International Journal of Innovation Engineering and Science Research

Open Access

Shear Behavior of Lightweight Fiber Reinforced Concrete Beams

Ali Magdy[1], Ghada Diaa[2], and Hany Abdalla[1]

[1]Structural Engineering Department, Faculty of Engineering, CairoUniversity, Cairo, Egypt
[2]Housing and Building National Research Center, Cairo, Egypt

ABSTRACT

In this study, fourteen reinforced concrete beams were tested to investigate the shear behavior of lightweight fiber reinforced concrete beams. Lightweight Expanded Clay Aggregate (LECA) was used as a partial and full replacement to the normal weight aggregate. The experimental program included three lightweight concrete beams with partial replacement of aggregate, nine lightweight concrete beams with full replacement of aggregate, and two normal weight control beams. In each group one beam was cast using steel fiber concrete, one with polypropylene fiber concrete, and one without fibers. The effects of parameters such as weight of concrete, type of fibers, area of stirrups, and shear span to depth ratio (a/d) on the beams behavior are presented. The response of the tested beams is analyzed in terms of mode of failure, deflection, strain, cracking load, and ultimatecapacity. The test results are compared to those estimated from different design codes for lightweight concrete structures.

***KEYWORDS** -lightweight concrete; shear behavior; failure mode; cracking load; ultimate load*

I. INTRODUCTION

The use of lightweight concrete (LWC) has increased rapidly in the last few years especially in the Western countries. While lightweight concrete derives considerable appeal from an improved strength-to-weight ratio, this material also boasts enhanced thermal insulation, fire resistance, and acoustic insulation properties. Lightweight concrete has thermal conductivity values half that of normal weight concrete (Chandra and Berntsson 2003) due chiefly to its low density and pore structure which traps air – being a poor conductor of heat. This low value means that heat does not easily penetrate through the material thus reducing a building's interior heating and/or cooling requirements, a reduction most welcome amid rising energy costs and growing concerns on climate change.

Although lightweight concrete is able to improve some properties of normal weight concrete, inevitably, trade-offs are made with others. From a structuralstand point, a lower modulus of elasticity causes member deflections to be greater than in normal weight concrete counterparts. In addition, lightweight concretes have lower tensile strengths and a subsequently reduced shear resistance (ACI 213R-03). This is in lieu of the improved interfacial transition zone in lightweight aggregate concrete. A smaller net solid area in aerated concretes may also be a contributing factor to its lower tensile strength. These limitations do not necessarily diminish the value of lightweight concrete since the weaknesses can be overcome with appropriate structural design and detailing.

Already, internationally recognized building codes of practice acknowledge the role and potential of lightweight aggregate concrete by allowing the structural use of the material with associated design guidelines and equations suggested. However much of these design provisions are modified forms of normal weight concrete requirements and have remained unchanged based on research and data on lightweight concrete obtained in the 1950's.

Past studies have shown that the addition of steel fibers into the concrete matrix will enhance the shear strength and ductility in reinforced concrete (RC) members (e.g. Batson et al. 1972, Narayanan and Darwish 1987). Steel fibers increase shear resistance by providing post-cracking diagonal tension resistance across the crack surfaces. They also control crack spacing, similar to the effect of stirrups, and this leads to reduced crack widths and an increase in shear resistance through aggregate interlock (Kwak et al. 2002). The use of steel fibers to enhance the shear response is particularly attractive in high strength concrete (Wafa and Ashour 1992) and lightweight concrete (Balaguru and Foden 1996), where the brittleness and suddenness of matrix failure is more pronounced compared to normal strength concrete. Several researchers have studied the shear performance of steel fiber reinforced concrete (SFRC) beams with normal and high strength matrices (e.g. Narayanan and Darwish 1987, Ashour et al. 1992, Kwak et al. 2002); however, the influence of steel fibers on shear strength of beams with lightweight aggregate has not been established, and very limited work on lightweight concrete with fibers has been reported (Swamy et al. 1993).

The advantages of using LWC in construction include its low density and low thermal conductivity. This leads to a reduction in dead load, faster building rates, and saving in air conditioning systems. However, the low shaear capacity of LWC results in reduction in the ultimate strength of such beams. The use of different types of fibers has been investigated to overcome such reduction in shear strength of LWC beams.

II. RESEARCH SIGNIFICANCE:

This research was carried out for the following purposes:

1. To evaluate the effect of different types of fibers on enhancing the shear capacity of lightweight concrete beams.
2. To compare the obtained test results with various design Codes recommendations.

III. EXPERIMENTAL PROGRAM

To achieve the main aim of the current study, an experimental program consisted of fabricating and testingfourteen reinforced concrete beams: Three beams contain light-weight expanded clay aggregates (LECA) as a partial replacement to the normal weight coarse aggregates with a percentage equals 50%. The unit weight of this type of concrete ranged between 1860 kg/m³ to 2000 kg/m³. Nine beams contain light-weight expanded clay aggregates (LECA) as a full replacement to the normal weight coarse aggregates with a percentage equals 100%. The unit weight of this type of concrete ranged between 1650 kg/m³ to 1700 kg/m³. The other two beams were cast with normal-weight concrete for comparison purposes.

3.1 Mix Proportions and Materials

Eight concrete mixes were designed in this research. Two mixes (No. 1 and 2) were normal unit weights (control mixes). Mix No. 2 possessed normal unit weight with steel fibers. Intended compressive strength was 30 MPa for all mixes. Table (1) shows the details of the eight mixes. The used cement was Ordinary Portland Cement type CEM I – 42.5 complied with the Egyptian Standard. In the lightweight aggregate mixes, silica fume having a silica content of 96.5%, a specific gravity of 2.15 and specific surface area of 20000 cm²/gm was used as an additive to the cement with the case of polypropylene fiber only. Silica fume was added by a ratio of 10% of the cement content in mix No. 5 and No. 8. Local dolomite crushed stone size 10 mm and natural sand were used as coarse and fine aggregates, respectively, in mixes 1 and 2. While, in the lightweight aggregate mixes (mixes 3 to 5), coarse and light-weight expanded clay aggregates (LECA) were used as partial replacements to the normal- weight coarse aggregate, with a percentage equals 50% and 100% (by volume). The used coarse LECA had a volume weight of 600kg/m³ and a specific weight of 1.0, while the fine LECA possessed a volumeweight of 1100 kg/m³ and a specific weight of 1.6. In addition, a high range water reducing and set retarding concrete admixture of modified synthetic dispersion basis (complies with ASTM C 494 Type G and BS 5075 Part 3) was used in the designed normal weight and lightweight mixes for reducing the amount of the mixing water. The used dosage of the admixture was 1% of the binding material. It must be mentioned that the amounts of water listed in Table 1 included the absorbed water by the coarse and fine aggregates. Finally, it should be mentioned also that the workability of the designed eight mixes was adjusted to be maintained at the same level. Slump tests were carried out on the fresh concrete and all mixes recorded slump values of 70 mm ± 20 mm.

Table 1: Proportions of Concrete Mixes

Mix No.	Type of Concrete	Cement (kg/m^3)	Silica Fume (kg/m^3)	Coarse Agg. (kg/m^3)		Fine Agg. (kg/m^3)	Fiber (kg/m^3)	Water (kg/m^3)	Admix. (kg/m^3)
				Dolomite	LECA	Sand			
1	NW	350	----	1224	----	612	----	180	3.5
2	NW	350	----	1224	----	612	SF-78.6	180	3.5
3	50-LW	350	----	381.32	235.4	612	----	180	3.5
4	50-LW	350	----	381.32	235.4	612	SF-78.6	180	3.5
5	50-LW	350	35	381.32	235.4	612	PPF-9.1	180	3.5
6	100-LW	350	----	----	470.77	612	----	180	3.5
7	100-LW	350	----	----	470.77	612	SF-78.6	180	3.5
8	100-LW	350	35	----	470.77	612	PPF-9.1	180	3.5

3.2 Details of the Test Beams

A total number of fourteen reinforced concrete beams divided to five groups (A, B, C, D and E) were fabricated and tested in this study. Table 2 shows the main properties of the tested beams. In group A; beam B1 was cast with mix No. 1 and beam S1 was cast with mix No. 2 (normal-weight concrete). In group B; beam B2 was cast with mix No. 3, beam S2 was cast with mix No. 4, and of lightweight aggregate, beam P2 was cast with mix No. 5 with reduced-weight concrete (partial replacement of lightweight aggregate). In groups C, D, and E; beams B3, B4, B5 were cast with mix No. 6 and beams S3, S4, S5 were cast with mix No. 7 and beams P3, P4, P5 were cast with mix No. 8 (full replacement of lightweight aggregate). In addition, theshear span was 600 mm (shear span to depth ratio ≈ 2.2) for all groups except group E which had shear span equals to 275 mm (shear span to depth ratio =1).

The steel fibers used in this research were 30mm long with an aspect ratio of 50 and ultimate tensile strength of 1000MPa. The polypropylene fibers were 12mm long with an aspect ratio of 50 and ultimate tensile strength 440MPa, Fig. 1.

All the beams were 2000 mm long, 1800 mm span, 150 mm width and 300 mm total depth, with an effective depth equals to 275 mm. The main tensile reinforcing bars were 3 Φ 16 (high tensile steel 400/600) while the compression reinforcement was 2 Φ 8 (mild steel 280/420). The shear reinforcement (stirrups) was of diameter 6 mm (mild steel 280/420) at a spacing of 200 mm for group A, B, C, and E. In group D the shear reinforcement was ofdiameter 8 mm (mild steel 280/420). The deometry and reinforcement details of the tested beams are shown Figure 2. Six standard cubes of 150x150x150 mm and six standard cylinders of 300 mm height and 150 mm diameter were cast with the test beams to determine the actual concrete compressive strength and splitting strength of each beam.

Table 2: Main Properties of the Test Beams

Group	Beam Ident.	Mix No.	Stirrups /m'	Type of Concrete	Mix. Designation	Concrete Strength, MPa
A	B1	1	5Φ6	Normal-weight	NC	41
	S1	2	5Φ6	Normal-weight	50-SFLW	37
B	B2	3	5Φ6	50% Lightweight agg.	50-LWC	26
	S2	4	5Φ6	50% Lightweight agg.	50-SFLW	27
	P2	5	5Φ6	50% Lightweight agg.	50-PPFLW	29
C	B3	6	5Φ6	100% Lightweight agg.	100-LWC	22
	S3	7	5Φ6	100% Lightweight agg.	100-SFLW	18
	P3	8	5Φ6	100% Lightweight agg.	100-PPFLW	19
D	B4	6	5Φ8	100% Lightweight agg.	100-LWC	22
	S4	7	5Φ8	100% Lightweight agg.	100-SFLW	18
	P4	8	5Φ8	100% Lightweight agg.	100-PPFLW	19
E	B5	6	5Φ6	100% Lightweight agg.	100-LWC	22
	S5	7	5Φ6	100% Lightweight agg.	100-SFLW	18
	P5	8	5Φ6	100% Lightweight agg.	100-PPFLW	19

Figure 1: Hooked steel fiber 30mm length, Polypropylene FIBERMESH® 30012mm length

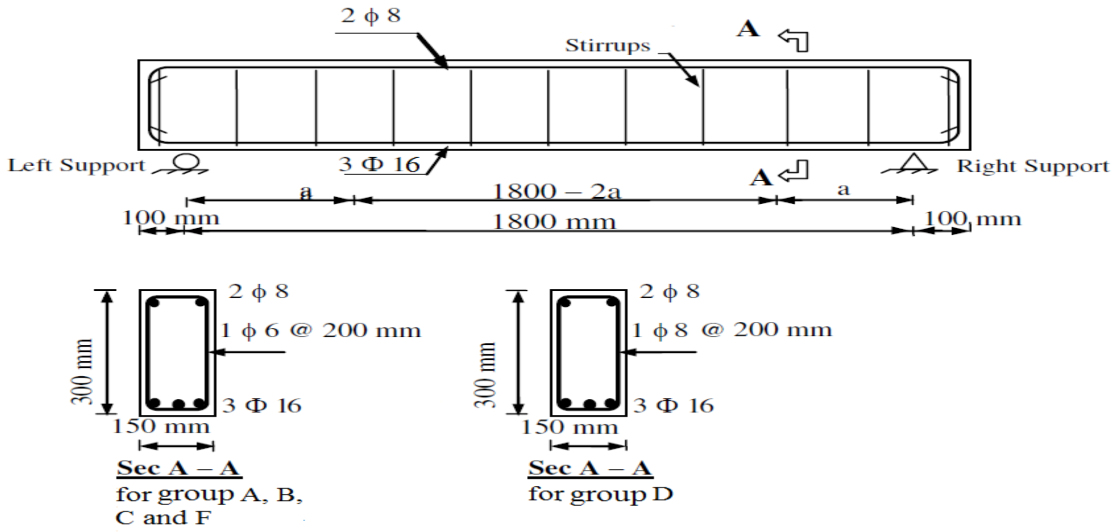
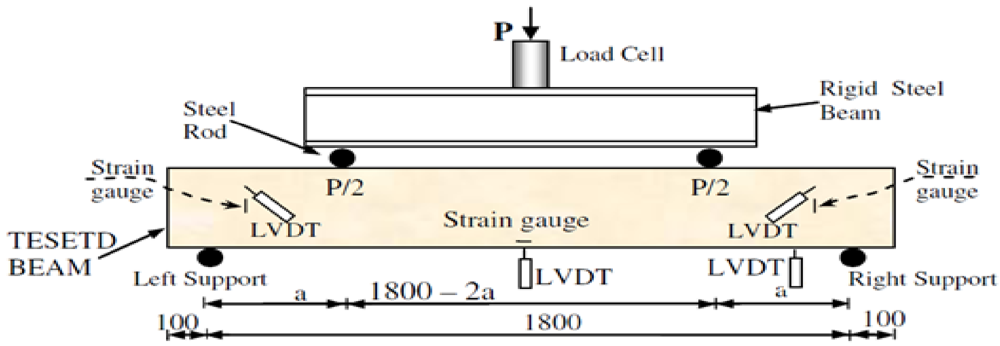


Figure 2: Geometry and Reinforcement Details of the Tested Beams

3.3 Instrumentation and Testing

The tests were performed using a 5000 kN hydraulic compressive machine. The mid-span deflection was measured for the tested beams using linear variable displacement transducer (LVDT). Similarly, the mid-shear span deflection and the mid-shear span deflection were measured using linear variable displacement transducer (LVDT). Strains were measured at the mid-span of the tensile steel by using 10 mm electrical strain gauges. Two 6mm electrical strain gauges were mounted on the vertical leg of the second left and right stirrups. Two LVDTs were attached in the maximum left and right shear regions at an angle of 45°. The strain gauges and LVDTs were connected to a data acquisition system. Figure 3 illustrates a schematic view of the loading setup and instrumentation of the tested beams. Also, Fig. 4 presents a general view of the test setup.



*All dimension are in mm.

Figure 3: Test Setup and Instrumentation of the Tested Beams

As shown in Figures 3 and 4, each beam was acted upon by symmetrical two vertical concentrated loads. In all groups spacing between the two loads were 600 mm except group E wherethe spacing was 1250 mm.

The measurements and observations were recorded at each load level. The test was continued after the ultimate load in order to assess the post peak behavior of the tested beams.

Figure 4: General View of the Test Setup

IV. Experimental Results

Table 3 illustrates the results of the compression and splitting tests of the specimens (cubes 150 x 150 x 150 mm for compressive strength and cylinders 150 mm diameter and 300 mm height for splitting strength and modulus of elasticity) which were cast with the test beams. These specimens were tested on the same day of testing of their beams. It must be mentioned that each value listed in Table 3 is the average of the test results of three specimens.

The compressive strength of mix No. 1, which was made of normal weight concrete, was 40.8 MPa while the splitting strength was 3.32 MPa, i.e. the splitting strength was 8.1% the compressive strength. In the same NW with steel fiber mix No. 2, the compressive strength was 35.5 MPa while the splitting strength was 2.75 MPa i.e. the splitting strength was 8.1% of the compressive strength. On the other hand, for the LW concrete partial replacement, mix No. 3, the compressive strength was 25.56 MPa and the splitting strength was 1.8 MPa, i.e. the splitting strength was 7% of the compressive strength.

Table 3: Actual Compressive Strength and Splitting Strength of the Specimens of the Test Beams

Beam Ident.	Type of Concrete	Actual Comp. Strength, MPa	Actual Splitting Tensile Strength, MPa	Ratio Splitting Tensile strength/ Comp. Strength
B1 (mix no. 1)	Normal aggregate	40.8	3.32	8%
S1 (mix no. 2)	Steel fiber with normal aggregate	35.5	2.75	7.75%
B2 (mix no. 3)	Partial replacement aggregate	25.56	1.8	7%
S2 (mix no. 4)	SF with partial replacement aggregate	26.66	2.37	9%

P2 (mix no. 5)	PPF with partial replacement aggregate	28.6	2.18	7.6%
B3, B4, B5 (mix no. 6)	Full replacement aggregate	21.35	2.01	9.4%
S3, S4, S5 (mix no. 7)	SF with full replacement aggregate	16.8	1.8	10.7%
P3, P4, P5 (mix no. 8)	PPF with full replacement aggregate	18.96	2.21	11.7%

The results indicate that, the light-weight concrete shows smaller tensile strength than the normal-weight concrete. In partial replacement and full replacementLECA aggregate, the splitting tensile strength of the reduced-weight concrete was 54%, and 61%, respectively, of that of normal-weight concrete.

Results of the Tested Beams

Theexperemental results are shown for mode of failure; load-deflection relationship; load-strain relationship; cracking load, and ultimate load for the tested beams. Table 4 lists the cracking and ultimate loads. In general, the results show that light weight concrete has smaller cracking and ultimate loads than normal weight concrete.

Modes of Failure

Figures 5shows the cracking pattern of all the tested beams. As shown in this figure and Table 4, the cracking behavior of the tested beams followed different trends based on the studied variables.

Table 4: Cracking Loads and Ultimate Loads of the Tested Beam

Group	Beam Ident.	First Cracking load (kN)	Ultimate load (kN)
A	B1	114	195.77
	S1	155	217.93
B	B2	108	137.97
	S2	123	197.16
	P2	113	197.17
C	B3	67	119.68
	S3	97	177.67
	P3	103	166.01
D	B4	87	139.71
	S4	75	149.71
	P4	99	149.17
E	B5	79	193.96
	S5	91	235.59
	P5	130	277.26

For all beam the first crack started at the beam mid-span. This crack was followed by inclined shear cracks which extended rapidly across the section leading to sudden failure.


Group A, beamB1
Group A, beam S1
Group B, beam B2
Group B, beam S2
Group D, beam B4
Group D, beam S4

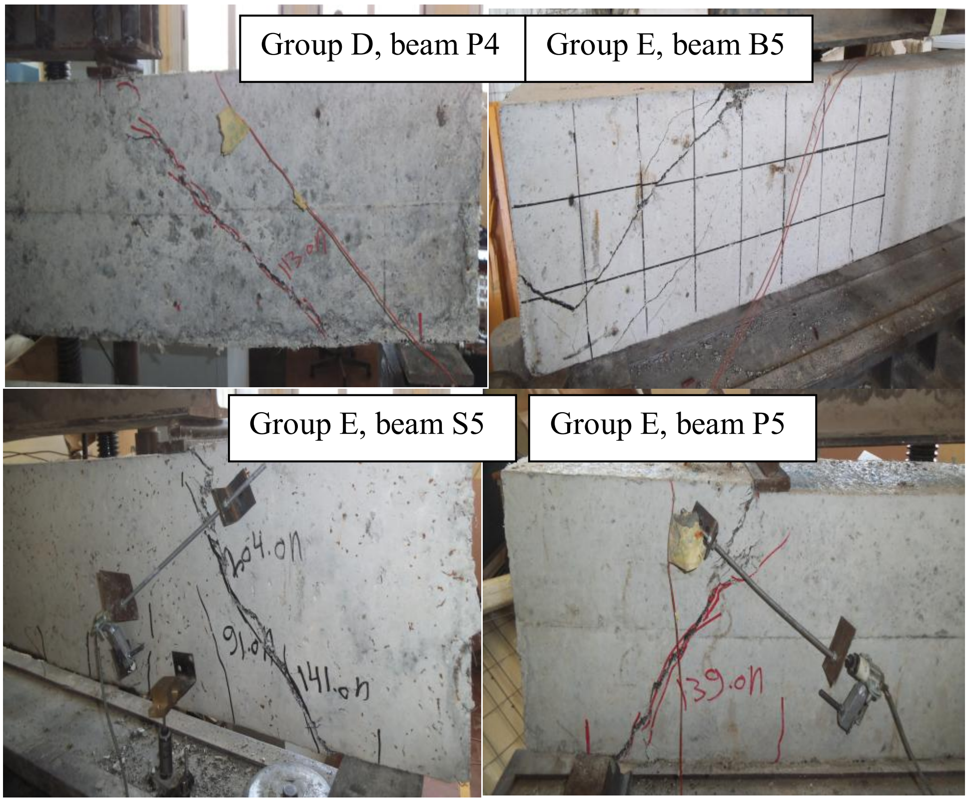


Figure 5: Failure Shape of Tested Beams

Deflection of the tested beams

The deflection behavior of the tested beams are shown infigures 6 to 8.For beams B1 to B5 without fibers, Fig. 6, beam B4 with 100% aggregate replacement and Φ8 stirrups showed the highest deflection before failure. This was due to the increase in stirrups diameter, which delayed the complete shear failure. Beam B5 had the maximum ultimate load among other beams due to the decrease in shear span and hence reduction in the applied moment.

For beams with steel or polypropylene fiber, there was an increase in the ultimate shear resistance of compared to beams without fibers. Also for beams with fibers, the brittle failure mode changed to ductile. Figure 7 shows that beam S2 with steel fibers and 50% aggregate replacement showed less deflection than beams S3 and S4 with 100% replacement. The same findings are applied in case of polypropylene fiber as shown in Fig.8.

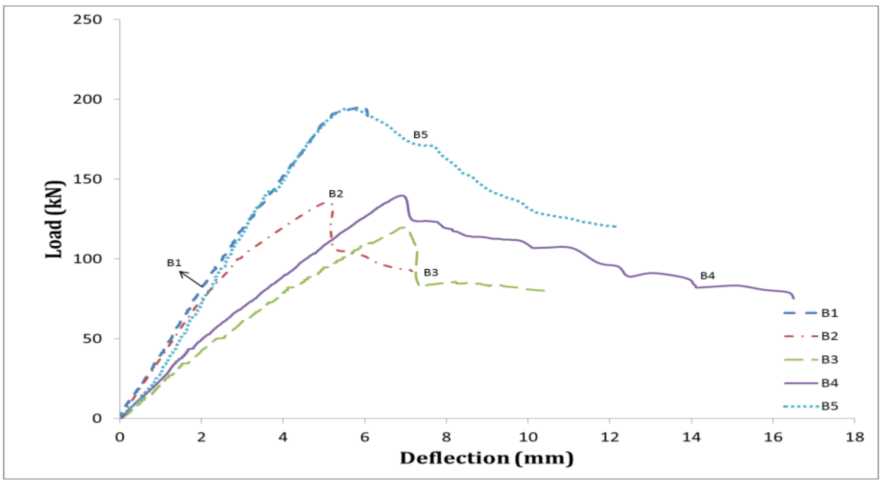


Figure 6: Load Mid-span Deflection Relationships of All groups without Fibers

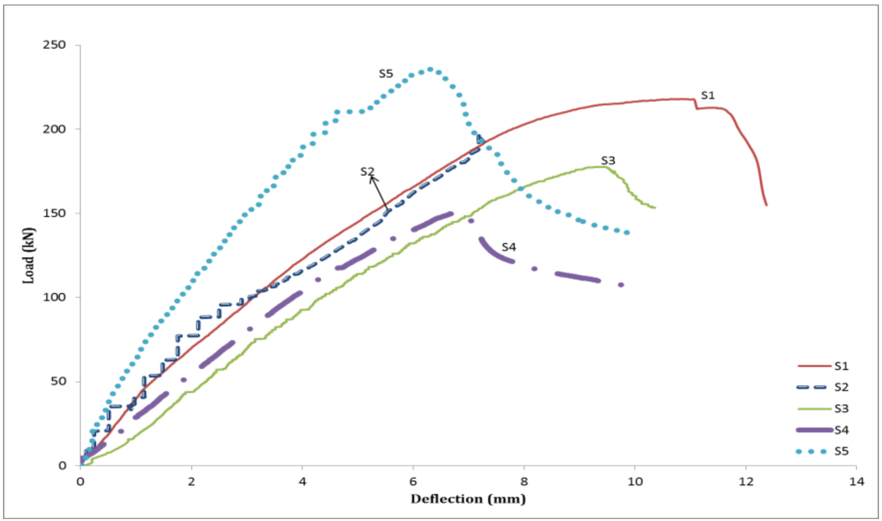


Figure 7: Load Mid-span Deflection Relationships of All groups with Steel Fibers

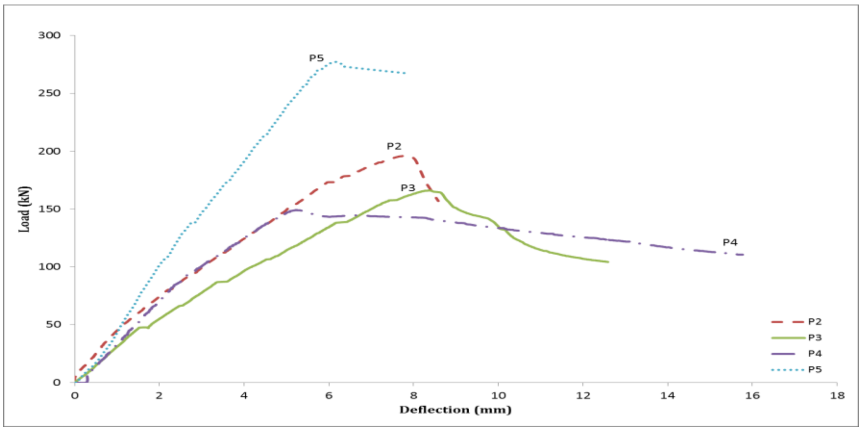


Figure 8: Load Mid-span Deflection Relationships of All groups with Polypropylene Fibers

Tensile Steel Strain

Figures 9 to 11 show the results of the steel tensile strainat the beam mid span. It can be seen from Fig.9 that in case of concrete without fibers, the normal weight beam B1 had the most ductile behavior compared to the light weight concrete beams. Beam B3 with 100% aggregate replacement experienced the largest strain at any load stage. Figure 10 shows that normal weight beam S1 with steel fiber had the most ductile behavior compared to all the tested beams. Comparing the results of beams B3 and S3, it can be shown that steel fibers enhance the ductility and help to delay the complete failure of the beam. The results show that the increase in stirrups diameter has the same positive effects as the steel fibers on the behavior of lightweight beams.

.

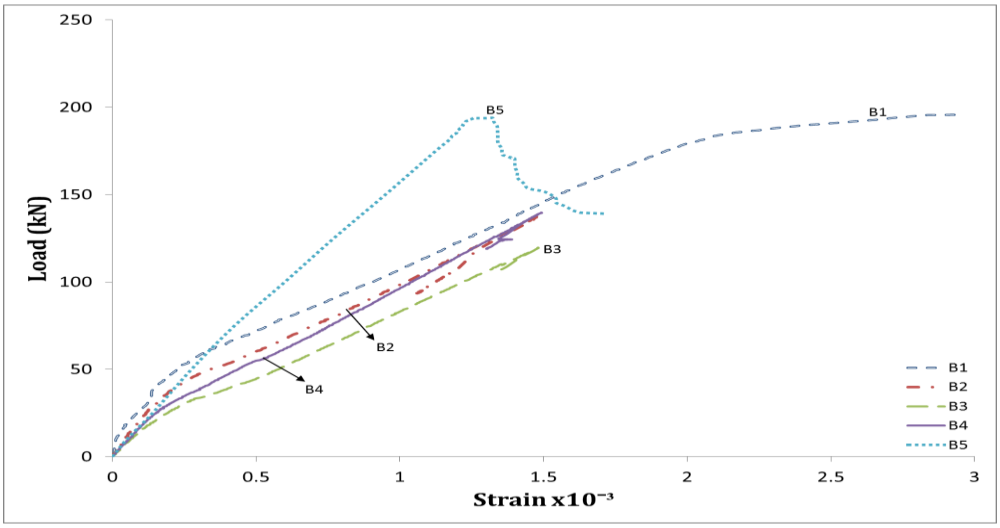


Figure 9: Load Tension Steel Strain Relationships of All groups without Fibers

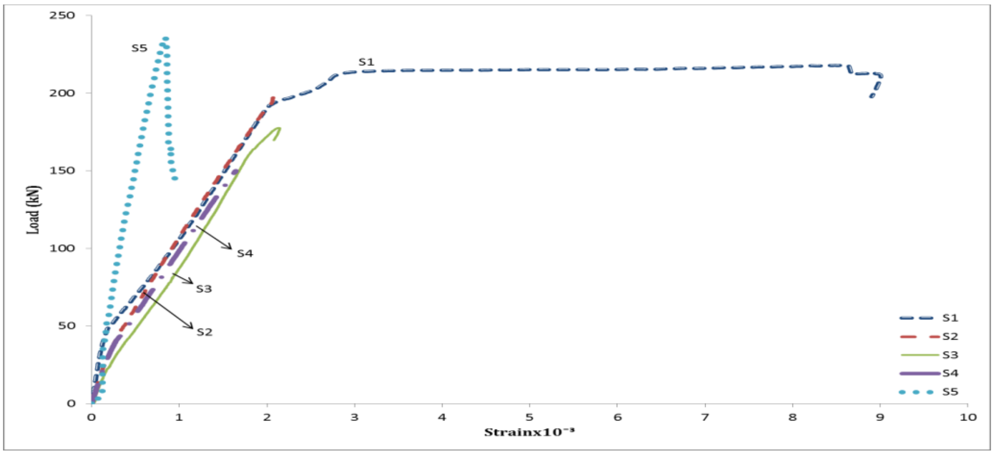


Figure 10: Load Tension Steel Strain Relationships of All groups with Steel Fibers

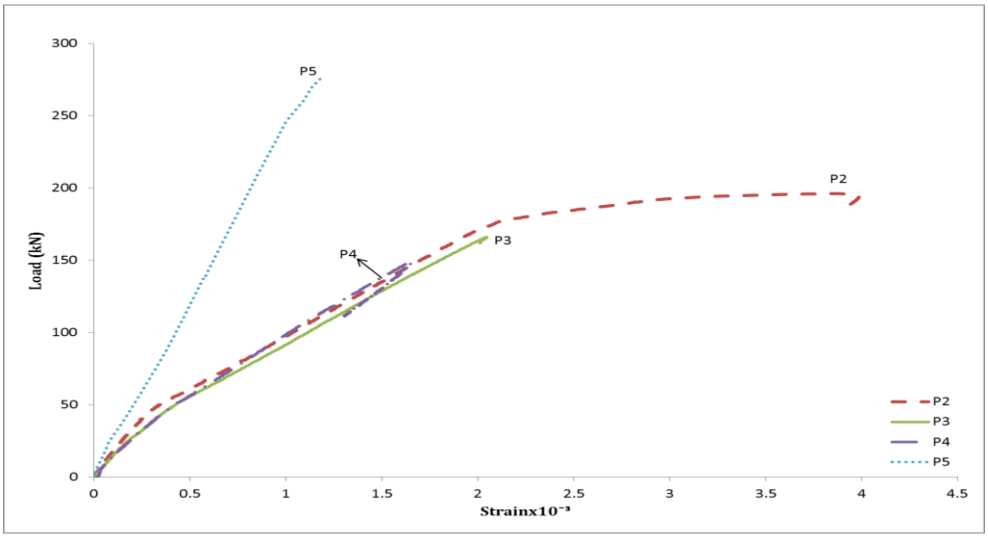


Figure 11: Load Tension Steel Strain Relationships of All groups with Polypropylene Fibers

Effect of weight of concrete

Figures 6 to 9 show the deflection and strain results for beams without fibers. Beam B1 has a control normal weight mix, while beams B2 to B5 have lightweight concrete mixture with different replacement ratio or stirrups size. Comparing the results of beam B1 with those of the LW beams, the following remarks can be made:

- Due to the brittleness of the LW concrete, beams B2 to B5 experienced a sudden shear failureat lower ultimate load compared to B1 .
- The LW concrete beams showed higher deflection than B1.
- Reductions in the ultimate load were observed in LW concrete beamscompared to the NW. The ultimate load of B2 was 70% of that of B1. The ultimate load of B3 was 61% of the ultimate load of B1. Also, for beam with steel fiber, the ultimate load of S2 was 90% of that of S1.
- Adding steel fibers to lightweight concrete helps to restore the ultimate capacity of beams.
- Ultimate capacity of beam S2 with 50% aggregate replacement and with steel fibers was 197.2 kN compared to 195.8 kN for NW beam B1. Beam S3 with steel fibers and full LECA aggregate strength had an ultimate load of 91% of the control beam B1.

Effect of stirrup ratio

Comparing the results of B3 and B4 in Fig. 6 showshat increasing the stirrups bar size from 6mm to 8mm has the effect of reducing the mid span deflection and increasing the ultimate beam capacity. The shear capacity oflightweight beam B4 is 17% higher than that of beam B3 with 6mm stirrups. Comparing the results of beam B4 with the normal weight B1 shows that the increase in stirrups size was not enough to substitutethe reduction in ultimate capacity due to the use of lightweight concrete. The ultimate capacity of beam B4 was 71% of beam B1, Table 4. On the contrary, when using 50% aggregate replacement and steel fibers (beam S2) the ultimate capacity exceeded that of the control beam B1.

Effect of Shear-Span-to-Depth Ratio

Comparing the results of beam B3 with full aggregate replacement where a/d=2.2 and B5 with a/d=1.0, it can be seen that the shear failure load of B3 was 119.68 kN where that for B5 was 193.96, Table 4. The ultimate moment capacity of beam B3 was 35.9 kN.mcompared to 26.67 kN.mfor B5. This is due to fact that the failure in beam B3 was flexural shear failure where as in beam B5 the small shear span led to a clear shear failure at the beam ends. Using steel or polypropylene fibers in light beams with a/d=1.0 increased the ultimate capacity by 21% and 43%, respectively.

Shear Strength of lightweight concrete according to design codes

Concrete shear strength of the tested beams was compared to those proposed by different international codes, e.g. ACI 318-14, BS 8110, and Eurocode 2. The shear strength of lightweight concrete can be estimated according to the follows equations.

ACI 318-14 (2014):

$V_c = 0.166\sqrt{f_c'}b_w d$(1)

Where,

$\lambda = lightweight\ concrete$ modification factor reflecting the reduced mechanical properties

$\lambda = 0.75$for$\gamma_c = 1700\ kg/m^3$ and $\lambda = 0.85$ for $\gamma_c = 2000\ kg/m^3$ where γ_c is the concrete density.

f_c' = specified compressive strength of concrete, MPa.

b_w= web width, mm. d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement, mm.

Eurocode 2 (1999):

$$V_{lRd,c} = \frac{A_{sw}}{s}.z.f_{ywd}.cot\theta \quad and \quad V_{lRd,max} = \alpha_{cw} b_w z v_1 f_{cd}/(cot\theta + tan\theta) \quad (2)$$

Where, $V_{lRd,c}$ design value of the shear resistance of a lightweight concrete member with shear reinforcement, f_{ywd} design yield strength of the shear reinforcement, α_{cw} coefficient accounts for the state of the stress in compression chord, v_1 strength reduction factor for concrete cracked in shear. f_{cd} is the design compressive strength of concrete, θ is the angle between concrete compression strut and the beam axis perpendicular to the shear force.
BS 8110-2:1985

$$V_c = 0.79\left(\frac{100\,A_s}{b_v d}\right)^{1/3}\left(\frac{400}{d}\right)^{1/4}\left(\frac{f_{cu}}{25}\right)^{1/3} \Big/ \gamma_m \quad (3)$$

Where, b_v breadth of the member, or for T-, I-, and L-beam, the breadth of the rib, A_s area of reinforcement, d effective depth to the centroid of the steel ares A_s , f_{cu} characteristic strength of concrete, γ_m partial safety factor for strength of materials.These result show that the three codes underestimate the concrete shear strength of partial and full replacement lightweight concrete beams.

Comparison results are shown in Table 5.

Table 5 Comparison of experimental results with other design codes

Beam	a/d	Stirrup diameter (mm)	$V_{u,test}$ (kN)	$V_{u,code}$ (kN)			$V_{u,test}/V_{u,code}$		
				ACI	Euro	BS	ACI	Euro	BS
B2 50% LW	2.2	6	69	35.85	36.51	34.24	1.92	1.89	1.75
B3 100% LW	2.2	6	60	31.54	31.75	31.35	1.90	1.89	1.89
B4 100% LW	2.2	8	70	42.2	56.42	44.14	1.65	1.24	1.59

V. Conclusions

This research investigated the shear behavior of light weight reinforced concrete and lightweight fiber reinforced concrete (FRC). A fixed amount of fibers (1.0% by volume) of steel and polypropylene fibers was used in FRC beams. LECA aggregate was used to replace the normal weight aggregate to produce partial or full lightweight concrete. The following conclusions can be drawn from the outcome of this study:

1. The ultimate shear strength of normal weight concrete beams and lightweight concrete beams increase by adding fibers to the mix.
2. The load deflection characteristics and the crack pattern of the lightweight concrete beams tested in this experimental program were similar to the expected behavior of normal weight concrete beams with and without fibers.
3. Decreasing the shear span to depth ratio a/d increases the shear strength of steel and polypropylene fiber reinforced light weight concretebeams.
4. Because of the low modulus of elasticity of polypropylene fiber, beams reinforced with this material have larger deflections and wider cracks than beams reinforced with steel fiber.

6. The use of end hooked steel and polypropylene fibers in volume fraction 1% did not influence the compressive strength of lightweight concrete. Polypropylene decreased the compressive strength of lightweight concrete full replacement because of high volume fraction which caused segregation and low workability. Adding 10% of silica fume had the effect of enhancing the compressive strength.
7. The tensile strength of LWC and NC were improved by using steel and Polypropylene fibers.
8. The results showed that both types of fibers improved the ductility behavior for normal and lightweight concrete beams compared to beams without fibers.
9. Increasing the area of stirrups was found to have more effect in increasing the shear capacity of lightweight concrete than adding steel or polypropylene fibers.
10. The shear strength of lightweight concrete estimated by different international codes are very conservative when compared to the shear strength obtained from the experimental tests in this research.

REFERENCES

[1.] ACI Committee 213, 2006, "Guide for Structural Lightweight-Aggregate Concrete (ACI213R-03)," American Concrete Institute, Farmington Hills, Michigan, 38 pp.

[2.] Balaguru, P. and Foden, A. (1996), "Properties of Fiber Reinforced StructuralLightweight Concrete", ACI Materials Journal, 93(1), 63-78.

[3.] Batson, G., Jenkins, E., and Spatney, R. (1972), "Steel Fibers as ShearReinforcement in Beams," *ACI Journal Proceedings*, 69(10), 640-644.

[4.] Chandra, S.; and Berntsson, L., 2003, "Lightweight Aggregate Concrete,"Noyes Publications, Norwich, N.J., 430 pp.

[5.] Finnimore, B., 1989, "Houses from the Factory: System Building and the WelfareState 1942-74," Rivers Oram Press, London, 278 pp.

[6.] Gerritse, A., 1981, "Design Considerations for Reinforced Lightweight Concrete,"International Journal of Cement Composites and Lightweight Concrete, V. 3,No. 1, Feb., pp 57-69.

[7.] Kang, T.H.-K. and Kim, W. (2010), "Shear Strength of Steel Fiber-ReinforcedLightweight Concrete Beams," Proceedings of Fracture Mechanics of Concreteand Concrete Structures Conference, Framcos-7, Jeju, South Korea, 1386 1392.

[8.] Kwak, Y.-K., Eberhard, M.O., Kim, W.-S., and Kim, J. (2002), "Shear Strengthof Steel Fiber-Reinforced Concrete Beams Without Stirrups,"*ACIStructuralJournal*, 99(4), 530-538.

[9.] Narayanan, R. and Darwish, I. Y. S. (1987), "Use of Steel Fibers as ShearReinforcement," *ACI Structural Journal*, 84(3), 216-227.

[10.] Swamy, R. N., Jones, R. &Chiam, A.T.P. (1993), "Influence of Steel Fibers onthe Shear Resistance of Lightweight Concrete I-Beams," *ACI Structural Journal*,90 (1), 103-114.

[11.] Wafa, F. F. and Ashour, S. A. (1992), "Mechanical Properties of High-StrengthFiber Reinforced Concrete," *ACI Materials Journal*, 89(5), 449-455.

[12.] Wee, T.H., 2005, "Recent Developments in High Strength Lightweight Concrete withand without Aggregates," Construction Materials: Performances, Innovationsand Structural Implications and Mindess Symposium, Proceedings of ThirdInternational Conference, N. Banthia; T. Uomoto; A. Bentur; and S. P. Shah,eds., Vancouver, British Columbia, Canada, 97 pp.