BEHAVIOR OF LIGHTWEIGHT SELF-COMPACTED CONCRETE USING ATTAPULGITE STONE AS AGGREGATE AND SUBJECTED TO AXIAL LOAD

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Abstract: This paper presents experimental studies of rectangular concrete beam behaviors under axial load and bending loads and investigating the possibility of producing Lightweight Self-Compacting Concrete (LWSCC) by using the Attapulgit stone with a bulk density of about 776 kg/m³. The experimental work included (5) specimens which included using the silica fume by 10% and 15% as an addition to the mixture M2 and M3. The shear span to effective depth (a/d) of beams was (2.5, 2.75, and 3.00). The test results showed an improvement in the mechanical properties of specimens containing silica fume by 15%, which was tested at 28 days. The first crack and the ultimate load were decreasing with increasing (a/d) ratios. Experimental results indicate a significant improvement in the properties of concrete and its resistance to shear stresses, as the axial load improves the shear capacity and reduces the shear failure in the (LWSCC).

Keywords: *Lightweight self-compacting concrete, Attapulgit, silica fume, shear span to effective depth*

1. Introduction

Concrete is of the most important available materials for construction in all over the world. The concrete construction is characterized by durability, resistance to fire and low maintenance costs [1]. Lightweight aggregate concrete is a type of concrete, it has been used in many applications such as bridges, offshore oil platforms, pre-stressed structural elements, multi-story buildings and floors [2]. In the last

years, there has been a need to develop concrete performance in durability, strength and flow ability. This leads to the innovation of a new type of concrete called Self-Compacting Concrete (SCC). SCC differs from ordinary concrete in that it compacts by means of its self-weight without the need for external or internal vibrators so it can fill all parts of the mold and segregation resistance [3]. Various types of SCC have been developed to meet the construction requirements. One of the most important innovations is the combination of lightweight concrete (LWC) and (SCC) to produce Lightweight Self-Compacting Concrete (LWSCC) can maximize the benefits and applications of concrete. Based on the previous studies, Attapulgit clay was used as a coarse aggregate to produce lightweight concrete that was excellent by its light weight and fire resistance. Al-Nuaimi [4] studied the effect of using Attapulgit with a replacement rate of (5-80)% with cement weight on the mechanical properties of Portland cement. The results showed that the compressive strength was better 5% and 15% at ages (28, 90, 180) days. The replacement rate of 25% was the highest compressive strength at ages 90 and 180 days. Jar-Allah [5] studied the use of Thermostone

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aggregates of size 9.5 mm and Porcelinite aggregates size 9.5 mm in addition to using high reactivity metakaoline (HRM) and silica fume (SF) on the mechanical properties of LWSCC. Two different of w/c ratios were used 0.32 and 0.35. The results showed the (HRM) which is better than silica fume in production of LWSCC. The values of compressive strength and air dry density at age 28 days for w/c 0.32 of LWSCC with Porcelinite aggregates were better than of the Thermostone aggregates. Khandaker M [6] study the possibility of producing lightweight aggregates concrete by using volcanic pumice (VP) stone as a substitute material for cement and coarse aggregate. Chao-wei et al., [7] discussed shear behaviors of longitudinally reinforcement lightweight concrete made from the sedimentary lightweight aggregate and compared them with normal weight concrete. The variables included in this study are compressive strengths of 23, 43 and 53 MPa in addition to shear span to the effective depth (a/d) of (1.5, 2, 2.5, 3). The test results were compared with ACI 318 Code, the comparisons show that the shear forces for (LWC) and (NWC) are within the acceptable limits of ACI 318 Code. S. Garcia et al., [8] This study discussed the shear behavior of reinforced concrete beams without transverse reinforcement. Two types of concrete were produced, the first is reference conventional concrete (RCC) and the second is lightweight self-compaction concrete (LWSCC). During the search, the longitudinal reinforcement was determined (0.89, 1.27, 1.68) % and the shear to the effective depth (a/d) was (1.87, 2.71). The results showed that the shear resistance of the beam was directly affected by the longitudinal reinforcement ratio regardless of the concrete type or (a/d), the higher the longitudinal reinforcement ratio, the greater the shear resistance of the beam. The results also showed

that LWSCC beams have a shear resistance less than RCC.

The main objectives of this study the effect of axial load on behavior of LWSCC contain Attapulgit stone as a coarse aggregate. Two variables were used, first the different value of compressive strength of concrete by using two different values of addition of silica fume 10% and 15%. While second variable was using different value of shear span ratio (a/d).

2. Material

2.1. Cement

Ordinary Portland Cement (OPC) was used in this research. Cement was achieved with Iraq Specification limits (IQS) No.5/ 1984 [9].

2.2. Fine Aggregate (sand)

Sand of 4.75 mm maximum size is used as a fine aggregate in (LWSCC) mixes. The sand used during this research was conforms to (IQS) No.45/1984[10].

2.3. Coarse Aggregate (Attapulgit)

Attapulgit stone from Tar AL-Najaf region the raw material for the production of the Attapulgit aggregate. The bulk density of the aggregate was 776 kg/m³. Attapulgit stone were crushed to give a final product of about 14mm a maximum coarse aggregate size. The crushed stone was sieved by a standard sieve conform to the (IQS) 45/1984[10]. Table (1) shown the grading of Attapulgit aggregate. Attapulgit is burned at a temperature of 1100 C° for half an hour to give the porous structure of the stone. Then the stone is soaked with sodium Hypochlorite solution for 24 hours. The Attapulgit stone treated with Sodium Hypochlorite solution increased the stone strength and improved abrasion resistance and specific gravity. In addition to improving the mechanical properties of concrete by increasing the resistance and hardness of the stone.

Table 1. Sieve analysis of Attapulgit stone

Sieve Size (mm)	Attapulgit (%passing)	Limit of IQS45/1984
20	100	100
14	90	90-100
10	53.75	50-85
5	9	0-10

2.4. Chemical Admixture

A high performance concrete super-plasticizer (Visco-Crete 5930L) is used in this research complies to ASTM C494 [11] Type A and F. Table 2. Shows properties of Super-plasticizer.

Table 2. Properties of super-plasticizer

Commercial Name	Visco-Crete 5930L
Form	Viscous liquid
Color	Light brown
Relative density	0.01-1.083 Kg/m ³
PH	4-6
Viscosity	128μ 30 cps @ 20° C
Labeling	No hazard label required
Transport	Not classified as dangerous
Chlorides	Free from chlorides

*Supplied by the Manufacturer

2.5. Mineral Admixture

2.5.1. Limestone Powder

Locally, this mineral is called to as (Al-Gubra). The cement in LWSCC mixes is generally replaced by limestone powder to enhance a properties of concrete.

2.5.2. Silica Fume (SF)

Silica fume was used in a ratio of 10% and 15% in this study .the chemical analysis of silica fume was conformed to the requirements of ASTM C1240[12]. Table (3) shows the chemical composition of silica fume.

Table 3. The chemical composition of silica fume

Chemical composition	Oxide Content%	Limit of specification requirements
Cao	0.5	-
Fe2O3	1.4	-
Al2O3	0.5	-
SiO2	92.1	85(min)
Mgo	0.3	-
SO3	0.1	-
K2O	0.7	-
Na2O	0.3	-
L.O.I	2.8	6(max)

*Supplied from manufacturers

2.6. Water

Tap water was used in all concrete mixes.

3. Details of Tested Beams

Five lightweight self-compacting reinforced concrete beams of rectangular sections in dimensions, 200mm×120mm with length 1500mm, as shown in Figure 1. The beams of LWSCC were reinforced in the tension zone by using 2 bars of 16mm diameter. The stirrup reinforcement was 6mm bars placed at spacing 80 mm center to center .the compression area was reinforced with a diameter of 4mm to fixed the stirrups. The (B1R) was cast as a reference beam, the (B2 and B3) were cast by using silica fume at rates (10% and 15%) and the (B4 and B5) discuss the effect of shear span to effective depth. the beams were tested by two points load. Table 4. Illustrates the specification and tensile test results of steel bars are accordance with standard specifications for steel reinforcement ASTM A615-86 [13] and ASTM A82-05 [14].

Figure 1. Details of tested beams: (a) beam span and (b) cross-section

Table 4. Specification and tensile test results of steel bars

Nominal Diameter (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Elongation %
6	655	831	-
16	445	635	10.21

4. Experimental Works

Table 5. shows the details of LWSCC beams that were used in this research include cement 500 kg/m³, the sand 850 kg/m³, Attapulgit stone 290 kg/m³, Limestone 75 kg/m³, w/c 0.3, and Superplasticizer 14 l/m³. The BR1 was the reference beam while the other beams were used to study the effect of using the silica fume and shear span to effective depth (a/d) of LWSCC. The beam was subjected to an axial load using a steel frame, in order to achieve the requirements of the axial force test. The beam is fixed inside the steel frame then, the beam placed vertically on the test machine to applied an axial force of 100 KN. after that, the beam is placed horizontally to

applied two point loads until failure. This test was conducted to study the behavior of the beams under the axial force, as this test simulates the reality through the exposure of the buildings to the axial force caused by the pressure of the walls of the buildings next to it. Figure 2. Shows the process of applying the axial load and the two point loads to the beams using the steel frame.

(a)

(b)

Figure 2. Applying the axial load and the two point loads to the beams

Table 5. Details of LWSCC Tested beams

Mix/Beam Symbol	Silica Fume %	% Super	(a/d)
M1R/BR1	0	0.7	2.5
M2/B2	10	0.7	2.5
M3/B3	15	0.7	2.5
M4/B4	0	0.6	2.75
M4/B5	0	0.6	3.00

4.1. Tests of Fresh Concrete

Tests of fresh concrete were used to determine the workability for reference concrete. Slump Flow test and T500mm,L-box,V-funnel are the available tests in the materials laboratory of the Mustansiriyah University as shown in figure 2. Slump flow test, L-box test and V-Funnel test were used to characterize the properties of LWSCC (passing ability, filling ability and segregation resistance) all these tests were performed according to EFNARC 2005[15].

Figure 3. Tests of fresh concrete

5. Results

5.1. Results of Fresh LWSCC

The concrete is considered as LWSCC if its fresh properties are in conformity with the specification such as EFNARC [15]. Table 6. Shown the test results of the fresh concrete and limitations of EFNARC.

Test	Unit	Test result	Range[15]
Slump flow	mm	760	650-800
T50	sec	2.89	2-5
V-funnel	sec	8.3	6-12
L-box	%	1.0	0.8-1.0

5.2. Mechanical Properties

The results of mechanical properties of LWSCC were illustrated in Table 7. and Figure 4. The maximum increase in compressive strength(f_c) was 22% by the addition of 15% of silica fume (M3). The reference value of compressive strength was 27.5 MPa, while the maximum value for this test was 33.6 MPa. The reference value of splitting strength (f_t) cylinders for the mixture of lightweight Self-Compacting Concrete was 3.51 MPa, while the maximum value calculated for this test was 4.59 MPa with 15% addition by silica fume, the maximum percentage increasing of this test was 31% in the mixture (M3). The maximum percentage increasing of modulus of rupture (f_r) was 21% at addition 15% of silica fume (M3). The modulus of elasticity(E_c) was increased by 17% with same mixture (M3). The mechanical tested of compressive strength, the splitting strength, modulus of rupture and modulus of elasticity of LWSCC were carried according to ASTM C39/C39-05 [16], ASTM C496-04 [17], ASTM C78-84 [18] and ASTM C469[19] respectively.

Table 7. Result of mechanical properties of LWSCC

Mix symbol	f_c (MPa)	f_t (MPa)	f_r (MPa)	E_c (GPa)
M1R	27.5	3.51	4.87	18.113
M2	31.7	4.20	5.36	20.149
M3	33.6	4.59	5.91	21.216
M4	25.5	3.11	4.07	18.003

(a)

(b)

(c)

(d)

Figure 4. Result of mechanical properties, (a) Compressive strength, (b) Splitting tensile strength, (c) Modulus of rupture and (d) Modulus of elasticity

Table 8. and figure 5 show the results of the first cracking load and ultimate loads of LWSCC beams tested. The first cracking load increasing about by 13% and 42% compare with beam B1R when 10% and 15% of the silica fume were added for B2 and B3 respectively. The increase in the silica content in LWSCC mixtures leads to an improvement in the microstructure and increase the density due to the pozzolanic

reaction of the silica. The maximum first cracking and ultimate load are recorded as 27 KN and 177.5 KN by addition 15% of silica fume in the mixture (M3) respectively. The results showed that increasing the (a / d) ratio leads to a decrease in the first cracking load and the ultimate loads. Three beams (B1R, B4, and B5) with different ratios of (a/d) were changed from 2.5 to 2.75 and 3.00 respectively. The variation of (a/d) from 2.5 to 2.75 resulted in decreasing percentage by (21) % for first crack and (18) % for the ultimate load (B4). The variation (a/d) ratio from 2.5 to 3.00 resulted in decreasing percentage by (34) % and (25) % respectively for first crack and the ultimate load (B5).

Table 8. Results of first cracking load and Ultimate load

Beam No.	First crack KN	Compare With B1 %	Ultimate Load KN	Compare With B1 %
B1R	19	-	155	-
B2	21.5	13	160	3
B3	27.0	42	177.5	15
B4	15	12	127	18
B5	12	34	116	25

(a)

Figure 5. Development in first crack and ultimate load of LWSCC beams: (a) content of silica fume and (b) the ratio of (a/d)

Table 9. and Figure 6 show the effect of the axial force on the lightweight self-compacting concrete beams, which led to an improvement in the capacity of the concrete and its resistance to applied loads. Regardless of the axial load applied on the beams tested, the stiffer load-deflection curves are obtained from the beams with smaller (a/d) ratios. The beams with smaller (a/d) ratios are failed at lower deflection compared with the beams with larger (a/d) ratios. The beam (B1R) has (a/d) of 2.5 and failed when deflection equal 5.8 mm, while the beams (B4 and B5) have (a/d) (2.75 and 3.00) respectively and failed at the deflection (7.71 and 8.15) mm respectively. The maximum load of (B4 and B5) decreases about (18% and 25%) due to early failure by concrete crushing. The axial load was beneficial for the LWSCC beams under bending it reduces tensile stresses on the bottom part of the beams. Illustrated by figure 6 (a) that the deflection increase with an increase in the silica fume under applied load. This is due to filling the voids between the concrete particles and addition to the chemical action of the silica fume, which leads to an increase in the compressive strength of the concrete. Silica fume was added to know the change in shear strength when the compressive strength rises under the influence of the axial load. In addition, found in figure 6. (B)

that the slope of the deflection curve increases under axial load with the lower (a/d) ratio.

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

Beam No.	Max Crack(mm)	Δc_r (mm)	Δu (mm)
B1R	0.18	0.92	5.8
B2	0.15	0.3	4.99
B3	0.2	0.9	6.61
B4	0.35	0.49	7.71
B5	0.3	1.11	8.15

Figure (7) shows, in the early stages of the loading, the vertical curvature cracks are observed on the underside of the mid-span of the beam with increasing loading, shear cracks grow from the upper end of the bending cracks to configure flexural-shear cracks. In the late stages of the loading, the critical diagonal crack extended towards the loading points and producing a shear compression failure. After that, these cracks spread and penetrate the beam compression area, where the concrete is crushing at the tip of the diagonal crack in the load application area. This failure occurs when the compressive strength of concrete is exceeded. This type of failure is called shear compression failure, which occurs due to the crushing of the concrete at the loading point's. When the reinforcement is yielded, the load distribution is not possible and the concrete reaches its ultimate capacity which leads to crushing at the loading points. Shear compression failure occurred in all beams except for B3 and B4, It failed by crushing due to the increase in the bearing strength of the tensile area in the mid-span of the beam extension resulting from the effect of the axial force, where the axial force increased the shear capacity and the flexural resistance of the beam. Shear compression failure occurred in all beams except for B3 and B4, It failed by crushing due to the increase in the bearing strength of the tensile

area in the mid-span of the beam extension resulting from the effect of the axial force, where the axial force increased the shear capacity and the flexural resistance of the beam. The maximum crack width decreases in the silica content of 10% and then the crack width increases in the silica content of 20%, but in general, the silica is used to reduce the width of the crack due to the filling of the voids inside the concrete. Figure 7. Shows the failure mode and the crack width of the LWSCC beams.

(a)

(b)

Figure 6. (a) and (b) Effect of silica fume and (a/d) on behavior Deflection at mid span

(a)

(b)

Figure 7. (a) Effect of silica fume and (b) (a/d) on Failure mode of beams

6. Conclusions

1. It is possible produce lightweight self-compacting concrete by using Attapulgitte as a coarse lightweight aggregate within the conformity to EFNARC 2005 for SCC workability and within the requirements of ASTM C 330-04 for structural (LWAC).

2. The effect of silica fume for LWSCC mixtures that filling of the voids between concrete due to its high softness of silica fume.
3. Improvement about 22%, 31%, 21% and 17% in compressive strength. Splitting tensile strength, modulus of rupture and modulus of elasticity of LWSCC respectively when 15% addition of silica fume.
4. By studying the variables on lightweight, self-compacting concrete to improve sample loading capacity compared to the reference beam, the highest increase was found by adding 15% of silica fume.
5. As (a/d) increases, the first crack and Ultimate loads decreasing, and the crack width values increase with decreasing (a/d).
6. This test shows that concrete models consisting of lightweight self-compacting concrete beams have increased shear capacity and resistance to bending, due to the effect of axial load.

Abbreviations

LWC	Lightweight concrete
SCC	Self-Compacting Concrete
LWSCC	Lightweight self-compacting concrete
RCC	Reference conventional concrete
NWC	Normal weight concrete
HRM	High reactivity metakoline
(a/d)	Ratio of the shear span to the effective depth
OPC	Ordinary Portland Cement
f _c	Cylinder Compressive strength
ft	Splitting tension strength
fr	Modulus of rupture

Ec	Modulus of elasticity
Δu	Mid- span deflection at ultimate load
Δcr	Mid-span deflection at first crack
SF	Silica fume
VP	Volcanic pumice

Conflict of Interest

The authors confirm that the current paper's publication does not result in a conflict of interest.

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