Area (mm²)
10	MED	625.61	534.3	200	78.5
12	MED	649.15	537.5	200	113.4

Table (3): GFRP Reinforcement

We chose the high durability resin and have researched the high durability GFRP bar. It has the property of excellent corrosion resistance and passed the highest level (D1) of the ISIS certified.

产品型号 Type No.	大小 Size	公称直径 Nominal Diameter (mm)	公称横截面积 Nominal Area (mm²)	极限抗拉力 Utimate Tensile Load (KN)	保证抗拉强度 Guaranteed Tensile Strength (MPa)	弹性模量 Modulus of Elasticity (GPa)	单位重量 Weight (g/m)	剪切强度 Transverse Shear Strength (MPa)
B100-6	2	6	31.67	28	896	46	77.4	
B100-10	3	10	71.26	59	827	46	159	
B100-13	4	13	126.7	96	758	46	281.3	
B100-16	5	16	197.9	143	724	46	427.1	
B100-19	6	19	285	197	690	46	607.2	
B100-22	7	22	387.9	254	655	46	809.6	150
B100-25	8	25	506.7	314	620	46	1046.2	
B100-29	9	29	641.3	376	588	46	1413.7	
B100-32	10	32	791.7	437	551	46	1711.4	
B100-35	11	35	958.1	462	482	46	1934.6	
B100-38	12	38	1160	520	448	46	2455.4	
B100-41	13	41	1338	554	413	46	2872.1	

2.2 Lightweight Foamed Concrete Mix Design

The main objective of this research is to obtain a lightweight foamed concrete with compressive strength (40 ± 5) MPa and dry density (1800 ± 5) kg/m3 within 28 days (ASTM C642-13) and then add LECA to know the improvement of the homogeneous concrete mixture and then compare them with each other. To produce a homogeneous mixture, several trial mixtures were conducted, which were governed by the basic requirements for density and strength.

Experimental trials involved a variety of variants, including cement-to-sand ratios of 1:1, 1.2:1, and 1.5:1, water-to-binder ratios of 32% and 28%, LECA ratio of (100,200,300) kg/m3 and a superplasticizer ratio of 2%, 1.63% and 1.12% by weight of the reinforcing material. These ratings were adopted based on manufacturer recommendations and previous research (Abbas et al., 2019). (Doostmohamadi, A. et al., 2020). Several experimental mixtures have been made to obtain lightweight foam concrete, And the control mix design without/with LECA highlighted with green color.

The mix proportions of the LWFC experimental mixtures are shown in Table (4).

Table (4). experimental mixtures

Mix No.	Mix Code	Cement (kg/m³)	Sand (kg/m³)	Silica Fume (kg/m³)	W/B %	SP. %	Foam (L/m3)	LECA (KG)	fcu/7 days (Mpa)	fcu/28 days (Mpa)	Dry Density (7days (kg/m3)	Dry Density (28 days) (kg/m3)
1	LWFCW1	1300	900	10	28	1.12	215	0	10	12	1300	1322
2	LWFCW2	1350	900	10	28	1.12	215	0	6	7	1250	1260
3	LWFCW3	1360	900	10	28	1.12	200	0	5	5.8	1265	1278
4	LWFCW4	1350	900	10	28	1.12	50	0	25	30	1780	1793
5	LWFCW5	1350	900	10	28	1.12	20	0	24	28	1785	1830
6	LWFCL6	1350	900	10	28	1.12	20	100	28	34	1790	1800
7	LWFCL7	1350	900	10	28	1.12	20	200	29.8	35	1793	1833
8	LWFCL8	1350	900	10	28	1.12	20	300	32	38	1810	1855

2.3Lightweight Foamed Concrete Mix Procedure.

To complete the foam concrete production process, a 180-liter rotating cylinder was used to mix the materials. In the beginning, the dry materials were mixed with specific proportions of cement, silica sand, and silica fume for 30 seconds, after which water was added gradually to homogenize the mixture to be in the form of balls, as shown in the plate (1)

Plate (1): Homogeneous foamed concrete

After that, the plasticizer was added to make the mixture more homogeneous for a minute

Then, the pre-prepared foam is added directly after its preparation to the mixture

It is added in the form of puffs to the mixture for at least 90 seconds Where the method of adding foam is very accurate because of its effect on the resistance and weight of the concrete mixture, to obtain a homogeneous, light foam concrete mixture.

This mixture is poured into cubes and cylinders coated with oil, which were previously prepared. As in plate (2) to complete the treatment.

Plate (2): cast the mixture into the molds

After that undergo the test process at the age of 7 days and 28 days, after obtaining the required results in terms of resistance and density, (Rafal,2021)

The second part of the research is carried out where the same components and mixing ratios were used, and LECA is added to mixture in different proportions as

shown in the plate (3), to reach the required results and then compare them with each other, where the results were compared for foam concrete with the presence of LECA and without LECA

Plate (3-16): LECA is added to the mixture

2.4 Casting of Slab Specimens

The molds were created after the concrete mix design was finished, as showed in plate 3.

The wood mold was cleaned and greased before the reinforcing steel layer was added for each mold. Plastic spacers were used before the casting process to achieve the required cover

Plate (3): Casting materials for slab

For each slab, the mixture was poured three times using a special mixer with an 80- liter capacity. During the casting of the specimens, cubes, prisms, and cylinders were used as control specimens as shown in plate (4).

plate (4): Samples for testing

After completing the casting process, the casting samples are covered with curing sheet for treatment as shown in plate (5).

plate (5): Slabs Curing

Test Setup

Before preparing for the testing process, the specimens were painted in color of white to observe the first cracks during the application of loads on the samples. At first, steel plates of (*75* mm) width have been placed. After that beam of I section steel was placed with length (1m) and depth (0.2 m) to apply the two-line load as shown in figure (2) The deflection was obtained from the hydraulic testing machine. In the test machine, the load cell has a displacement sensor to record the sample deviation as shown in figure (3).

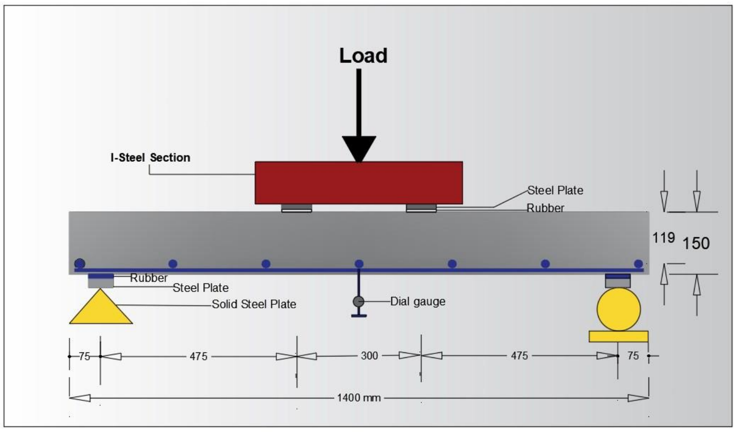


Figure (2): Details of Specimens Testing

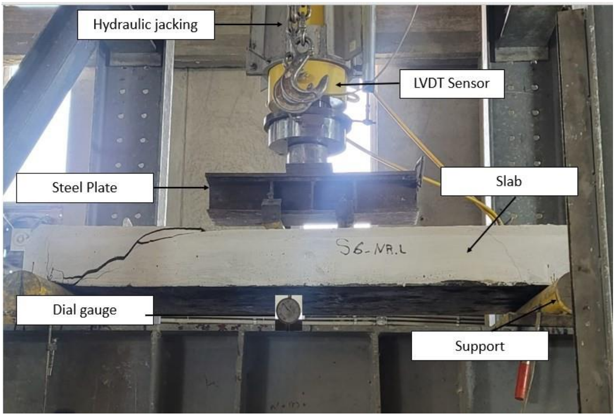


Figure (3) Test Setup for slab.

3 Test results

3.1 Mechanical properties

Cubes 150 × 150 × 150 mm were tested according to BS EN 12390-3:2019 [21] and cylinders 150 × 150 mm were tested according to ASTM C496/C496M-11 [22] to determine compressive strengths and splitting tensile strengths at 7, and 28 days using a digital universal hydraulic device (ELE-Digital Elect 2000). In addition, the slump test was to measure the workability of all mixes, which was carried out in accordance with the procedure described in ASTM C143-01a [23]. The results are shown in Table 5 The 28-day compressive, dry density, and splitting tensile strength tests

Table 5: Results of compressive and tensile strengths.

Typical specimens	f'cu/7 Typical specimens [Mpa]	f'cu/28 days [Mpa]	Flowability test (mm)	Dry Density (7 days)[kg/m3]	Dry Density (28 days) [kg/m3]	Splitting Tensile Strength (ft) [Mpa]	Modulus of Elasticity (E) (GPa)	Modulus of Rupture (fr) (Mpa)
LWFC without LECA (L.W)	26	35.2	125	1785	1830	2.3	11.53	2.53
LWFC with LECA (L.L)	32	42	100	1810	1885	2.61	16	3.6

3.2 Experimental Test Results and Discussions.

The outcomes of 18 lightweight foamed concrete one-way slabs were organized into six groups were tested, each divided into three types of slabs with different types of reinforcement (Normal reinforcement and GFRP) and each group has different ratio of reinforcement (ρmax, ρmin, ρavg). it displayed in the tables (6), The experimental work was displayed for each slab that was tested and to noting the load against the deflection for the initial stage of cracking and the load against the deflection for the final stage.

Table 6 Experimental Result of The Slabs.

Group no.	Name of slab	Load at first crack Pcr(kN)	Deflection at first crack (Δcr) (mm)/Max Upper Displacement	Ultimate load (Pu)(kN)	Ultimate deflection (Δu) (mm)	Pcr / Pu [%]
G.NO.1	S1-NR. LWFCW-ρ_{Max}	14.61	0.48	184.39	11.2	7.923
	S2-NR. LWFCW-ρ_{Avg}.	14.2	0.68	150.3	12.85	9.448
	S3-NR. LWFCW-ρ_{Min}	12.34	0.86	135.54	13.2	9.104
G.NO.2	S4-NR. LWFCL-ρ_{Max}	25.9	1.18	216	13.4	11.991
	S5-NR. LWFCL-ρ_{Avg}.	20.25	1.65	192.8	15.2	10.503
	S6-NR. LWFCL-ρ_{Min}.	15.12	1.7	142.9	29.19	10.581
G.NO.3	S7-GFRP.LWFCW-ρ_{Max}.	19.16	0.96	96.36	21.5	20.340
	S8-GFRP. LWFCW-ρ_{Avg}.	14.6	1.129	92.7	23.7	15.750
	S9-GFRP. LWFCW-ρ_{Min}.	10.64	1.3	85.5	26.8	12.444
G.NO.4	S10-GFRP. LWFCL-ρ_{Max}.	20.29	1.3	107.15	18.76	18.936
	S11-GFRP. LWFCL-ρ_{Avg}.	13.4	1.3	96.2	22.3	13.929
	S12-GFRP.L-ρ_{Min}.	10.46	1.56	82.175	57.6	12.729
G. NO.5	S13-NR&GFRP.W-ρ_{max}.	15.18	1.129	124.75	22.93	12.168
	S14-NR&GFRP. LWFCW-ρ_{Avg}.	13.48	2.432	116.23	28.32	11.598
	S15-NR&GFRP.W-ρ_{Min}.	11.21	2.25	101.47	33.27	11.048
G.NO.6	S16-NR&GFRP. LWFCL-$_{Max}$.	18.02	1.04	115.67	23.72	15.579
	S17-NR&GFRP. LWFCL-ρ_{Avg}	16.32	1.08	93.9	26.67	17.380
	S18-NR&GFRP. LWFCL-ρ_{Min}	7.8	1.82	80.47	27.05	9.693

Load Capacity and Deflection at Mid-Span for Group No1 and Group No.2

As shown in Figure (4) and (9) below, the shear failure of the bending of the slabs increases as the compressive strength rises for lightweight foamed concrete with LECA. It was discovered that the maximum reinforcement ratio of the LWFC is responsible for the ultimate load resistance, and on the other hand, the deflection ratio decreases as the resistance increases

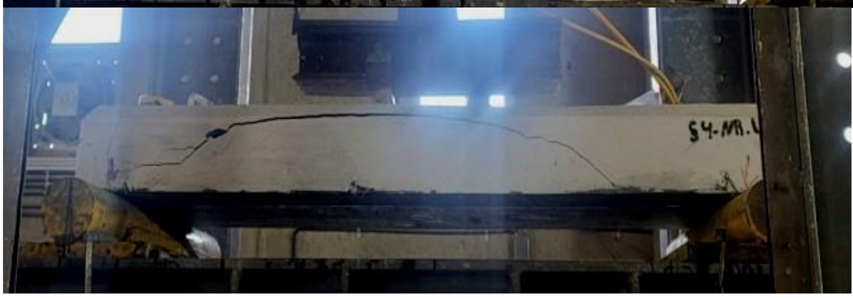


Figure (4 to 6) Crack patterns of Slabs (S1to S6)

Result and Discussion for Group No.3 and Group No.4

The slabs in group no.3 and group no.4 that reinforced with GFRP bars were subjected to monotonic load testing until failure. During the early loading stages, no cracks were found in the region of the reinforced concrete slabs' pure bending moment or shear zone. As the applied load increased, shear cracks appeared in the middle region of the slab. The first shear cracks appeared at (19.16) kN for the monotonic load, with an equivalent mid-span deflection of (0.96) mm for the control slab S7-GFRP.LWFCW-ρMAX. When the load increased, the cracks began to grow and widen until they failed. Shear cracks appeared in the slab specimens from the middle zone to the bottom half. At a deflection of 21.28mm, an ultimate monotonic load of 96.368kN was measured is depicted in figures (7 to12).

Figure (7to 12) Crack patterns of Slabs (S4to S12)

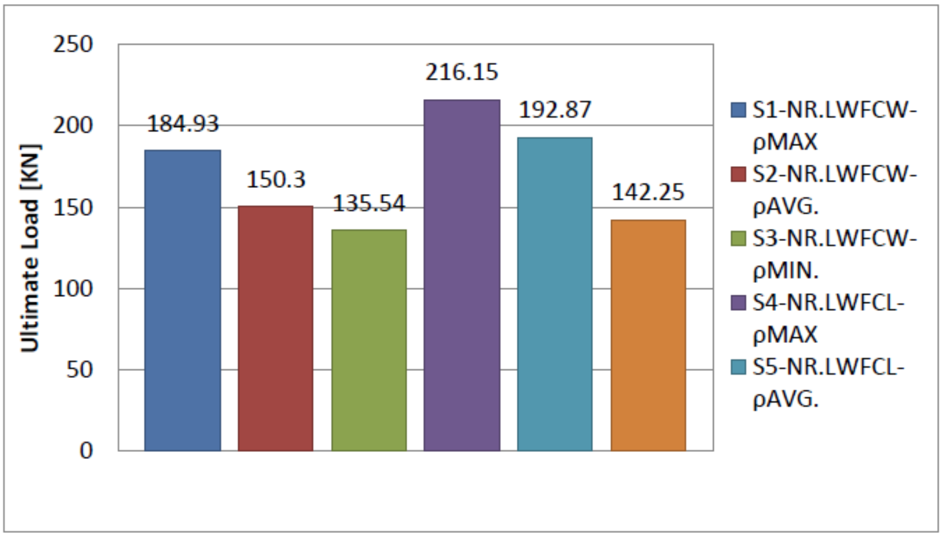
1 Load Capacity and Deflection at Mid-Span for Group No3 and Group No.4

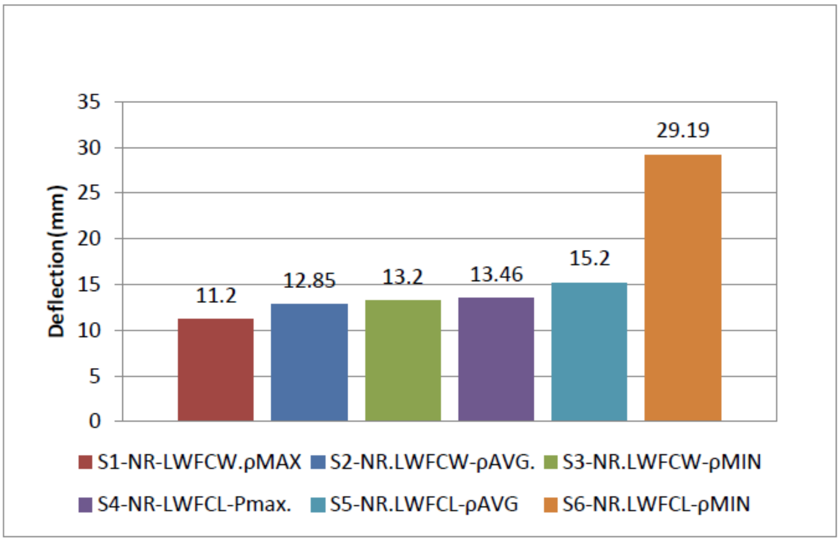
Effects ratio of GFRP reinforcement and the shape of LECA content in different proportions increase the resistance strength of the slab to shear failure compared to the control slab (S7), shear failure in slab bending increases with increasing compressive strength for lightweight foam concrete with LECA. It was discovered that the maximum reinforcement ratio of GFRP is responsible for the maximum resistance to the load, and on the other hand, the deflection ratio decreases with increasing resistance, as shown in figures (13-18)).

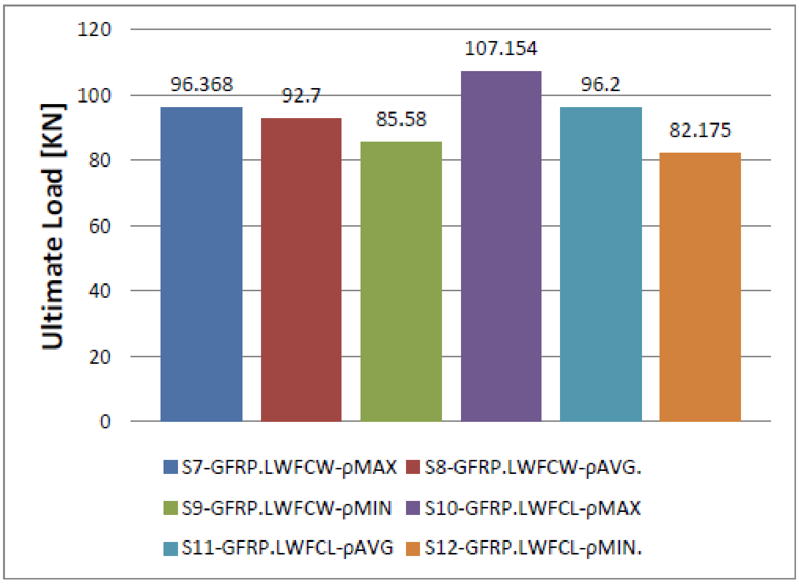
Figures (13 to 18) Crack patterns of Slabs (S13to S18)

3.5 Load-deflection behavior

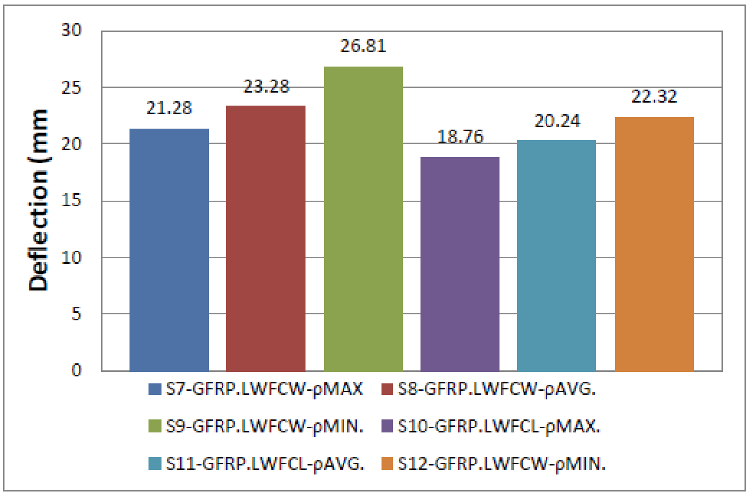
Fig. 19 to fig.24 all the curves showed similar behavior, which led to a sudden decrease in the load in the shear failure samples of the slabs. As for the samples. The behavior was different, as It was noted from this that the failure was gradual for the slabs



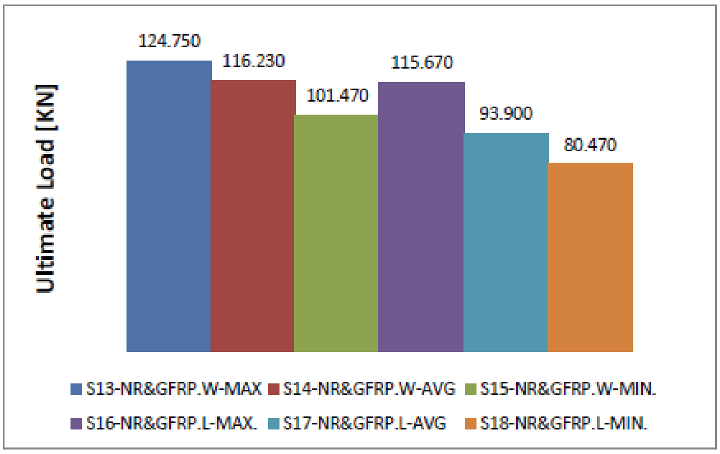




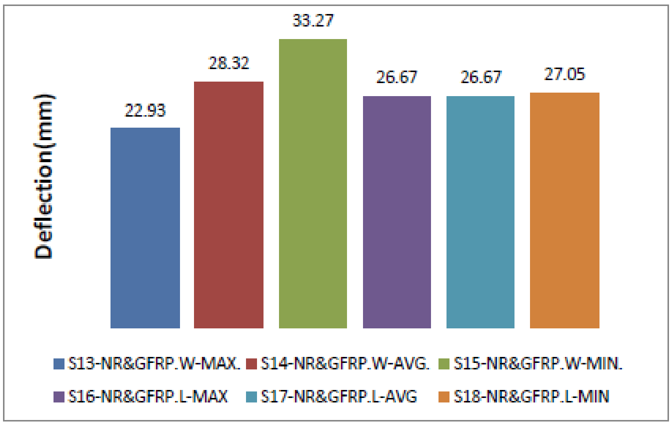
Ultimate Load [KN]
120
100
80
60
40
20
0
96.368
92.7
85.58
107.154
96.2
82.175
S7-GFRP.LWFCW-ρMAX
S8-GFRP.LWFCW-ρAVG.
S9-GFRP.LWFCW-ρMIN
S10-GFRP.LWFCL-ρMAX
S11-GFRP.LWFCL-ρAVG
S12-GFRP.LWFCL-ρMIN.



Deflection (mm
30
25
20
15
10
5
0
21.28
23.28
26.81
18.76
20.24
22.32
S7-GFRP.LWFCW-ρMAX
S8-GFRP.LWFCW-ρAVG.
S9-GFRP.LWFCW-ρMIN.
S10-GFRP.LWFCL-ρMAX.
S11-GFRP.LWFCL-ρAVG.
S12-GFRP.LWFCW-ρMIN.



Ultimate Load [KN]
124.750
116.230
101.470
115.670
93.900
80.470
S13-NR&GFRP.W-MAX
S14-NR&GFRP.W-AVG
S15-NR&GFRP.W-MIN.
S16-NR&GFRP.L-MAX.
S17-NR&GFRP.L-AVG
S18-NR&GFRP.L-MIN.



Figures (19 to 24) Ultimate Load/ Mid-Span Deflection for all groups

Conclusion

The following conclusion is summarized based on the experimental work of this research

1. Light-weight foam concrete was produced after many trail mixes to achieve suitable compressive strength (35.2 MPa) and dry density (1830 Kg/m3) at 28 days, without adding LECA to the mixture.

2. Adding LECA to fresh LWFC led to a reduction in flowability 25% and an increase in compressive strength and density by 16.19% and 2.9% respectively.

3. The results showed that the addition of LECA to the mixture improved the mechanical properties of LWFC were as follows (i.e. compressive strength, splitting tensile strength, modulus of elasticity, and modulus of rupture), were improved by 16.19%, 11.8%, 27.93%, and 29.7% respectively. Because the LECA content helps close the pores resulting from the bubbles of foam concrete

4. It was found that the failure of the slab was a shear failure, and the slab reinforced with normal reinforcement and having the maximum ratio of reinforcement (ρ max) had the highest resistance recorded, as the failure occurred by breaking the concrete the failure occurred without giving any alarm alerts.

5. The results showed that the GFRP has less resistance than normal reinforcement, as the percentage of resistance decreased for the slabs reinforced with GFRP by 20% without LECA and 35% for the slabs reinforced with GFRP with LECA.

6. The results showed that slabs reinforced with normal reinforcement has a higher resistance than slabs reinforced with GFRP, as well as slabs reinforced with a combination of two types of reinforcement (normal and GFRP). In addition, LWFC slabs that contains LECA has a higher resistance than LWFC slabs without LECA.

7. slabs reinforced with normal reinforcement and has maximum ratio of reinforcement ρ maximum (without LECA) have a higher ultimate load than the slabs reinforced with GFRP or the slabs reinforced with the combination of two types of reinforcement (normal & GFRP) at a rate of 47% and 32%, respectively. And it increases slightly with the addition of LECA by 53% and 46%, respectively.

8. Results shows that slabs reinforced with the combination of two types of reinforcement (normal & GFRP) with maximum ratio of reinforcement is higher than slabs reinforced with just GFRP by 22%without LECA and 7% with LECA

9. slabs reinforced with normal reinforcement and has average ratio of reinforcement ρ average has a higher ultimate load than the slabs reinforced with GFRP or the slabs

reinforced with the combination of two types of reinforcement (normal & GFRP) at a rate of 38.3% and 22.6%, respectively without LECA. And it increases slightly by 50% and 51% respectively with LECA content. In other hand, for slabs reinforced with the combination of two types of reinforcement (normal & GFRP) is higher than slabs reinforced with GFRP by 20.2%. but its decreased by 0.2% with LECA content.

10. For minimum ratio of reinforcement (ρ minimum) without LECA, we notice that the slabs reinforced with normal reinforcement and has a higher ultimate load than the slabs reinforced with GFRP or the slabs reinforced with the combination of two types of reinforcement (normal & GFRP) at a rate of 36.9 %and 25%, respectively and increased when using LECA content by 42% and 3% respectively. Also, for slabs reinforced with the combination of two types of reinforcement (normal & GFRP) without LECA is higher than slabs reinforced with GFRP by 15.7%. but is decreased by 0.2% when LECA content using

11. As a result, slabs reinforced with (NR) are considered to have higher resistance than slabs reinforced with GFRP, because NR weighs more than GFRP and also has a greater modulus of elasticity than GFRP

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