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Flexural Behavior of RC Light-Weight Beams Containing Steel Fiber

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Abstract

The purpose of the experimental research is to investigate the impact of incorporating steel fiber into lightweight aggregate concrete (LWAC) by combining the addition of three volume fractions (Vf) of end-hooked steel fiber (0.5%, 1%, and 1.5%) as a layer starting from the bottom fiber of the beam with three thicknesses (20%, 30%, and 40%) of the beam's height. The beams that were evaluated as simply supported beams under two-point loads included a reference beam that did not include any steel fibers as well as five extra beams that had steel fibers in varying volume fractions (Vf). Flexure failure was incorporated into the beams throughout the construction process to guarantee that this would be the mechanism of failure. In comparison to the concrete used as a reference, the findings showed that an increase in the volume fractions (Vf) of steel fibre led to an increase in both the compressive strength and the density of the concrete. The density, compressive strength, split tensile strength, ultimate load, and ductility of the concrete all rose up to 7.68%, 25.74%, 92.71%, 79.1%, and 12.96%, respectively, with the volume fractions of steel fibre in the mixes increasing by 1.5%.

Keywords: reference beam, LWAC, end-hooked steel fiber, reinforced beams, volume fractions.

1. Introduction

In comparison to normal concrete., lightweight concrete has a number of benefits, including a lower density and a greater strength-to-weight ratio. This results in minuscule concrete elements, reduced costs for foundation, and cost savings via simpler transport and construction. Lightweight concrete also provides a number of other advantages. In addition to this, the coefficient of heat conductivity of this material is lower **[1].** When it comes to the manufacturing process, lightweight concrete may be broken down into three distinct varieties. The first kind is known as lightweight aggregate concrete. This type of concrete is made by completely or partly exchanging regular aggregate with lightweight aggregate. Examples of lightweight aggregate include pumice, expanded clay, shale, slate, perlite, and other similar materials. The second kind of concrete is known as cellular concrete, and it is produced by adding air or another gas to a mixture of fine sand and cement in a slurry form. Last but not least, concrete free of fines: This kind of concrete does not include any fine aggregate; instead, the only components used are cement and coarse aggregate with the standard amount of weight. The use of lightweight aggregate is by far the most frequent approach to the production of LWC **[2].** The dry density of lightweight concrete ranges between 1400 and 2000 kg/m3 **[3].** and weights (23-80%) less than regular concrete of the same volume **[4].** The elasticity of LWC exhibits a progressively linear behaviour up to about 90% of its maximum strength. This linear elastic behaviour is also assumed to be the consequence of a stronger link between the lightweight particles and the cement paste. This stronger binding is connected to the rough surface of the aggregates, which creates interlocking, and it is thought that this interlocking contributes to the linear elastic behaviour **[5].** Because of the current boom in the engineering construction industry, high-performance concretes, such fiber-reinforced concrete, have become the material of choice for most large engineering construction projects. Steel-fiber reinforced concrete is certainly commonly used in the present engineering area as one of these superior performance concretes due to the advantages of cheap cost, easy production, and performance boosts. This is definitely due to the fact that steel-fiber reinforced concrete is among the superior performance concretes **[6,7].** The ductility of SFRC is significantly affected by the volume fractions used in the manufacturing process. Other factors, such as fibre morphologies, aspect ratio, orientation of the fibre, and tensile strength, may also have an effect on the performance of concrete. Tensile strength is the most important of these qualities **[8].** When steel fibres are embedded into concrete, the material's compressive strength, flexural strength, and split tensile strength are all improved. This is in addition to the compressive strain being increased at the very end of the process **[9].** However, the research concluded that the incorporation of steel fibre into lightweight concrete would increase its density in addition to having an effect on the failure mechanism by rendering it less brittle and more ductile, decreasing the width of cracks, improving compression strength, splitting-tensile strength, and flexural strength, and reducing the width of cracks. Lightweight natural pumice is commonly discovered in volcanic areas. It has a low specific gravity due to increased porosity and higher water absorption **[10].**

The present paper examines the mechanical characteristics and beam behavior of lightweight aggregate reinforced concrete containing steel fiber.

2. Experimental Program

To determine the influence of steel-fibers on the characteristics of lightweight aggregate concrete: cubes, cylinders, and beams, they were cast and tested. Three cubes of (150mm × 150mm ×150mm) and three cylinders of (150mm × 300mm) for each mix were tested to estimate the compressive strength (fcu) and splitting-tensile strength. A total of six beams of 1200 mm in length, 180mm in depth, and 120mm in width were loaded under two points to investigate the performance of the beams, such as first cracking, yielding, ultimate load, and ductility. Table 1, presents the details of specimens.

Table 1 Details of specimens.

Beam ID	Vf %	Thickness of SFLWAC (mm)	Length of SFLWAC (mm)
RB	---	---	---
SF1-T3.6	1	36	1200
SF1-T5.4	1	54	1200
SF1-T7.2	1	72	1200
SF0.5-T5.4	0.5	54	1200
SF1.5-T5.4	1.5	54	1200

2.1 Materials and Proportion of Mix

Ordinary Portland cement, sand as a fine aggregate with a nominal maximum size of 4.75 mm, lightweight aggregate (pumice) as a coarse aggregate with a nominal maximum size of 9.5 mm, pure water, super-plasticizer, and hooked end steel fiber were the materials used in this study. A summary of the four mixes utilized in this research is presents in Table 2. Table 3 lists the characteristics of the steel fibers provided by the manufacturer.

Table 2 Mix design.

Mix ID	Cement (Kg/m^3)	W/C	Super-plasticizer	Sand (Kg/m^3)	Pumice (Kg/m^3)
R	500	0.37	2%	650	425
0.5%	500	0.37	2%	650	425
1%	500	0.37	2%	650	425
1.5%	500	0.37	2%	650	425

Table 3 The characteristics of steel fiber.

Characteristics	Value
Density (kg/m^3)	7860
Length (mm)	30
Diameter (mm)	0.5
Aspect ratio	60
Tensile strength (MPa)	1200

(a)

(b)

Fig.1 (a) pumice aggregate, (b) end-hooked steel fiber

2.2 Details of Reinforcement

As illustrated in Figure 2, The beams were reinforced with 2Ø10 mm longitudinal reinforcing bars at the tension zone, 2Ø10mm longitudinal bars at the compression zone, and Ø10 mm stirrups at 40 mm center to center with 15 mm in cover. The test results satisfy the requirements of ASTM A615 **[11].**

Table 4 Mechanical characteristics of steel bars

Bar diameter (mm)	10
Measured diameter (mm)	9.5
Yield-strength (MPa)	622
Tensile-strength (MPa)	746
Total elongation (%)	9.3

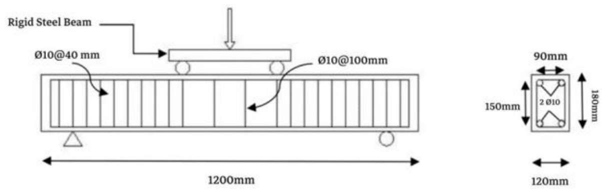


Fig.2 Details of reinforcement

Fig.3 Tensile test of steel bar

2.3 Casting and Curing of Beams

The experimental program for this study involves casting, curing, and testing six RLWAC beams: one is a reference beam without steel fiber, and the others have steel fiber with varying volume fractions and different heights of SFLWAC. For all beam samples, the concrete mix was intended to achieve a cylinder compressive strength of 20 MPa. Following the finish of the mixing process, the molds were cleaned, and before casting, all molds (beams, cubes, and cylinders) had been coated to prevent concrete adhesion once it was cured. The reinforcing steel was then placed in the beam mold while taking into consideration covers from all sides. To remove air spaces and produce compacted concrete, each layer is compressed for around 20 seconds using an external electrical vibrator table. Level and modify their surface after that. A polyethylene covering was put over the specimens to prevent water evaporation. All specimens are removed from their molds after 48 hours have passed after casting, and they are all cured under identical conditions for 28 days by being covered in damp burlap and plastic sheets. The casting and curing processes are shown in **Figure (4).**

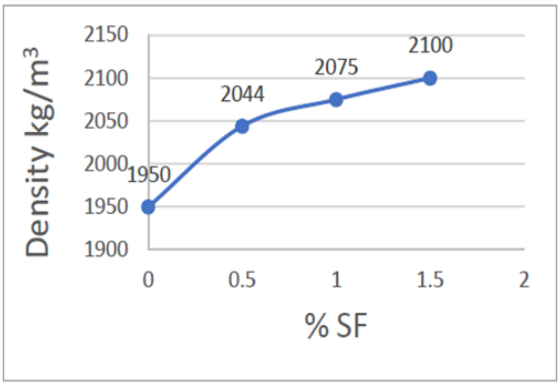
Fig.4 Casting and curing processes of specimens

3. Results and Discussion

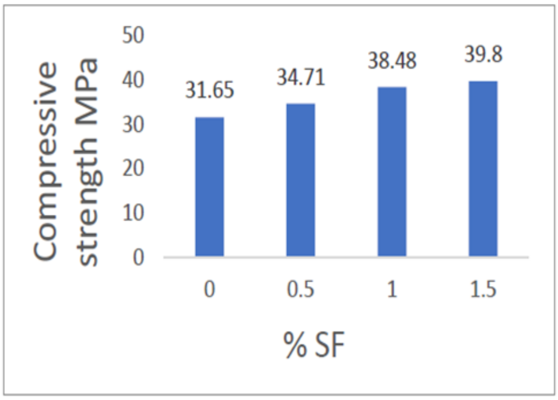
3.1 Mechanical Properties

3.1.1 Density and Compressive Strength

The test results of this study explained that adding steel fibers to LWAC increase the density of concrete compared to the density of LWAC without steel fibers due to its weight. The density was increased by (4.82%, 6.41%, 7.69%) of (0.5%, 1%, 1.5%) of steel fiber (Vf) respectively. The results of test also indicated the utilization of steel fiber enhanced the compressive strength and increased with the increasing of steel fiber in all cases because the steel fiber stronger the bond between particles of concrete then, improve the strength of the concrete. Increasing the (Vf) of steel fiber from 0% to 0.5%, 1.0%, and 1.5% increases the compressive strength by approximately 9.67%, 21.58% and 25.75%. as shown in Figure 5.



(a)



(b)

Fig. 5 (a) the density of mixes (b) the compressive strength

3.1.2 Splitting Tensile Strength (fsp)

Cylindrical specimens of 150 x 300 mm were used to assess the splitting-tensile strength. The results of the splitting-tensile strength tests for each LWAC mixture are shown in Figure 6. The results demonstrate that adding steel fibers to LWAC at various Vf increases the splitting tensile strength relative to fiberless lightweight aggregate concrete and that this increase in splitting-tensile strength is linear with the addition of steel fiber. The value of splitting tensile strength for structural lightweight aggregate concrete shall not be less than 2 MPa, per ASTM C330 **[12].**

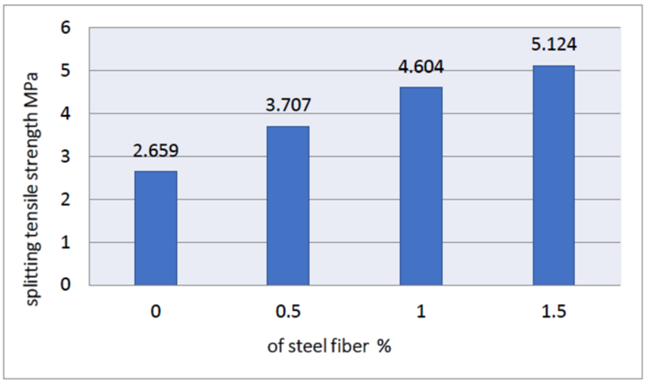
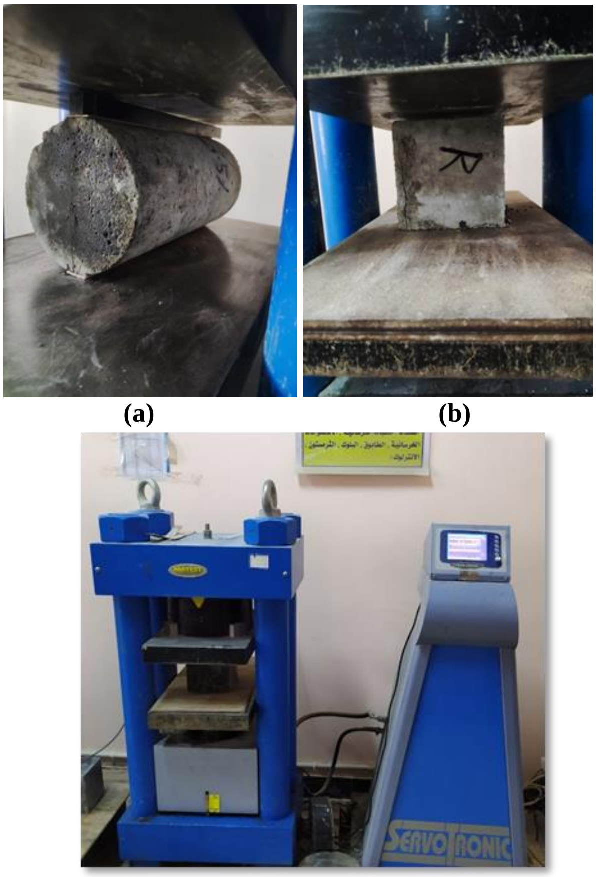


Fig.6 splitting-tensile strength



(a) **(b)**

(c)

Fig.7 (a) splitting-tensile test, (b) compressive strength test, (c) Standard testing machine for cubes and cylinders specimens.

3.1.3 Static Modulus of Elasticity (Ec)

ACI 318 **[13],** states that the density and compressive strength of concrete affect its elastic modulus. Because the moduli of lightweight aggregate are lower than those of the normal aggregate, lightweight concrete has a lesser Ec than conventional weight concrete. According to ACI 318-19, the modulus of elasticity of concrete was established.

The static modulus of elasticity is calculated by the following relations:

$$E_{c=W_c}{}^{1.5}\, 0.043\sqrt{f_c}$$

Wc: air dry density of concrete
f'c´: average cylinder compressive strength
The modulus of elasticity was found increased with the increment in steel fiber by (13.23%, 26.68%, and 40.53%) for (0.5%, 1%, and 1.5%), respectively. This is due the adding steel fiber increase the density and compressive strength and the elastic modulus depend on them.

3.2 Behaviors of Beams Under Loading

3.2.1 Cracks Pattern and Failure Mode

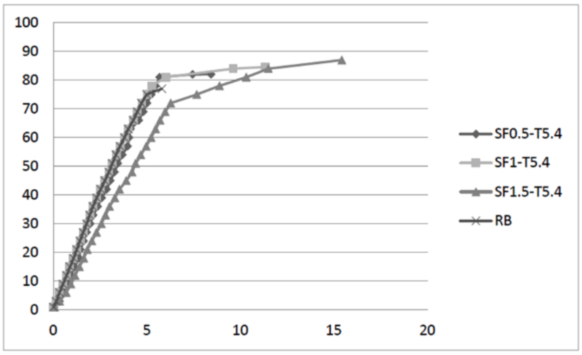
The first crack in the reference beam (RB) was of the flexural type and began during the initial stages of loading in the tension zone. In response to the increased load, a few cracks appeared and developed along their length in the direction of the compression zone. The cover of concrete in the compression zone started separating when the load approximately reached its maximum value. The reference beam as plot in Figure 9 (a), experienced widely spaced cracks within the flexural zone. It can be seen from Figure 9 (c), (d), (e), and (f) the beams that contain steel fiber experienced small cracks; this could be because the steel fibers in RLWAC perform in connecting the cracks, which has resulted in a reduction in the start and development of cracking. The reference beams (RB) failed due to yielding of the steel followed by crushing of the concrete (ductile behavior under failure). The beams (SF1-T3.6, SF1-T5.4, SF1-T7.2, and SF0.5-T5.4) failed by flexure because the steel fiber increased the ductility of the RLWAC beams. The beam (SF1.5-T5.4) failed by flexure in the tension zone and crushing in the compression zone.

3.2.2 Load-Deflection Characteristics

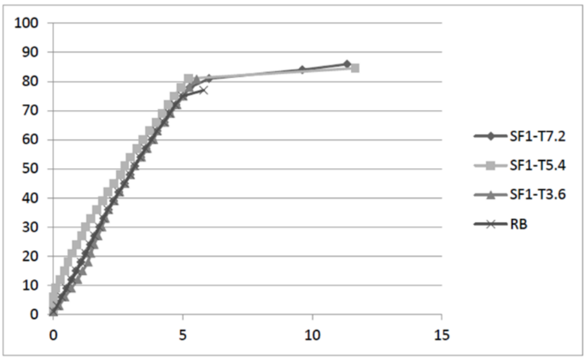
To determine how varied ratios of steel fiber volume fractions (Vf) and SFLWAC layer thickness improve the flexural performance of lightweight aggregate reinforced concrete beams employed in this investigation. Figure 8 shows all lightweight beams' load-mid-span deflection curves. Load-deflection relationships have three stages: elastic, yielding, and collapse. Figure 8 illustrates that as the elastic stage load rises, the tested beams deflect linearly. Tensile reinforcement yielding extends this linear connection to the plastic hinge zone. With a little load increase, deflection rises until the beams collapse. At the elastic loading stage, steel fiber beams deflected less than the reference beam because ductile material layers increased cross-section stiffness.

1: Figure 8 (a) shows the behavior of beam specimens that have different volume fractions of steel fiber. SFRLWAC beams have more ductile load-deflection curves than RLWAC beams. The steel fiber may cause SFRLWAC beams to deflect more than RLWAC beams. It can be notice from the curves of load-deflection of beams containing varied volume fractions, that its impact was small during the stage of elastic but noticeable after yielding. 1.5% Vf increased ultimate load and deflection.

2: Figure 8 (b) compares the load-deflection correlations of the variable SFLWAC thickness layer to the reference beam. SFLWAC layer thickness increased beam yielding and deflection. 54 mm is less costly than 72 mm since the difference was small.
See tables 6, 7, and 8.



(a)



(b)

Fig. 8 (a, b): the comparison of the load-deflection curves for SFRLWAC beams

Ductility Index

In addition to strength and stiffness, ductility is one of the most essential design requirements for lightweight aggregate reinforced concrete. Ductility in structural design may be defined as a material's, a particular part of a member's, the member's, or the structure's, capacity to resist a load after yielding in the inelastic region without failing. Structures with more ductile behavior have a greater capacity to absorb and release energy. Ductile failure is preferred to brittle failure because it gives more warning before the failure.

The following equation is to determine the ductility index (μ).

$$\mu = \frac{\Delta_u}{\Delta_y}$$

where Δ_u and Δ_y were the deflections at ultimate and yielding load, respectively.

Table 5 Ductility index of specimens.

Specimen	Δ_u (mm)	Δ_y (mm)	μ
RB	5.18	4.71	1.1
SF1-T3.6	6.21	4.93	1.25
SF1-T5.4	10.35	5.25	1.97
SF1-T7.2	9.88	5.28	1.87
SF0.5-T5.4	6.54	5.69	1.14
SF1.5-T5.4	11.33	6.28	1.8

Table 6 Test results.

Specimen	Load of first Cracking (kN)	Displacement at first cracking load (mm)
RB	23	1.42
SF1-T3.6	33	1.45
SF1-T5.4	35	1.98
SF1-T7.2	34	1.58
SF0.5-T5.4	33	2.34
SF1.5-T5.4	31	2.32

Table 7 Test results.

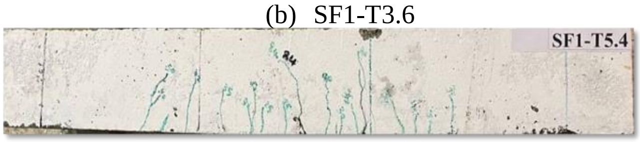
Specimen	Ultimate load (kN)	Displacement at ultimate load (mm)
RB	77	5.18
SF1-T3.6	80.82	5.21
SF1-T5.4	84.55	11.35
SF1-T7.2	85.96	5.54
SF0.5-T5.4	82.04	8.44
SF1.5-T5.4	86.99	26.33

Table 8 Test results.

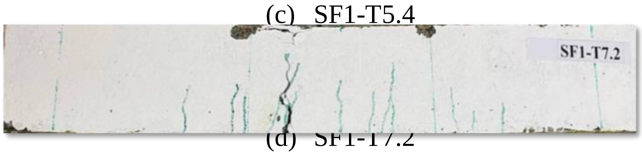
Specimen	Load of Yielding (kN)	Deflection at yielding (mm)
RB	72	4.71
SF1-T3.6	78	4.93
SF1-T5.4	80	5.25
SF1-T7.2	82	5.28
SF0.5-T5.4	79	5.69
SF1.5-T5.4	83	6.28

(a) Reference beam (RB)

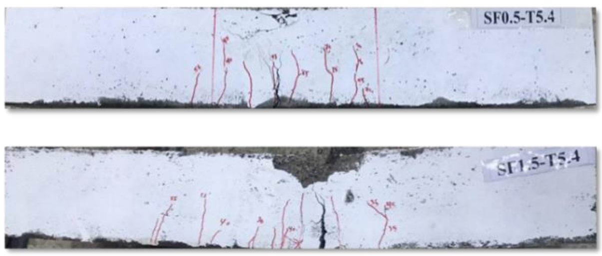
(b) SF1-T3.6



(c) SF1-T5.4



(d) SF1-T7.2



(f) SF1.5-T5.4

Fig. 9 Crack pattern for all beams

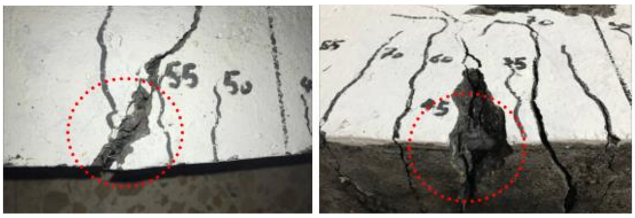


Fig. 10 Comparison between crack widths of concrete beams with and without steel-fiber

Conclusions

Based on the conclusions drawn from the experimental research, the following conclusion was attained:

1. Using pumice as coarse aggregate reduce the self-weight of concrete.
2. Utilizing end-hooked steel fibers with volume fractions Vf of (0.5 %, 1%, and 1.5%) to LWAC increased all of the compressive strength by (9.67, 21.58 and 25.75) %, the splitting tensile strength by (39.41, 73.15 and 92.7) %, and modulus of elastic by (13.23, 26.68, and 40.53) %, respectively.
3. Adding steel fiber reduced the workability of mixes, generally, the steel fiber enhances the performance of lightweight aggregate concrete.
4. The width of cracks for beams contain steel fiber was small compared to reference beam because the steel fiber contact between particles, Furthermore, the occurrence of hooked-end steel fibers (ductile materials) transformed the failure modes of LWAC beams from brittle failure to ductile.
5. The first crack, ultimate load, yielding, and ductility will improve with adding steel fiber until 1.5% of Vf.
6. The reference beam RB appear first crack at load of 23 kN, while the first crack up to 35 kN for SF1-T5.4, the ultimate load increased from 77 kN for (RB) to 86.99 kN for (SF1.5-T5.4), and the yielding improve from 72 kN for (RB) to 83 kN for (SF1.5-T5.4).
7. The volume fractions (Vf) and thickness layer of steel fiber had an obvious influence. In this study, the mechanical characteristics and flexure behavior of the concrete improved to 1.5% of Vf and 72 mm of thickness. whereas increases are occurring between 1% and 1.5%. and between 54 mm and 72 mm, there is little variation. Therefore, the Vf of 1% and the thickness of 54 mm are economically preferred.

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