Proceedings of the 7h World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)
~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022
Paper No. ICSECT 187
DOI: 10.11159/icsect22.187

Behavior of R.C. Lightweight Deep Beam

Alaa Morsy [1], Karim Helmi [2]and Waleed Alsaadi [3]
College of Engineering & Technology/AASTMT[1, 2]
Alexandria, Egypt[1, 2]
First. alaamorsy@aast.edu ; Second. karim_helmi@aast.edu
College of Engineering & Technology/AASTMT[3]
Alexandria, Egypt[3]
Third. W.Alsadi60@student.aast.edu

Abstract **-** This paper includes an experimental program to study the shear behavior of lightweight reinforcement concrete deep beams. Nine specimens were tested to examine the effect of four variables on the behavior of the beams. The variables included two types of concrete mixes using Perlite and Leca aggregates, the shear span-to-the-depth ratio (a/d), the use of FRP stirrups as a substitute for steel stirrups and the spacing between steel stirrups. All specimens were tested under four-point loading. The results showed that the first crack load in Perlite LWC specimens was significantly lower compared to both NWC and Leca LWC specimens, the ultimate load in Leca LWC lower than that of NWC and higher than Perlite LWC. Reducing the shear span to depth ratio (a/d) reduces the maximum deflection at failure while increasing the ultimate load, FRP stirrups could be used as a replacement for steel transverse reinforcement and increasing the ratio of transverse reinforcement for Leca LWC deep beams increases the load carrying while slightly increasing both the stiffness and deflection at failure.

Keywords**:** deep beam, lightweight concrete, FRP, shear span to the depth ratio, shear failure.

1. Introduction

Deep beams are structural members that are loaded as beams where a substantial amount of load is transmitted to the supports via compressive and shear actions. Transfer girders, wall footings, foundation pile caps, floor diaphragms, and shear walls are only a few of the applications for deep beams [1].

Because of their convenience and economic effectiveness, the use of deep beams at lower levels in tall buildings for both residential and commercial reasons has expanded rapidly.

According to ACI 318-19 [2], deep beams are members that are loaded on one face and supported on the opposite face such that strut-like compression elements can develop between the loads and supports and that satisfy (a) or (b): (a) Clear span does not exceed four times the overall member depth h.

(b) Concentrated loads exist within a distance of 2h from the face of the support.

The principal application of structural lightweight concrete is to reduce the dead load of a concrete structure, allowing structural designers to minimise the size of columns, footings, and other load-bearing members. The strength of structural lightweight concrete mixtures can be engineered to be comparable to that of normal weight concrete. Structural lightweight concrete provides a more fire-resistant concrete structure [3].

Anis et al. [4] carried out an experimental study of the Behavior of deep beams using lightweight structural leca (lightweight expanded clay aggregate) concrete. The test variables were the depth of deep beams, lightweight concrete density, the ratio of main reinforcement, the ratio and shape of web reinforcement, and shear span to depth ratio (a/h). It was observed that using LWC in deep beam instead of NWC decreased the diagonal cracking load, ultimate load, and reserve strength. In addition, the increment of the main tensile reinforcement ratio by 45% increased the ultimate load by 4.4% and reduced the reserve strength by 14%. No effect has been observed on the diagonal cracking load. The researchers also observed that increasing the vertical web reinforcement ratio improved the behavior of the LWC deep beam by increasing ultimate load, maximum deflection, and stiffness after first cracking. This improvement increased with using inclined web reinforcement and dropped in beam without web reinforcement.

Tao. et al. [5] studied the applicability of shear models for deep beams with lightweight aggregate concrete. Eight lightweight aggregate concrete deep beams were constructed and tested to failure under concentrated loading. Tests were conducted to investigate the effects of the shear span-to-effective depth ratio (a/d), and an effective span–depth ratio (le/h), on the failure mode and shear behavior of deep beams. All specimens failed in shear compression or shear flexure. Failure from the flexure mode showed a dominant pattern with increasing a/d. The le/h value minimally influenced the diagonal cracking and ultimate strength of deep beams. In contrast, a/d significantly affected the beam strength. The results were compared with predictions proposed by American Concrete Institute 318-14, Canadian Standard, EC2, the Tan and Cheng model, the softened strut-and-tie model, and the simplified softened strut-and-tie model, which are all based on the strut-and-tie model.

Keun and Ashraf [6] tested the behavior of 12 continuous beams made of all lightweight, sand-lightweight, and normal weight concrete. The load capacities of beams tested were compared with the predictions of strut-and-tie models presented in ACI 318-08 and EC 2 provisions, including the modification factor for lightweight concrete. The beam load capacity increased with the increase in maximum aggregate size, although the aggregate interlock contribution to the load capacity of lightweight concrete deep beams was less than that of normal-weight concrete deep beams. The conservatism of the strut-and-tie models specified in ACI 318-08 and EC 2 decreased with the decrease of maximum aggregate size.

The number of studies on lightweight deep beam are few; therefore, more research is needed. In this paper, the behavior of lightweight deep beams was studied. Several parameters were included in this study, some of which have not been studied previously, like the use of perlite in the concrete mix and the use of FRP as transverse reinforcement. In addition to other parameters, that have been previously studied, including the a/d ratio and the ratio of transverse reinforcement.

2. Experimental Program

2.1. Details of Test Specimens

All specimens were 1.6 m in long, 0.4 m high, and 0.12 m wide. The longitudinal reinforcement for all beams had a 16 mm diameter (4 lower and 2 upper) grade B350DWR steel according to ECP-203-2020[7] as shown in figure 1. Two types of transverse reinforcement materials were used; steel and FRP stirrups, and the spacing between the steel stirrups ranged from 50 mm to 100 mm. The steel for the transverse reinforcement (stirrups) had an 8 mm diameter, and was of grade B240D-P and the FRP stirrups had the same area as the steel stirrups. The FRP stirrups were constructed by wrapping FRP strips cut from unidirectional FRP fabric directly on the main reinforcement after using four steel stirrups in the end and in the middle to hold the main reinforcement in place.

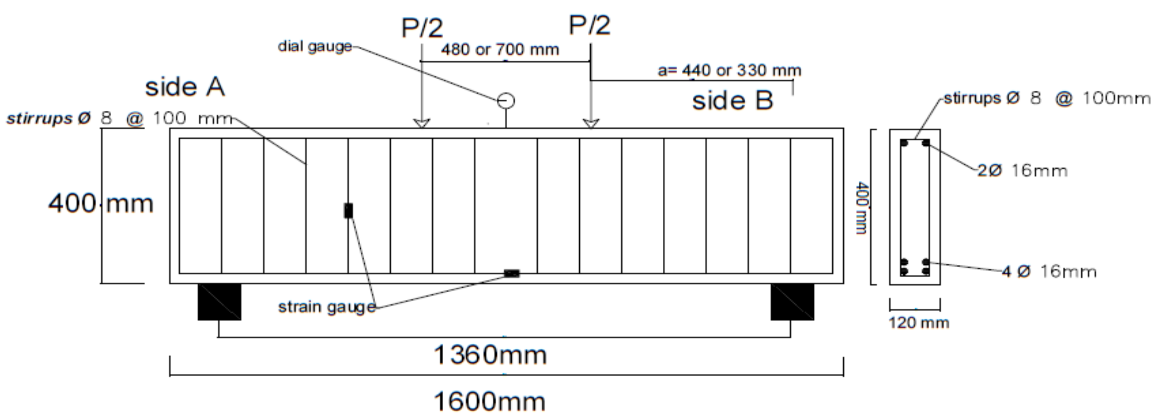

Figure 1, specimens details and dimensions tools.

In this paper, nine specimens were tested to study four parameters, which are:

1. Type of mix: a. Normal weight concrete b. Leca lightweight concrete c. Perlite lightweight concrete.
2. The shear span to the depth ratios of 0.9 and 1.2.
3. Type of stirrups materials steel and FRP.
4. The spacing between steel stirrups, which was 100 mm, 75 mm, and 50 mm.

The code below is used to define specimens and the difference between them and consists of four symbols. The first symbol, the letter “N” indicates normal weight concrete, the letter “L” indicates Leca concrete, and the letter “P” indicates perlite concrete. The second symbol indicates the shear span to depth ratio (1.2 or 0.9) the third symbol indicates a type of stirrup material “S” for steel and “F” for FRP, and finally, the last symbol indicates the stirrup spacing (100 mm, 75 mm or 50 mm). Details of the specimens are presented in Table 1.

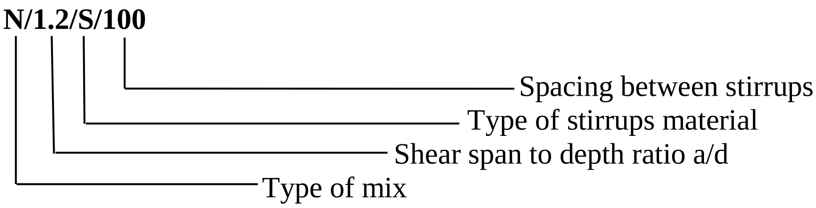

Fig. 1: Naming code for specimens

Table 1. Details of all specimens:

NO	Specimen code	f_{cu} N/mm^2	a/d	Density Kg/m^3	Type of stirrups	Spacing between stirrups
1	N/1.2/S/100	31	1.2	2420	Steel	100 mm
2	L/1.2/S/100	14.8	1.2	1748	Steel	100 mm
3	P/1.2/S/100	13.6	1.2	1822	Steel	100 mm
4	L/1.2/F/100	14.6	1.2	1738	FRP	100 mm
5	P/1.2/F/100	13.5	1.2	1810	FRP	100 mm
6	L/0.9/S/100	14.9	0.9	1780	Steel	100 mm
7	P/0.9/S/100	13.7	0.9	1837	Steel	100 mm
8	L/1.2/S/75	15	1.2	1701	Steel	75 mm
9	L/1.2/S/50	14.7	1.2	1720	Steel	50mm

2.2. Material properties

2.2.1 Aggregate

The properties of all aggregates are shown in Table 2.

Crushed stone was used as coarse aggregate in the normal concrete mix in order to compare it with other mixtures. Leca® was used in the second mix, where all coarse aggregate has been replaced with Leca aggregate.
Perlite aggregate was used in the third mix where 65% of coarse aggregate was replaced with Perlite aggregate.

The three types of mixtures were made using different aggregates. Several mixes were tried and the mixes chosen in this study are shown in Table 3.

Table 2. Details of aggregates:

	PH	Density(kg/m^3)	Size(mm)	Water absorption (%)
Crush stone	4 to 6.5	1462	10-20	0-2
Leca agg.[8]	8.05	220 to 325	7-15	30
Perlite agg.[9]	7	70 to 95	2-4	60-70

2.2.2 Cement

Ordinary Portland cement, grade 42.5, was used, conforming to the Egyptian standard specifications ES 4756 / 1-2013 and complying with the European specifications EN 197 / 1-2011.

2.2.3 Sand

The fine aggregate used in this paper for concrete is graded desert sand. It selected on the basis that it is free from salts, organic matter, clays and silts.

2.2.4 FRP

"Sika Wrap Hex 430G" FRP sheets were used in this study. The sheets are glass fiber sheets in the form of dry unidirectional flexible fabric. 15 mm strips were cut from the fabric and used to make the FRP stirrups

Table 3. The mix ratios:

mix	Cement (Kg/m^3)	Water (L/m^3)	Crush stone aggregate (Kg/m^3)	Leca aggregate (Kg/m^3)	Perlite aggregate (Kg/m^3)	sand (Kg/m^3)
1	350	160	1160	-	-	730
2	420	180	-	360	-	780
3	460	280	406	-	220	690

2.3 Test setup and instrumentation

The supports were placed at 0.12 m from the edges of the beam, which means that the distance between the supports was 1.36 m; the distance between the loading points was 480 mm and 700 mm as shown in figure 1. All concrete deep beams were tested under four-point loading and were loaded at 10 kN increments, cracks were measured after each load increment. A dial gauge in all specimens was installed in the middle of the span to measure deflections. Strain gauges were installed on the third stirrup on the left as shown in Figure 1.

3. Results and discussions

3.1 Failure mode and failure load

For all the specimens, the crack initiated from the support and extended to the load exertion point. The first crack load and the failure loads are presented in table 4

Table 4. Summary of test results:

Name	**First crack load(kN)**	**Load failure(kN)**	**Mode of failure**
N/1.2/S/100	80	230	**Shear Side A**
L/1.2/S/100	80	150	**Shear Side B**
P/1.2/S/100	40	120	**Shear Side B**
L/1.2/F/100	80	160	**Shear Side B**
P/1.2/F/100	40	120	**Shear Side A**
L/0.9/S/100	60	170	**Shear Side B**
P/0.9/S/100	60	150	**Shear Side A**
L/1.2/S/75	70	180	**Shear Side B**
L/1.2/S/50	70	195	**Shear Side B**

The mode of failure for specimens (L/1.2/S/100 and P/1.2/S/100) was shear tension at an angle of about (45^o). The crack initiated from the support and extended to the load exertion point as shown in figures 2.

Figure 2: (P/1.2/S/100) mode failure.

The mode of failure for specimens (N/1.2/S/100, L/0.9/S/100 and P/0.9/S/100) was tension shear crack accompanied with crushing of concrete at the supports. The crack started from the support and extends to the point of load exertion as shown in Figure 3.

Fig. 3 (P/0.9/S/100) mode failure.

The mode of failure for specimens (P/1.2/F/100, L/1.2/F/100) was shear tension because of the rupture of most of the sheet from the corner and the middle, as shown in Figure 4. Most of the rupturing occurred in the corners due to stress concentration at the corner at the point of load application as shown in figure 4.

Fig. 4 (P/1.2/F/100) mode failure.

The mode of failure for specimens (L/1.2/S/75, L/1.2/S/50) was tension shear crack accompanied by crushing at the load point. The crack initiated from the support and extended to the load exertion point as shown in figure 5.

Figure 5 (L/1.2/S/50) mode failure.

3.1.1 Effect of type of mix

The first crack load for the specimen constructed using LECA LWC mix similar to that of the specimen constructed using normal weight, while the failure load for the specimen constructed using Perlite LWC mix was less than the specimens constructed using normal weight concrete and Leca concrete by about 50%. The failure load for the specimen constructed using LECA LWC mix was less than the specimen constructed using normal weight concrete by 34%, while the failure load for the specimen constructed using Perlite LWC mix was less than the specimen using normal weight concrete by 46%.

3.1.2 Effect of shear span to the depth ratio

When the shear span to depth ratio was reduced to 0.9 in (L/0.9/S/100), the failure load increased by 11.7% compared to (L/1.2/S/100) and the failure load of (P/0.9/S/100) increased by 20% compared to (P/1.2/S/100).

3.1.3 Effect of the type of stirrups material

Comparing the results obtained from specimens reinforced with FRP or steel stirrups, which were constructed using LECA LWC and Perlite LWC, showed no significant effect on load.

3.1.4 Effect spacing between stirrups

Increasing the transverse reinforcement ratio increased the failure load in (L/1.2/S/75) by 16.6% compared to (L/1.2/S/100), and increased the load in (P/1.2/S/50) by 23% compared to (L/1.2/S/100).

3.2 Load & Deflection curve

3.2.1 Effect of type of mix

The first crack in specimen N/1.2/S/100 appeared at a load of 80 kN. At the cracking load, the deflection was 4.28 mm, and the maximum deflection was 13.89 mm at failure. The load of specimen L/1.2/S/100 for the first crack was 80 kN, the deflection was 7.85 mm, and the maximum deflection was 14.67 mm at failure, which represented an increase in stiffness for the first crack load and almost the same for the failure load. The first crack of specimen P/1.2/S/100 occurred at a load 40 kN and the deflection was 2.12 mm. The stiffness of specimens N/1.2/S/100 and P/1.2/S/100 was approximately the same as shown in figure 6, while the stiffness of specimen L/1.2/S/100 was less.

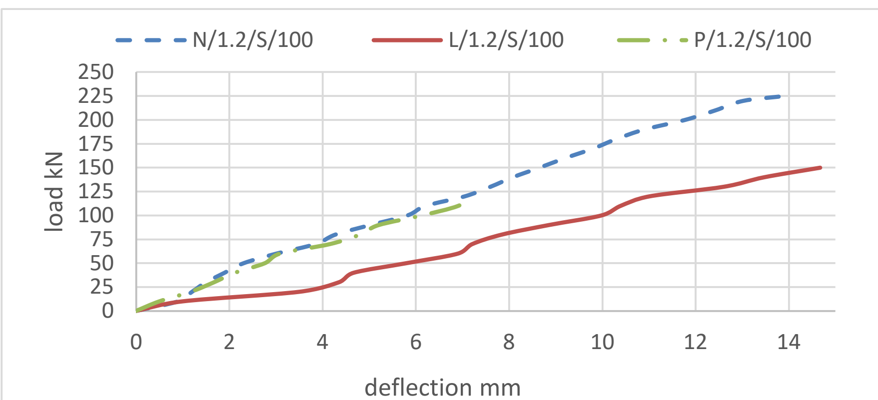

Fig 6: deflection in specimens P/1.2/S/100, L/1.2/S/100 and N/1.2/S/100.

3.2.2 Effect of shear span to the depth ratio (a/d)

For specimen P/0.9/S/100, the first crack occurred at a load of 60 kN and the deflection was 2.81 mm and the maximum deflection was 7 mm, as shown in figure 7(A). For specimen L/0.9/S/100 had a deflection of 6.24 mm when the first crack occurred, and the maximum deflection was 13.82 mm as shown in figure 7 (B).

3.2.3 Effect of the type of stirrups material

For specimen P/1.2/F/100, the first crack occurred at a load of 40 kN and the deflection was 2.02 mm and the maximum deflection was 7.4 mm as shown in figure 7(A) .For specimen L/1.2/F/100 a deflection of 4.5 mm occurred at the time of the first crack, and the maximum deflection was 10.4 mm as shown in figure 7(B).

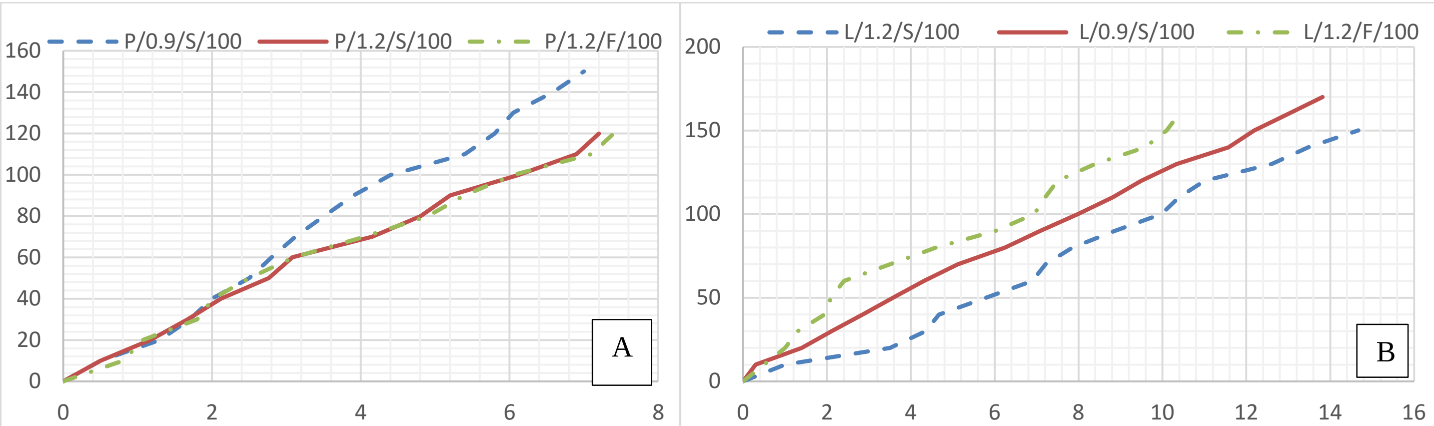

Fig. 7 (A): deflection in specimens P/1.2/S/100, P/0.9/S/100 and P/1.2/F/100.
Fig 7 (B): deflection in specimens L/1.2/S/100, L/0.9/S/100 and L/1.2/F/100.

3.2.4 Effect spacing between stirrups

For specimen L/1.2/S/75 the first crack occurred at a load of 70 kN, the deflection was 5.83 mm, and the maximum deflection was 16.91 mm. It had a 25.7% decrease in the deflection at first crack load and a 13% increase in deflection at ultimate load compared to specimen L/1.2/S/100. Specimen L/1.2/S/50 had a deflection of 5.19 mm at the time of the first crack occurred, and the maximum deflection was 17.42 mm, which represents a decrease of approximately 33.8% in deflection at first crack load and increase in deflection of 15.7% at ultimate load compared to specimen L/1.2/S/100. Figure 8 shows that increasing the ratio of transverse reinforcement slightly increases both the stiffness and deflection at failure for Leca LWC deep beams.

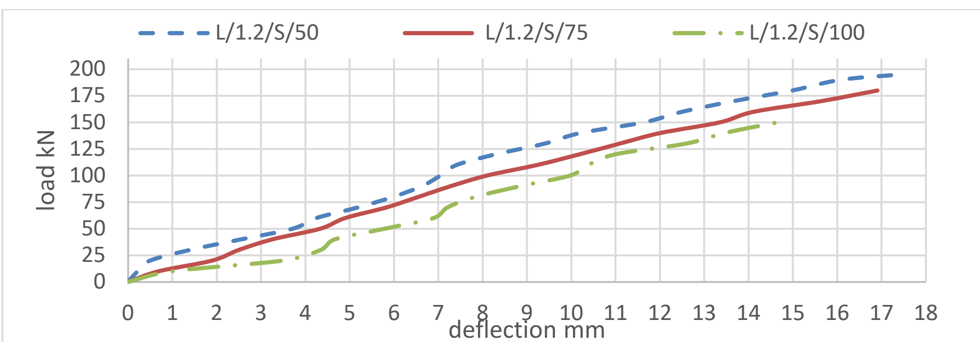

Fig 8: deflection in specimens L/1.2/S/100, L/1.2/S/75 and L/1.2/S/50.

3.3 Load & strain curve

3.3.1 Effect of type of mix

For specimen (N/1.2/S/100), the maximum strain was (2647 mm/mm×10-6) and for specimen (P/1.2/S/100), the maximum strain was (1712 mm/mm×10-6) a 35% decrease. For the specimen (L/1.2/S/100), the maximum strain was (2640 mm/mm×10-6); which is very similar to specimen N/1.2/S/100, as shown in the figure 9.

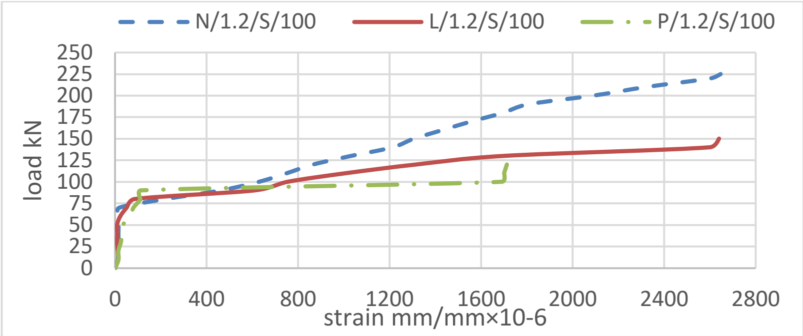

Fig. 9: strain in stirrups for specimens N/1.2/S/100, L/1.2/S/100 and P/1.2/S/100.

3.3.2 Effect of shear span to the depth ratio (a/d)

For the specimen (P/0.9/S/100), the maximum strain was (2600 mm/mm×10-6) a 34% increase, as shown in figure 10. For the specimen (L/0.9/S/100), the maximum strain was (2620 mm/mm×10-6), which is almost the same as shown in figure 11.

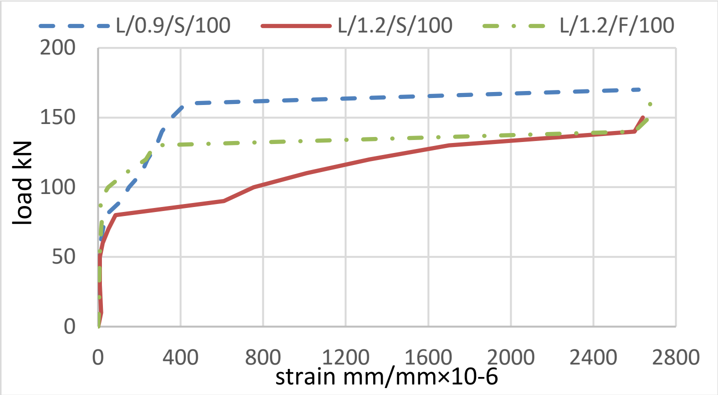

Figure 10 strain in stirrups for specimens L/1.2/S/100 and L/0.9/S/100.

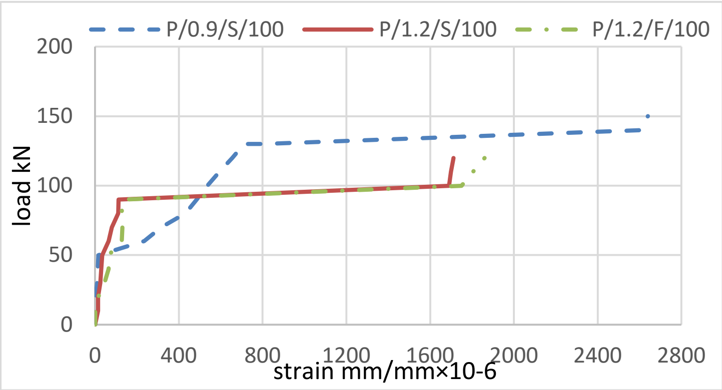

Figure 11 strain in stirrups for specimens P/1.2/S/100 and P/0.9/S/100.

3.3.3 Effect of the type of stirrups material

In the specimen (P/1.2/F/100), the maximum strain was (1860 mm/mm×10-6). For the specimen (L/1.2/F/100), the maximum strain was (2670 mm/mm×10-6) indicating that the type of stirrup material did not change the failure strain for this case as shown in figures 10 and 11.

3.3.4 Effect spacing between stirrups

For specimen (L/1.2/S/100), the maximum strain was (2640 mm/mm×10-6) and for the specimen (L/1.2/S/75), the maximum strain was (1670 mm/mm×10-6), a 36.7% decrease. For the specimen (L/1.2/S/100), the maximum strain was (2640 mm/mm×10-6) and for the specimen (L/1.2/S/50), the maximum strain was (1954 mm/mm×10-6) a 25.9% decrease as shown in the figure 12.

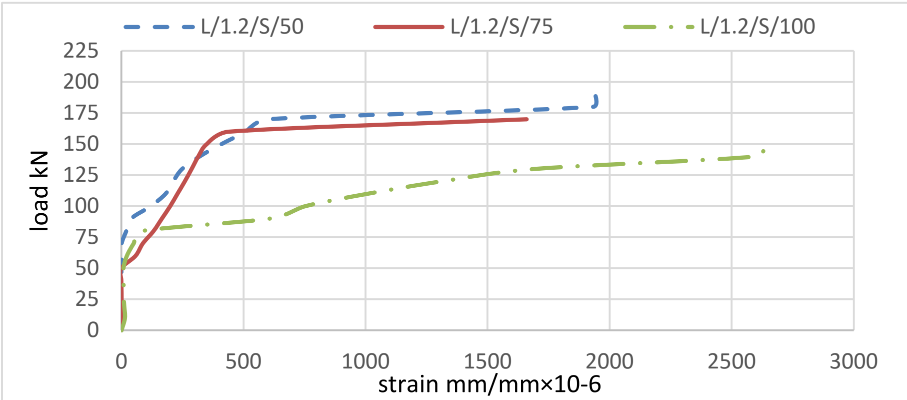

Figure 12 strain in stirrups for specimens L/1.2/S/100, L/1.2/S/75 and L/1.2/S/50.

4. Conclusion

The results shows that the first crack load in Perlite LWC specimens was 50% lower compared to both NWC and Leca LWC specimens. Also, the ultimate load in Leca LWC was 34% lower than that of NWC, and for Perlite LWC it was 46% lower than that of NWC. Reducing the shear span to depth ratio (a/d) reduces the maximum deflection at failure while increasing the ultimate load. Specimens reinforced with FRP stirrups showed no significant change in first crack or ultimate load compared to specimens reinforced with steel stirrups, and thus could be used as a replacement for steel transverse reinforcement. Increasing the ratio of transverse reinforcement for LWC deep beams increases the load carrying capacity and slightly increases both the stiffness and deflection at failure.

5. References

[1] RUSSO, Gaetano; VENIR, Raffaele; PAULETTA, Margherita. Reinforced concrete deep beams-shear strength model and design formula. ACI Structural Journal, 2005, 102.3: 429.
[2] ACI Committee 318 Building Code Requirements for Reinforced Concrete (ACI 318–14) and Commentary (318R-14). Farmington Hills, 2014 MI: American Concrete Institute.
[3] American Concrete Institute. (1981). Standard practice for selecting proportions for structural lightweight concrete.
[4] ALI, Anis A. Mohamad; HUSSEIN, R. Lazim. Experimental study of the behavior of deep beams using light-weight structural leca concrete. Int. J. Innovat. Res. Sci. Eng. Technol., 2016, 5.1: 428-436.
[5] WU, Tao; WEI, Hui; LIU, Xi. Experimental investigation of shear models for lightweight aggregate concrete deep beams. *Advances in Structural Engineering*, 2018, 21.1: 109-124.
[6] YANG, Keun-Hyeok; ASHOUR, Ashraf F. Aggregate interlock in lightweight concrete continuous deep beams. *Engineering Structures*, 2011, 33.1: 136-145.
[7] Egyptian Code Committee. 2020 for the Design and Constructions of Concrete Structures.
[8] The first supplier Expanded Clay Lightweight Aggregate in Europe for your infrastructure, housing and water management projects [online]available: https://www.leca.co.uk/
[9] TOPÇU, İlker Bekir; IŞIKDAĞ, Burak. Effect of expanded perlite aggregate on the properties of lightweight concrete. *Journal of materials processing technology*, 2008, 204.1-3: 34-38.