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Feasibility of Using Lightweight Artificial Course Aggregates in the Manufacture of R. C. Elements

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Abstract- In recent years lightweight concrete is considered as one of the most important materials in the special concrete groups. It has extensive applications in the architect and insolation work. Lightweight aggregates and chemical admixtures play an important role in the production of lightweight concrete. New artificial course aggregate has been recently developed and has the attention of the researches to be used in the manufacture of lightweight concrete. This research was conducted to determine the feasibility of lightweight aggregate type commercially available in the Egyptian market in the concrete industry. Plan concrete specimens as well as reinforced concrete beams and slabs cast with concrete containing such lightweight aggregate were cast and tested in the research. The main variable taken into consideration were the aggregate type, cement and water content as well as the chemical and mineralogical admixtures content. The percentage of reinforcement of the beams and slabs tested were also taken in to consideration. The mechanical properties of fifteen concrete mixes were determined. The structure behavior of the tested beams and slabs were investigation with special attention to their deflections, longitudinal strain and cracking under different stages of loading as well as the ultimate loads and modes of failure.

Keywords: Lightweight concrete, lightweight aggregate, foam, new artificial course aggregate, compressive strength, R. C. Beams and R. C. Slabs

I. INTRODUCTION

Lightweight concrete (LWC) was defined according to (ACI 211.2-98-2004) [1] "as a concrete which is made with lightweight aggregates (LWA). It has a compressive strength in excess of 2500 psi at 28 days age and it has an air dry weight not exceeding 115 lb/ft3. Concrete in which a portion of the lightweight aggregate is replaced by normal weight aggregate is within the scope of this standard. When normal weight fine aggregate is used "Lightweight concrete can be defined as a type of concrete which includes an expanding agent in that it increases the volume of the mixture while giving additional qualities such as lessened the dead weight [2,3].

LWAC is a very versatile material for construction. It offers a range of technical, economic and environment enhancing and preserving advantages. The strength and durability have been proved to be good in LWAC. Compared with its normal weight concrete NWC or NC counterpart, lightweight aggregate has higher water absorption rate and lower relative density. In addition to being light, it has good strength, fire resistance and heat insulation. [4, 5]

The use of the lightweight aggregate (LWA) for making lightweight pervious concrete (LWPC) was presented with no fine aggregate". The connected voids allow water and air to pass through. [6] The volume fraction and aggregate properties have great effect on the mechanical performance of lightweight aggregate concrete (LWAC). Higher volume content of LWA resulted in a more brittle failure [7].

Mineral admixture as fly ash, pulverized fly ash, granulated blast furnace slag and steel slag enhanced the lightweight aggregate concrete [8]. Pozzolans enhanced the properties of the lightweight foamed concrete. The palm oil fuel ash (POFA) affected the properties of lightweight foamed concrete (LWFC). (LWFC) increased the thermal conductivity compared to that of the control LFC specimens with better strengths performance compared to the controlled specimens [9].

The mechanical properties and the durability parameters of lightweight aggregate concrete (LWAC) incorporating rigid polyurethane (PUR) foam waste as coarse aggregates were investigated. The influence of both the increasing incorporation of PUR foam waste and the presence of super plasticizer on the fresh, hardened and durability of lightweight aggregate concretes (LWAC) diffusion coefficient of the different concretes, the use of PUR foam waste enabled to reduce dry density of concrete compared to that of the normal weight concrete (made without foam waste). The reduction of density was due to the increase of total porosity in the lightweight concretes, which also induced higher gas permeability and chloride diffusion coefficient. These negative effects on durability of concrete were lowered by improving the characteristics of the cementitious matrix [5, 10, and 11].

Using fibers in LWAC improves its mechanical properties, and significantly increase its toughness, ductility performance and energy absorption, and effectiveness in splitting tensile and flexural strengths while decreasing its workability, particularly when steel fibers are used in the concrete mixture [12].

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Consistency and stability of fresh mixed foamed concrete are needed to prevent a separation of artificial air bubbles and cement mortar as well as broken of the bubbles, and eventually affect its hardened properties. [13, 14], The replacement of sand with coarse fly ash as filler in foamed concrete exhibited higher spread value compared to cement–sand mix. This enhanced consistency and workability is attributed to different particle shape and size of fine aggregate [14, 15]. The finer low lime fly ash as compared with sand increased the water to solid ratio, thus satisfy the consistency requirement. Incorporation of pozzolans, either naturally occurring or artificially made into concrete has been in practice since the early civilization. Besides its economic advantages, it can give useful modification or enhancements to concrete properties. (POFA) [16, 17].

In recent years, lots of researches scope the using of foamed as a course aggregates in lightweight concrete [LWC] and the effective of it in LWC. Structural lightweight concrete can be produced by using the fine and coarse pumice aggregates mixes without using any additions or admixtures [18]. The applications of lightweight concrete composite successfully were for structural members and elements in buildings and bridges to reduce the dead weight and the dimensions of structural members. The properties of LWAC mixed using lightweight aggregates made from sintered silt dredged from reservoirs were also investigated [15 to 22].

II. RESEARCH SIGNIFICANCE

The main objective of this research is to establish the performance of lightweight concrete with the replacement of the course aggregate by light weight aggregate, using Addipore55 which was manufactured by Chemicals Modern building group as a light weight aggregate. The main variables of concrete mixes taken into considered in this study were the replacement ratio of Addipore55 to course aggregate, cement content, water cement ratios; chemical admixtures / cement ratio and silica fume / cement ratio on the concrete mixes. The behavior of the structural elements casted with light weight concrete as R. C. beams and R. C. slabs were investigated. The main variables of structural elements concrete were the type of concrete used, the value of reinforcement and the strength of the concrete used.

III. EXPERIMENTAL PROGRAM

The experimental program conducted in this study was performed in the laboratory of testing of building materials at the Faculty of Engineering, Menoufia University, Egypt. Cubes 10x 10 x10 cm, cylinders 10x20 cm and beams 10x10x40 cm. were cast and tested to determine the compressive strength, indirect tensile strength and modulus of elasticity of the concrete using foamed investigate as replacement of course aggregates with different ratios of water content, admixtures cement ratio and silica fume cement ratio on structural element concrete. The flow chart of the experimental program is shown in figure (1) and table (1).

Nine R.C. beams with dimensions of 15x 10 x115 cm and Six R.C. slabs with dimensions of 5x 40 x115 cm were cast and tested in this research. Details of this R.C. beams and R.C. slabs were shown in tables (2, 3) and Figures (2, 3). They were designed according to the Egyptian code of practice (E.C.P. 203/2007) [23].

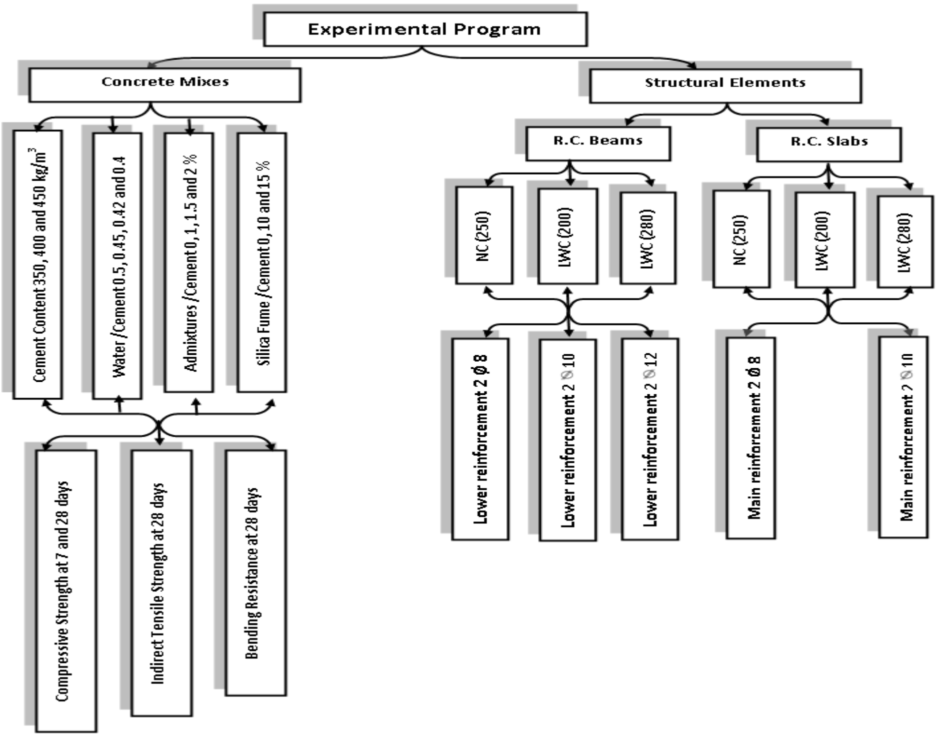

Figure (1): Flow Chart of the Experimental Work Program

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Table (1): Proportions of the concrete mixes used.

Mixes	Cement kg/m^3	Sand/ Course Aggregate	Sand (m^3)	Course Aggregate (m3)		W/C	Add./C	S. F./C
				Dolomite	Addipore55			
M1	350		0.377	0.764	----	0.5	0	0
M2	350		0.377	0.382	0.382	0.5	0	0
M3	400		0.356	0.36	0.36	0.5	0	0
M4	400		0.364	0.369	0.369	0.45	1	0
M5	400		0.37	0.374	0.374	0.42	1.5	0
M6	400		0.373	0.378	0.378	0.4	2	0
M7	400	1 /2	0.363	0.368	0.368	0.4	2	10
M8	400		0.359	0.363	0.363	0.4	2	15
M9	450		0.346	0.35	0.35	0.45	0	0
M10	450		0.35	0.356	0.356	0.42	1	0
M11	450		0.355	0.359	0.359	0.4	1.5	0
M12	450		0.341	0.345	0.345	0.42	1	10
M13	450		0.346	0.35	0.35	0.4	1	10
M14	450		0.335	0.339	0.339	0.42	1	15
M15	450		0.34	0.34	0..34	0.4	1	15

W/C= Water /Cement Add./C= Admixture/Cement S.F./C= Silica Fume/Cement

III-1- Materials

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007) [23], (E.S.S. 1109/2008) [24]. It was clean and nearly free from impurities with specific gravity 2.65 t/m^3 and modulus fineness 2.7.

The coarse aggregate used was of crushed dolomite, which satisfies the Egyptian Standard Specification (E.S.S. No. 1109\ 2008) [24] and the American Society for Testing and Materials (ASTM C 33, 2003)[25], USA Its specific gravity is 2.67 t/m3 and modulus fineness 6.64. The shape of these particles was irregular and angular with a very low percentage of flat particles. The delivered crushed dolomite size 1 had a maximum nominal size of 9.5 mm.

The cement used was the Ordinary Portland cement, type (CEM (I) 42.5 N) produced by the Suez cement factory. Its chemical and physical characteristics satisfied the Egyptian Standard Specification (E.S.S. 4657-1/2009) [26].

The water used was clean drinking fresh water free from impurities used for concrete mixing and curing the plain concrete specimens and the R.C. beams and slabs. It was tested according to the (E.C.P. 203/2007) [23].

Super plasticizer used was a high rang water reducer HRWA. It was used to improve the workability of the mix. The admixture used was produced by CMB GROUP under the commercial name of Addicrete BVF. It meets the requirements of ASTM C494 (type A and F) [27]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWA was 1.0 % of the cement weight.

Addipore55 used was produced from Chemicals Modern building group, Addipore55 is expanded and extruded foam grains with special size and grading used for producing the light concrete which has sufficient thermal and acoustic insulation properties. The specific gravity of Addipore55 is about by (20- 22 kg /m^3). It is used to produce Light weight sloping concrete for roofs, Light weight thermal insulation concrete, Light weight flooring concrete, Light weight bricks and pre-cast units.

High tensile deformed steel bars use was produced from the Ezz Al Dekhila Steel - Alexandria Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011) [28]. High tensile deformed steel bars (nominal diameters 10 and 12 mm) were used in reinforcing the concrete beams and used as main reinforcing in the concrete slabs, their yield stress was 400 MPa and there tensile strength was 600 MPa.

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Mild steel bars of (8 mm and 6 mm) diameter were used for concrete beams and concrete slabs with yield strength of 240 MPa and had tensile strength of 350 MPa. Mild steel bars of 8 mm diameter were used for lower reinforcing of three beams and as a secondary reinforcing of the slabs. Mild steel bars of 6 mm diameter were used for upper reinforcing and stirrups of all beams with yield strength of 240 MPa and had tensile strength of 350 MPa.

III- 2- Concrete Investigation

Fifteen concrete mixes were cast and cured in this study to investigate the effect of using Addipore55 as 50% replacement of course aggregate on the hardened properties of concrete mixes. The effect of using Addipore55 on the density and mechanical properties of the concrete as compressive strength, indirect tensile strength and flexural strength at different ages (7 and 28 days) was studied. The main variables taken in to consideration were different cement content (350, 400 and 450 kg/m3), different water cement ratio (0.5, 0.45, 0.42 and0.4), admixtures to cement ratio (0, 1, 1.5 and 2%) and silica fume (0, 10 and 15%).

The samples were mixed and cast in steel cubes (100 x100 x100mm) cylinders (100 x 200 mm) and beams (500 x100 x 100 mm) after oiling its surface. The molds were placed on the vibration table at a low speed. After casting the specimens were covered with wet burlap in the laboratory at 24ºC and 68% relative humidity. The specimens were demolded after 24 hours and wrapped with damp cloth till they were tested. The properties of the concrete mixes used are shown in Table (1). Description and detailing of the tested beams and slabs are shown table (2 and 3) and figures (2, 3 and 4).

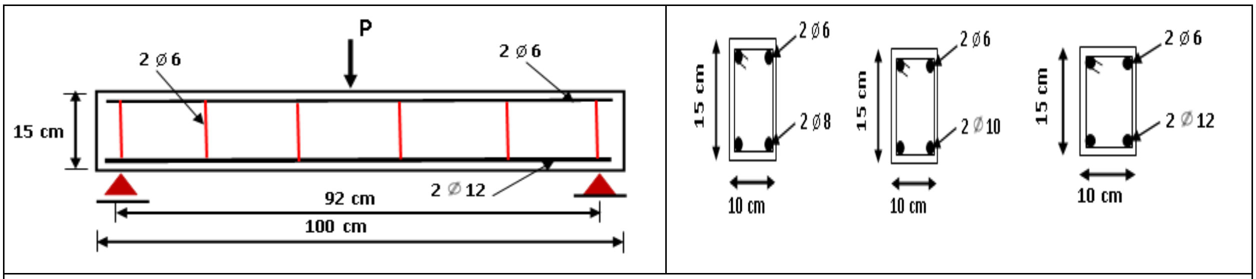

Figure (2): Detailing of the Tested Beams Samples

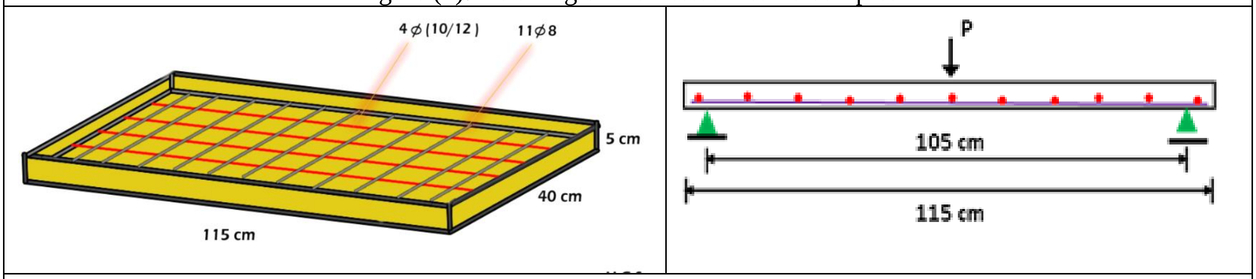

Figure (3): Detailing of the Tested Slabs Samples.

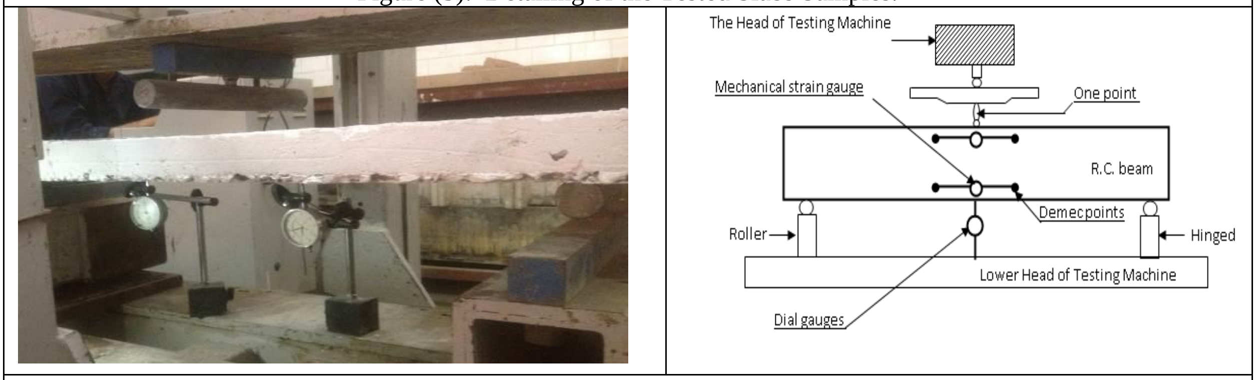

Figure (4): Flexure beam and slab test, three lines loading

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Table 2. Details of Beam Samples Used

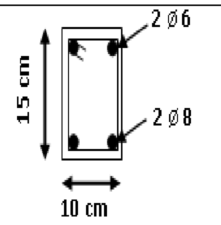
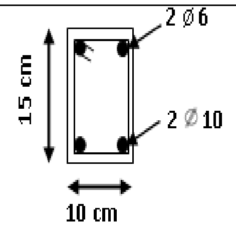
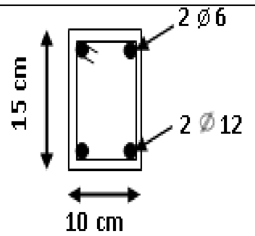
Beam	Concrete used	$F_{cu.}$	Reinforcement of beam used: Upper rft	Lower rft	Stirrups	Beam cross section
I	M8	200	2 Ø 6	**2 Ø 8**	6Ø6\m'	
C	M1	250		**2 Ø 8**		
G	M12	280		**2 Ø 8**		
H	M8	200		**2 Ø 10**		
F	M1	250		**2 Ø 10**		
A	M12	280		**2 Ø 10**		
D	M8	200		**2 Ø 12**		
B	M1	250		**2 Ø 12**		
E	M12	280		**2 Ø 12**		

Table 3: Details of Slab Samples Used

Slab	Concrete used	$F_{cu.}$	Reinforcement of slab used: Main rft	Second rft	Initial crack Load (kg)	Ultimate Load (kg)
SL 8	M8	200	2 Ø 8	2 Ø 8	300	1000
SL 10	M8	200	2 Ø 10	2 Ø 8	350	1080
SN 8	M1	250	2 Ø 8	2 Ø 8	400	1080
SN 10	M1	250	2 Ø 10	2 Ø 8	500	1500
SH 8	M12	280	2 Ø 8	2 Ø 8	600	1560
SH 10	M12	280	2 Ø 10	2 Ø 8	700	2040

III-3- Reinforced Concrete Beams and Slabs Investigation

Out of the fifteen concrete mixes tested in this study, two mixes were chosen (M8 and M12) casting in the R.C beams and slabs. M8 and M12 had compressive strength 200 and 280 kg/cm^2 respectively, at 28 days age, However, M1 which was cast with normal concrete and compressive strength 250 kg/cm^2.

Nine reinforced concrete beams with dimensions of 10x 15 x 110 cm were reinforced with 2 Ø 6 upper reinforcement and stirrups, (2 Ø 8, 2 Ø 10 and 2 Ø 12) as lower reinforcement with different concrete strength. These beams were cast with concrete having different strength concrete as 200 and 280 kg/cm^2 lightweight concrete and normal concrete have strength 250 kg/cm^2 as shown in figure (2).

Six reinforced concrete slabs with dimensions of 5x 40 x115 cm were reinforced with 5 longitudinal main steel bars with 8 and 10 mm diameter and 11 bars as secondary with 8 mm diameter. These slabs were cast with concrete having different strength concrete as 200 and 280 kg/cm^2 lightweight concrete and normal concrete have strength 250 kg/cm2 as shown in figure (3).

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I. ANALYSIS AND DISCUSSION OF THE TEST RESULTS

IV-1- The Mechanical Properties of the Concrete Mixes

Feasibility were obtained the lightweight concrete with replacement the course aggregate by light weight aggregate as Addipore55. The Addipore55 replacement ratio was 50% by volume of the total course aggregate (dolomite). The compressive strength, the indirect tensile strength and the bending strength of all the concrete mixes under investigated are discussed in this section.

IV-1-1-**The Compressive Strength of Concrete**

Figures (5 to 7) show that lightweight concrete with density between 1.85 gm./cm^3 and 2.1 gm./cm^3 (79% and 89.7%) of the control mix (normal concrete and compressive strength between 135 kg/cm^2 and 284 kg/cm^2 (54% and 113.6% of the control mix were obtained. Increasing cement content from 350 to 400 and 450 kg/m^3 improved the compressive strength of the lightweight concrete. The mixes (M2, M8 and M12 give variable ratios of the compressive strength 54%, 80% and 113.6% compared to the control mix.

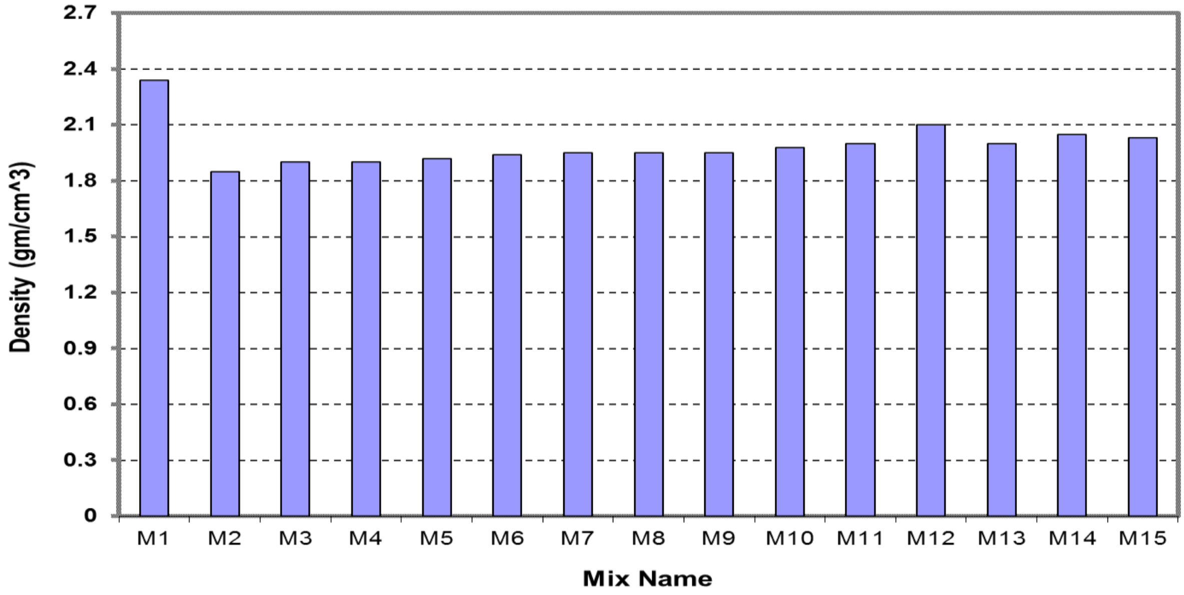

Figure (5) : The Density of All Concrete Mixes

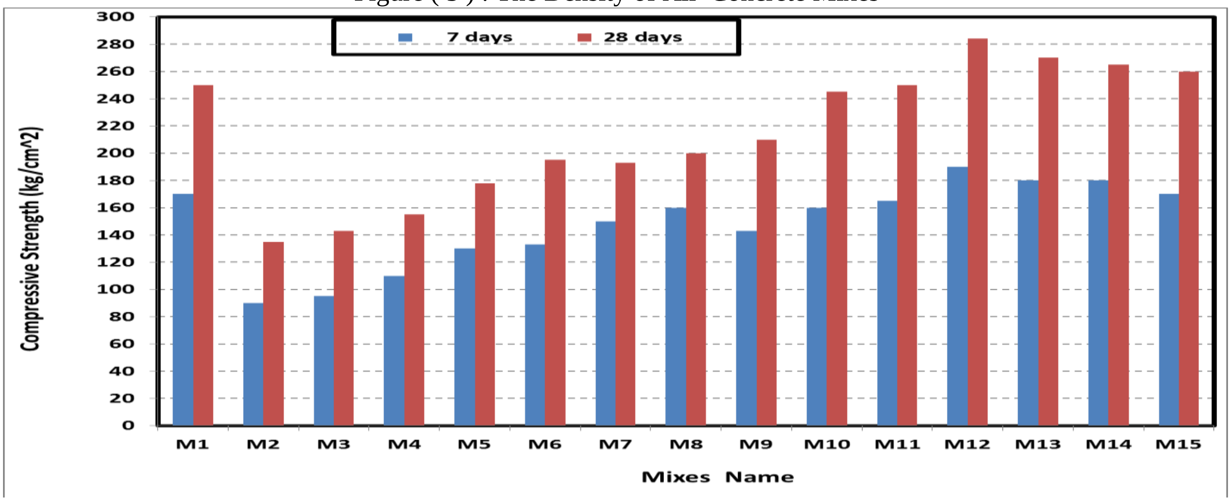

Figure (6): Compressive Strength of all concrete mixes

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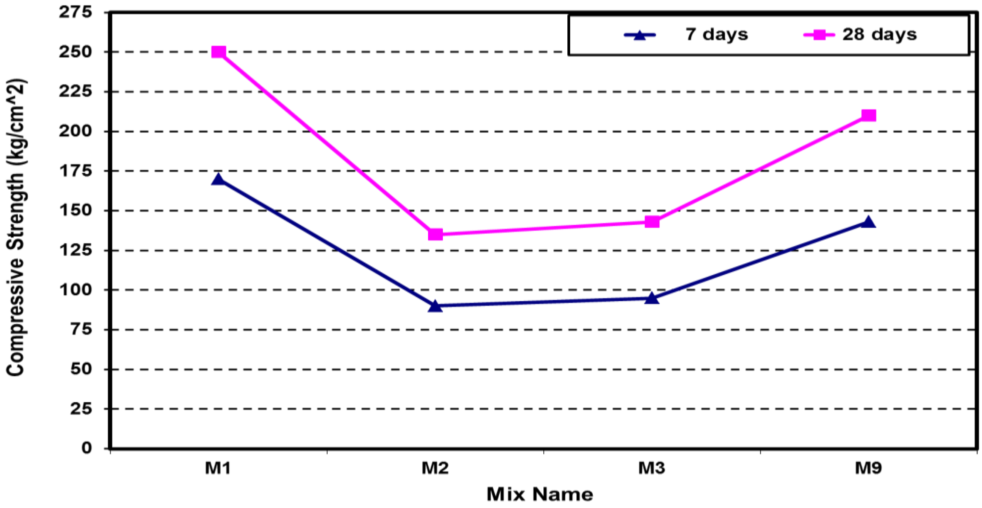

Figure (7): Effect of Using Addipore55 on Compressive Strength with Different Cement Content at 7 and 28 days

Reduction of water cement ratio (w/c) in concrete mix improved the compressive strength as (8.4%, 24.5% and 39.9%) for mixes (M4, M5 and M8) with w/c as (0.45, 0.42 and 0.4) compared to the mix M3 containing w/c ratio by 0.5, and 400 kg/m^3 of cement where using cement content 450 kg/m3 and reduce w/c ratio by (0.42 and 0.4) increase the compressive strength by (16.7 and 35%) for mixes M10 and M12 compared to the mix M9 with w/c ratio 0.45. see figures (8 and 9)

Using Super plasticizer admixtures (1, 1.5 and 2%) improve the workability of the mixes (M4, M5 and M8) and enhancing the compressive strength by (8.4%, 24.5% and 39.9%) compared to the mix M3(0% Admixtures) containing 400 kg/m3 cement content however using cement content 450 kg/m3 and the admixtures increasing by (1and 1.5%) the compressive strength were enhancing by (16.7 and 19%) of the control mixes for the mixes (M10 and M11) compared to the mix M9 (0% Admixtures) without S.F. as shown in figure (10 , 11)

Using silica fume (S.F.) as a replacement of cement by 10% and 15% (M7 and M8) decreases the compressive strength by1% and improves the compressive strength by 2.6% respectively compared to M6 (S.F.= 0%) for cement content 400 kg/m3, but for cement content 450 kg/m^3 using S.F. by 10% and 15% for mixes (M12 and M14) increase the compressive strength by (35% and 26%) respectively compared to the mix M9 without S.F. as shown in figure (12 and 13)

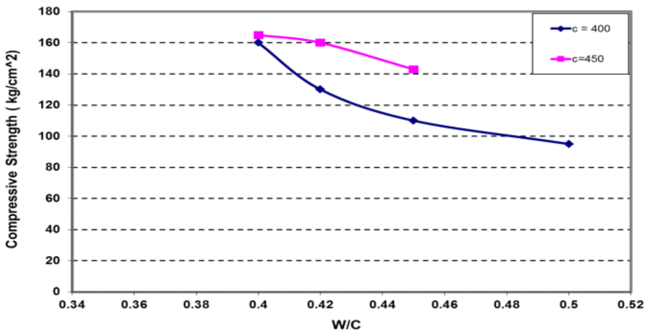

Figure (8): Effect of Water Cement Ratio on the Compressive Strength at 7 days

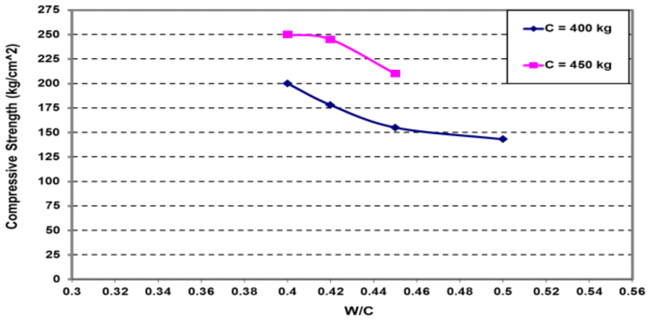

Figure (9): Effect of Water Cement Ratio on the Compressive Strength at 28 days

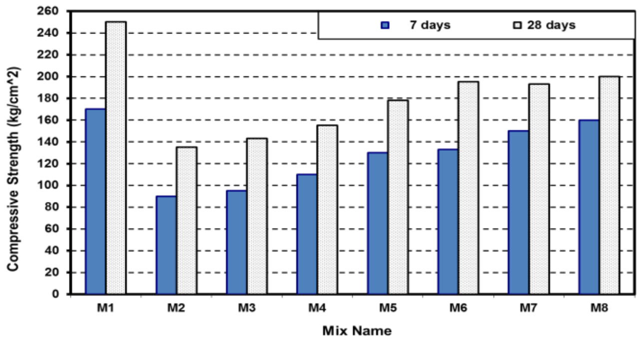

Figure (10): Effect of Using Cement Content C= 400 kg with Different Admixtures/Cement Ratio at 7 and 28 days

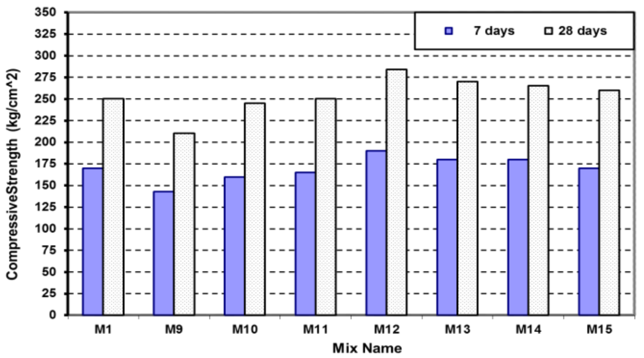

Figure (11): Effect of Using Cement Content C= 450 kg with Different Admixtures/Cement Ratio at 7 and 28 days

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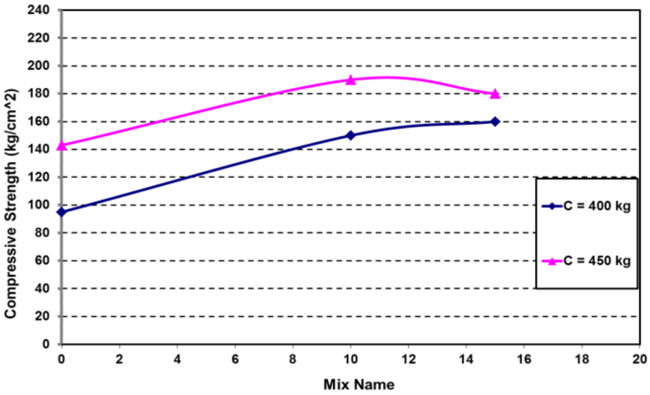

Figure (12): Effect of Silica at 7 Days

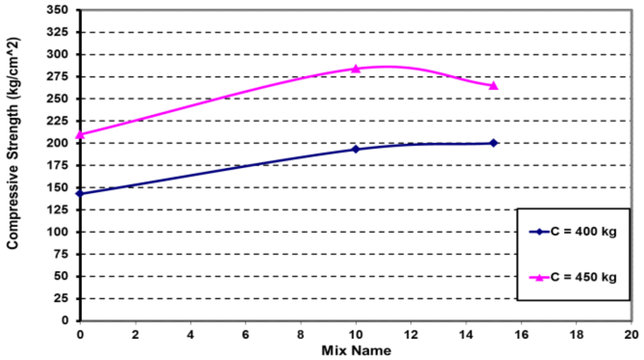

Figure (13): Effect of Silica at 28 Days

The compressive strength and specific compressive strength of lightweight concrete improved with time by increasing cement content, decreasing w/c ratio, using admixtures and using silica fume. The best mix using in the construction building were M8 and M12 for cement content 400 and 450 kg/m^3 respectively with time in the range of this study.

IV-1-2-The Indirect Tensile Strength of Concrete

Figures (14 to 19) show that the indirect tensile strength of lightweight concrete was improved by increasing cement content, reduction of water cement ratio (w/c), using admixtures and using silica fume. Increasing cement content from 350 to 400 and 450 kg/m^3 improving the indirect tensile strength of lightweight concrete. The maximum increasing of the indirect tensile strength of lightweight concrete was at the mix M12 by 113.6 % with cement content 450 kg/m^3 compared to the control mix.

Reduction of water cement ratio (w/c) in concrete mix improved the indirect tensile strength as (39.7 % and 35.2 %) for mix (M8 and M12) with w/c as (0.4 and 0.42) compared the mix M3 and M9 with 400 kg/m^3 and 450 kg/m^3 of cement respectively. Increasing of Super plasticizer admixtures to cement by 2% and 1.5%) of mix (M8 and M11) enhance the indirect tensile strength by (39.7% and 19%) compared the mix M3 and M11 with (0% Admixtures) containing 400 kg/m3and 450 kg/m^3 cement content respectively without S.F. Increase of using silica fume (S.F.) as a replacement of cement to 15% and 10% (M8 and M12) improve the indirect tensile strength by (39.7% and 35.2%) for cement content 400 and 450 kg/m^3 respectively.

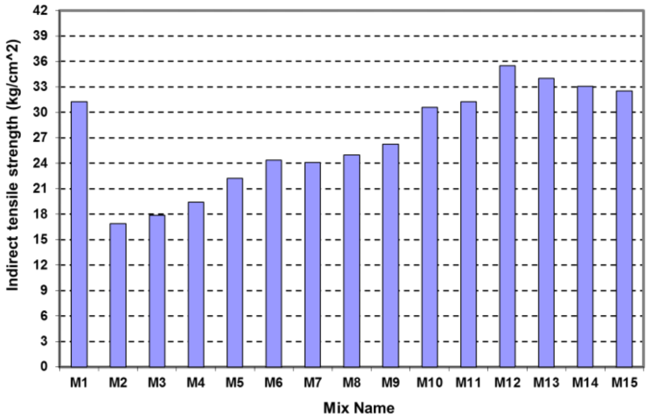

Figure (14): Indirect tensile strength of all mixes

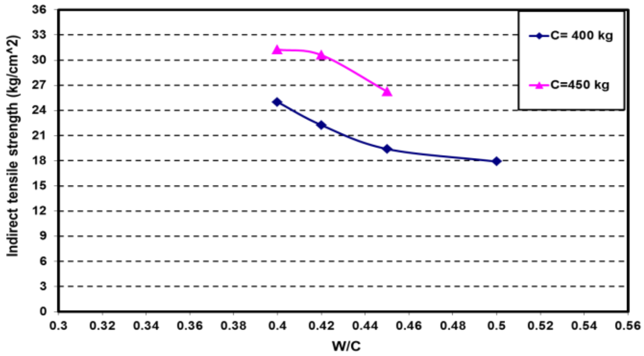

Figure (15): Effect of water cement ratio on the indirect tensile strength with different cement content 400 and 450 kg

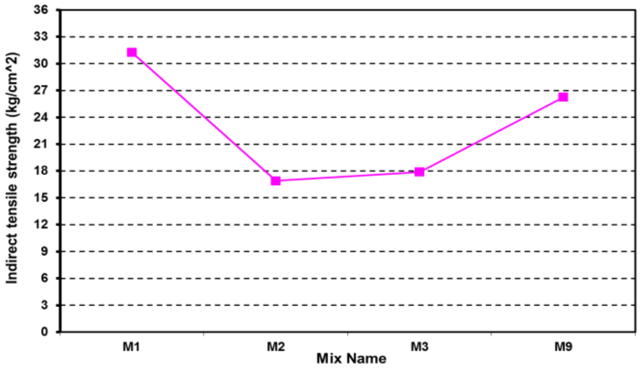

Figure (16): Effect of Addipore55 on the indirect tensile strength with different cement content

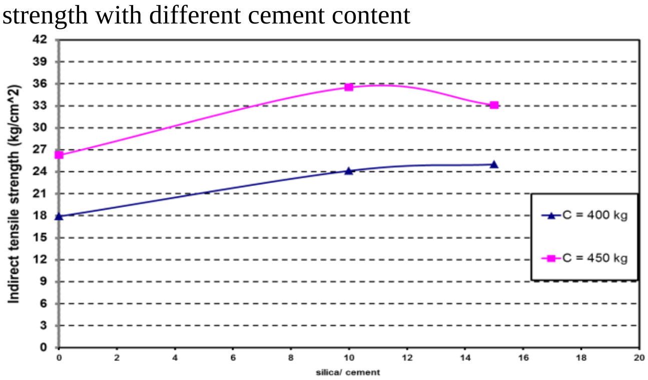

Figure (17): Effect of using silica on indirect tensile strength with different cement content 400 and 450 kg compared to control mix

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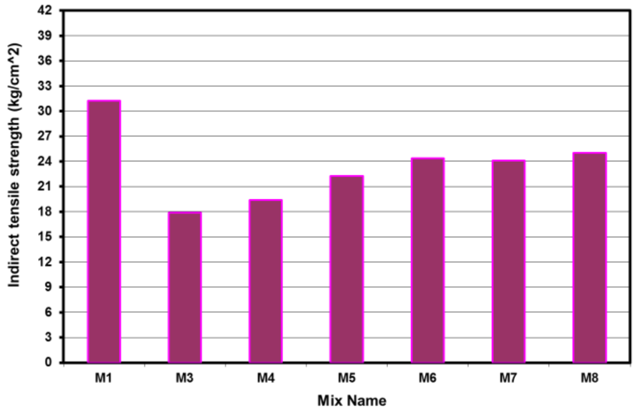

Figure (18): Effect of using cement content 400 on indirect tensile strength

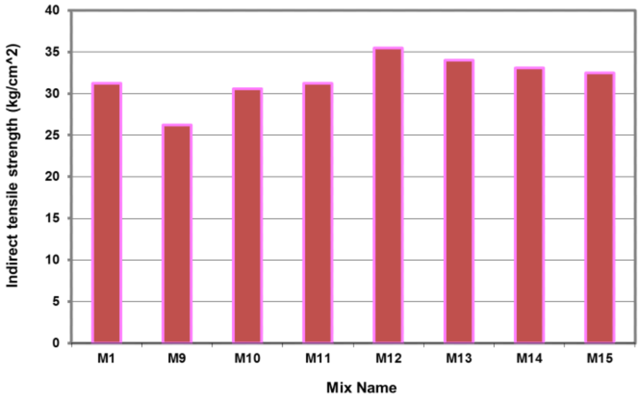

Figure (19): Effect of using cement content 450 on indirect tensile strength

IV-1-3-The Flexural Strength of Concrete

Figures (20 to 26) show that the flexural strength of the lightweight concrete was improved by increasing cement content, reduction of water cement ratio (w/c), using admixtures and using silica fume. Increasing cement content from 350 to 400 and 450 kg/m^3 improved the flexural strength of the lightweight concrete. The maximum increasing of the bending stress of lightweight concrete was at the mix M12 by 112.5 % with cement content 450 kg/m^3 compared to the control mix.

Reduction of water cement ratio (w/c) in concrete mix improved the flexural strength as (40 % and 35 %) for mix (M8 and M12) with w/c as (0.4 and 0.42) compared the mix M3 and M9 with 400 kg/m^3 and 450 kg/m^3 of cement respectively. Increasing of Super plasticizer admixtures to cement by 2% and 1.5%) of mix (M8 and M11) enhance the flexural strength by (40 % and 19%) compared the mix M3 and M11 with (0% Admixtures) containing 400 kg/m^{3}and 450 kg/m^3 cement content respectively without S.F. Increase of using silica fume (S.F.) as a replacement of cement to 15% and 10% (M8 and M12) improve the flexural strength by (40% and 35%) for cement content 400 and 450 kg/m3 respectively.

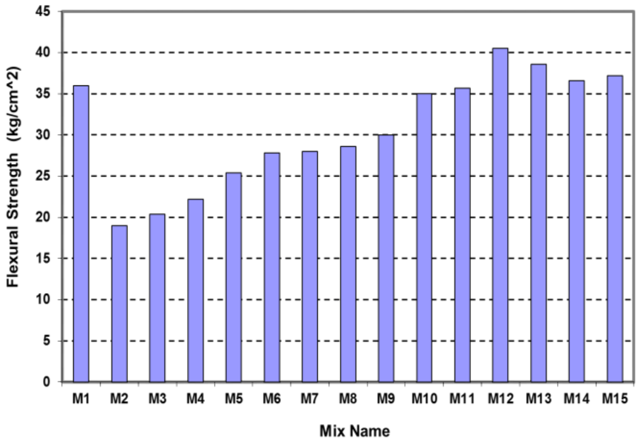

Figure (20): Flexural Strength of all Concrete Mixes

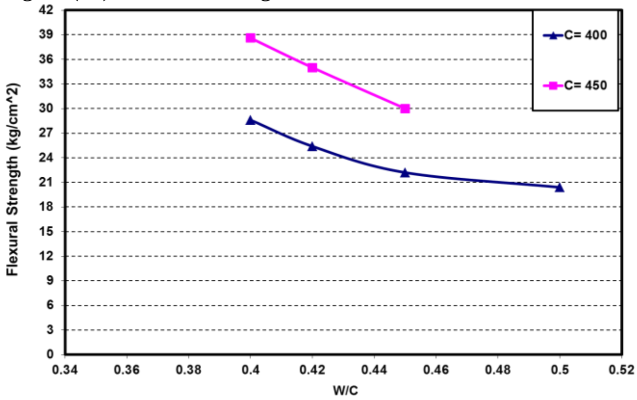

Figure (21): Effect of Water / Cement Ratio on the Flexural Strength of LWC and NC with Different Cement Content at 28 days

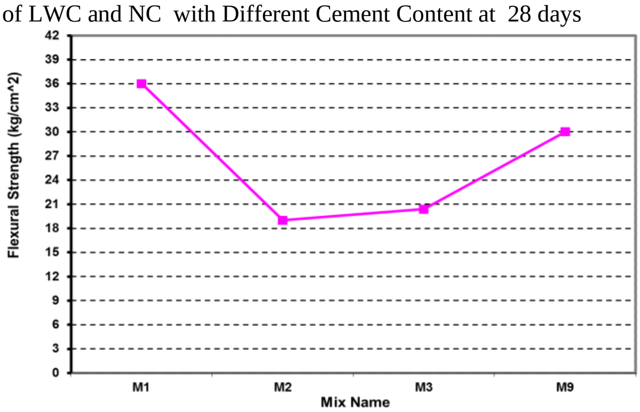

Figure (22): effect of Addipore55 on the Flexural Strength of LWC and NC with Different Cement Content at 28 days

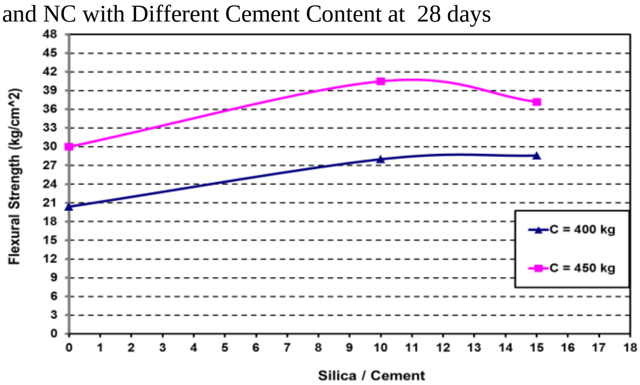

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Figure (23): Effect of Silica Fume on the Flexural Strength of LWC and NC with Different Cement Content at 28 days

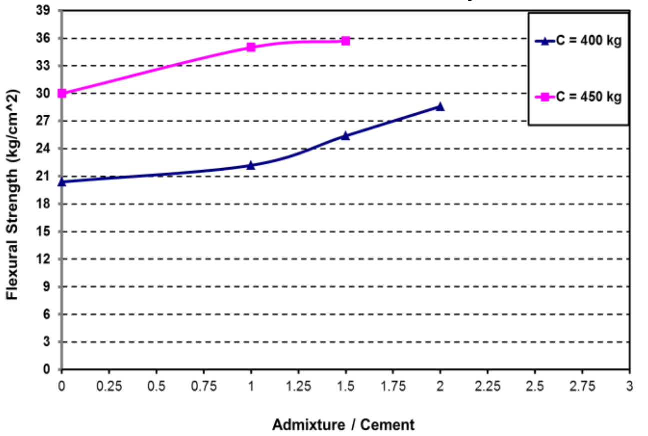

Figure (24): effect of admixtures on the flexural strength of LWC and NC with Different Cement Content at 28 days

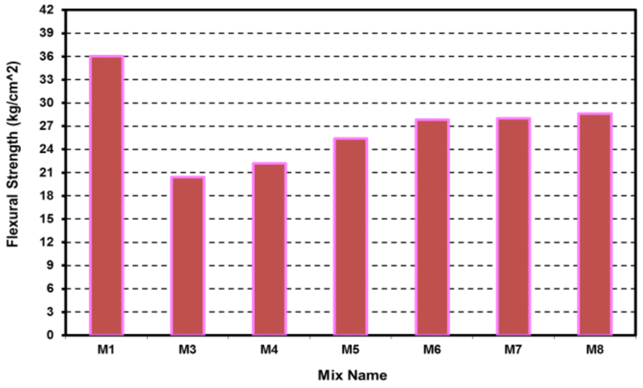

Figure (25): Effect of Using Cement Content 400 on the Flexural Strength

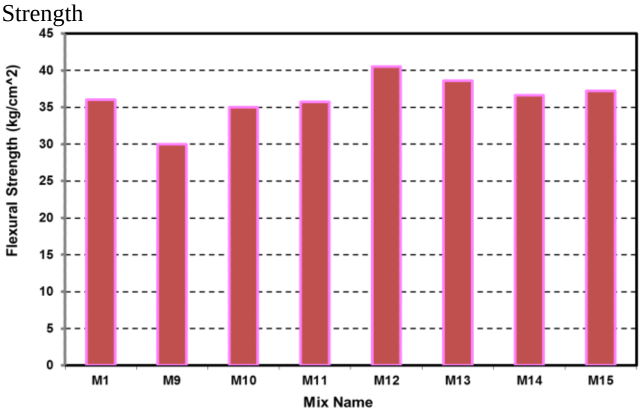

Figure (26): Effect of Using Cement Content 450 on the Flexural Strength

Table (4) : The Properties of Different Hardened Concrete Mixes

Mixes	Compressive Strength (kg/cm^2)		Specific Compressive Strength ($kg/mm^2/g$)	Indirect Tensile Strength (kg/cm^2)	Specific Indirect Tensile Strength ($kg/mm^2/g$)	Bending Resistance (kg/cm^2)	Specific Bending Resistance ($kg/mm^2/g$)
	7 days	28 days					
M1	170	250	106.8	31.25	13.35	36	15.38
M2	90	135	73	16.9	9.14	19	10.27
M3	95	143	75.3	17.9	9.42	20.4	10.74
M4	110	155	81.6	19.4	10.21	22.2	11.68
M5	130	178	92.7	22.25	11.6	25.4	13.23
M6	133	195	100.5	24.4	12.58	27.8	14.33
M7	150	193	99	24.12	12.37	28	14.36
M8	160	200	102.6	25	12.82	28.6	14.7
M9	143	210	107.7	26.25	13.46	30	15.38
M10	160	245	123.7	30.6	15.45	35	17.7
M11	165	250	125	31.25	15.625	35.7	17.85
M12	190	284	135.2	35.5	16.9	40.5	19.29
M13	180	270	135	34	17	38.6	19.3
M14	180	265	129.3	33.1	16.15	36.6	17.85
M15	170	260	128	32.5	16.	37.2	18.3

IV-2- Structural Performance of Beams

Out of the fifteen concrete mixes tested in this study, two mixes were chosen (M8 and M12) casting in the R.C beams and slabs. M8 and M12 had compressive strength 200 and 280 kg/cm^2 respectively, at 28 days age. However, M1 which was cast with normal concrete and compressive strength 250 kg/cm^2.

IV-2-1 First Cracking Loads and Ultimate Loads

The cracking and ultimate loads of all the tested beams are listed in Table (5). Figure (27) shows the first cracking loads Pcr and ultimate loads Pu for all the tested beams.

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Beams cast with fcu 280 kg/cm² indicated higher values of first crack and ultimate loads. The values of increasing depend on the reinforcement percentage and compressive strength of the concrete.

First cracking loads for beams (E, A and G) cast with lightweight concrete M12 with fcu 280 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) increased by about (20%, 22.2% and 25%) respectively compared to the normal control beams (B, F and C) with the same reinforcement and fcu 250 kg/cm². However the initial crack load of beams (D, I and H) cast with lightweight concrete M8 with fcu 200 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) decreased by about (40%, 33.3% and 37.5%) respectively compared to the normal control beams (B, F and C). The increasing of reinforcement in lightweight concrete increased the initial crack load which is the same of normal concrete. The increase may be referred to the increase the compressive strength of concrete. (In the range of this study).

The ultimate loads for beams (E, A and G) cast with lightweight concrete M12 with fcu 280 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) increased by about (24.1%, 29.4% and 30.4%) respectively compared to the normal control beams (B, F and C) with the same reinforcement and fcu 250 kg/cm². However the ultimate load of beams (D, I and H) cast with lightweight concrete M8 with fcu 200 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) decreased by about (31.7%, 24% and 24.7%) respectively compared to the normal control beams (B, F and C). The increasing of the reinforcement in lightweight concrete beams increased the ultimate load which is the same of normal concrete. The increase may be referred to the increase of the compressive strength of concrete and the increasing of reinforcement. (in the range of this study).

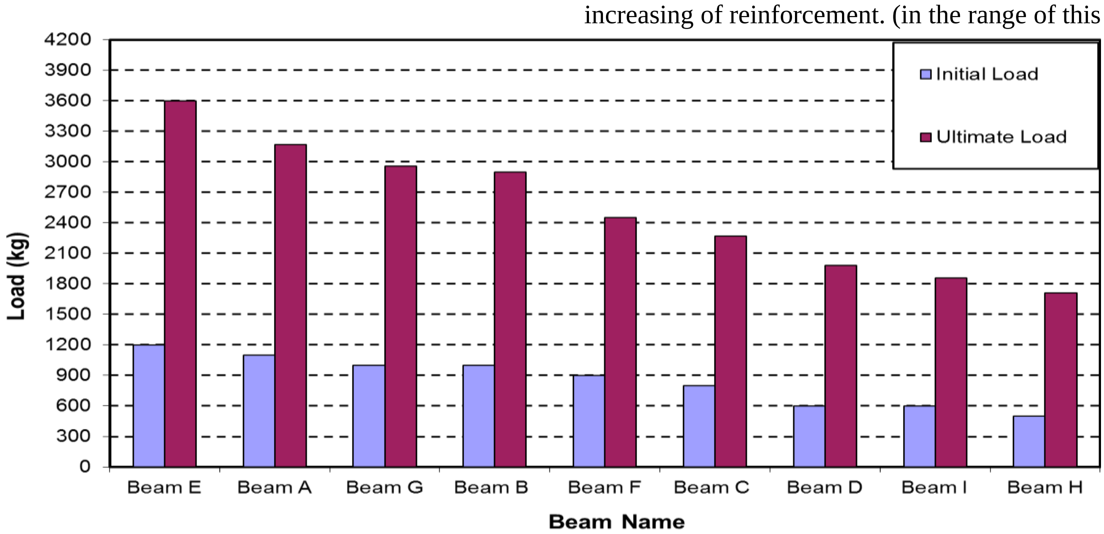

Figure (27): Initial Crack , Ultimate Load for all beams

IV-2-2 Deflection Values

The load-deflection curves of all beams can be seen in Figures (28 to 32). It can be seen that the load is proportion to the deflection values before cracking of concrete. The mechanical behaviors of all beams have three stages. The first stage is elastic stage. The load-deflection relationship is linear (load is proportion to deflection values). It ends once the first crack emerges. The second stage is crack propagation stage. The load-deflection relationship is nonlinear line (curve). The third stage is failure stage.

The deflection values of beams cast with lightweight concrete M8 with fcu 200 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) had the largest deflection values, and the ultimate load was the smallest load value compared to control beams (B, F and C) but the deflection values decreased as the load increased in accordance with the compressive strength of concrete increasing.

For beams (E, A and G) cast with lightweight concrete M12 with fcu 280 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) the decreasing of the deflection values were 12.1%, 6.8% and 10% compared to control beams respectively. The deflection values of the beams cast with lightweight concrete M8 with fcu 200 kg/cm² and the reinforcement (Ø12, Ø10 and Ø8) had the largest deflection values recorded higher deflection values compared to other beams. Their deflection values decreased by about 38%, 39.9% and 22.8% for beams D, I and H compared to the deflection of control beams

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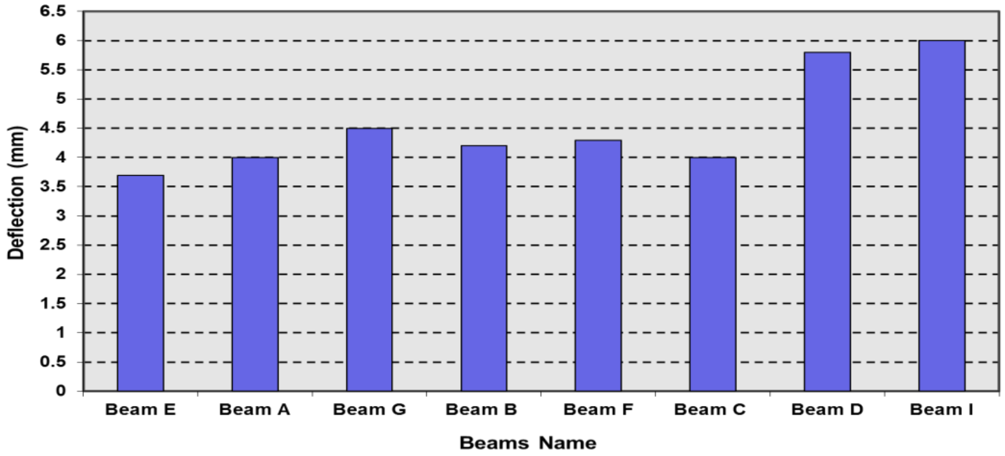

Figure (28): maximum deflections for all beams

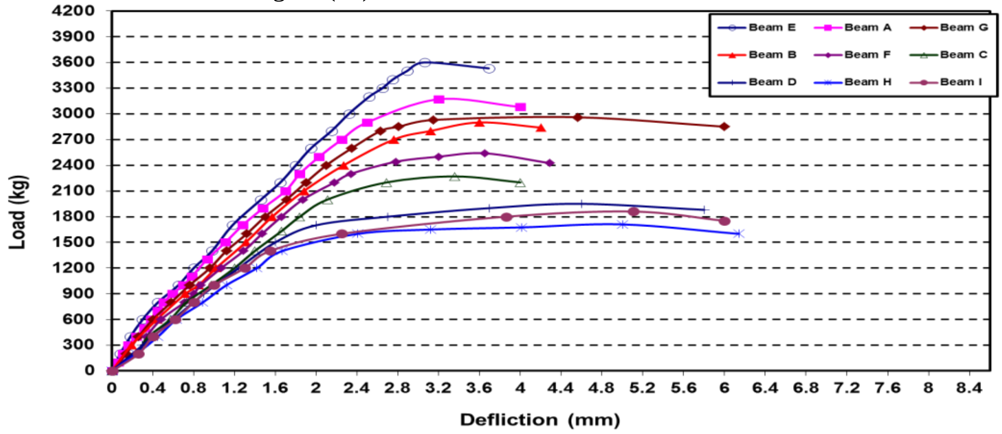

Figure (29): Deflections load curve for all beams

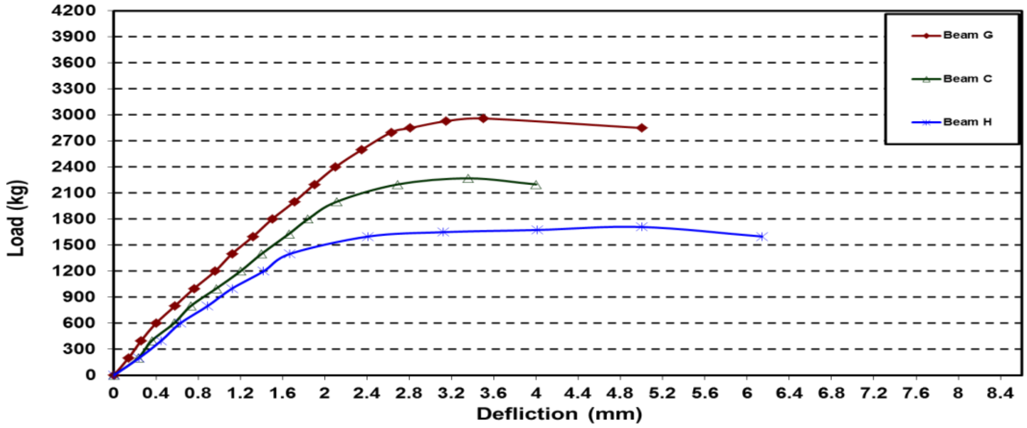

Figure (30): Deflections load curve for Reinforced Beams by 8 mm with different stress concrete 200, 250 and 280 kg/cm^2

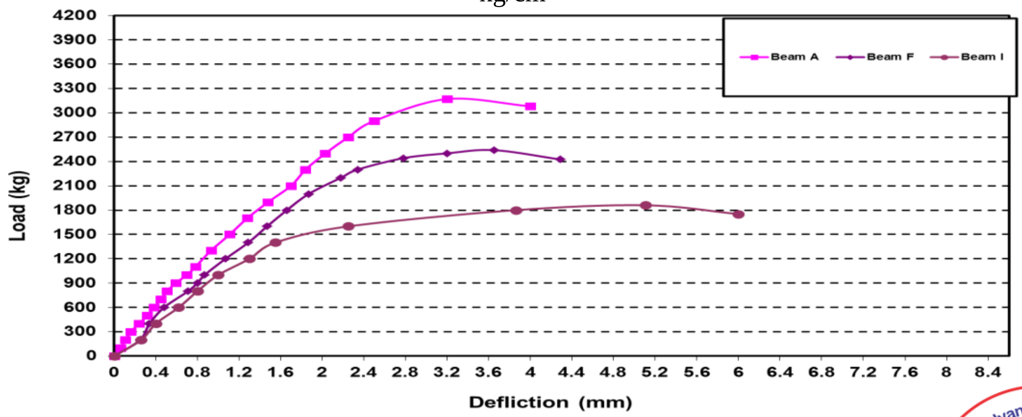

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Figure (31): Deflections load curve for Reinforced Beams by 10 mm with different stress concrete 200, 250 and 280 kg/cm^2

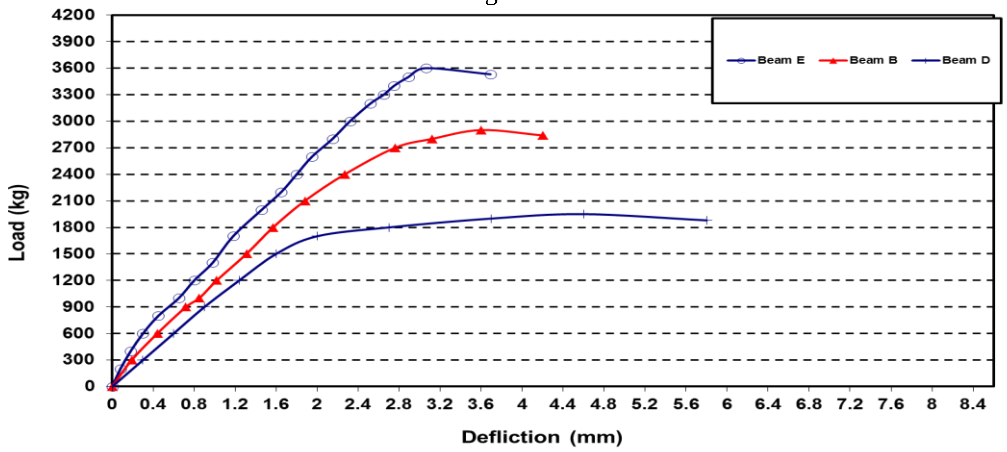

Figure (32): Deflections load curve for Reinforced Beams by 12 mm with different stress concrete 200, 250 and 280 kg/cm^2

IV-2-3 Ductility Ratio

The ductility of the beam can be expressed based on deflection of the beam. According to ACI Committee 363 [29], the first ductility index is defined as $\mu 1 = \Delta\mu \setminus \Delta y$. where $\Delta\mu$ is beam deflection when beam collapsed. Δy is beam deflection when longitudinal reinforcement yielded. According to (Sung et al, 1989) [30], the second ductility index is defined as $\mu 2 = \Delta\mu 0 / \Delta y$. Where, $\Delta\mu 0$ is beam deflection when load is equal to 80% of ultimate load in descending branch of load-deflection curve. The ductility indexes of all beams are listed in Table (5).

It can be seen that from Table (5), the first ductility index µ1of reference beam H is better than recorded for beams. Increasing compressive strength of concrete and main reinforcement decreases the first ductility index µ1. It means that higher compressive strength of concrete make beam flexural ductility fall down.

Table 5. The Ductility Indexes of Tested Beams

Beam	Concrete used	F_{cu}.	Reinforcement of beam used		Initial cracking load *(kg)*	Ultimate load *(kg)*	First Ductility Index $\mu_1 = \Delta\mu \setminus \Delta y$	Second Ductility Index $\mu_2 = \Delta\mu_0 \setminus \Delta y$	Toughness (Kg/cm^2)
			Upper rft	Lower rft					
H	M8	200	2 Ø 6	2 Ø 8	500	1710	9.9	3.06	70
C	M1	250		2 Ø 8	800	2270	5.48	1.78	60.5
G	M12	280		2 Ø 8	1000	2960	7.9	2.70	118.4
I	M8	200		2 Ø 10	600	1860	9.52	2.56	74.4
F	M1	250		2 Ø 10	900	2450	5.36	2.29	70.07
A	M12	280		2 Ø 10	1100	3170	6.85	2.60	84.6
D	M8	200		2 Ø 12	600	1980	9.67	3.92	76.6
B	M1	250		2 Ø 12	1000	2900	4.94	2.52	81.2
E	M12	280		2 Ø 12	1200	3600	4.61	3.13	88.6

IV-2-4 Strain Values

Figure (33) shows the compressive-strain values of tested beams. Test results indicated that the values affected by the type of concrete used and the value of reinforcement. Results indicated also that the values of the strain decreased by noticed values due to the increasing in the stiffness values of the beam samples.

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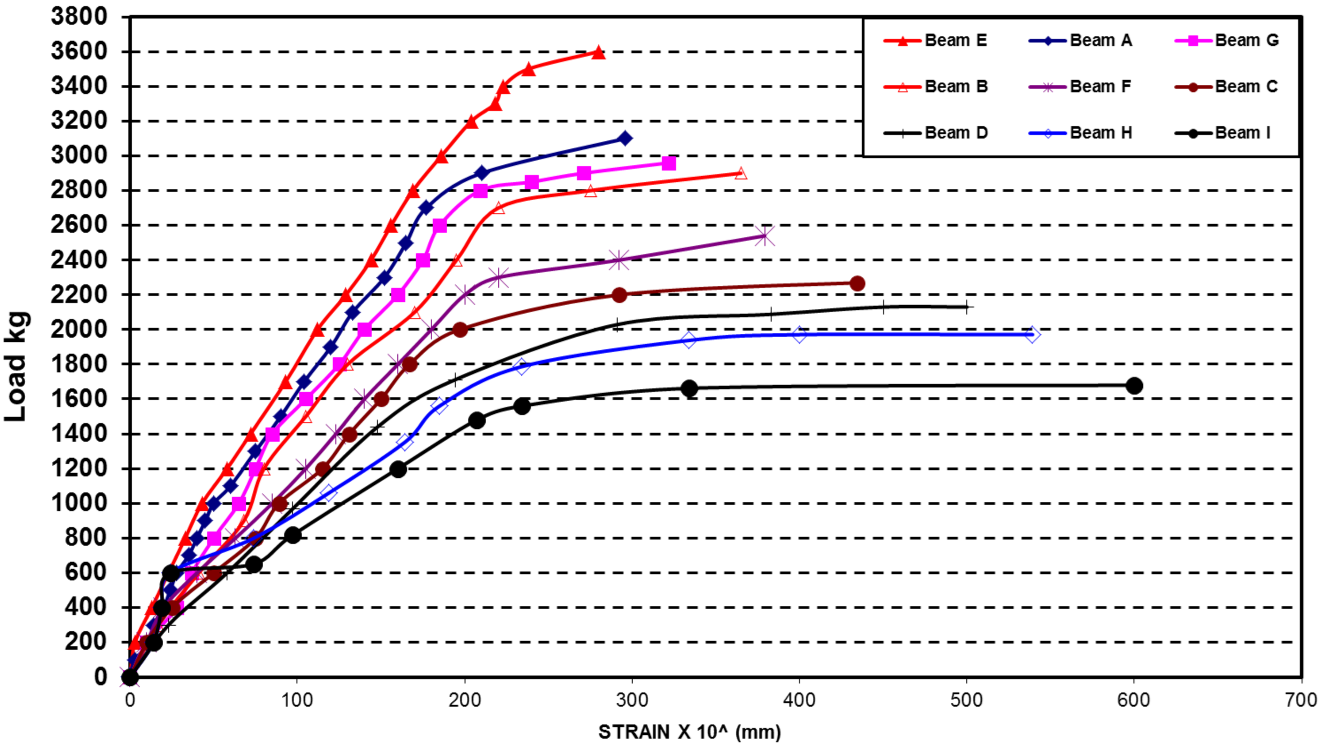
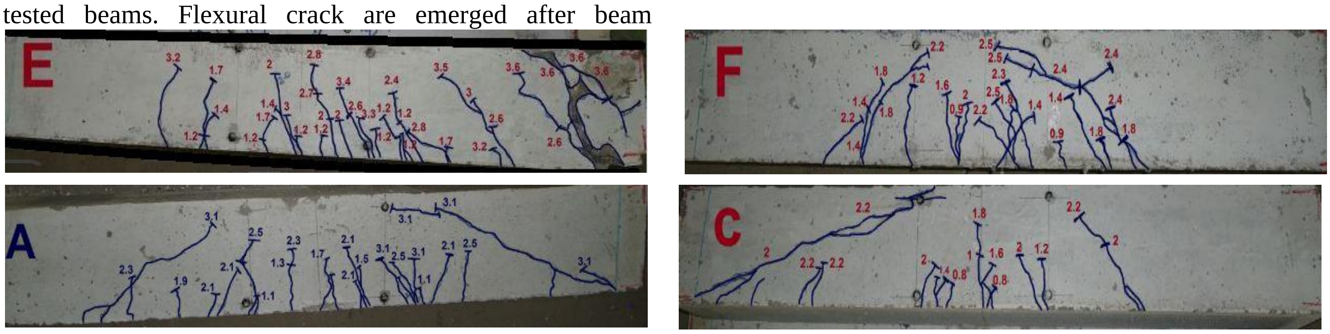


Figure (33): Strain load curve for all beams

IV-2-4 Crack pattern

Figure (39) illustrate an example for crack pattern of some tested beams. Flexural crack are emerged after beam collapsed. The number of cracks decreased as both value of reinforcement and strength of concrete increased.



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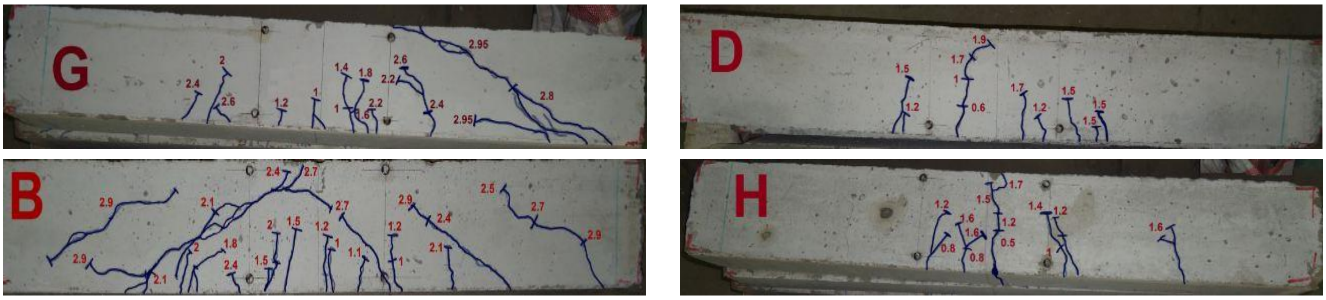

Figure (34): Crack patterns for some of the tested beams

IV-3- Structural Performance of Slabs

Concrete mix M8 had compressive strength fcu 200 kg/cm2 at 28 day ages and Concrete mix M12 had compressive strength fcu 280 kg/cm^2 at 28 day ages, with different main reinforcement (Ø12, Ø10 and Ø8). The Reinforced Concrete Slabs under investigation to study the behavior of the lightweight concrete under the flexural load. However, M1 was the concrete mix with ordinary coarse aggregate with compressive strength fcu 250 kg/cm^2

IV-3-1- Initial crack and ultimate loads

Initial crack load: For slabs (SH10 and SH8) cast with lightweight concrete M12 with fcu 280 kg/cm^2 and the main reinforcement (Ø10 and Ø8) increased the initial crack load by about (40% and 50%) respectively compared to the normal control slabs (SN10 and SN8) with the same reinforcement and fcu 250 kg/cm^2. However the initial crack load of slabs (SL10 and SL8) cast with lightweight concrete M8 with fcu 200 kg/cm^2 and the main reinforcement (Ø10 and Ø8) decreased Initial crack load by about (30% and 25%) respectively compared to normal control slabs (SN10 and SN8). The increasing of reinforcement in lightweight concrete increased the initial crack load the same as for normal concrete. The increase may refer to the increase of compressive strength of concrete. (in the range of this study). See figure (35)

Ultimate load: For slabs (SH10 and SH8) cast with lightweight concrete M12 with fcu 280 kg/cm^2 and the main reinforcement (Ø10 and Ø8) increased ultimate load by about (36% and 44.4%) respectively compared to the normal control slabs (SN10 and SN8) with the same reinforcement and fcu 250 kg/cm^2. However the initial crack load of slabs (SL10 and SL8) cast with lightweight concrete M8 with fcu 200 kg/cm^2 and the main reinforcement (Ø10 and Ø8) decreased ultimate load by about (28% and 7.5%) respectively compared to normal control slabs (SN10 and SN8). The increasing of reinforcement in lightweight concrete increased of ultimate load as the same of normal concrete. The increase may refer to the increase of compressive strength of concrete. (in the range of this study). See figure (35)

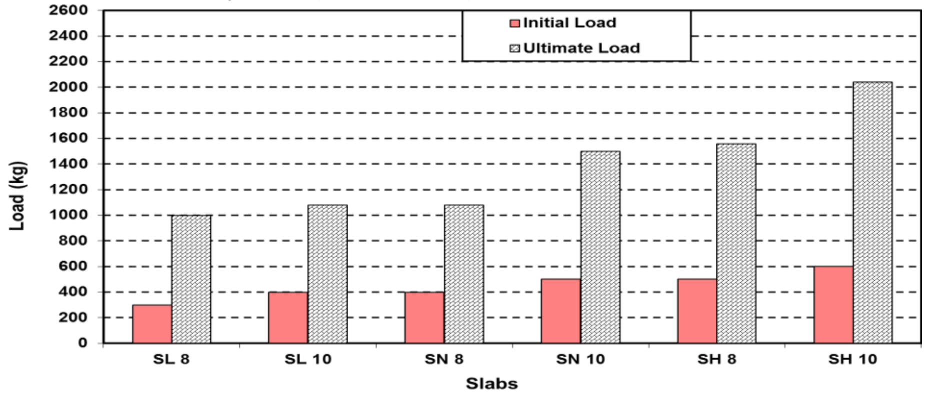

Figure (35): Initial Crack and Ultimate Load for all Slabs

IV-3-2- Deflection Values

Figures (36 and 37) show the load-deflection curves of all the tested R.C. Slabs. For slabs SH10 and SH8 cast with lightweight concrete M12 with fcu 280 kg/cm^2 and the main reinforcement (Ø10 and Ø8) decreased deflection values by about (16.5% and 14.3%) respectively compared to the normal control slabs (SN10 and SN8) with the same reinforcement and fcu 250 kg/cm^2. However the deflection values of slabs (SL10 and SL8) cast with lightweight concrete M8 with fcu 200 kg/cm^2 and the main reinforcement (Ø10 and Ø8) increased ultimate load by about (16.5% and 21.4%) respectively compared to normal control slabs (SN10 and SN8). The increasing of reinforcement in lightweight concrete decreased of deflection values as the same of normal concrete. The increase may refer to the increase of compressive strength of concrete. (in the range of this study).

IV-3-3- Crack pattern

Figure (38) illustrate an example for crack pattern of some tested slabs. Flexural crack are emerged after slab collapsed. The number of cracks decreased as both value of reinforcement and strength of concrete increased.

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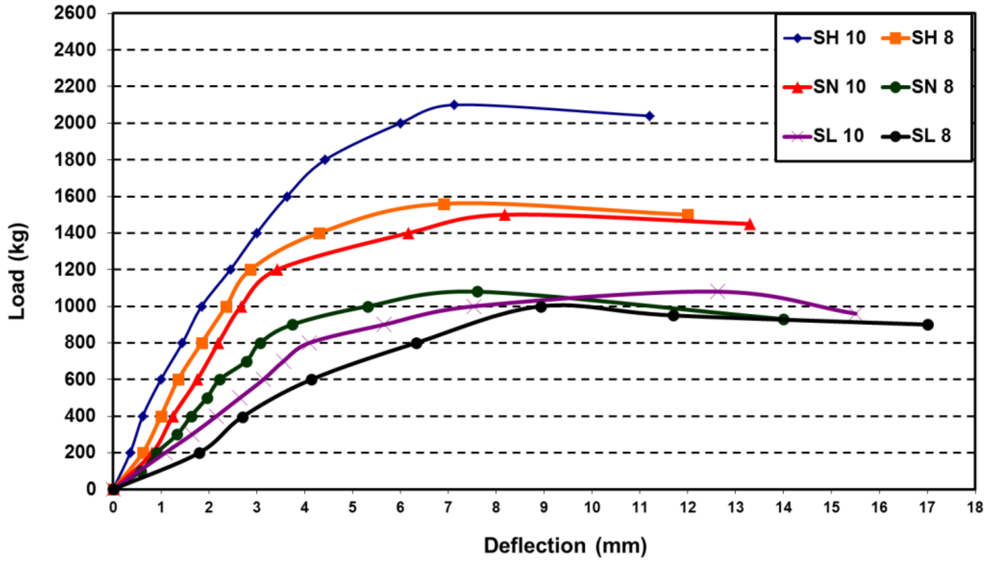


Figure (36): The load deflection curve for all slabs

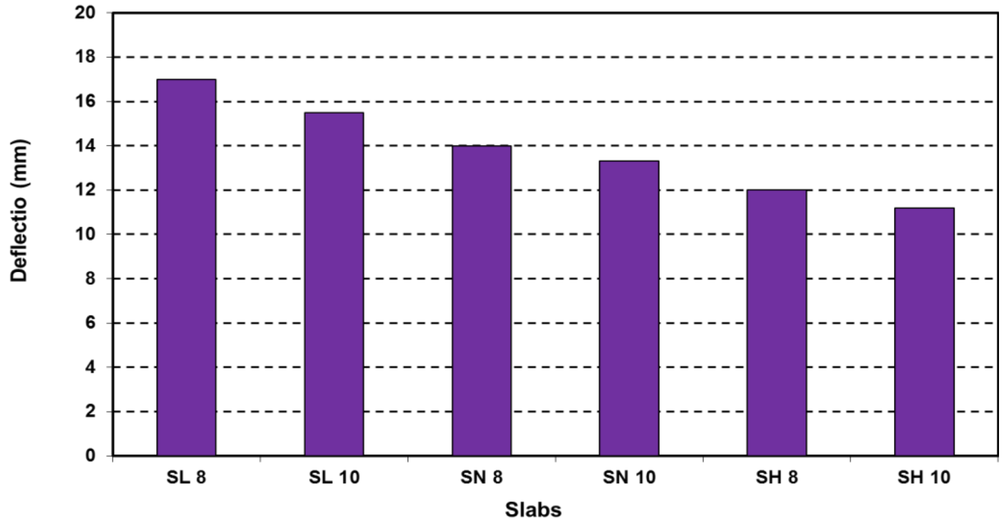
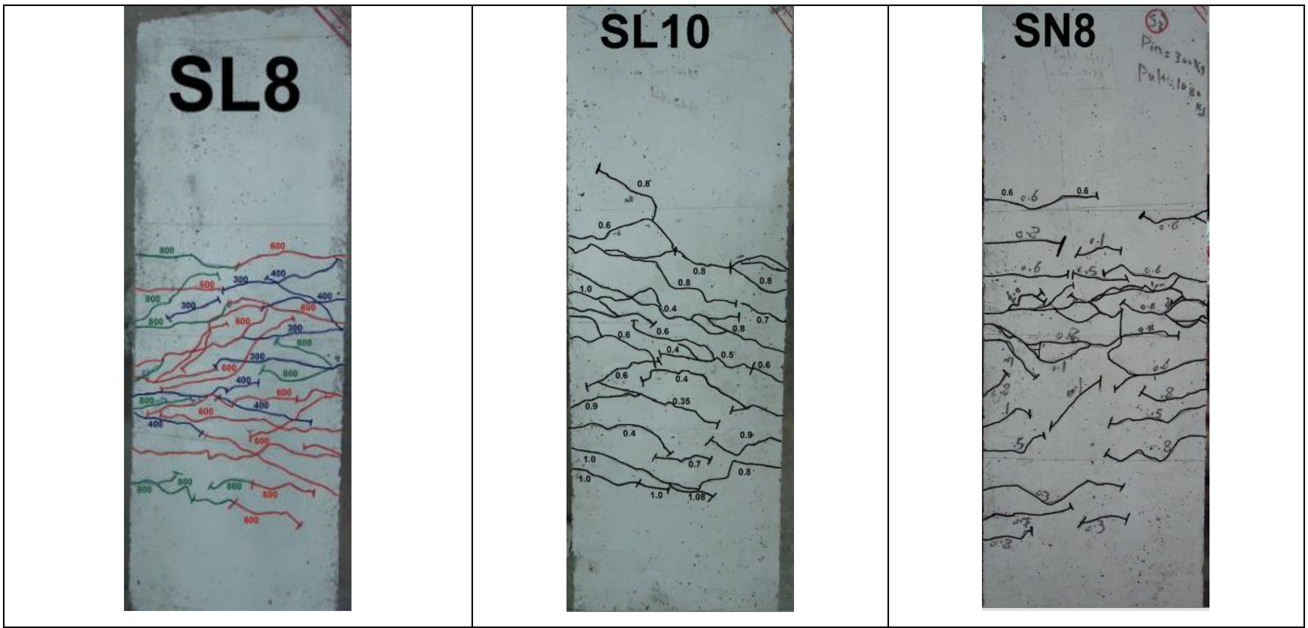


Figure (37): The deflection curve for all slabs



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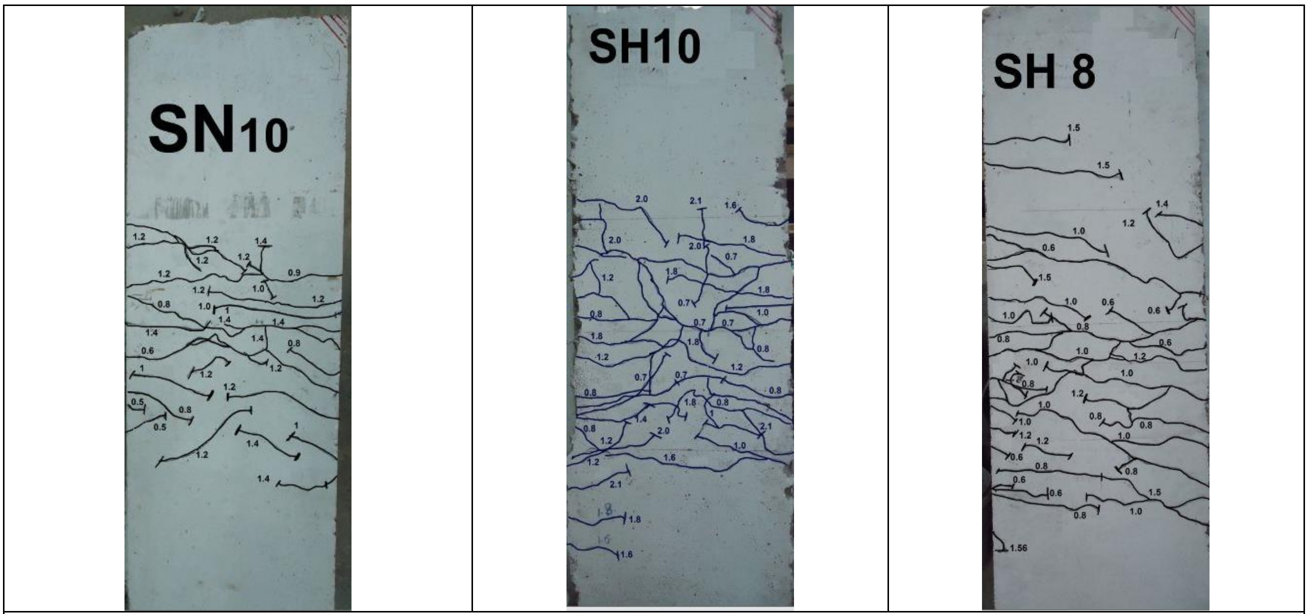

Figure (38): Crack patterns for some of the tested slabs

I. Conclusion

1) Production of lightweight concrete could be achieved to be applied for structural works as well as density of artificial applications.

2) The concrete mix with cement content 450 kg/m^3, compressive strength of 284 kg/cm^2, indirect tensile strength of 35.5 kg/cm^2 and flexural strength of 40.5 kg/cm^2 could be produced using new artificial lightweight aggregate under investigation in this research.

3) Different amounts of cement, silica fume, super plasticizer with 50% replacement of the dolomite aggregate by artificial lightweight aggregate led to concrete mixes with wide span of different physical and mechanical properties.

4) Very close behavior and strength was obtained for beams and slabs cast with ordinary aggregate and partially replaced lightweight aggregate

5) Partial replacement of lightweight course aggregate decreases compressive strength, indirect tensile strength and flexural strength.

6) Increasing water cement ratio decreases the compressive strength, indirect tensile strength and flexural strength.

7) Increases cement content than 350 kg with different W/C increases the compressive strength, indirect tensile strength and flexural strength.

8) The optimum replacement ratio of S.F. to cement was 10% for cement content 450 kg.

9) Increasing the reinforcement in lightweight concrete beams and slabs increased the initial crack and ultimate load which is the same as normal concrete.

10) Increasing the reinforcement in lightweight concrete beams and slabs decreased the deflection value.

11) Increasing the compressive strength of lightweight concrete increases the initial crack and ultimate loads and decreases the deflection values which is the same of normal concrete.

12) The number of cracks decreased as both values of reinforcement and strength of concrete increased.

13) The crack pattern in the tested beams showed flexural failure.

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