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SHEAR CAPACITY OF SUSTAINABLE LIGHT WEIGHT CONCRETE BEAMS

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Abstract: This Lightweight concrete is one of the important types familiar of concrete, as the local stone Attapulgite was used as aggregate after treating it with a solution of minors, then it was used in pouring five - reinforced concrete beams by adding steel fiber and iron filing separately with two percentages of 0.5 and 1, these beams were examined to determine the shear capacity. The results showed that iron filing by 1% improve the mechanical properties of concrete and similar to that of using steel fibers, but with a minimum effect. The results also showed that adding 1% of steel filing improves the maximum shear resistance and the first cracking resistance of the concrete by 38%.

Keywords: *light weight; Attapulgite; shear; steel fibers; iron filing.*

1. Introduction

1.1. General

Lightweight concrete (LWC) has been very successfully used a construction material for many years. It offers design flexibility and substantial cost saving by providing less dead load , thinner sections , smaller size structural members , etc. Structural LWC has been applied in infrastructure construction and building, many tall buildings and bridges have utilized high performance lightweight concrete [1]. According to many researches, Attapulgite aggregate can be used as lightweight coarse aggregate Al- Obaidey, Sh. J. K. [2] in this study the author investigated the effect of the maximum size of coarse Attapulgite aggregate and micro steel fiber content on fresh and some mechanical properties of steel fibers reinforced lightweight self-compacting concrete (SFLWSCC). In that study ,two series of mixes were used depending on maximum aggregate size (12.5 and 19) mm, for each series three different steel fibers content were used (0.5 %, 1%, and 1.5%).The results showed that the larger maximum aggregate size of 19 mm exhibited better fresh properties, while mechanical properties negatively affected by using a larger maximum aggregate size. The results also showed that using steel fibers led to negative effects on fresh properties, especially with higher steel fibers content and larger maximum aggregate size. The marginal effect of steel fibers on compressive strength was noticed, while for both splitting and flexural tensile strength, significant increase was obtained with increasing of steel fibers content.

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Hammad, H. et al [3] presented an experimental work to produce structural and insulating concrete by using Attapulgite as a lightweight aggregate. The crushed Attapulgite stone was used as partially or completely replaced with ordinary aggregates to produce low-density concrete. The result indicated that, structural and insulating lightweight aggregate concrete can be produced with locally available materials (Attapulgite) , with a density of 1668kg/m^3 ,by using ,(50 and 100)% fine and coarse Attapulgite aggregate respectively.
The use of iron filing in lightweight concrete pointed out by number of authors .Iron filing is one of the wastes materials that can be recycled and used in engineering fields, the use of this concrete leads to economic and environmental benefits.

AL-Hashimi , M. N. and Najim, W. A. [4] evaluated the possibility of using iron filing as one of the components of the concrete mix. In order to determine the performance of concrete containing iron filing. The results of the compressive strength indicate that the strength of concrete decrease when the ratio of iron filing increases in concrete while the compressive strength of the concrete shows a good development ,when the ratio of iron filing increase as a replacement from the sand.

A different study was carried out to investigate the shear capacity of lightweight concrete beams

Al Saraj , W. K. et al [5] tested nine modified reactive powder lightweight concrete beams without web reinforcement under two points loading system. Three variables ,volume fraction of fiber (Vf), the ratio of longitudinal reinforcement (ρ), and the ratio of the shear span to the effective depth (a/d), were study and explain their effects on mid span deflection ,the diagonal cracking load and ultimate shear load. The test results were shown the increasing both volume fraction and the ratio of longitudinal reinforcement caused an increase in shear strength.

Yang , K. H. et al [6] discuss the impact of maximum aggregate size on the shear actions of lightweight concrete beams. The microphotograph utilized to compare the typical features of the failure surface along the inclined cracks of the beams along with the supreme aggregate size and the type of concrete. The check results displayed that the shear strength of light-weight concrete (LWC) continuous beams improved with the maximum aggregate size, though the growth rate was less than that of normal weight concrete (NWC) continuous beams. The microphotograph presented that the inclined crack of mortar beams with an aggregate size of 4 mm (0.16 in.) had a near-linear shape and a smooth failure surface, whereas that of the concrete beams was emboss-shaped with a failure plane partly formed along with the pastes around the aggregate particles, irrespective of the kind of concrete.

Al-Dhalimi and Sarsam [7] investigated the behavior of 12 beams made from porcelinite concrete in shear with web reinforcement . Comparisons of test results are made with the predicted values from ACI 318M-99, ACI 318M-14, CSA-M84, BS-8110, Zsutty, Hanson, and Russ and Puleri equations. The parameters in tried project were the shear span-to-depth fraction (a/d = four, three, two and half, two, one half and one) . The results indicated that all the tested beams failed in shear although the mode of failure differ from one a/d ratio to another . The values of shear failure load for the shear span to depth ratio of 1.0 are 247 % higher than the corresponding values for the ratio of 4.0 .The predicted values of shear strength obtained from the program "Response 2000" (Modified compression field theory) are more conservative in comparison with the experimental and Code results.

Vakilia et al [8] investigated the impact of fibers and hybrid fibers on the shear force of LWAC beams reinforcement by the GFRP bar. In this study, polypropylene fibers, glass fiber and steel fibers were used to study its impact on shear strength . The results exposed that the fibers and hybrid fibers supplemented into lightweight concrete upgraded the shear strength and improved ultimate load carrying about (55 to 233) by percentage to the pure LWAC beam.

1.2 Objectives

The essential aims of this work are as follows

1. The different between steel fibers and iron filing for lightweight concrete containing Attapulgite aggregate for beams.
2. The mechanical properties of lightweight concrete containing Attapulgite aggregate.

2. Material

The binders used include Ordinary Portland Cement (OPC), (Iraqi Specification, No. 5/1984) [9]. The cement was tested and checked according to Iraqi Specification5:1984[9]. The fine aggregate was natural sand with a fineness modulus of 2.6, a specific gravity of 2.65. Attapulgite rocks of low bulk density, 778 kg/m^3, was utilized in this study as coarse aggregate ,the Attapulgite stone crushed by hand hammer and by crush machine, to give a final product of about (14mm) maximum aggregate size. The Attapulgite aggregate was prepared by calcinations of the aggregate at 1100 C° for 1/2 hr. ,The burnt aggregate was soaked in a tank of Sodium Hypochlorite solution for 24 hr. This process is based on the work-done by Abdulla, A. I. et al [10]. Two percentage of steel fibers and iron filing(0.5 and 1)%were used for purpose of this study , as shown in Figure 1.A and 1.B respectively . The properties of steel fibers are shown in Table 1. The grading of iron filing which conforms to the Iraqi Standard Specifications IQS45/1985 zone 2 [11] are shown in Table 2.

Table 1. Properties of steel fibers

Property	Specifications
Density	7860 kg/m^3
Ultimate strength	1130 MPa
Modulus of Elasticity	200000 MPa
Strain at proportion limit	5650 x10^{-6}
Poisson's ratio	0.28
Average length (ℓf)	50mm
Nominal diameter (df)	0.5mm
Aspect ratio (ℓf/df)	100

Table 2. Sieve analysis of iron filings

Size	Pass percentage	I.Q.S 45/1985
4.75	100	90-100
2.36	99.32	75-100
1.18	87.18	55-90
0.6	36.26	35-59
0.3	10.3	8-30
0.15	3.25	0-10

A. steel fibers

B. Iron filing

Figure 1. Steel fibers and Iron filing

2.1. Treatment Efficiency of Aggregates

To test the success of the treatment Attapulgite stone with sodium hypochlorite solution for 24 hrs, the following laboratory tests were performed to identify the improvement of the properties of the coarse aggregate prepared from this stone.

2.1.1. Aggregate Impact Value Test

This test is performed to identify the resistance of the aggregate to the impact force according to B.S.818:P3 [12] as shown in Table 3.

Table 3. Impact value index

Aggregate	*Impact %Value*
High Strong	10>
Strong	20-10
Good	30-20
Weak	45-30

3.

2.1.2. Aggregates Crushing Value Test

This test is performed to determine the resistance of the aggregate to the crushing force under the influence of the compressive load applied to it. Step by step as the test is performed according to B.S.818:P3. An aggregate whose crush strength value exceeds 30% is considered weak.

2.1.3 Abrasion Test (Los Angelo's Test)

In this experiment, the ASTM C-131[13] standard was adopted, in this standard, the aggregate must pass through a 37.5 mm sieve and be fixed on a 5 mm sieve, but if the aggregate is greater than 37.5mm, the test is performed according to ASTM - C-535[14] ,the difference in the specification is the number of machine revolutions. The percentage of erosion is calculated and then determines the suitability of the aggregate for any type of construction.
Usually, the specifications are limited the value of this test in the surface layer with smaller than 30%, and for the base and sub base layers are less than 50%.
In Table 4 the values of the previous investigations are listed for Attapulgite stone before and after treated with sodium hypochlorite solution for 24 hrs.

Table 4. Treatment efficiency of aggregates

Test	After	Before
Impact Value %	25	11
Crushing Value%	28	17
Abrasion Value %	26	9

3. Experimental Works

Table 5 shows the details of concrete five mixtures that were used in this study include cement 560 kg/m^3, the sand 500 kg/m^3, Attapulgite 400 kg/m^3, Super-plasticizer 6 l/m^3, w/c 0.3. The M1 was the reference mixture while other used to study the effect of use sustainable material (Iron Filing) in the strengthening of reinforced concrete light weight concrete.

Table 5. Mixes proportions of lightweight aggregate concrete

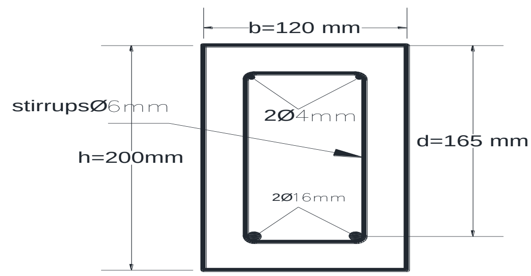
Mix.Sym.	*Steel fiber*	*Iron filing*
M1	0	0
M2	0.5	0
M3	1	0
M4	0	0.5
M5	0	1

3.1 Mechanical Properties

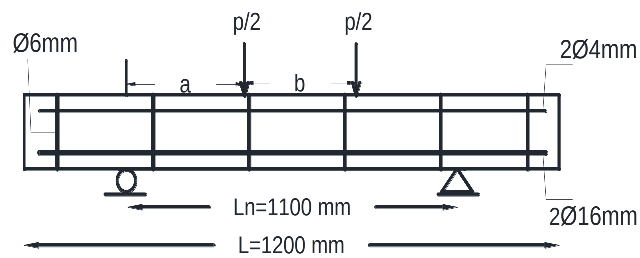
The mechanical test of the compressive strength of lightweight concrete was carried according to ASTM C39 [15], The splitting strength of lightweight concrete with Attapulgite aggregate was carried out according to ASTM-C496 [16] while the mechanical test of the modulus of rupture of lightweight concrete was carried out according to ASTM C78/C78M – 15b[17]. The modulus of elasticity was carried out on the cylinders with dimensions 150 mm diameter and 300 mm in height, according to ASTM C469-02[18].

3.2 Shear capacity of reinforced light weight concrete beams

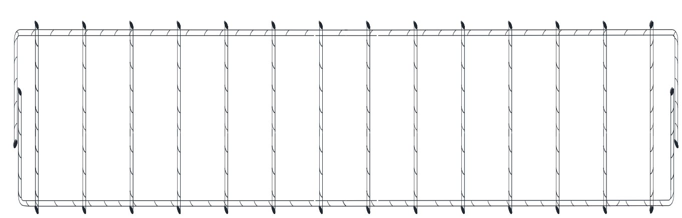
Five lightweight reinforced concrete beams of rectangular sections, 200mm x 120 mm, with length 1200 mm, as shown in Figure 2.(A, B and C).The beams were cast by using treated Attapulgite aggregates to investigate the shear capacity with constant shear span to effective depth (a/d) equal to 1.7. All beams reinforced by 2 deform bars of 16 mm diameter, with 410 MPa yield stress, the large area of bottom reinforcement is used to avoid flexural failure. The stirrup reinforcement is, 6 mm deform bars, with yield stress 525 MPa placed at spacing 80 mm center to center. In the compression zone, use two bars with 4mm diameter, this reinforcement was placed to fixed stirrups. The first specimen (B1) was cast as a reference beam, the next two specimens (B2, and B3) were strengthened with 0.5% and 1.0% steel fiber content respectively, the last two specimens (B4, and B5) had been strengthened with 0.5% and 1.0% iron filing content respectively. The beams tested under two points load and the load applied gradually, the results are recorded during the test. Both longitudinal and transverse steel reinforcement were designed according to ACI318-14 [19].



A. Cross section



B. Span beam



C. Spacing between stirrups @80

Figure 2. Details of tested beam specimens

4. Results

4.1 Mechanical properties

The results of mechanical properties were illustrated in Table 6,7 and Figure 3. The maximum increase of compressive strength was achieved with a 1% addition of steel fiber and iron filing content by 9% and 8%, respectively.

Table 6. Result of mechanical properties of LWC

Mix Symbol	f'c, MPa	Ft, MPa	Fr, MPa	Ec, GPa	Density Kg/m3
M1	37.6	4.0	4.6	17.3	1885
M2	39.9	5.5	6.7	22.9	1910
M3	41.1	7.8	9.2	23.1	1923
M4	39.2	4.0	6.0	23.3	1895
M5	40.7	4.7	6.5	23.0	1905

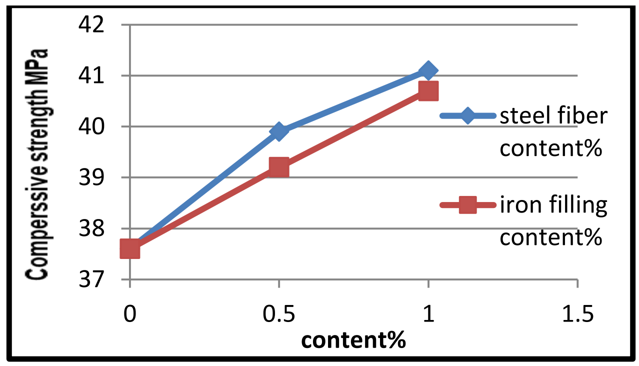
The reference value of splitting strength cylinders was 4.0 MPa, while maximum value recorded for this test was 7.8 MPa for mixture of lightweight concrete of Attapulgite aggregate with 1% addition by steel fibers. The maximum percentage increasing was notice by addition 1% steel fibers (M3) with value 95%. The splitting tensile strength was increased 18% with 1% iron filing content.

Table 7. Result of increasing mechanical properties of M1of LWC

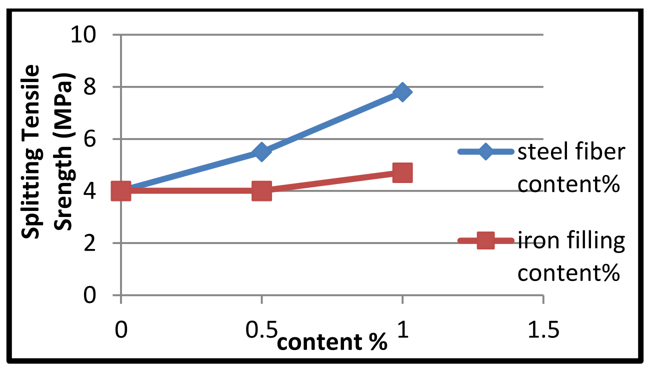
Mix Symbol	f'c, of % M1	Ft, of % M1	Fr, of % M1	Ec, of % M1
M1	-	-	-	-
M2	6	38	46	32
M3	9	95	100	34
M4	4	0	30	35
M5	8	18	41	33

The maximum percentage increasing of modulus of rupture was notice at addition of 1% steel fibers (M3) with value 100%. The modulus of rupture was increased by 41 % with addition of iron filing content 1%.

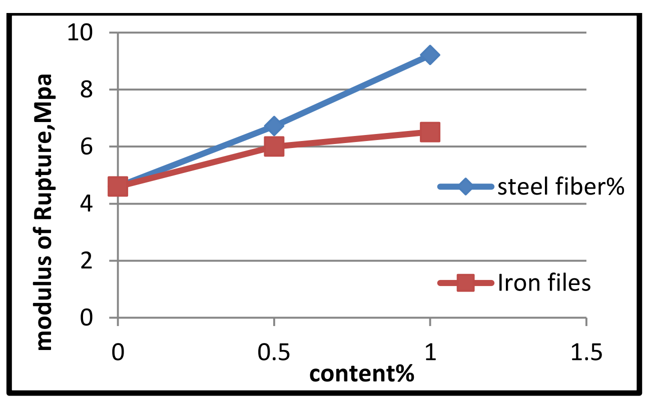
The maximum percentage increasing for modulus of elasticity was noticed by addition 0.5% iron filing (M4) with value 35.% , and the modulus of elasticity was increased by 32% with same ratio of addition of steel fibers.



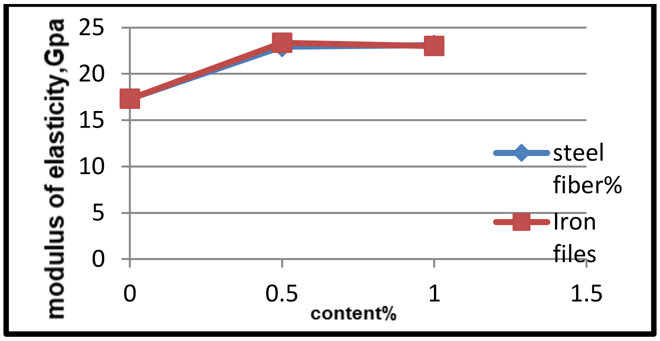
A. Compressive strength



B. Splitting tensile strength



C. Modulus of rupture



D. Modulus of elasticity

Figure 3. Result of mechanical properties.

4.2 Shear capacity of reinforced light weight concrete beams

Table 8 and Figure 4 are illustrated the results of first crack load and ultimate shear loads. the first cracking load increasing about by 15% and 35% compare with reference beam B1 when the steel fiber had been added by 0.5% and 1% for beams B2 and B3 respectively, and the increasing become 23% and 38% by using the same ratio of iron filing for beams B4 and B5 respectively .

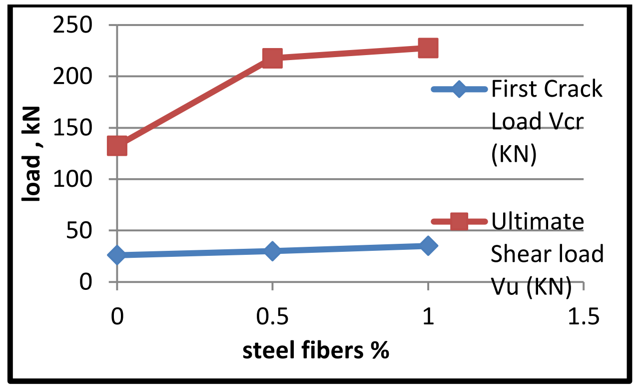
Also increasing value in the ultimate shear loads for beams B2, B3, B4 and B5 were 64%, 72%, 31% and 38% compare with reference beam B1 respectively.

Table 8. Results of first cracking load and ultimate shear load

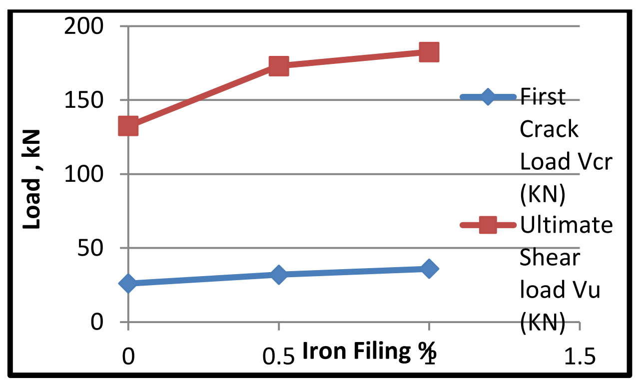
Beam No.	First crack KN	Compare withB1%	Ultimate Load KN	Compare withB1%
B1	26	-	132.5	-
B2	30	15	217.5	64
B3	35	35	227.5	72
B4	32	23	173	31
B5	36	38	182.5	38

It has been found that, addition of steel fibers to the concrete mixture improves ultimate loading capacity for tested specimens through improving the tensile properties of concrete by retard cracks propagation from micro-cracks to macro-cracks.

The increase in the percentage of iron filing leads to increase the first cracks and maximum loads capacity, but this increase was limited by the use of percentages of iron filing.The effect of iron filing ratio was more obvious in its first cracking loads because it works to resist the first crack but it is unable to transfer loads from the affected areas to the new areas due to the relatively few aspect ratio



A. Steel fibers



B .Iron filings

Figure 4. Development in cracking and ultimate shear loads

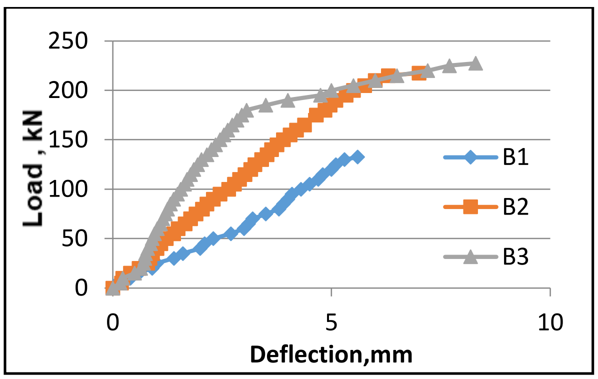
Figure 5 shows the mid-span deflection during the test while Table 9 listed the deflection values at first cracking load and ultimate stages with the value of the ductility factor. It seems that the presence of steel fiber or iron filing improve the deflection at ultimate load and this led to an increase in the ductility factor of concrete.

It can be observed from the lightweight concrete of Attapulgite aggregate results that, the maximum crack's width of the concrete beams decreasing when the ductility factor is increased. Also When using steel fiber, the crack width decreases as they reduce the cracking motion.

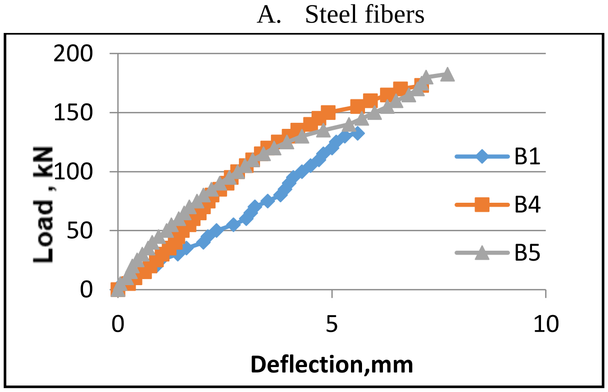
Table 9. Mid span deflection at first crack and ultimate stages

Beam No.	Max crack	Δ*cr* mm	Δu mm	Ductility	% Ductility Increasing
B1	0.90	0.79	5.6	7.1	0
B2	0.60	0.85	7	8.2	15
B3	0.55	0.465	8.3	17.8	151
B4	0.75	0.45	7.1	15.8	123
B5	0.65	0.45	7.7	17.1	141

Indirect Ductility Ratio (Ψ∘Δ=/Δcr).
*



A. Steel fibers



B. Iron filings

Figure 5. Effect of Steel Fibers and iron filing on the behavior Deflection at Mid Span

The modes of failure of all beams show in Table 10 and Figure 5 it can be seen the diagonal splitting mode was dominant for all beams and was accompanied by cracking in the pressure zone in case of adding the steel fibers.

Table 10. Failure mode of beams

Beam	Failure Mode
B1	Diagonal splitting mode
B2	Diagonal splitting mode with crushing at support zone
B3	Diagonal splitting mode+ some of flexural perpendicular
B4	Diagonal splitting mode
B5	Diagonal splitting mode

A. Steel fibers

A. Iron filings

Figure 6. Failure mode of beams

5. Conclusions

1. The increase in the splitting strength there was clear evolved in due to steel fiber and iron filing presence in the concrete mix. Iron filing and steel fiber increasing the compressive strength of concrete.
2. The presence of steel fiber and iron filing are improved the tensile strength of

concrete especially when using the steel fiber.

3. There was a great improvement in the value of the modulus of elasticity of this type of lightweight concrete when the addition of steel fiber and iron filing there is some similarity to effect of steel fiber and iron filing on the modulus of elasticity.
4. It has been found that the addition of steel fiber and iron filing to the concrete mixture improves the ultimate loading capacity of tested specimens.
5. The behavior of lightweight concrete with the use of Attapulgite aggregate and iron filing was acceptable to produce sustainable concrete using local materials.
6. The results of the study showed that iron filing may be a fairly successful alternative to steel fibers in improving some mechanical properties and shear behavior.

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Abbreviations

LWC:	Light weight concrete
SFLWSCC:	steel fibers lightweight self-compacting concrete
V_f :	Volume Fraction of Steel Fiber self-
ρ :	ratio of longitudinal reinforcement
a/d :	ratio of the shear span to the effective depth
OPC :	Ordinary Portland cement
I.F :	Iron Filings
f'c :	Cylinder Compressive strength
Ft :	Splitting tension strength
Fr :	Modulus of rupture
Ec :	Modulus of elasticity
Ψ :	Indirect Ductility Ratio
Δu :	Mid-span deflection at ultimate Load
Δcr :	Mid-span deflection at first Crack Load

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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