Civil Engineering Infrastructures Journal xx,xx
DOI: 10.22059/ceij.2025.381789.2142

Experimental investigations on the effect of internal sulfate attack on the behavior of normal and lightweight self-compacting reinforced concrete beam under flexural loading

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Received: 02/09/2024
Revised: 12/10/2024
Accepted: 08/11/2024

ABSTRACT
Among the crucial issues facing the concrete industry in Iraq and the Middle East is the contamination of fine aggregate with high levels of sulfate (SO_3), consequently resulting in internal sulfate attack (ISA). Therefore, the major objective of the current research is to examine the influence of various levels of sulfate contaminated fine aggregate on flexural behavior of light weight self-compacting concrete (LWSCC) incorporates lightweight expended clay (LECA) as coarse aggregate, and comparisons are made with normal weight self-consolidating concrete (NWSCC). The sulfate (SO_3) levels were (0.31, 0.5, 1.5, 3, and 4.5) % by sand weight. Tests conducted on mixes included slump flow, V-funnel, and L-box tests in fresh state, as well as evaluations of mechanical characteristics such as strength of compressive and splitting tensile at ages of 28, 90, and 180 days. And flexural performance of R.C beam models at ages of 28, and 180 days. The results obtained from this work showed that all tested beams exhibited the typical flexural behavior and with an increase in SO_3 content up to 0.5%, the highest values of such mechanical properties for LWSCC and NWSCC and first crack load for R.C beam models were achieved. However, when the SO_3 content increased beyond (0.5%), the results indicated a reduction in the mechanical properties and the load of first crack for both concrete types at all ages. Additionally, the findings revealed that increasing the sulfate content in the mixture did not yield a significant difference in the ultimate load values of the R.C beam models, as the final load values remained quite similar.

Keywords: R.C beam, Lightweight self-compact concrete (LWSCC), Lightweight expended clay (LECA), internal sulfate attack (ISA), sulfates contents (SO_3) %.

1. INTRODUCTION

Concrete is a widely utilized construction material globally, due to its diversity and widespread availability and cost-effectiveness (Rodriguez et al., 2015), (Mansourghanaei et al., 2023). Self-compacting concrete an innovative concrete, possesses the ability to placed and consolidated under its own weight without requiring any additional mechanical vibration which allows for the easy casting of concrete in formworks containing densely reinforced steel areas (Sandip Sonule et al., 2023), (Sandip Sonule et al., 2021). Its primary purposed to reduce construction duration, guarantee adequate compaction, and remove the noise attributed to mechanical vibration (Aslani, and Nejadi, 2012), (Rizzuto et al., 2020). High density poses a significant challenge for traditional concrete, while the weight of concrete typically plays a crucial role in calculating the strength of concrete structures (Shaaban et al., 2021). Therefore lightweight concrete is primarily employed to diminish the dead load (self–weight) of concrete structures, thereby reducing the dimensions of structural element sections and lowering the overall construction costs (Chao and Tran, 2015). Recently, the emergence of self-compacting lightweight concrete (LWSCC) has marked an inventive advancement in the building sector. (LWSCC) represents a form of high-performance concrete that aim to blend the useful features of LWC with the desirable characteristics of SCC (Lotfy et al., 2016), (Hossain et al., 2020). LWSCC can be produced by substituting NWA with LWA in SCC. As per (ACI 213, 2021), structural lightweight concrete should have a density ranging from 1120 kg/m³ to 1920 kg/m³.In concrete, Aggregates typically account for the majority of the weight and comprise approximately 60% of its volume (Iqbal et al., 2016).

Newly, the utilization of LWSCC in structural buildings has been progressively increasing, especially in strengthening and rehabilitating existing buildings, in addition to its use in the field of marine structures (Yang et al., 2014). From reviewing previous researches, it is often indicated that Lightweight concrete (LWC) elements demonstrate greater deformation, quicker propagation of cracks, and the inclined segment of the stress-strain curve was more steeper in comparison to normal-weight concrete (Carmo et al., 2017), also it is indicated that the diminished flexural ductility observed in LWC members may be result from the focused spread of cracks within the particles which have low-density and lower fracture toughness. The study carried out by (Sin et al., 2011) to evaluate the behavior of LWC members subjected to flexural loading, it was found that the maximum strengths of LWC beams closely comparable to those of NWC beams, However, LWC exhibited diminished ductility. (Bernardo et al., 2016) observed practically that incorporating LECA aggregate in a reinforced concrete beam (RC) results in reduced ductility when the tensile reinforcement ratio reaches approximately (1.5-2.0) % and the failure tends towards brittle, when the ratio exceeds these limits. Also, the increment in compressive strength with the same ratio of longitudinal steel reinforcement leads to a slight enhancement in ductility. (Yasin et al., 2023) discovered that Artificial neural networks (ANNs) have been used to predict the optimum content of Tuff fine aggregate to produce structural lightweight concrete with a wide range (20 to 50 MPa) of compressive strength. Three different types of Tuff aggregates, namely gray, brown, and yellow Tuff, were experimentally investigated. A set of 68 mixes was produced by varying the fine-tuff aggregate content from 0 to 50%. Both experimental and ANN results showed that the optimum content of the various types of used Tuff fine aggregate ranges between 20 to 25%. The results revealed that there is a clear agreement between the predicted values using ANN and the experimental ones. The use of ANNs may help to cut costs, save time, and expand the applications of Tuff aggregate in lightweight concrete production. (Kryeziu et al., 2023) conducted an experimental study on various concrete mixes to evaluate the effect of using recycled concrete aggregates (RCA) instead of natural aggregates (NA) on the physical and mechanical properties of fresh and hardened concrete. The main novelty of this study lies in meeting one of the principles of circular economy, reducing the carbon footprint, by recycling concrete waste collected locally. prepared and investigated test specimens containing 0%, 20%, 40%, and 60% of fine and coarse recycled concrete aggregates. Results for fresh concrete were determined for temperature, consistency, air content, and density, while on the other side, in hardened concrete, results were determined for compressive strength, tensile splitting strength, and density. Results showed that, with the use of RCA in the concrete mix, construction companies can significantly reduce their carbon footprints and help conserve natural resources. RCA can help create a more sustainable and affordable construction industry and is better suited to meet future challenges. For many years, concrete degradation due to sulfate attack is an important problem that has attracted the attention of researchers. Internal sulfate attack in concrete occurs when inner sulfates sourced from the main concrete components react with the tricalcium aluminate found in cement, with presence of water, this reaction forms ettringite, which may be responsible factors to the deterioration of concrete. Sulfate-contaminated fine aggregate is one of the sources of inner sulfate attack within concrete, and it is the most common in Iraq and the other Middle East countries. During the initial stages of hydration, gypsum reacts with C_3A (found within cement) to generate ettringite ($3CaO.Al_2O_3.3CaSO_4.31H_2O$). At this stage, the ettringite is not considered harmful as it contributes to an enhancement in the concrete's strength. However, the presence of excess amounts of gypsum in the concrete hardening stage, it leads to the continued reaction of SO3 with C3A, and ettringite at this stage is harmful. Harmful ettringite leads to deleterious expansion and weakened strength in concrete caused by creating a significant stresses within the cement paste, thus lead to concrete deterioration and spalling (Leemann, 2011). The main objective of this paper was to examine the impact of sulfate-contaminated fine aggregate on the behavior of lightweight self-compacting concrete (LWSCC) incorporating LECA aggregate, focusing specifically on flexural beam behavior.

2. Experimental program

2.1. Materials

The ordinary portland cement **(**OPC**)** was used in this work. Its conforms to specification of the Iraqi Standard (IQS. No. 5, 2019). Natural sand brought from Al-Akaidur region of Karbala governorate was used. Its grading was conformed to the (IQS No.45: 1984 zone2). The findings regarding the physical and chemical characteristics of the sand are Summarized in Table (1). Expanded clay (LECA) aggregate was used for all mixes, with regular sizes of between 0.475 cm and 1.2 cm, as shown in Figure (1). Table (2), presented the LECA gradation, which conforms to the ranges specified by (ASTM C330, 2017). Natural coarse aggregate with the maximum size of 12.5 mm was used in the experiments of this study. Its conforms to the (IQS No.45, 1984). The gypsum, sourced as a natural stone with 47.39% SO_3 content, was ground to a granular size capable of passing through a 150-micron sieve. It was added to the mixture as partially replacement from weight of fine aggregate in order to achieve the targeted sulfate content. In this study, the samples were mixed and cured using tap water. Test samples were reinforced with deformed steel bars measuring Ø10 mm in diameter for bending reinforcement. Additionally, Ø8 mm diameter were employed for shear reinforcement (stirrups).The mechanical characteristics of the steel bars conformed to the American standards specified in (ASTM A370-07, 2007) as indicated in Table (3).

Fig.1. Lightweight expended clay (LECA).

Table 1. The physical and chemical properties of fine aggregate.

Physical properties	Test Results	Iraqi Specification No.45/1984
Specific Gravity (SSD)	2.6	------
Absorption %	2.5%	------
Percentage of fine material passing through a 75 μm sieve.	2.8	Not more than 5.0
Fineness Modulus	2.41	-----
Sulfate Content %	0.31	Not more than 0.5%

Table 2. LECA sieve analysis.

Sieve size (mm)	Cumulative Passing %	Limits of ASTM C330-17a.
12.5	100	100
9.5	88.3	80 -100
4.75	11.5	5 -40
2.36	0	0 -20
1.18	0	0 - 10

Table 3. Findings from the tensile test conducted on the reinforcing steel bars.

Diameter (mm)	Yield Strength (MPa)	Ultimate Strength (MPa)	Elongation (%)
8	481	625	24.1
10	470	595	22.6

2.2. R.C Beam Samples Description.

The R.C. beam sample with rectangular section was carried out to evaluate flexural behavior of LWSCC and NWSCC under effect of sulfate and compare it with the NWSCC beams. Details of the dimensions of the R.C. beam used in this experiment program and the distribution of the reinforcement are as described in Figure 2. All R.C. beam samples were designed in accordance with ACI 318. The dimensions for all R.C beam samples kept constant featuring a cross-section of 200 mm in height and 100 mm in width, with a length of 1200 mm at a clear span of 1050 mm. while shear span to effective depth ratio (a/d) was kept at constant equal to (6.28). The tensile longitudinal reinforcement consists of two deformed bar with Ø10 mm diameter (2Ø10) at the top and bottom to ensure flexural failure occurs, while the stirrups and adequate shear reinforcement was Ø8mm diameter was placed at a spacing of 62 mm $^{c}/_{c}$. A clear cover of 20 mm in each side. The sulfate (SO_3) levels in R.C. beam samples were (0.31, 0.5, 1.5, 3, and 4.5) % by sand weight which represent typical contamination levels found in sand used in Iraq and the Middle East.

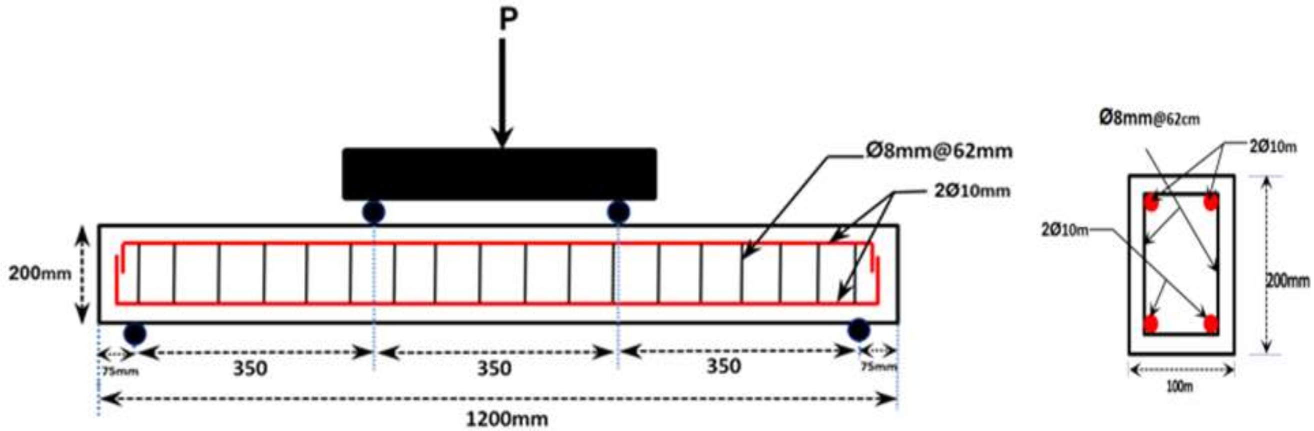


Fig.2. The Geometry of R.C beams samples and the arrangement of reinforcement configurations.

2.3 Mixing, Casting and Curing

The mixture components were selected as described in Table 4. Because of the high porosity of the LECA, It underwent immersion in water for duration of 48 hours to ensure that the pores were saturated with water. After that, the excess water was removed and the LECA was dried with air to obtain a saturated surface dry (SSD) aggregate to overcome the problem of water absorption during mixing. To achieve the desired sulfate content in concrete, gypsum was added as a substitute for the weight of the fine aggregate. Then, all the components of the mixture were mixed using a mechanical mixer with a capacity of 0.6 m^3 until a homogeneous mixture was achieved. Once the mixing process was completed. Tests on fresh concrete included slump flow, V-funnel, L-box, and unit weight, were carried out on both LWSCC and NWSCC mixes produced. The freshly mixed concrete was subsequently casted into the molds without compaction, and then the samples were demolded for 24 hours. After removing the mold, all the samples were put in water tank at approximately 20 C^0 until testing, when temperature and humidity increase, sulfate attack increases. Figure 3, illustrates the preparation and casting of the twenty R.C beam samples.

Table 4. Mix proportions for LWSCC and NWSCC.

Concrete Type	Cement (kg/m^3)	Water (kg/m^3)	Fine Aggregate (kg/m3)	Coarse Aggregate (kg/m^3)		LP (kg/m^3)	SP by wt. of cm (%)	W/C
				LWA	NWA			
NWSCC	449	180	762	---	820	120	1.65	0.4
LWSCC	449	180	762	372	--	120	1.65	0.4

Fig.3. The preparation and casting of the R.C beam samples.

3. Test Procedures

3.1. Tests for Fresh Concrete

The fresh state characteristics of LWSCC and NWSCC mixtures were estimated by tests comprising slump flow, L-box, and V-funnel measurements as described in the EFNARC guidelines (EFNARC, 2005). The densities of two type concrete mixes in their fresh state were measured directly after pouring According to (ASTM C138/ C138 M, 2017).

3.2. Mechanical properties tests

The tests performed on hardened state of LWSCC and NWSCC comprised compressive strength, and tensile splitting strength. The concert's compressive strength was determined using cubes measuring (10x10x10) cm according to the (BS.1881:Part 116, 1989). The average of three cubes was considered. The concert's tensile splitting strength was conducted in accordance with (ASTM C496, 2017), using a cylinder measuring (10x20) cm.

3.3. Instrumentation and test setup for R.C beam samples

The flexural behavior of R.C beam samples was examined as simply supported under two-point loading (see Figure 2). All beams were tested until reaching the point of breakdown. Monotonic load was incrementally applied utilizing a 500 kN capacity hydraulic jack, and computer to monitor the force. During loading, the appearance of cracks was observed at each increment in loading. The first crack was visually identified and the crack propagation throughout the test was closely observed. An LVDT (Linear variable displacement transducer) was installed in the mid span point of beams to monitor the vertical deflection.

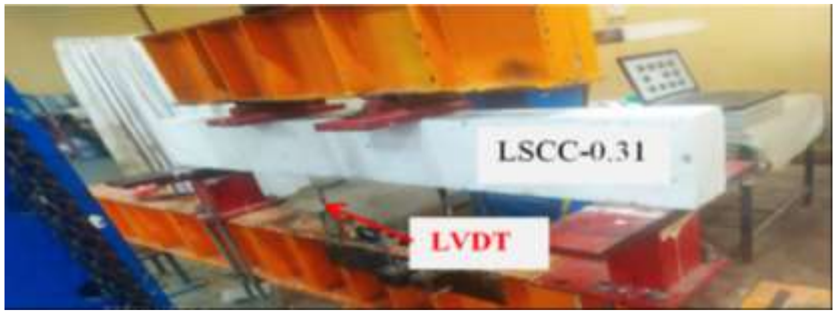


Fig. 4. Experimental set-up and instrumentation for R.C beams.

4. RESULTS AND DISCUSSIONS

4.1. Fresh properties

The fresh density of LWSCC measured at (1891) kg/m^3. Whereas, the NWSCC exhibited a fresh density of (2330) kg/m^3, the decreases in fresh density could be tightly related to using the LECA aggregate to produced LWC, The results also illustrates the slump flow test of the NWSCC and LWSCC mixtures ranged from (675 - 705) mm respectively. It could be seen that the slump flow falls within the SF2 category ranges (660 -750) mm, according to EFNARC. The concrete's V-funnel flow time ranged from (13.17 to 10.28) sec for LWSCC and NWSCC, respectively. Which falls in the VF2 (9-25 sec.) category described in EFNARC. And the results of L-box ratio, ranged between (0.96-0.9) for LWSCC and NWSCC, respectively. These values were within the limits of EFNARC. It's noticeable that the lower density of lightweight aggregate (LWA) resulted in higher flowability, attributed to the more spherical shape and relatively smooth surface compared with normal weight aggregate. This results in improved flow of both aggregate and paste, due to the reducing internal friction (Gesoğlu, 2014).

4.2 Mechanical Properties

4.2.1 Compressive Strength

The compressive strength tests revealed that NWSCC exhibited higher strength than LWSCC. The decrease in compressive strength can be ascribed to the replacement of normal coarse aggregate (NCA) with lightweight aggregate (LECA), resulting in a notable reduction in concrete density and consequently diminishing the strength of LWSCC. The results also demonstrated that the compressive strength of both LWSCC and NWSCC were affected by increasing sulfate content as shown in Figures. (5) and (6). It was observed that the optimal sulfate content for LWSCC and NWSCC was 0.5% by weight of sand, resulting in an enhancement of compressive strength by (2.27%, 4.79%, and 3.54%) for LWSCC, and (4.62%, 3.83%, and 3.64%) for NWSCC, at all ages of (28, 90, 180) days, respectively. However, an increase in sulfur trioxide (SO_3) content up to (4.5%) by weight of sand resulted in a reduction in compressive strength by (17.69%, 20.61%, and 17.88%) for

LWSCC and (33.41%, 34.28%, and 32.77%) for NWSCC at (28, 90, and 180) days, respectively. The variations in compressive strength can be ascribed to quantity of the ettringite formation which is useful up to (0.5% SO_3) content because it fills the voids within the cement paste without causing expansion damage. However, beyond this optimal SO_3 content, the excess ettringite formation induces internal stress, leading to a noticeable decline in compressive strength (Al Ameeri and Issa, 2013).

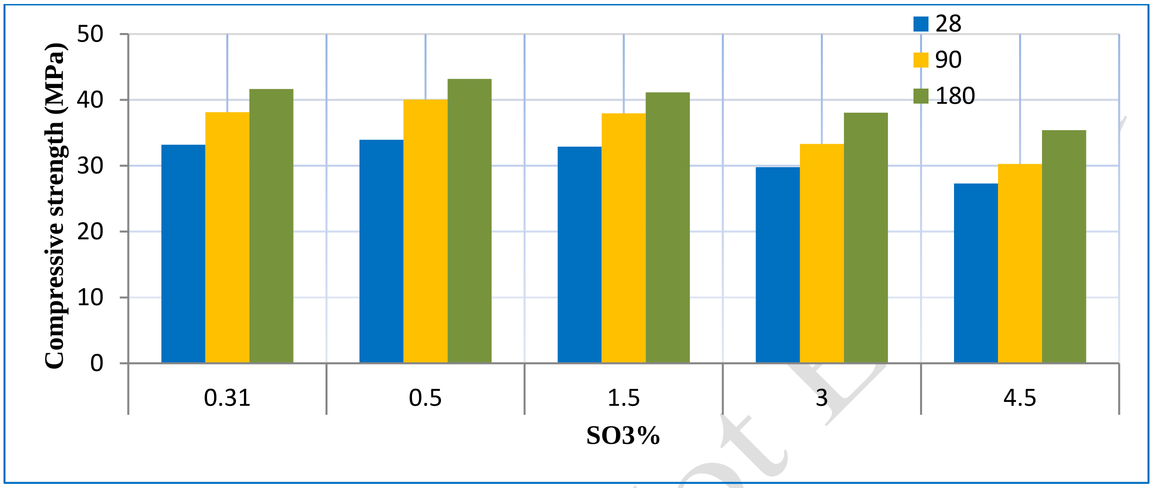


Fig.5. The impact of SO_3 on compressive strength at (28, 90,180) days for LWSCC.

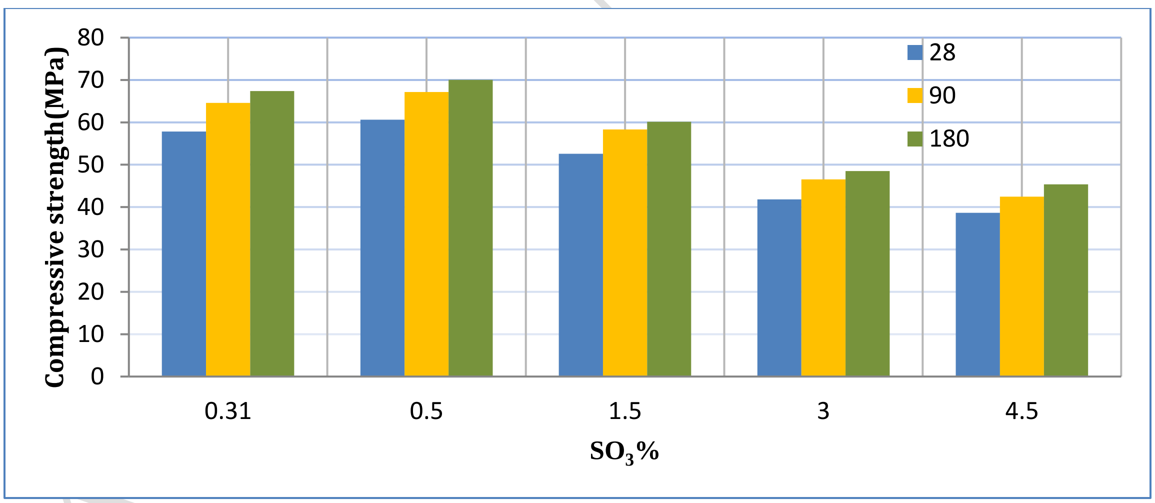


Fig.6. The impact of SO_3 on compressive strength at (28, 90,180) days for NWSCC.

When observing Figure (5,6) to compare the decrease in compressive strength for LWSCC and NWSCC, noticed that the decrease in compressive strength for LWSCC is less than NWSCC, and this is due to the porous nature of LWSCC and LECA aggregate, which absorbs some of the volumetric expansion caused by the ettringite, which reduces internal stresses.

4.2.2 Splitting tensile strength

The tensile strength of concrete is an important characteristic that governs the behavior of cracking when the concrete is subjected to tensile stress. For all mixtures, Figures (7) and (8) illustrated a decrease in the concrete's indirect tensile strength with increasing SO_3 content. As increasing the SO_3 content up to 0.5% from weight of fine aggregate led to an increase in tensile strength by (4.43, 3.8, and 3.6)% for LWSCC and by (5.26, 4.25, and 4.09)% for NWSCC at (28, 90, and 180)days of age, respectively. However, an increasing in SO_3 content from (0.31 to 4.5) %, led to a decrease in splitting tensile strength by (20.53, 23.73 and 22.13) % for LWSCC and by (33.32, 35.34, and 32.42) % for NWSCC at ages of (28, 90 and180) days, respectively. The explanation of such behavior is as described in the compressive strength, at the optimal sulfate content, the formation of ettringite resulting from the reaction between sulfate and the C_3A compound was beneficial as it fills some voids within the paste and increases cement paste density. Consequently improving tensile strength. However, with an excessive amount of SO_3, continued formation of ettringite leads to the development of internal stresses, resulting in concrete cracking and the strength was decreased.

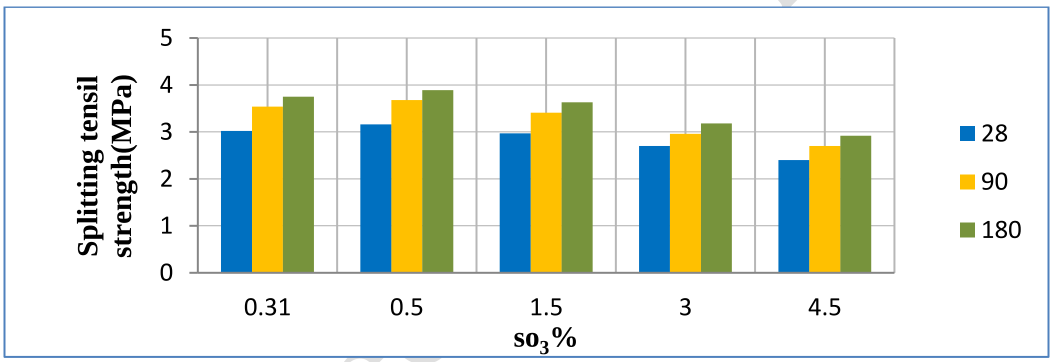


Fig.7. The impact of SO_3 on Splitting-strength of LWSCC mixes at (28, 90,180).

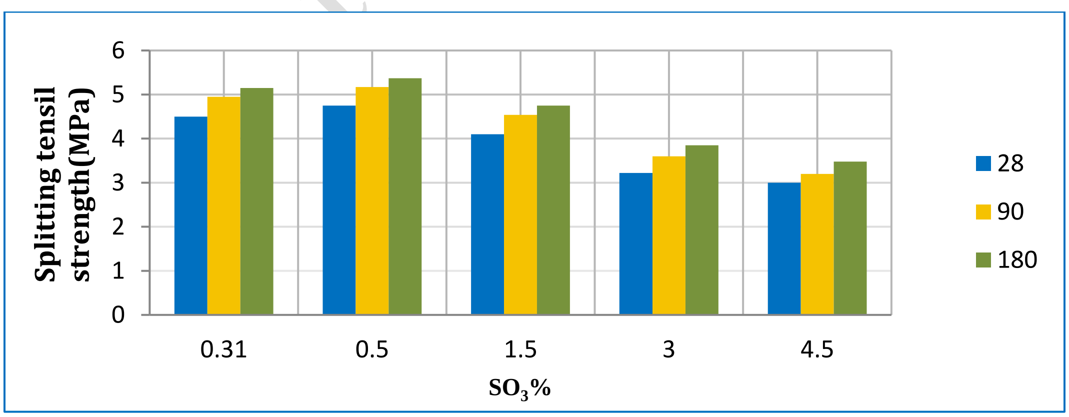


Fig.8. The impact of SO_3 on Splitting-strength of NWSCC mixes at (28, 90,180).

When observing Figure (٧,٨), noticed that the decrease in tensile strength for LWSCC is less than NWSCC, It is due to the same reason as compressive strength. This means that LWSCC is more resistant to sulfate attacks than NWSCC.

4.3 Results from the R.C beam specimens

The tests findings of the R.C beam specimens were analyzed concerning on the load-deflection curves, load of first cracks, cracking pattern, and the failure mode.

4.3.1 Load- Deflection curves

Figure (9) illustrates the load-deflection curves of the tested R.C. beams. It is evident that the plotted curves exhibit three distinct stages in the behavior of the R.C beams under flexural loading. The first stage, marked by pre-cracking, during which all R.C beams demonstrated a load-deflection response characterized by a linear pattern with an elevated slope indicating significant rigidity. At this stage, both concrete and reinforcement are within the elastic limits. With increasing of the applied load, the second stage occurs; cracking begins in the concrete within the tensile zone leading to a decrease in the slope of this stage. With further increase in load, the steel reinforcement in the tensile zone reached to yield point and subsequently failed, resulting in a transition of the load-deflection relationship from linear to curved. Consequently, the stiffness of the beam decreases notably, as the slight increase in loading results in a significant deformation of the beam. For all R.C beams samples, the transition in slope of load - deflection curve from linear to nonlinear occurred within the range of (20-25) % from the ultimate load.

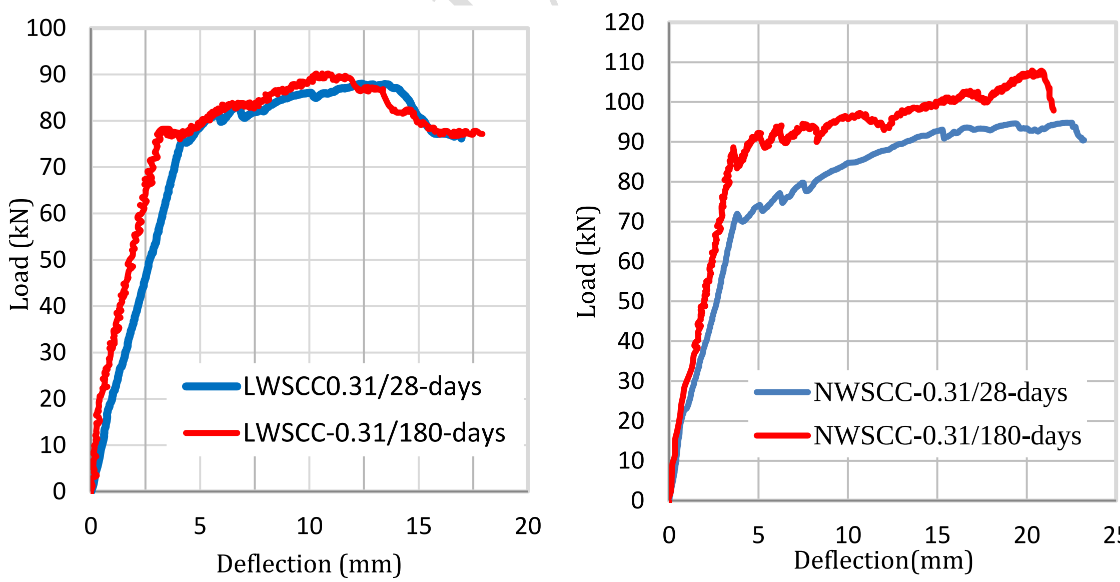
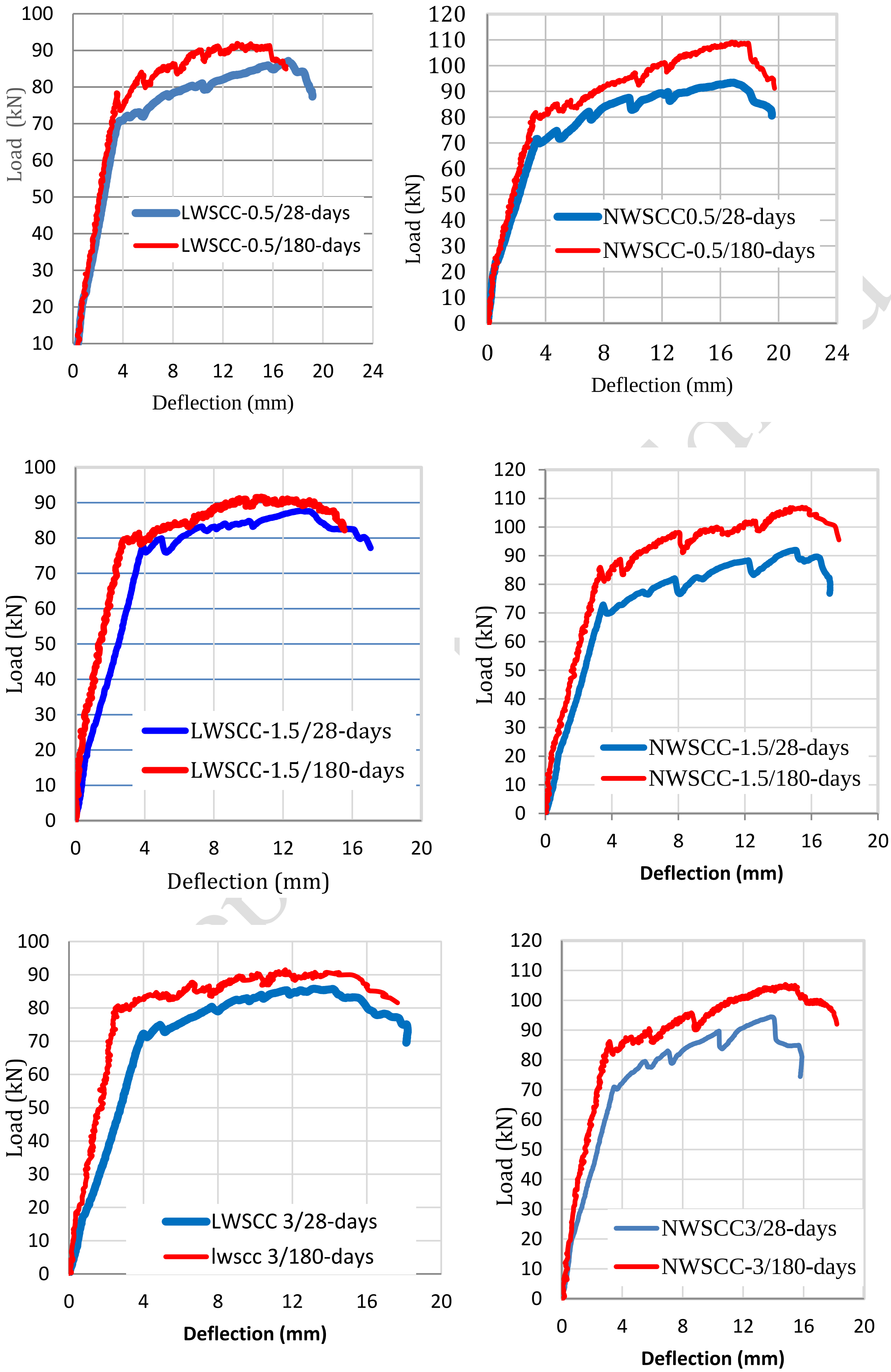


Fig. 9. The load-deflection curves for the tested R.C beams.


Load (kN)
Deflection (mm)
LWSCC-0.5/28-days
LWSCC-0.5/180-days
NWSCC0.5/28-days
NWSCC-0.5/180-days
LWSCC-1.5/28-days
LWSCC-1.5/180-days
NWSCC-1.5/28-days
NWSCC-1.5/180-days
LWSCC 3/28-days
lwscc 3/180-days
NWSCC3/28-days
NWSCC-3/180-days

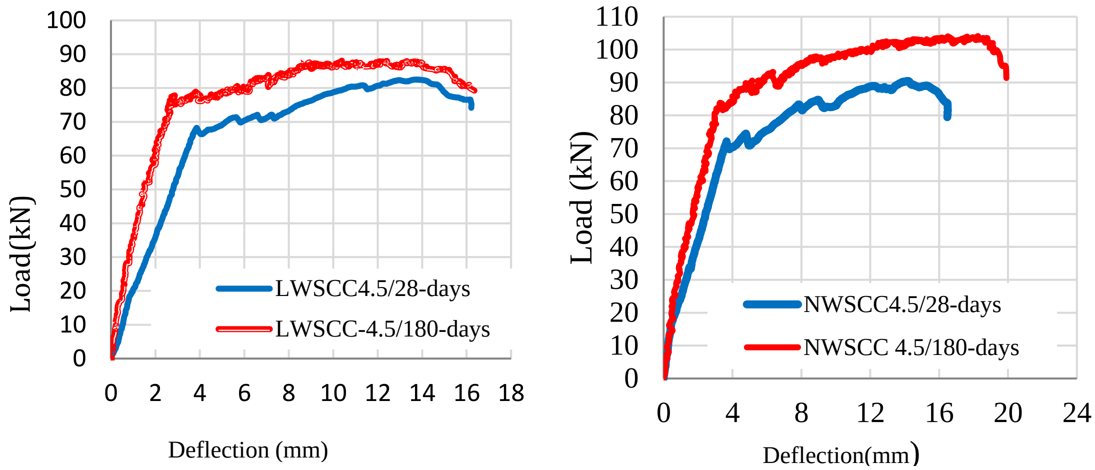


Fig.9. Continued.

4.3.2 Mode of failure and ultimate load

All R.C beams tested exhibited the typical flexural behavior. No significant differences in the performance of the reinforced steel were observed in LWSCC versus NWSCC. No horizontal cracks were observed at the reinforcement level, suggesting the absence of failure bond among the reinforcement and concrete. Vertical flexural cracks were observed in the pure moment region represents a flexural crack and the final failure was a result of the crushing of compression concrete accompanied by a significant value of ultimate deflection. The tensile reinforcement yielded before the concrete crushed in the pure bending zone because the singly reinforced beams were designed to be under-reinforced. From Table 5, it was observed that the maximum load values for the LWSCC beams ranged between (82.49- 91.67) KN, while the values for the NWSCC beams ranged from (90.35-107.94) KN. The NWSCC beam models exhibited a higher ultimate load compared to the LWSCC beams. Additionally, the NWSCC beams exhibited higher deflection under the ultimate load than the LWSCC beams, suggesting a notable decrease in the flexural strength of LWSCC in comparison to NWSCC. This decrease in LWSCC could be due to the incorporation of LECA aggregate, that have a weak strength due to the porous particles structure, resulting in lowering of concrete flexural strength and brittle behavior under loading comparison with the NWSCC. The experimental findings also suggested that as the sulfate content within the mixture was raised, there was minimal variation observed in the values of ultimate load of the R.C. beams samples and the ultimate load values samples, which were fairly close to each other. Since all the tested beam models exhibited flexural failure resulting from the yielding of the tensile steel reinforcement.

Table 4. Ultimate load and deflection for LWSCC and NWSCC R.C beams

at 28 and 180 days.

Type of concrete	Beams Symbol	Ultimate Load and Deflection at 28-days		Ultimate Load and Deflection at 180-days	
		Ultimate Load (Pu) KN	Center deflection mm	Ultimate Load (Pu) KN	Center deflection mm
LWSCC	LSCC-0.31	87.93	13.45	91.67	10.58
	LSCC-0.5	88.64	17.33	92.75	13.11
	LSCC-1.5	87.74	13.018	91.55	10.57
	LSCC-3	85.78	13.183	90.21	10.9
	LSCC- 4.5	82.49	13.48	89.06	10.38
NWSCC	NSCC-0.31	93.2	21.96	107.94	20.8
	NSCC-0.5	94.41	17.02	109.13	17.15
	NSCC-1.5	92.68	15.06	106.78	14.86
	NSCC-3.0	91.47	14.01	104.9	14.6
	NSCC-4.5	90.35	14.21	103.26	13.6

4.3.3 Behavior of cracking.

The crack development was observed during the tested R.C beams of LWSCC and NWSCC to assess their cracking behavior. The first crack loads and the cracking patterns of all R.C beams are as follows:-

1- First crack load

The first crack formation depends on the concrete's modulus of rupture (f_r), the crack occurs insomuch as the tensile stresses applied on the section exceed its tensile strength. Since the NWSCC tensile strength exceeds that of LWSCC concrete, therefore, the occurrence of a crack in the LWSCC beams requires a lower applied load compared to the NWSCC beams. From Table 5, the results indicated that LWSCC R.C beams exhibited lower first crack load than NWSCC R.C beams. In this regard, the initial crack loads varied between (16-21) kN and (19-25) kN for the LWSCC and NWSCC beams, respectively.

Also it could be noted that the noticeable impact of sulfate on the first crack load value. As the sulfate content in the LWSCC mixtures is increased up to (0.5% SO_3) resulted in an increment in the load of first flexural crack of R.C beams LSCC-0.5 by (5-4.76)% from the reference beams for ages of 28 and180 days, respectively. Further increasing the sulfate content up to (4.5% SO_3), led to a decrease in the first crack load of the beam LSCC-4.5 by (15.79 and 15) % from reference beams at the ages of 28 and 180 days, respectively. Whereas, the NWSCC mixtures, an increase in the SO_3 content up to (0.5%SO_3) by weight of sand caused an increment in the load at the first crack of the beam NSCC-4.5 by (4.16-3.84) % from the reference beams (NSCC-0.31) at 28 and 180 days of age, respectively. Further increasing the SO_3 content up to 4.5% by weight of the sand led to a decrease in the first crack load of the beam NSCC-4.5 by (17.4 -20)% the reference beams at 28 and 180 days of age, respectively. This mean an increase in SO_3 content in concrete mixes up to 0.5% result in increase in tensile strength of concrete due to formation of beneficial ettringite. Further increase in SO_3 contents in mixture beyond this value led to formation a harmful ettringite. This led to a rapid formation of cracks as the concrete's tensile strength decreases. From a practical point of view, this reduces the service life of the structure and the appearance of the structure is distorted. It also does not meet the service requirements recommended by the ACI code.

Table 5. The first crack load for all R.C. beams and failure mode.

Type of Concrete	Beam Symbols	First Crack Load (KN)		Failure Mode
		28-days	180-days	
LWSCC	LSCC-0.31	19	20	Flexural
	LSCC-0.5	20	21	Flexural
	LSCC-1.5	18	19	Flexural
	LSCC-3.0	17	18	Flexural
	LSCC- 4.5	16	17	Flexural
NWSCC	NSCC-0.31	24	25	Flexural
	NSCC-0.5	25	26	Flexural
	NSCC-1.5	21	22	Flexural
	NSCC-3.0	20	21	Flexural
	NSCC-4.5	19	20	Flexural

2. Crack patterns

The samples of the reinforced LWSCC beam showed crack patterns similar to those of the reinforced NWSCC beam, but in LWSCC beam it was more widespread and appeared faster, starting from the load at a first crack up to the ultimate load, as evidenced by Figures 10 and 11. Within the region bounded by the two loading points (pure bending moment), the first vertical crack appeared, subsequently, under continued loading, cracks began to form and propagate from the beam's bottom towards its top. With additional loading, these cracks increased in depth and width.

Fig.10. Crack pattern of LWSCC R.C. beams at 28 and 180-days tested.

Fig.11. Crack pattern of NWSCC R.C. beams at 28 and 180-days tested.

Conclusion

Based on the results of experimental work, could be derived the following conclusions:

- It is possible production the lightweight self-compacting concrete (LWSCC) incorporating LECA aggregate, which has a density of approximately 1891 kg/m^3, achieves a strength of compressive that suitable for the structural demands of various elements .
- In the fresh state, the results indicated that LWSCC exhibits better workability compared to NWSCC.

- The results of this study influence the choice between LWSCC and NWSCC in real projects, as the current study has shown that NWSCC is better than LWSCC especially considering factors such as cost, material availability, and ease of construction, but LWSCC More resistant to sulfate attacks.
- The optimal content of sulfate (SO_3) in the mixtures of LWSCC and NWSCC was found to be 0.5% from weight of sand, resulting in enhancements to strength of compressive at age of 28 days by (2.27, 4.62)% and in splitting tensile strength by (4.43, 5.26)% for LWSCC and NWSCC, respectively. Further increasing the SO_3 content up to 4.5% of the sand's weight led to a noticeable decline in the concrete's compressive strength by (17.69, 33.41)% and the tensile strength by (20.53, 33.32)% at age of 28 days for LWSCC and NWSCC, respectively.
- All R.C beam samples showed typical flexural behavior under flexural load, with the design ensuring that the tensile reinforcement yielded prior the compression concrete crushed in the pure bending zone.
- From the results of the study regarding the design of reinforced concrete beams in sulfate-contaminated environments, engineers should consider the sulfate content and choose concrete mix designs to address the effects of internal sulfate attack.
- The ultimate flexural loads of normal weight self-compacting concrete (NWSCC) beams were slightly higher than those of the lightweight self-compacting concrete (LWSCC) beams.
- As the SO_3 content in the mixture increased, there were no significant differences in the ultimate load and load-deflection curves, as the values were fairly close for all SO_3 contents examined in this study for both types of concrete.
- The influence of SO_3 content in the mixture appeared clearly on the value of the first crack load, as increasing the sulfate content up to 4.5% of the weight of the sand resulted in a decrease in the values of the first crack load at ages of 28 days by (15.7-20.83) % for the reinforced beams constructed from LWSCC and NWSCC, respectively.

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