

# Flexural Behavior of Composite Reinforced Concrete Slabs

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## Abstract

The main objective of this study is to get more information about the flexural behavior of composite reinforced concrete slabs using two layer of concrete, first layer is light weight concrete (LWC), and second layer is normal weight concrete (NWC), through an experimental tests carried out on five samples different in their details and the position of the concrete type layer within the slabs. In this study, simply supported slabs subjected to one point load were adopted. The effect of concrete grade for the (LWC) was also studied. The light weight coarse aggregate which that used in this study is the expanded light clay aggregate (LECA). Using this type of light aggregate in concrete leads to reducing the weight of composite concrete slabs about (11.4%-17.5%). In this study, one grade of NWC was used of (25 MPa), while three of grade types were adopted for LWC (25 MPa, 18 MPa, 15 MPa).

Keywords: Composite concrete, Light weight concrete, Normal weight concrete.

## سلوك الألواح الخرسانية المركبة المسلحة المعرضة للانحناء

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## الخلاصة

الهدف الرئيسي من هذه الدراسة هو الحصول على مزيد من المعلومات حول سلوك الألواح الخرسانية المسلحة المركبة باستخدام طبقتين خرسانيتين، الطبقة الأولى مصنعة من الخرسانة الخفيفة الوزن (LWC)، والثانية هي من نوع الخرسانة الاعتيادية (NWC)، من خلال الفحوصات العملية والتي اجريت على خمسة عينات مختلفة. في هذه الدراسة، تم اعتماد ألواح خرسانية ذات اسناد بسيط ومعضة لحمل مركز في نقطة واحدة. كما تم تناول تأثير الاختلاف في قيم مقاومة الخرسانة الخفيفة على تصرف الألواح المعتمدة في هذه الدراسة. ان نوع الركام الخفيف الوزنة المستعمل في عمل الخرسانة الخفيفة هو عبارة عن (LECA)، حيث ان استخدام هذا النوع من الركام الخفيف الوزن في عمل الخرسانة المركبة يؤدي الى تقليل وزن السقف المركبة بمقدار يتراوح بين (11.4%-17.5%) بالمقارنة مع الخرسانة الاعتيادية. في هذه الدراسة، تم استخدام خرسانة اعتيادية ذات مقاومة مقدارها (25 ميكا باسكال)، في حين تم اعتماد ثلاثة اصناف لمقاومة الخرسانة الخفيفة الوزن (15، 18، و 25 ميكا باسكال).

## 1. Introduction

Light Weight Concrete (LWC) may be defined as a kind of concrete which includes an expanding agent which has the capability to increase the volume of the mixture while gives addition qualities and reduced the dead weight. It is lighter than the classical concrete with a maximum dry density of  $300 \text{ kg/m}^3$  up to  $1840 \text{ kg/m}^3$ . The using of light weight concrete has been mostly spread across world countries such as USA and UK. Lightweight concrete has strength comparable to normal weight concrete, yet is typically 25% to 35% lighter. The main specifications of the light weight concrete are its little density and thermal accessibility. There are other advantages which are a reduction of weight, faster building rate in construction and lower freightage and also cost (Mohd Roji Samidi, 1997). Light weight concrete can be prepared either by jabbing air in its composition

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or it can be done by cancelling the finer size of aggregate or even replacing them by a blank, porous aggregate. Particularly, light weight concrete can be classified into three groups (Kamsiah Mohd Ismail and Dinar Mohd Nordin, 2003).

(A) No fines concrete.

(B) Light weight aggregate concrete.

(C) Aerated / Foamed concrete.

Using of Light Weight Concrete (LWC) in structural members has most application in Europe and USA ago the 1950s; it has not been used at all in some of world country despite much and economical sources of natural light weight aggregates. The cause for this unwillingness is lack of confidence and technical ignorance. In order to mollify, to some extent, the fear from using this type of concrete in the construction members, Composite Reinforced Concrete (CRC) was suggest to use. The (CRC) slabs consists of two layers, the first one lower layer cast like normal weight concrete (NWC) and the second one layer upper as a layer of light weight concrete (LWC), both layers of concrete are placed in the fresh state, LWC over the NWC. After that, the bond strength will be near to that in normal reinforced concrete elements. Because of the prevalent practice of ready mixed concrete providers, it is workable for some mixers to carry LWC and others lug NWC (Alten F. and Haktanir T., 2001).

The main objective of this study is to get more information about the flexural behavior of composite reinforced concrete slabs using two layer of concrete, the first layer is light weight concrete (LWC) which prepared from light weight coarse aggregate (LECA), while the second one is normal weight concrete (NWC), through an experimental tests carried out on (five) samples different in the concrete strength of LWC layer and the position of the concrete type layer within the member. In this study, simply supported slabs subjected to one point load were adopted.

## 2. Review of literature

Many researchers were interested in studying of the behavior of composite reinforced concrete (CRC) members which consist of two types of concrete materials, light weight concrete (LWC) and normal weight concrete (NWC).

Samuel and Young (1992) showed in their study that the most composite slab designs in the USA are depended on the results of general testing programs. Analytical methods were used in this study for obtaining initial stiffness and strength of composite slabs based on conventional reinforced concrete. The test results of (nine) experimental composite slabs that incorporated typical construction details were showed and compared with results of the analytical expressions.

Altun and Haktanir (2001) achieved a theoretic ultimate strength for composite reinforcement concrete element and studied experimentally the mechanical behavior for many samples of (CRC) elements by subjecting them to bending supported by four point loading frame setup. They showed that general behavior of CRC elements was like normal reinforced concrete elements with special advantage of reducing the weight of constructions. As a general rule of this study, it was determined that the ultimate load bearing capacity of the composite reinforcement concrete flexure elements drops about (20) %, while the reduction in gross weight was about (35) % as compared with normal weight concrete elements. The vertical displacements under bending moments of the composite reinforced concrete elements within specifications limits. The depths of such slabs can be increased for the purpose of keeping the deflections yet smaller.

Yardim et. al (2013) showed that the using of Autoclaved Aerated Concrete (AAC) as an in fill material for semi precast panel was investigate empirically. The activity of suggested light weight slab was reach by comparing the behavior of samples with that of normal solid slab. The comparison was based on the structural performance and the reduction in total weight of concrete. The composite autoclaved aerated concrete slabs section chosen was one way slabs with a size of

(Width×Length×Depth) (1m×3m×0.13m). The samples vary in the autoclaved aerated concrete blocks layouts and the ratio of total weight reduction. The results of test showed that the autoclaved aerated concrete composite precast panel gives reasonable weight reduction without victimization the structural capacity.

### 3. Experimental investigations

#### 3.1 Materials

The materials used in this investigation are cement, natural gravel, light weight coarse aggregate (LECA), natural silica sand, water, and deformed reinforcement bars. Tables(1, 2, and 3) show the properties of the used cement, reinforcement bars, and aggregates, respectively.

Figures(1 and 2) show the results of sieve analysis according to ASTM C33-2003 for fine and normal coarse weight, respectively. Figure(3) shows the results of sieve analysis for light coarse aggregates according to ASTM C330-2004.

Table 1. Properties of the used cement and Iraqi specifications.

Cement Properties	Test result	Iraqi Specifications
Fineness using Blaine air permeability apparatus ( $\text{m}^2/\text{kg}$ )	310	250 min.
Setting time using Vicat's instrument		
Initial (min)	140	45 min
Final (min)	250	600 min
Compressive strength for cement		
3 days (MPa)	18.2	15 min.
7 days (MPa)	29.0	23 min.
$\text{SiO}_2$	22.3	-
$\text{Al}_2\text{O}_3$	4.2	-
$\text{Fe}_2\text{O}_3$	6.1	-
CaO	61.0	-
MgO	4.5	Not more than 5%
$\text{SO}_3$	1.8	Not more than 2.5%
Loss on Ignition	2.4	Not more than 4%
Insoluble Residue	0.96	Not more than 1.5%
Lime Saturation Factor	0.88	0.66-1.02
$\text{C}_3\text{A}$	2.9	Not more than 3.5%

Table 2. Physical properties of steel reinforcement and ASTM Requirements.

Bar Diameter (mm)	16	ASTM A615 Requirements
Yield Strength ( $\text{N}/\text{mm}^2$ )	509	Not less than 420
Ultimate Strength ( $\text{N}/\text{mm}^2$ )	680	Not less than 620
Elongation (%)	17.5	Not less than 9%

Table 3. Physical and chemical properties of used aggregates.

Properties	Test Result		
	Fine aggregate	Normal weight aggregate	Light weight aggregate
Density ( $\text{kg}/\text{m}^3$ )	1650	1620	373
Specific gravity	2.60	2.64	1.3
$\text{SO}_3$ (%)	0.39	0.075	0.048
Cl (%)	0.06	0.091	0.081
Absorption (%)	0.05	0.09	17.0

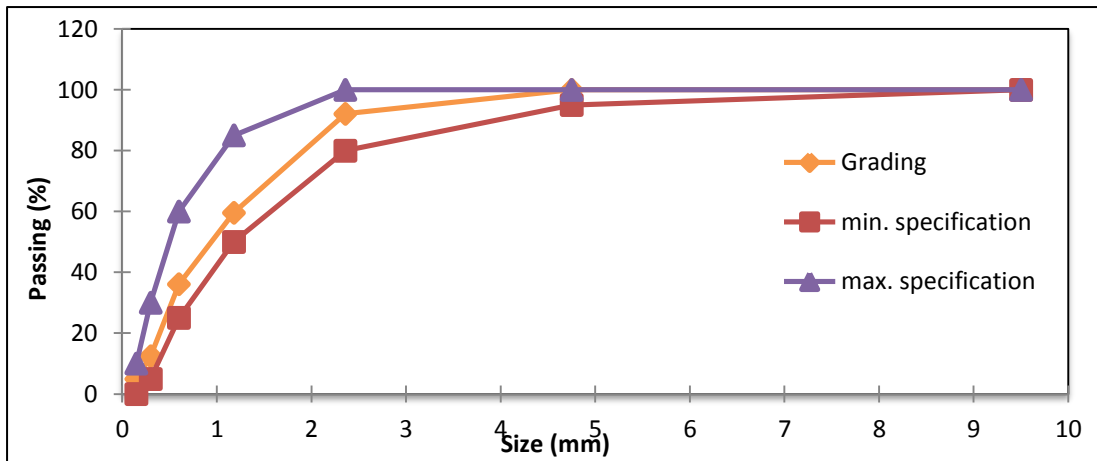


Figure 1. Results of sieve analysis for fine aggregate.

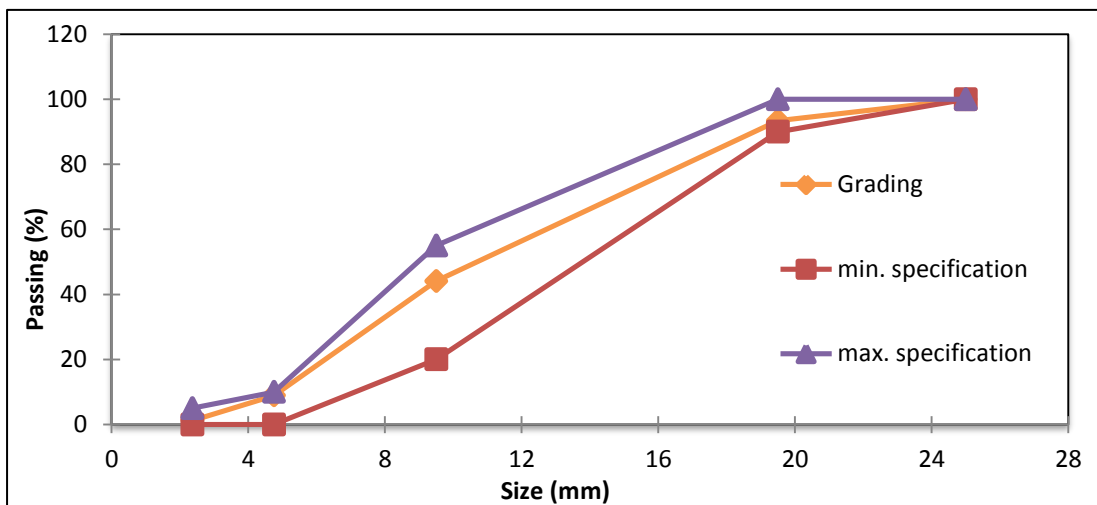


Figure 2. Results of sieve analysis for normal weight coarse aggregate.

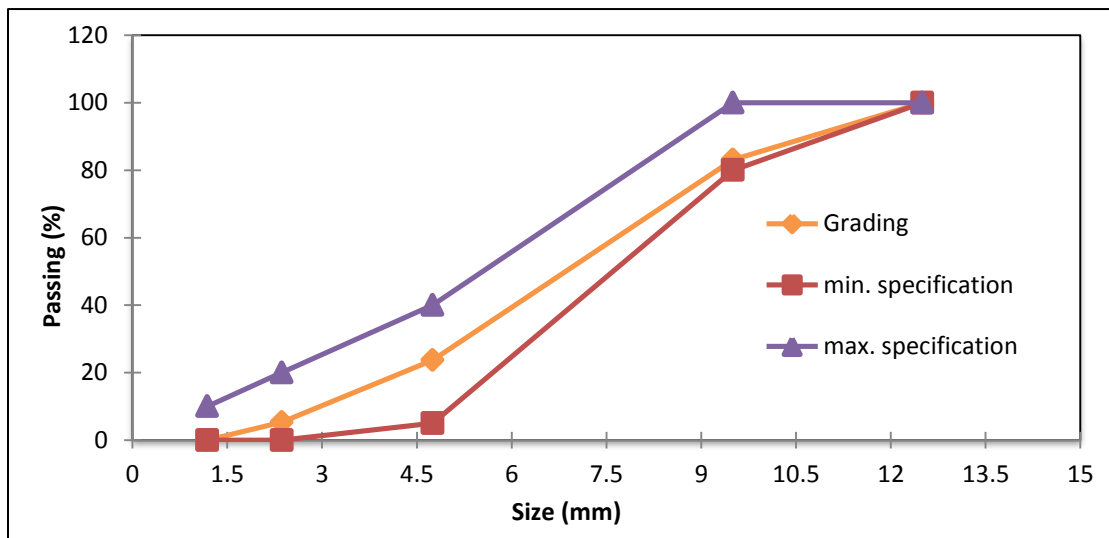


Figure 3. Results of sieve analysis for light weight coarse aggregate.

### 3.2 Concrete mix design

Table (4) shows the components of mixes which designed according to (ACI 211.1.91), where using the LWC in composite slabs causes reducing in the weight of these slabs about (11.4%-17.5%). Table (5) shows the properties of hardened concrete for these mixes.

Table (4) Components of mixes

Mix grade and code	W/C	Water (kg/m <sup>3</sup> )	Cement (kg/m <sup>3</sup> )	N.W Coarse agg. (kg/m <sup>3</sup> )	L.W Coarse agg. (kg/m <sup>3</sup> )	Fine agg. (kg/m <sup>3</sup> )
NWC (25 MPA)	0.51	193	380	1085	0	722
LWC1 (25 MPA)	0.48	220	460	380	162	615
LWC2 (18 MPA)	0.50	230	460	200	217	605
LWC3 (15 MPA)	0.51	235	460	0	250	600

Table (5) Properties of hardened concrete (Average values).

Concrete Type	Cube Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Modulus of Rupture (MPa)	Elastic modulus (GPa)
NWC	27.59	1.96	5.47	25.1
LWC1	23.29	1.84	3.72	22.9
LWC2	18.03	1.80	3.91	18.6
LWC3	15.07	1.56	3.60	17.5

### 3.3 Details of tested slabs samples

Slabs were cast in timber forms with plywood face. Prior the casting and before placing of reinforcement cage in its position, the forms were coated with oil. After casting, the level of top surface of the samples was finished. Thereafter, the samples were cured one day after casting by using damp canvas for 28 days. Table (6) shows the details of the tested samples, while Fig. (4) an illustration for these samples.

Table (6) Details of tested slabs samples.

Sample code	Dimensions (cm)				Design Load (P) (KN)	Design Moment Capacity (M <sub>d</sub> )(KN.m)	Description of Samples
	Width (W)(cm)	Length (L)(cm)	Thickness of Normal layer (T <sub>N</sub> ) (cm)	Thickness of light weight layer (T <sub>L</sub> )(cm)			
MAS1	80	80	6 <sup>(4)</sup>	6 <sup>(1)</sup>	105.0	14.0	Normal weight concrete in reinforcement zone
MAS2	80	80	12 <sup>(4)</sup>	0	105.0	14.0	Normal weight concrete only
MAS3	80	80	6 <sup>(4)</sup>	6 <sup>(2)</sup>	105.0	14.0	Normal weight concrete in reinforcement zone
MAS4	80	80	6 <sup>(4)</sup>	6 <sup>(3)</sup>	105.0	14.0	Normal weight concrete in reinforcement zone
MAS5	80	80	6 <sup>(4)</sup>	6 <sup>(2)</sup>	105.0	14.0	Light weight concrete in reinforcement zone

#### Notes:

- (1) Light weight mix concrete LWC1 (F<sub>c</sub> = 25 Mpa).
- (2) Light weight mix concrete LWC2 (F<sub>c</sub> = 18 Mpa).
- (3) Light weight mix concrete LWC3 (F<sub>c</sub> = 15 Mpa).
- (4) Normal weight mix concrete NWC (F<sub>c</sub> = 25 Mpa).

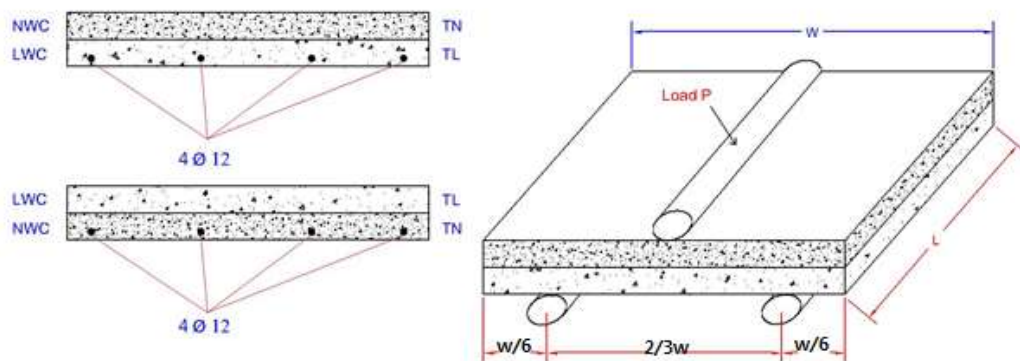


Figure 4. Details of tested slabs.

### 3.4 Instrumentation and test procedure

The samples were painted to facilitate tracing the cracks. Thereafter, the demecs were attached using an epoxy resin at sections of maximum bending moment so as to measure strains between these points by using mechanical strain gauge with gauge length of 100 mm and accuracy of 20 micro strains. The mid-span deflection of each sample was measured by using dial gauge with magnetic base. The accuracy of the dial gauge was 0.01mm. Width of concrete cracks were monitored using hand microscope of accuracy 0.02mm per division. The samples were tested at age of 28 days, and the supports were of the roller type. The bottom spreader consisted of two universal steel I section beams.

Each sample was loaded from top at the center of the top spreader. Where the load was applied in equal increments. At each load level, mid-span deflection, concrete strain, and crack width were measured. Figure (5) shows the test equipment.



Figure 5. Test equipment

### 3.5 Design load and moment capacity

As mentioned previously, the samples designed as simple supported slabs. Their design load and moment capacity are calculated according to ACI-318, where these values are listed in Table (7).

Table 7. Measuring and design values for loads and moment capacity for the tested samples slabs

Sample code	Design Load (KN) (P)	Measured Load failure (KN) (P <sub>m</sub> )	P <sub>m</sub> /P %	First Crack Load (KN) (P <sub>crack</sub> )	P <sub>crack</sub> /P <sub>m</sub> %	Design Moment Capacity (KN.m) (M <sub>d</sub> )	Calculated Moment Capacity (KN.m) (M <sub>c</sub> )
MAS1	105.0	100	95.2	20	20.0	14.0	13.3
MAS2	105.0	98	93.3	20	20.4	14.0	13.1
MAS3	105.0	92	87.6	20	21.7	14.0	12.3
MAS4	105.0	95	90.5	20	21.1	14.0	12.7
MAS5	105.0	105	100.0	20	19.1	14.0	14.0

## 4. Discussion of test results

### 4.1 General behavior of samples under loading

The tested slabs samples were designed to fail by bending where their general behavior under the applied load is same and all the samples failed under flexural effect.



The first visible cracks have been observed at the bottom face of slabs at load levels ranging between (19.1-21.7) % of the measured load, as shown in Table (7). As the load increases, these cracks widened and grown upward to the supports.

Generally, for all tested samples, deflection values at mid span of the bottom face for these samples increased with increasing the applied load until the load level at which the first visible crack appears. Thereafter, deflection values increase at an increasing rate until failure load, as shown in Figs. (6, 8, and 10). This could be explained that all the applied load, before cracking, was resisted by the concrete at the tension zone, thereafter, most of the applied load was resisted by steel reinforcement at this zone until the failure load.

From the load-strain curves shown in Figs. (7, 9, and 11), we can observe that the strain values were too small before appearing of the first crack, thereafter, the strain values increased largely and irregular because of the large number of cracks that appear at different areas of the sample, some of these cracks appeared at measurement area, and other cracks appeared beside it, so we observed that the load strain curves did not take regular path and were winding.

## 4.2 Parameters of the study

The parameters that investigated in this study are the effect of LWC layer, strength of LWC layer, and position of (LWC) top or bottom of the (NWC).

### 1- Effect of LWC layer

To study the effect of LWC on the behavior of composite concrete slabs, two samples were adopted; the first one is MAS1 is a composite slab consists of NWC at reinforcement zone of (6mm) thickness and (6mm) of LWC layer lies over of NWC layer. The second one is MAS2 is made of NWC alone. Table (6) shows that the two samples have the same dimensions and reinforcement details. Also, the designed concrete strength for the LWC and NWC is (25MPa).

The general behavior under loading for the two models, was same, as it discussed previously. Table (7) shows that the load at which first visible cracks appear for sample MAS1 and MAS2 is same (20KN), while the failure loads for the two models are very close.

Figure (6) shows the relationship between the applied load and deflection at the bottom face of the mid-span for the two tested samples. The values of mid span deflection for sample MAS2 larger compared to that of sample MAS1. The reason of this behavior may be illustrated due to the presence of LWC layer in sample MAS1.

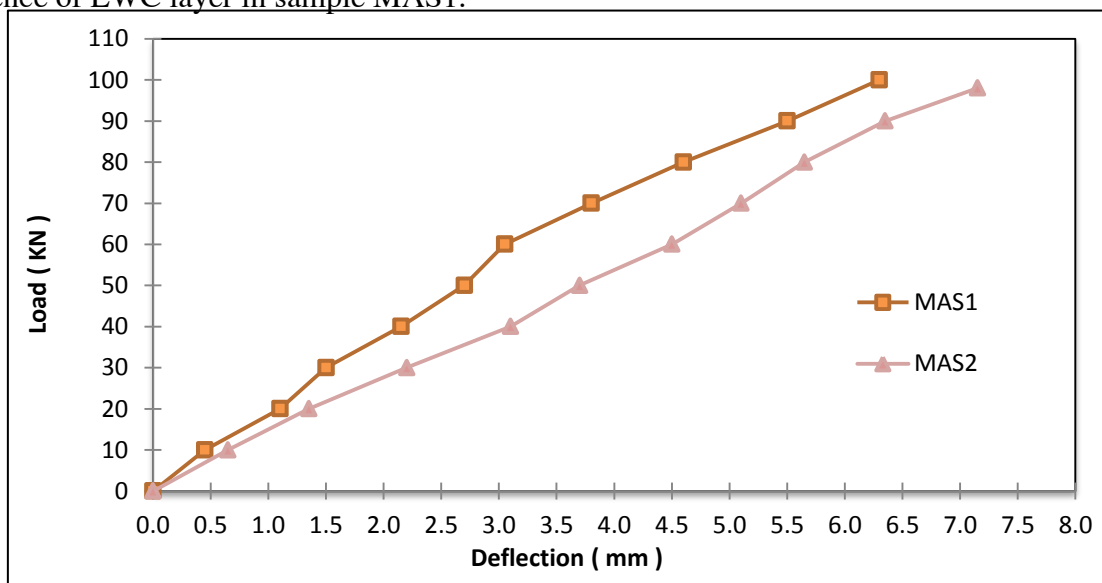


Figure 6. Load-mid span deflection curve for samples (MAS1 and MAS2)

Figure (7) shows the relationship between the applied load and strain values at mid-span for samples MAS1 and MAS2. This figure shows that strain values were small before appearing of first cracks. After that, it was noticed an irregular and large increase in these values. Because of the NWC which casted at the reinforcement zone of the sample, it can be observed that strain values for the two samples were somewhat close.

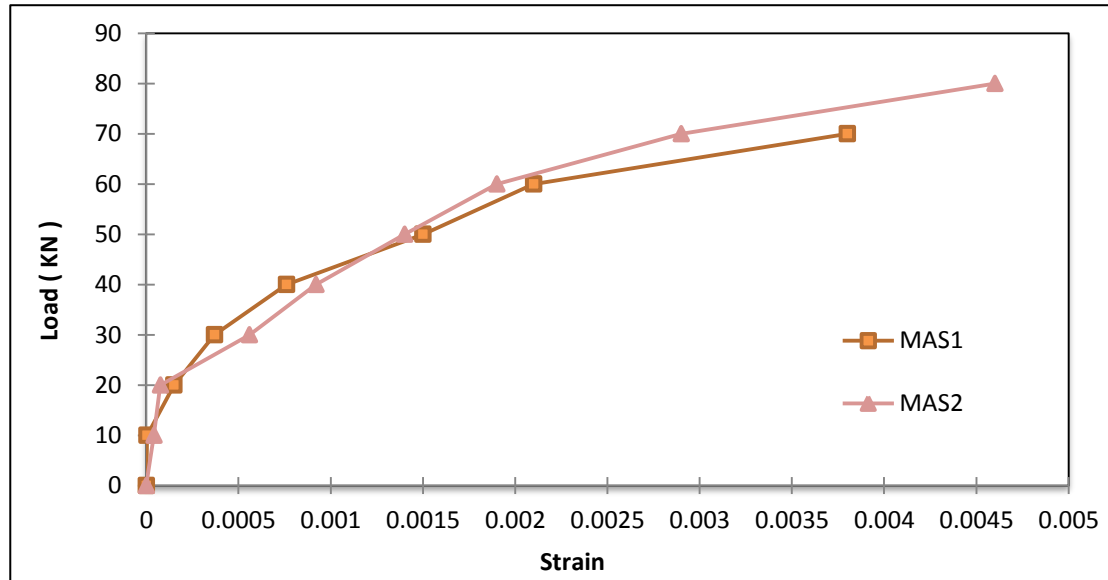


Figure 7. Load-mid span strain curve for samples (MAS1 and MAS2)

## 2- Concrete Strength of LWC

Table (3) shows that the designed compressive strength for the adopted normal weight concrete mix ( $f_{cu}$ ) is (25.0MPa), while the designed compressive strength for light weight concrete mixes are (25MPa, 18MPa, and 15MPa) for mixes LWC1, LWC2, and LWC3, respectively.

To study the effect of the concrete strength, three samples were adopted which are MAS1, MAS3, and MAS4. As shown from Table (6), the three samples have the same details but they are differing in the concrete strength of the LWC.

As mentioned previously, all the tested samples have the same general behavior under the effect of applied load. From the test results, it can be noticed that the loads of the first cracks and failure loads are close for three samples. Taking into consideration that ultimate load for MAS1 largest compared with other samples, the differences in the failure loads was not more than 8%, while the load at which the first cracks appear is (20KN) for the three samples, as shown in Table (7). From the relationship between the applied load and deflection at the bottom face of the mid-span for the three samples shown in Figure (8), it could be noticed that the measured values of mid span deflections for the three samples are very close along the loading process. The reason for this rapprochement in results may be due to NWC strength at the level of steel reinforcement have the same value.

As mentioned previously, the strain values for the three samples were too small before appearing of the first cracks, thereafter, these values increase largely and irregularly, as shown in Fig. (9). This shows that the measured values of mid span strains for samples MAS1 and MAS3 are also close, while the values of sample MAS4 are somewhat large compared to the other two



samples. The reason for this difference may be explained because of the differences in the locations of the cracks, as mentioned previously.

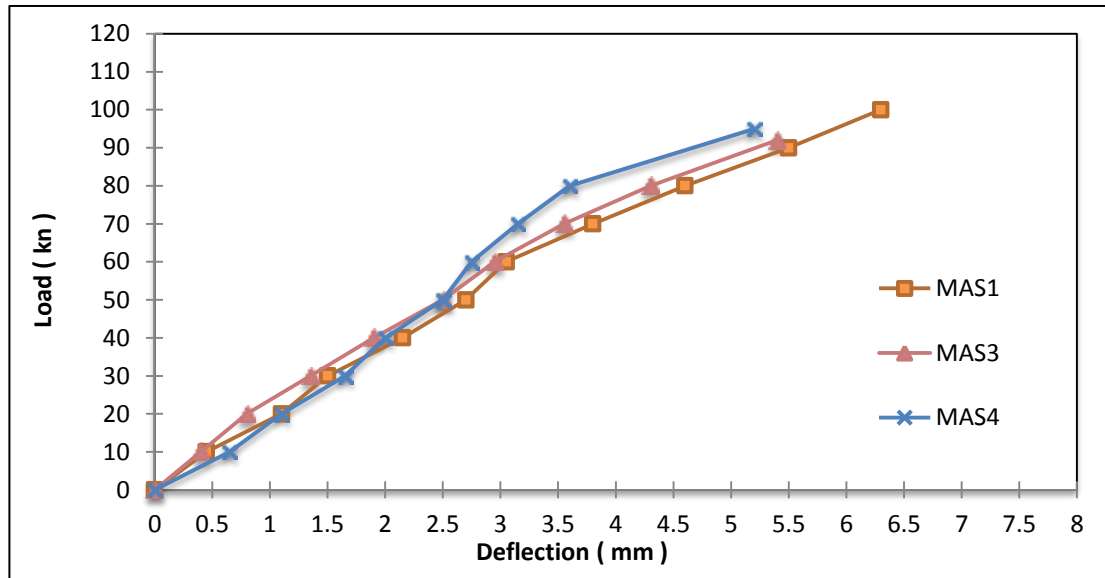


Figure 8. Load-mid span deflection curve for samples (MAS1, MAS3, and MAS4)

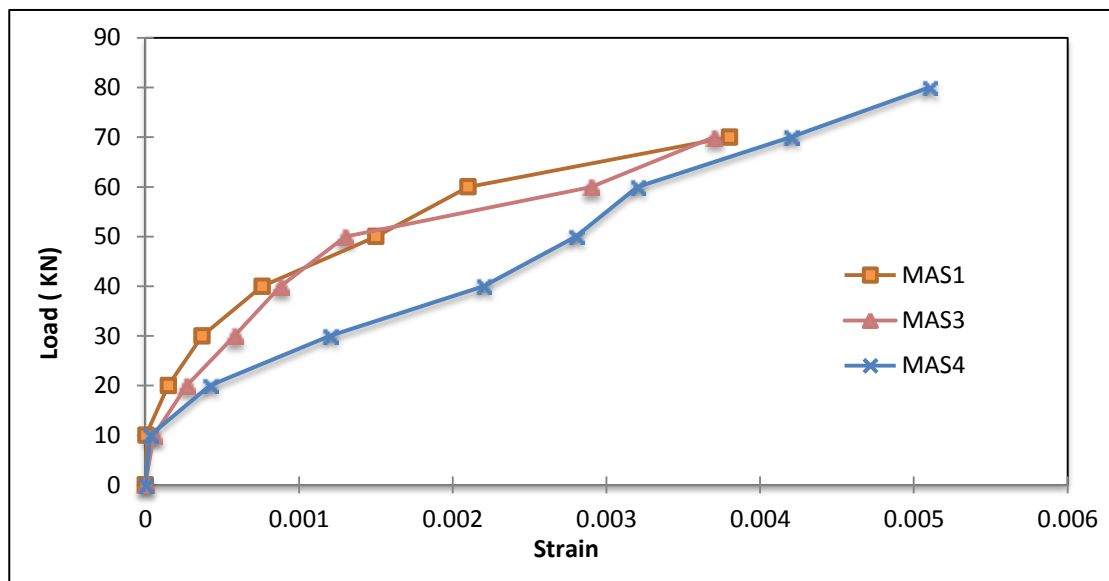


Figure 9. Load-mid span strain curve for samples (MAS1, MAS3, and MAS4)

### 3- Position of LWC layer

To study the effect of this parameter two samples were adopted (MAS3 and MAS5) having same dimensions and properties, but the layer of NWC lies below the LWC in model MAS4, while for model MAS5 LWC lies below NWC. The concrete strength for each of NWC and LWC are 25 MPa and 18 MPa, respectively. Table (6) shows the details of the two samples.

The general behavior for the two models was same under the applied load until failure as mention previously. Table (7) shows that the first cracks appear at the same load (20 kN) for the two samples. Also the failure load for sample MAS5 is larger compared to that of sample MAS3 by (14.1%). Fig.(10) shows that the values of deflections at all load levels at mid span for sample MAS5 is larger compared to that of sample MAS3. This behavior could be illustrated due to rapid

growth of cracks in the LWC layer, which lies above the NWC layer, in sample MAS3 and then it crushed more rapidly causing failure of the sample MAS3 at load less compared to that of sample MAS5.

Figure (11) shows that the measured strain values at mid span of the two samples are very close until the load levels of the first visible cracks, thereafter, these values for sample MAS5 are larger compared to that of sample MAS3. The reason of this behavior could be explained due to LWC layer which lies in the bottom face of sample MAS5.

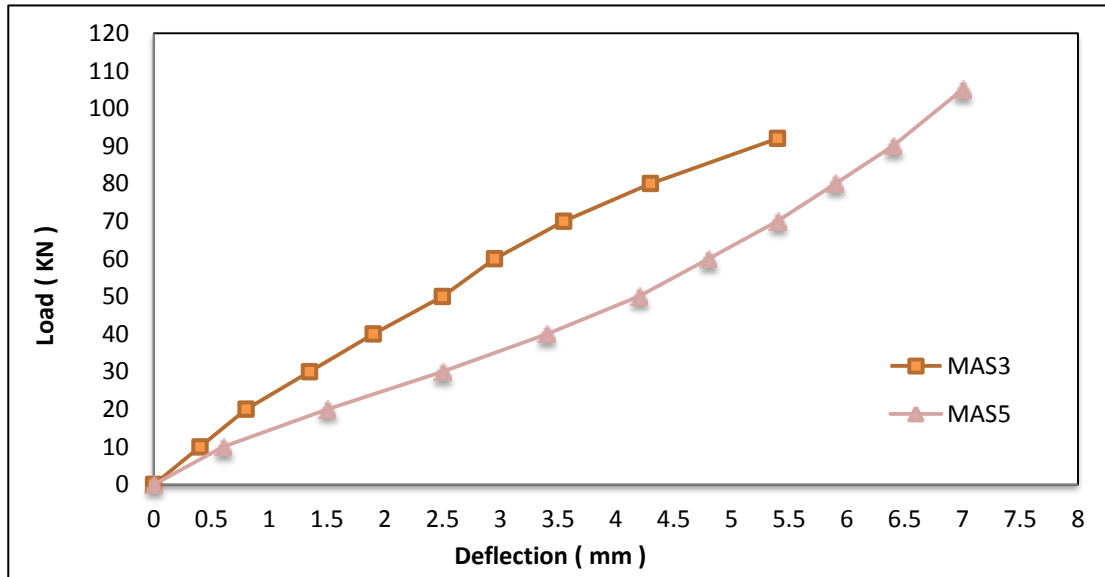


Figure 10. Load-mid span deflection curve for sample (MAS3 and MAS5)

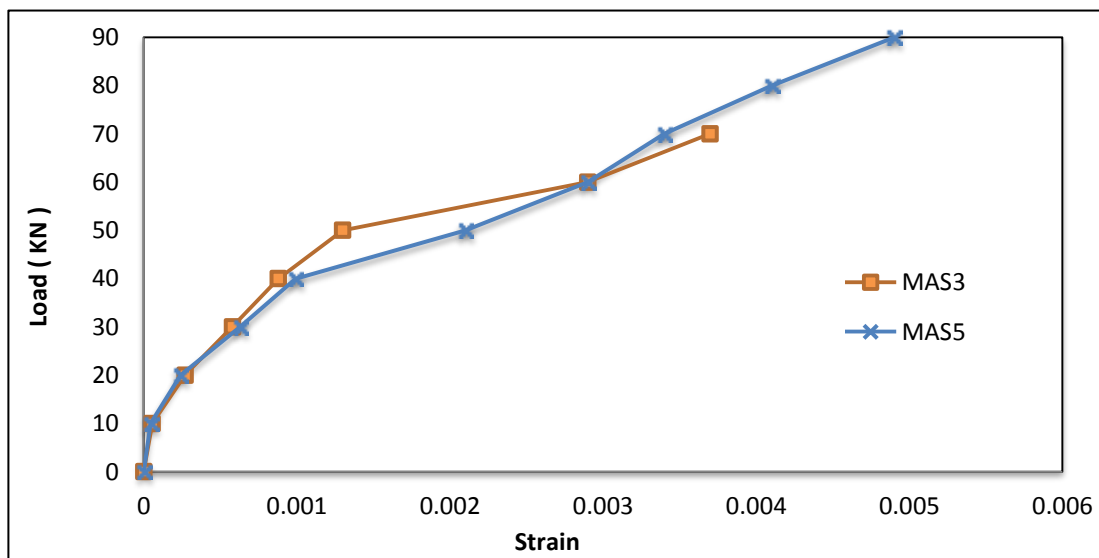


Figure 11. Load-mid span strain curve for sample (MAS3 and MAS5)

## Conclusions

Based on the test results presented in study, the following main conclusions are drawn;

- 1- Using the light weight concrete in composite slabs causes reducing in the weight of these slabs about (11.4%-17.5%).

- 2- The same behavior for tested slabs was noticed under loading for each of normal weight concrete and composite concrete slabs.
- 3- The differences in strength of the LWC layer, in the case of its presence over the steel reinforcement zone, will not affect the resistance for the tested samples.
- 4- Flexural capacity for composite reinforced concrete members is less compared to that of normal weight concrete members.
- 5- The first visible cracks observed at the bottom face of slabs at loads ranging from (19.1-21.7) % from the failure measured load.
- 6- The growth of cracks in the LWC layer is more rapidly compared to that in the NWC layer.

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