Behavior of Steel-Fiber Reinforced Lightweight Self-Compacting Concrete Containing LECA after the Exposure to Internal Sulfate Attack

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Abstract. For many years, lightweight concretes (LWC) have been utilized successfully in the construction of buildings because of their low specific weight, high thermal insulation capacity, and sound insulation. The development that led to lightweight self-compacting concrete (LWSCC) is a significant step forward in recent years. These concrete chains self-compacting concrete's beneficial properties with lightweight concrete. The purpose of this experimental investigation is to determine how the internal sulfates attack effect fresh and hard properties of lightweight self-compacting concrete (LWSCC) made by using lightweight expanded clay aggregate (LECA) before and after the addition of 0.5 volume fraction (V_f) of steel fibers. In fine aggregate, several concrete mixes were cast in different SO_3 percentages (0.34, 2, 4, and 6%). The fresh properties of LWSCC concrete were tested, such as (slump, sieve segregation resistance, and L-box test). The hard properties of LWSCC were (Compressive, splitting tensile strength, flexural strength, oven-dried density, and modules of elasticity). The results showed that the presence of SO_3 in fine aggregate affects the properties of LWSCC. A significant decrease in fresh properties of LWSCC mixes with (2, 4, and 6%) of SO_3 in fine aggregate. In addition, the mechanical properties (compressive St., splitting tensile St., flexural St., density, and modulus of elasticity) decreased as curing age increased, and SO_3 % increased. When sulfate percent rose from (0.34% to 2%, 4%, and 6%) in compressive St., the reduction was (16.53, 22.45, and 26.47%) at 120 days. Adding 0.5% V_f of steel fiber enhanced the mechanical properties of LWSCC.

Keywords: Lightweight self-compacting concrete, LECA, Natural gypsum, steel fiber.

1. INTRODUCTION

The phrase "sulfate attack" refers to the deterioration of concrete caused by any interactions between sulfate and cement paste that are independent of curing temperature and sulfate source. As the amount of C_3A in cement decreases, the resistance of cement to be attacked by sulfate salt solutions increases. High resistance was discovered for Portland cement having not more than 5.5% C_3A. [1]. Since the internal sulfate attack-related damage was first discovered in the middle of the 1980s, it is relatively "new" compared to the "classic" external sulfate attack [2]. At later ages, the concrete's mechanical and physical properties after hardening may be harmed by high sulfate percentages. Early Ettringite formation (EEF) is the word used to describe the Ettringite (E) formation that happens homogeneously and quickly in a mixture or in deformable concrete (during hours or days), according to Eq. 1 [3,4].

$$C3A + 3(CaSO4.2H2O) + 26H2O \rightarrow C_3A.3CS.H32 \quad (1)$$

The associated expansion is not thought to have any major disruptions that are only limited. The expansion occurs when crushed gypsum combines with anhydrous calcium and aluminates in a matter of hours or when calcium aluminates sulfate (C4A3S) hydrates in a matter of days. Generating a very tiny homogenous, harmless, and beneficial stress (expansive cement for shrinkage compensating concretes). On the other hand, delayed Ettringite formation (DEF), which happens when Ettringite develops later (months or years afterward), causes localized expansion that results in cracking, spilling, and strength loss in stiff hardened concrete. [4].

A study by Hadeel Khalid (2017) [5] investigated the comparison of the effect of using two Portland cement with various chemical compositions with varying percentages of high reactivity metakaolin (HRM) (5, 10, and 15%) and a W/Cm ratio of 0.35. The SCC mixes with Saudi Arabian-produced AL Shemalia OPC cement (C_3A =7.02%) exhibit stronger resistance than mixes with Iraqi-produced Tasluja OPC cement (C_3A =4.13%) to ISA. The outcomes demonstrate that the SCC mixes with 15% HRM exhibits greater resistance to internal sulfate attack (ISA). The results demonstrated that HRM-containing mixtures improve concrete's compressive strength and increase its resistance to ISA. Additionally, for mixes containing less than 1.5% SO_3 by weight of sand, the compressive St. and splitting tensile St. of concrete mixes containing HRM increase with the progression of curing age. Beyond this point, increasing the SO_3 % will cause a decrease in mechanical properties sharply over time.

Al-Anbori [6] studied the effect of two types of sulfate-resistant Portland cement with varied percentages of silica fume replacement by cement weight and W/cm being studied (0.3 and 0.35). In comparison to mixes with cement type 2 (C3S= 61.22 and C3S/C2S =4.44), SCC mixes with cement type 1 (C3S = 46.39 and

C3S/C2S = 1.78) exhibit more excellent resistance to external sulfate attack (Es). The SCC mixtures with 10% SF as cement replacement exhibit greater resilience to external sulfate attack. Compared to reference concrete mixes, there was an increase of 17.95%, For SCC mixes with type 1 cement with W/cm 0.3 and 17.88% for SCC mixes with type 2 cement with W/cm 0.3.

The production of SCC involves using (SF) as a partial weight replacement of cement with a percentage of (5%). The sand was partially volume replaced by thermostone chips, which were used as fine lightweight aggregate (LWA) for the use of internal curing material. Two external curing conditions (water and air) were used. Three parts were made in the experimental work: the first part included testing the fresh SCC properties. The second part involved performing compressive St. tests and modulus of rupture tests (7, 28, and 90) days. Shrinkage was tested in the third part at ages 7, 14, 21, and 28 days. The findings demonstrate that when compared to reference concretes, the greatest properties of hardened concrete and the best workability are found in internally cured SCC, including (compressive St. and modulus of rupture). Additionally, compared to percentages of (5 and 15%) for both external curing conditions, the greatest outcomes were seen in the hardened properties of internally cured SCC with a replacement percentage of 10% by thermostone chips. The shrinkage test results showed that internally cured SCC shrank less than the reference [7].

The total sulfate content (TSC) and total effective SO3% (TES) in cement (C), sand (S), and gravel (G) were studied by Mahdi et al. [8]. 3 sets of SO_3 in S, two sets of SO_3 in G, and two sets of SO_3 in C made up the materials used. Since the effect of sulfate in each component of concrete depends on its granular size, the outcomes demonstrate that considering the TES is preferable to the TSC. The effectiveness of the sulfate in a material increases with its particle size. Because it allows for greater flexibility in the use of S and G with larger sulfate contents, it is advised to meet the requirements for total effective sulfate content set forward by Iraq. According to the compressive strength data after 90 days, the TES of 2.647%, 2.992%, and 3.424%, which corresponds to TSC of 3.778, 3.294, and 4.528%, respectively, reduce the compressive strength by 7.53, 11.44, and 14.59%. These results display strong resistance in high-strength concrete (HSC) to the action of sulfate at various ages. The decline in compressive strength varied approximately (7-40%) at seven days for mixes with TES content of (2.6-6.9) % and with TSC of (3.77-11.72) % (by weight). On the properties of concrete, increasing the SO_3 content in C has a greater impact than increasing the SO_3 content in S, and S has a more significant impact than increasing the SO_3 content in G. The cement's surface area and fineness are responsible for this decline. The TES, which is influenced by the materials' particle sizes, exhibits a positive trend when the sulfate content of concrete constituents rises. HSC mixtures see severe deterioration in all their properties. And with an increase in total effective SO_3 concentration of (2.6-6.9) %, the compressive St., flexural St., U.P.V., and density findings drop at an early age by around (5-40%) %, (3-28) %, (1-10) %, and (0.38-4.8) %, respectively.

2. MATERIALS CHARACTERISTICS

2.1 Cement

The cement used in this project was ordinary Portland cement type (CEM I 32.5 R), which is manufactured in Iraq under the trade name (Al Mass). Tables 1 and 2 display the cement's chemical composition and physical properties. According to the investigation, the cement complies with Iraqi Standard Specification IQS. No. 5/2019. [9].

Table 1: Chemical composition and main compounds of the cement *.

Oxide	Content, %	Limit of I.Q.S (IQS-5-2019)
CaO	61.55	-
SiO_2	21.62	-
Al_2O_3	5.94	-
Fe_2O_3	3.32	-
MgO	2.85	Max. 5
SO_3	2.25	SO_3 < 2.8 If C_3A > 5
Insoluble Residue I.R	0.73	Max. 1.5
Loss on ignition L.O.I	0.94	Max. 4.0
Lime Saturation Factor, L.S.F	0.76	0.66-1.02
Main Compounds (Bogue's equations)		
C_3S	35.18	-
C_2S	35.51	-
C_3A	10.12	-
C_4AF	10.10	-

* The National Center for Construction Laboratories and Research carried out the chemical properties.

Table 2: Physical properties of cement *.

Physical properties	Test results	(IQS 5-2019)
Specific surface area (Blaine method), m^2/kg	376	≥230
Setting time (Vicate apparatus) Initial setting time, hrs: min Final setting time, hrs: min	 1:46 4.50	 ≥45 min. ≤ 10 hrs
Compressive strength (MPa) 2 days 28 days	 12 MPa 35 MPa	 More than 10 MPa More than 32.5MPa

* The National Center for Construction Laboratories and Research completed the physical properties.

2.2 Aggregate

To produce LWSCC, two different kinds of aggregate were used:

- Light Expanded Clay Aggregates (LECA). LECA gradation is between 4-10 mm, and the LECA properties are referred to in Table 3

Table 3: LECA properties*.

properties	Results	Limit of IQS No.45/1984
Specific gravity	0.64	---
Absorption (%)	20	---
Bulk density (kg/m^3)	317	---
SO_3 (%)	0.07	Max. 0.1

* Tests conducted at the Engineering College of Baghdad University's Material Laboratory

- Fine aggregate. The Al-Ukhaider district was chosen to supply the study's natural fine aggregate. The sand compliance with zone 2 of IQS N45/1984. Table 4 shows the sieve analysis of the fine aggregate used, Whereas Table 5 shows the fine aggregate's physical properties and sulfate content [10].

Table 4: Sieves analysis of fine aggregate.

Sieve Size	% Passing by Weight	Limits of IQS NO.45/1984 (Zone 2)
10 mm	100	100
4.75 mm	95.1	90-100
2.36 mm	80.5	75-100
1.18 mm	72.8	55-90
600 µm	45.5	35-59
300 µm	24.5	8-30
150 µm	4.8	0-10

Table 5: The fine aggregate's physical characteristics and sulfate content used in the experiment*.

Properties	Results	IQS NO.45/1984
Specific gravity	2.58	
Absorption (%)	1.2	
Material passing sieve size 75 µm (%)	2.5	Max. 5% for natural fine aggregate
Sulfate content (SO_3) (%)	0.34	Max. 0.5

*Tests conducted at the Engineering College of Baghdad University's Material Laboratory.

2.3 Natural Gypsum

To avoid the impact of large particle surface areas and obtain the same gradation. The natural gypsum NG is crushed and ground by hammer and passed through the same sieve set of fine aggregate used in the internal sulfate attack mix. Gypsum was partially replaced by the weight of sand as a small percentage. From a previous study [2], the amount of natural gypsum added to the sand was determined by the amount of SO_3, which is present in Eq. (2)

$$W= [(R- M\ \%) \times S]/N \tag{2}$$

Where:
W the weight of NG ground that must be added to sand (kg).
R is the needed SO_3 in sand percentage.
M is the actual SO_3 content of the sand (0.1%).
S is the weight of sand in the mix (kg).
N represents the amount of SO_3 in the gypsum that was used.

For the chemical composition of the gypsum, see Table 6.

Table 6: The chemical properties of gypsum.

Compound Composition	Value (%)
SiO_2	8.34
R_2O_3	2.25
CaO	32.02
MgO	0.95
SO_3	40.4
I.R	6.99

2.4 Mixing Water

According to Iraqi standard No. 1703, 1992, tap water was used throughout this study for mixing and curing. [11].

2.5 Admixture

BETONAC-1030-3 SR is a high-range water reduction additive as a superplasticizer. This type of superplasticizer conforms with the ASTM C494-04 requirement. Table 7 shows the typical properties of it. [12].

Table 7: The high range water reducing admixture's technical description *.

Technical Properties @ 25° C	
Color	Light yellow
Specific gravity	1.07±0.02 gm/ml
Chloride content	Non
Flash point	Concrete's initial and final hardening times are influenced by temperature, cement type, and the amount of an additive applied.

* Based on the manufacturer.

2.6 Silica Fume

Micro silica fume SF supplied from the SICA Company Iraq branch is used as mineral admixture. The chemical and physical properties of silica fume are listed in Table 8, which conform to the requirements of ASTM C1240, 2015 [13].

Table 8: chemical and physical properties of Silica Fume.

Chemical properties *			Physical properties		
Oxide composition	Valuation (%)	(ASTM C1240,2015) limitation	Physical properties	SF	(ASTM C1240,2015) limitation
SiO_2 (%) Min.	93.05	85	Percent retained on 45mm (No. 325) sieve, max.% **	6.5	10
Loss in the ignition (%) Max.	0.45	6.0	Strength Activity Index at 7 days, min. % **	120.5	105
Moisture content%, Max.	0.5	3.0	Specific surface, min, (m^2/g) *	20	15

*The building research center's laboratories.
**Tested in the University of Baghdad.

2.7 Micro Steel Fibers

A steel fiber with a straight configuration, excellent tensile, bending, and shearing strength, and resistance to fatigue, impact, and cracking. Refer with Table 9 lists the dimensions and mechanical properties of the micro steel fiber.

Table 9: properties of steel fiber*.

Description	Length (mm)	Diameter (mm)	Density (kg/m³)	Tensile strength Fu (MPa)	Aspect ratio L/D
Steel fiber	12	0.2	7860	>2850	60

* Property of the Manufacturer.

3. PREPARATION OF CONCRETE SAMPLES

3.1 Mix Proportion

The LWSCC mix design employed in this study complied with EFNARC, 2005. After determining adequate self-compatibility by evaluating the fresh properties of the concrete used, several trial mixes were made to choose the appropriate LWSCC according to EFNARC, 2005. All of the mixes used in this research have a water-to-cementitious ratio of 0.35, with the best amount of superplasticizer (Sp) (BETONAC-1030-3 SR) to add (1.5% by weight of cement). Table 10 shows the mix proportion for the mixes used in this study. [14].

Table 10: The mixture ratios used to create the test specimens.

Mix.	Cement, kg/m³	LECA, kg/m³	Sand, kg/m³	SO_3 % in fine aggregate	Limestone powder, kg/m³	SF, %*	W/Cm	Sp, %	V_f ,%
CM	480	150	800	0.34	30	14.3	0.35	1.5	0
CG2	480	150	800	2	30	14.3	0.35	1.5	0
CG4	480	150	800	4	30	14.3	0.35	1.5	0
CG6	480	150	800	6	30	14.3	0.35	1.5	0
CGS2	480	150	800	2	30	14.3	0.35	1.5	0.5
CGS4	480	150	800	4	30	14.3	0.35	1.5	0.5
CGS6	480	150	800	6	30	14.3	0.35	1.5	0.5

*by weight of cement.

3.2 Mixing, Casting, and Curing of Concrete

The lumps in the cement were eliminated by passing it through sieve No. 14 (1.18mm). The mixer is used to combine the ingredients. Before beginning the concrete mixing process, cast iron cube molds measuring(100x100x100mm), cylinders measuring (100*200) mm and (150*300) mm, and prism measuring (80*80*380) mm are prepped, cleaned, and lubricated. After casting, the molds were covered with nylon sheets for almost 24 hours. They were then put in a water-filled curing tank until testing (7, 28, 90, 120, and 180 days). [15].

4. TEST PERFORMED

4.1 Fresh Concrete Tests

4.1.1 Slump flow test and t500 mm test

The test estimates the self-compacting concrete's horizontal free flow. This frequently used test assesses resistance to segregation and provides a hint as to followability, according to EFNARK, 2005. Table 11 shows the classification of SCC. [14].

Table 11: Slump-flow classes according to EFNARC 2005.

Class	Slump-flow (mm)
SF1	550-650
SF2	660-750
SF3	760-850

4.1.2 L-Box test

According to this test, SCC must move through small gaps, such as those between reinforcing bars and other impediments, without segregating or clogging. The process of calculating the self-compacting concrete's passing ratio using the L-box test, according to EFNARK, 2005. Table 12 shows the classification of SCC [14].

Table 12: Passing ability classes (L-box) according to EFNARC 2005.

Class	Passing ability
PA1	≥ 0,80 with 2 rebars
PA2	≥ 0,80 with 3 rebars

4.1.3 Sieve segregation resistance test

The SCCs resistance to segregation was evaluated using the Sieve segregation resistance test according to EFNARK, 2005. Table 13 shows the classification used in the specification of SCC [14].

Table 13: Segregation resistance classes (sieve segregation) according to EFNARC 2005.

Class	Segregation resistance in %
SR1	≤ 20
SR2	≤ 15

4.2 Hardened Concrete Tests

4.2.1 Compressive strength test

In this investigation, the test was conducted following BSEN12390/3. The (100x100x100) mm concrete cubes were checked at ages (7, 28, 90, 120, and 180 days). The compressive strength is computed after recording the load at failure by taking the average of the three cubes for each test age [16].

4.2.2 Splitting Tensile Strength

Concrete specimens measuring 100 mm by 200 mm were utilized for the ASTM C496-/C496M-11 splitting tensile St. Test. This test was performed at 7, 28, 90, 120, and 180 days of age [17].

4.2.3 Flexural strength test

The flexural St. test was performed following ASTM C293/C293M, 2016, which covers the assessment of concrete's flexural St. using prism samples with dimensions of (80×80×380) mm and center point loading. The average outcome of three mixtures of prisms was calculated at ages 7, 28, 90, 120, and 180 days [18].

4.2.4 Oven-dried density test

Its oven concrete's dried density was assessed with ASTM C567/C567M-19. We used (100*100*100) mm cube specimens. The concrete test samples were dried in an oven for 72 hours at 110 C. Each specimen was then taken out of the oven and allowed to cool in dry air for 30 minutes, but no more than an hour, and its mass was calculated. Repeat the oven-drying, cooling, and mass determination steps every 24 hours until the change in mass is less than 0.5%, at which point the mass is determined. [19]

4.2.5 Modules of elasticity test

Concrete specimens measuring 150 mm by 300 mm were utilized for the ASTM C469-02 modulus of elasticity test. This test was performed at 28 days [20].

5. RESULTS AND DISCUSSION

5.1 Fresh Concrete

The results that slump flow test results for concrete mixes shown in Table 14 significantly decreased for all cases when the total SO_3/% content in fine aggregate was raised. For LWSCC, slump flow values varied from (750 - 560) mm, and the T500 mm values varied from (2.31 – 4.93) sec. The L-box values varied from (0.89-0.82), and the sieve Segregation Test ranged between (19.7 – 16.03). These are all shown in Table 14.

Table 14: Fresh concrete test results (slump flow, T 500 mm, L-box, and Sieve Segregation test).

Concrete Mix.	Tests						
	Slump Flow (mm)	EFNARC 2005	T500 Slump Flow (sec)	L-box (h2/h1)	EFNARC 2005	Segregation %	EFNARC 2005
CM	750	SF2	2.31	0.89	PA2	19.7	SR1
CG2	720	SF2	3.12	0.88	PA2	18.8	SR1
CG4	685	SF2	3.87	0.86	PA2	17.9	SR1
CG6	650	SF1	4.67	0.85	PA2	17.01	SR1
CGS2	670	SF2	3.80	0.86	PA2	17.82	SR1
CGS4	627	SF1	4.21	0.84	PA2	16.65	SR1
CGS6	560	SF1	4.93	0.82	PA2	16.03	SR1

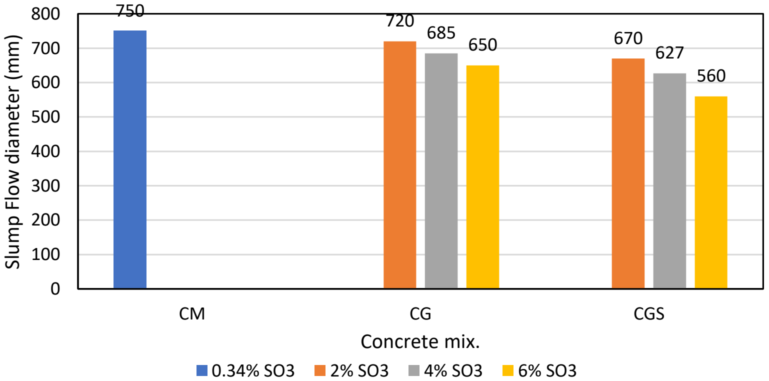

Figure 1: Results of slump flow diameter of reference mix and different mixes used.

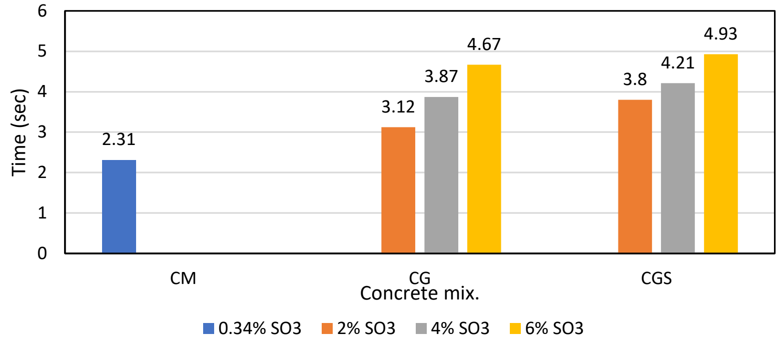

Figure 2: Results of T500 mm of reference mix and different mixes used.

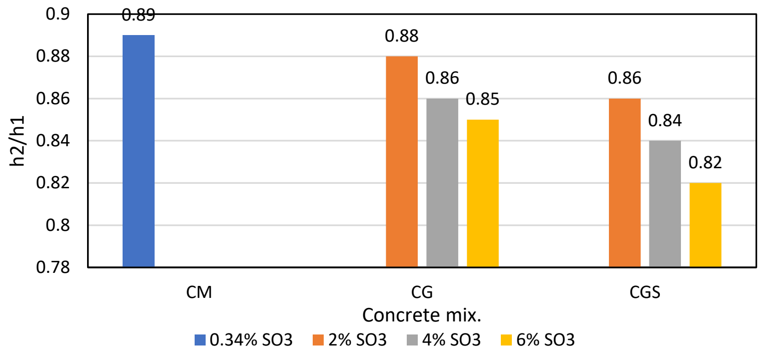

Figure 3: Results of L-box of reference mix and different mixes used.

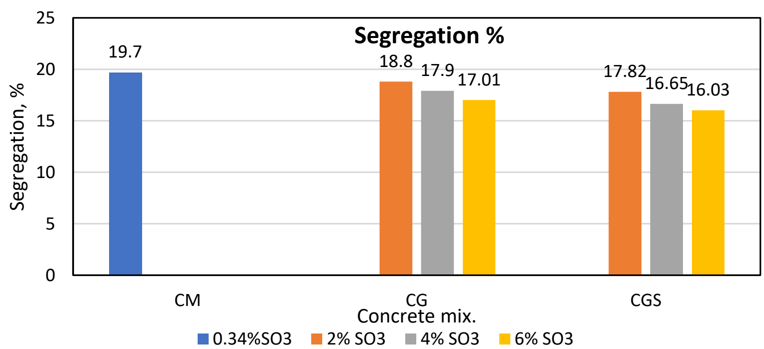

Figure 4: Results of Sieve segregation resistance test of reference mix and different mixes used.

5.2 Hardened Concrete

5.2.1 Compressive strength and oven-dried density

The values of compressive St. are demonstrated in Table 15 for reference mix and different mixes used at (7, 28, 90, 120, and 180) days. Figure 6 shows just how compressive St. has decreased as curing age has increased and SO_3 % has increased. The decrease in compressive St. was caused by a rise in sulfate percentage in fine aggregate from 0.34% to 2% was 16.15% and 16.53% at 90 and 120 days, respectively. Increasing the sulfate percent to 4%, the reduction in compressive St. was 21.96% and 22.45% at 90 and 120 days, respectively. Sulfate increased to 6% the reduction in compressive St. was 25.4% and 26.47% at 90 and 120-day respectively. This decrease in compressive St. is due to the formation of Ettringite, which weakens the concrete. This indicates that the percentage of decrease in compressive St. increases with the increase of SO_3 % in fine aggregate.

The addition of 0.5 % V_f of steel fiber enhanced the compressive St. by (8.05, 13.88, and 15.89%) from the reference mix for concrete mixes with (2, 4, and 6%) of SO_3 at 28 days, and the compressive St. is increased by a percentage of (10.34,14.36, and 16.15%) in concrete mixes with (2, 4, and 6%) at 90 days. The compressive St. is increased by a percentage of (10.82,15.82, and 17.59%) in concrete mixes with (2%, 4%, and 6%) at 120 days. The improvement in compressive St. increases with the decrease in the SO_3 %, as the improvement in compressive st. by using 2% SO_3 with the addition of steel fiber was higher than 4% and 6% SO_3. Table 15 illustrates the oven-dried density values for the reference mix and different mixes used at 28 days. Figure 2 demonstrates the decrease in density with the increase of SO_3 % and the progress of curing age. When the sulfate percentage raised from 0.34% to 2% in fine aggregate, the reduction in density was 1.31% at 28. Increasing the sulfate percent to 4%, the reduction in density was 2.35% at 28. Sulfate increased to 6%. The reduction in density was 3.28% at 28 days. This decrease in density is due to the formation of Ettringite, which weakens the concrete. This result indicates that the decrease in density increases with the increase in the percentage of SO_3 in fine aggregate. Adding 0.5% V_f of steel fiber enhances the density by 1.14% for mix CG2 and is reduced by 0.11 % in CG4 and 1.25% in CG6. The improvement in density increases with the decrease in the percentage of SO_3, as the improvement in density by using 2% SO_3 with steel fiber was higher than 4% and 6%.

Table 15: Compressive St. and density for all LWSCC.

Concrete mix.	**Compressive strength (MPa)**					**Density kg/m^3**
	7d	28d	90d	120d	180d	28d
CM	19.65	27.3	34.6	39.56	41.03	1830
CG2	16.79	23.2	29.01	33.02	34.13	1806
CG4	15.97	21.85	27	30.68	31.72	1787
CG6	15.41	20.88	25.81	29.09	30.01	1770
CGS2	18.2	25.1	31.02	35.28	36.54	1851
CGS4	17.48	23.51	29.63	33.3	34.5	1828
CGS6	16.93	22.96	29.01	32.6	33.71	1807

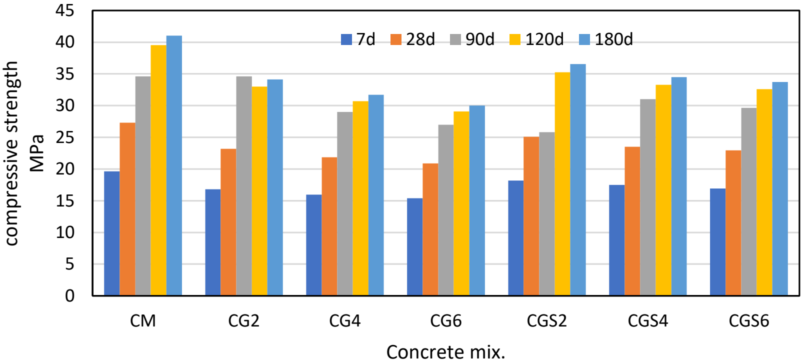

Figure 5: Results of compressive strength of reference mix and different mixes used.

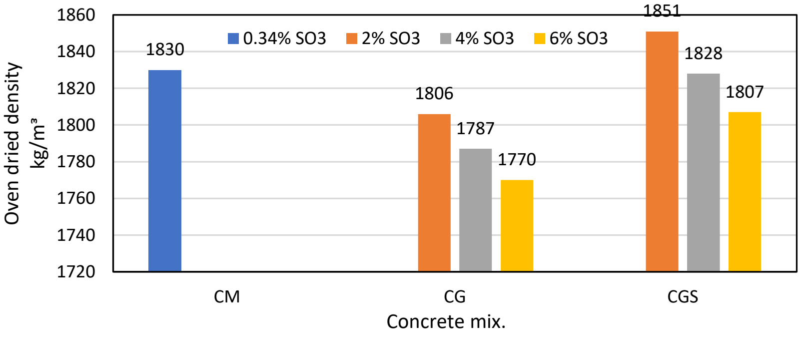

Figure 6: Results of oven dry density between reference mix and different mixes used.

5.2.2 Splitting Tensile St. and Flexural St.

The values of splitting tensile St. are demonstrated in Table 16 for reference mix and different mixes used at 7, 28, 90, 120, and 180 days. Figure 7 demonstrates how splitting tensile St. has been reduced with the increase of SO_3% at different curing ages. When sulfate percent increased from 0.34% to 2% in fine aggregate, the reduction in splitting tensile St. was 16.12% and 16.25% at 90 and 120 days, respectively. Increasing the sulfate percent to 4%, the reduction in splitting tensile St. was 25.8% and 26.38% at 90 and 120 days, respectively. When the sulfate increased to 6%, the reduction in splitting tensile St. was 30.64% and 31.59% at 90 and 120-day consecutive. This decrease in splitting tensile St. is due to the formation of Ettringite, which weakens the concrete. This result indicates that the decrease in splitting tensile St. increases with the increase of the %SO_3 in fine aggregate. The addition of 0.5 % V_f of steel fiber enhanced the splitting tensile St. by (26.53%, 16.92%, and 6.92%) from the reference mix for concrete mixes with (2%, 4%, 6%) of SO_3 at 28 days, and the splitting tensile St. is increased by a percentage of (25.8%,16.12% and 6.45%) %). In concrete mixes with (2%, 4%, and 6%) at 90 days, the splitting tensile St. increased by a percentage of (25.22%, 15.94%, and 6.09%). In concrete mixes with (2%, 4%, 6%) at 120 days. The improvement in splitting tensile St. Increases with the decrease in the percentage of SO_3, as the improvement in splitting tensile St. by using 2% SO_3 with the addition of steel fiber was higher than 4% and 6% SO_3

Table 16 shows flexural St. Values for reference mix and different mixes used at (7, 28, 90,120, and 180 days). Figure 8 demonstrates how flexural St. has been reduced with the increase of SO_3 % and for different curing ages. When sulfate percent raised from 0.34% to 2% in fine aggregate, the reduction in flexural St. was 26.61% and 27.06% at 90 and 120 days, respectively. Increasing the sulfate percent to 4%, the reduction in flexural St. was 37.84% and 38.27% at 90 and 120 days, respectively. When the sulfate increased to 6%, the reduction in flexural St. was 46.10% and 47.15% at 90 and 120-day respectively. This result decreased in flexural St, due to the formation of Ettringite, which weakens the concrete. This result indicates that the percentage of decrease in flexural St. increases with the increase of SO_3 in fine aggregate. The addition of 0.5% V_f of steel fiber enhanced the flexural St. by (40.94,31.23, and 21.25%) from the reference mix for concrete mixes with (2, 4, and 6%) of SO_3 at 28 days, and the flexural St. is increased by a percentage of (39.91,30.04, and 19.49%) %). Concrete mixes with (2, 4, and 6%) at 90 days, and the flexural St. is increased by a percentage of (38.9,29.18, and 18.39%). Concrete mixes with (2, 4, and 6%) at 120 days. The improvement in flexural St. increases with the decrease in the percentage of SO_3, as the improvement in flexural St. by using 2% SO_3 with steel fiber was higher than 4% and 6% SO_3.

Table 16: splitting tensile strength and flexural results for all LWSCC mixes.

Concrete mix.	Splitting tensile (MPa)					Flexural (MPa)				
	7d	28d	90d	120d	180d	7d	28d	90d	120d	180d
CM	1.7	2.6	3.1	3.45	3.59	2.61	3.81	4.36	4.73	4.87
CG2	1.45	2.2	2.6	2.88	2.98	1.98	2.83	3.2	3.45	3.51
CG4	1.3	1.96	2.3	2.54	2.63	1.69	2.42	2.71	2.92	3
CG6	1.21	1.83	2.15	2.36	2.45	1.44	2.06	2.35	2.5	2.56
CGS2	2.16	3.29	3.9	4.32	4.48	3.7	5.37	6.1	6.57	6.72
CGS4	1.99	3.04	3.6	4	4.15	3.45	5	5.67	6.11	6.32
CGS6	1.83	2.78	3.3	3.66	3.79	3.19	4.62	5.21	5.6	5.7

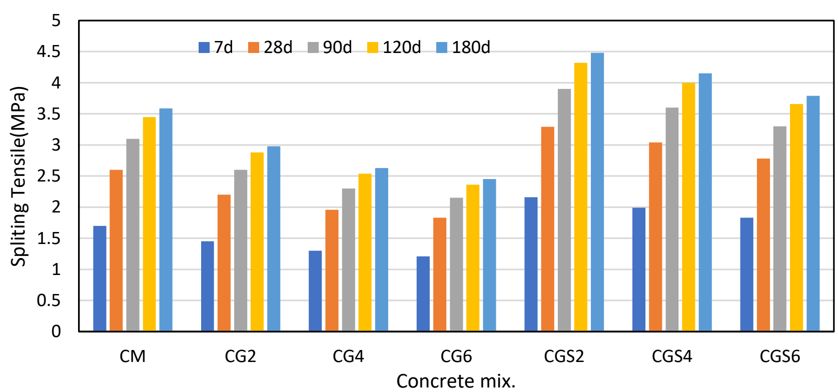

Figure 7: Results of splitting tensile strength between reference mix and different mixes used.

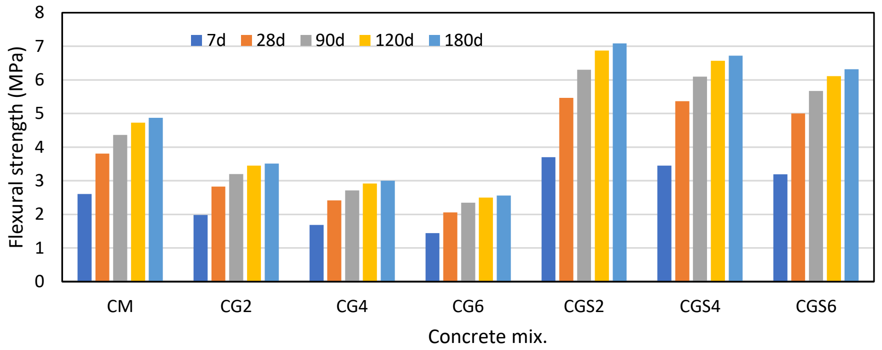

Figure 8: Results of flexural strength between reference mix and different mixes used.

5.2.3 Modules of Elasticity Test

The modulus of elasticity values is illustrated in Table 17 for reference mix and different mixes used at 28 days. Figure 9 demonstrates how the modulus of elasticity has been reduced with the increase of SO_3%. When sulfate percent raised from (0.34% to 2%, 4%, and 6%) in the fine aggregate, the reduction in modulus of elasticity was (12.69, 19.45, and 19.85%) respectively. This result decreased in modulus of elasticity is due to the formation of Ettringite, which weakens the concrete. This result indicates that the decrease in modulus of elasticity increases with the increase of the percentage of SO_3 in fine aggregate. Adding 0.5% V_f of steel fiber enhanced the modulus of elasticity by (19.9, 15.67, and 13.59%), from the reference mix for concrete mixes with SO_3 (2%, 4%, 6%) at 28 days. The improvement in modulus of elasticity increases with the decrease in the percentage of SO_3, as the improvement in modulus of elasticity by using 2% SO_3 with steel fiber was higher than 4% and 6% SO_3.

Table 17: Modules of Elasticity at 28 days.

Concrete mix.	**Modules of Elasticity (GPa)**
	28 days
CM	16.78
CG2	14.65
CG4	14.02
CG6	13.45
CGS2	20.12
CGS4	19.41
CGS6	19.06

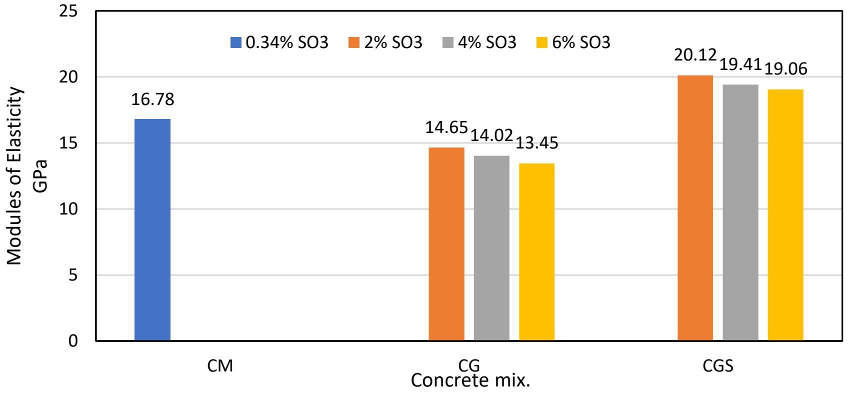

Figure 9: Results of Modules of Elasticity between reference mix and different mixes used.

6. CONCLUSIONS

- A decrease in workability properties of fresh concrete was detected for all LWSCC mix cases when the total SO_3% content in fine aggregate was excessed. At the same time, the addition of steel fiber further reduced the workability properties of fresh concrete.
- With the increase in the percentage of SO_3 in the mixes, the values of the mechanical properties (compressive St., splitting tensile St., flexural St., density, and modulus of elasticity) decrease. For example, the decrease in compressive St. was caused by a rise in sulfate percentage in fine aggregate from 0.34% to 2% was 16.15% and 16.53% at 90 and 120 days, respectively. Increasing the sulfate percent to 4%, the reduction in compressive St. was 21.96% and 22.45% at 90 and 120 days, respectively. Sulfate increased to 6% the reduction in compressive St. was 25.4% and 26.47% at 90 and 120-day respectively.
- With progressing age, the effect of sulfate on mechanical properties is increased. For example, the decrease in compressive St. was caused by a rise in sulfate percentage in fine aggregate from 0.34% to 2% was 16.15% and 16.53% at 90 and 120 days, respectively.
- Adding steel fiber improved the decrease caused by the sulfate, so it improved compressive strength and density with a little improvement. Adding 0.5 % V_f of steel fiber enhanced the compressive St. by (8.05%, 13.88%, and 15.89%), From the reference mix for concrete mixes with (CG2, CG4, and CG6) Of SO_3 at 28 days and enhanced the density by 1.14% for mix CG2, and reduced by a percentage of 0.11 % in CG4 and 1.25% in CG6. But splitting tensile St. flexural St. and modulus of elasticity with a significant improvement. The addition of 0.5 % Vf of steel fiber enhanced the splitting tensile St. by (26.53, 16.92, and 6.92%) from the reference mix for concrete mixes with (CG2, CG4, CG6) of SO_3 at 28 days and enhanced the flexural St. by (40.94%,31.23% and 21.25) and enhanced the modulus of elasticity by (19.9%, 15.67% and 13.59) for the same percentage.
- Adding steel fiber improved the properties by using 2% SO_3 better than 4% and 6% SO_3. For example, adding 0.5 % Vf of steel fiber enhanced the compressive St. by (8.05%, 13.88%, and 15.89%) from the reference mix for concrete mixes with (2%, 4%, 6%) of SO_3 at 28 days and the compressive St. is increased by a percentage of (10.34%,14.36% and 16.15%). In concrete mixes with (2%, 4%, 6%) at 90 days, and the compressive St. increased by a percentage of (10.82%, 15.82% and 17.59%) in concrete mixes with (2%, 4%, and 6%) at 120 days.

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