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Investigating the Effect of Internal Sulphate Attack on some Properties of LECA Lightweight Self-Compacting Concrete Reinforced by Polypropylene Fiber

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Abstract

Internal sulfate attack (ISA) among the most popular significant problems facing the industry of concrete in Iraq and the Gulf Arab states, as it causes concrete to deteriorate, thereby decreasing its Compressive St., increasing its expansion, and possibly leading to its cracking to investigated the effect of adding of 0.5 volume and destruction. This investigation aims fraction (V_f) polypropylene fiber to LECA lightweight self-compacting concrete (LWSCC) with internal sulfate attack (ISA) at both fresh and hardened stages. Different SO_3% (0.34%, 2%, 4%, and 6%) in sand concrete mixtures were cast. The L-box, Sieve segregation resistance, and slump flow as fresh characteristic of LWSCC concrete were examined. Compressive st., splitting st., flexural st., oven-dried density, elasticity modules (ME), and water absorption were among LWSCC's hard characteristic. The results demonstrated a considerable decline in the fresh characteristics of LWSCC mixes with varied SO_3 in sand, which in turn affected the characteristics of LWSCC. Additionally, the Compressive St., density, ME, splitting st. and flexural st.) dropped whereas water absorption increased as SO_3% increased. At 180 days, the drop in Compressive St. was (16.81%, 22.69%, and 26.85%) as the sulfate proportion increased. The mechanical properties of LWSCC were improved and the amount of water absorption was decreased by adding 0.5% Vf of PP.

.**Keywords:** LECA, Compressive St., Tensile st., Flexural St., Water absorption

دراسة تأثير هجوم الكبريتات الداخلية على بعض خواص LECA خفيفة الوزن ذاتية الرص بالخرسانة المدعمة بألياف البولي بروبلين

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الخلاصة

يعتبر هجوم الكبريتات الداخلية (ISA) من أهم المشاكل التي تواجه المنشأت الخرسانية في العراق ودول الخليج العربية ، حيث يتسبب في تدهور الخرسانة وبالتالي التقليل من مقاومة الانضغاط وزيادة

تمددها وربما يؤدي إلى تكسيرها وتدميرها. تهدف هذه الدراسة إلى التحقق من تأثير إضافة ٠.٥% من ألياف البولي بروبيلين كنسبة حجمية (Vf)% إلى الخرسانة خفيفة الوزن ذاتية الرص (LWSCC)مع حصى خفيف الوزن Leca بوجود هجوم الكبريتات الداخلية (ISA) في كل من المراحل الطرية والمتصلبة. تم صب العديد من الخلطات الخرسانية بنسبة مختلفة من SO_3٪ (٠.٣٤٪ ، ٢٪ ، ٤٪ ، ٦٪) في الركام الناعم. تم اختبار الخواص الطرية للخرسانة LWSCC مثل فحص نسياب الهطول ومقاومة الانعزال و فحص L-box. وكانت الخواص المتصلبة لـــ LWSCC وهي مقاومة الانضغاط، مقاومة الشد، مقاومة الانثناء، الكثافة الجافة، معامل المرونة وامتصاص الماء. حيث أظهرت النتائج أن الزيادة في نسبة SO_3 في الركام الناعم أثرت على خصائص LWSCC ، وانخفاض ملحوظ في خواص الخرسانة الطرية. بالإضافة إلى ذلك ، انخفضت الخواص الميكانيكية (مقاومة الانضغاط ، مقاومة الشد، مقاومة الانثناء ، الكثافة الجافة ومعامل المرونة) مع زيادة SO_3٪ ، بينما ازدادت نسبة امتصاص الماء بزيادة SO_3. عندما ارتفعت نسبة الكبريتات من (٠.٣٤٪ إلى ٢٪ ، ٤٪ ، ٦٪) في الركام الناعم ، كان الانخفاض في مقاومة الانضغاط مع نسبة الكبريتات هي (16.81٪ ، 22.69٪ ، 26.85٪) بعمر ١٨٠ يوم. أدت إضافة ٠.٥٪ Vf من ألياف البولي بروبلين إلى تحسين الخواص الميكانيكية لـــ LWSCC وتقليل امتصاص الماء.

الكلمات الرئيسية : ليكا، مقاومة الانضغاط، مقاومة الشد، مقاومة الانثناء، امتصاص الماء.

INTRODUCTION

Modern advancements in concrete technology have produced SCC and LWC as practicable and lightweight building materials. SCC, which is a more recent material that facilitates pouring and solves construction-related issues and SCC is a material that has been utilized for decades and LWC, which is well recognized in the industry, is an excellent choice for reducing the dead weight of the structure. Recent years have witnessed a few efforts to combine the benefits of these two varieties of concrete into a product known as light-weight self-compacting concrete (LWSCC). **(Vakhshouri and Nejadi**, **2016)**

Salts do not harm concrete in its solid form; they only do so when they are present in solutions, when they may react with hydrated cement paste. Calcium, magnesium, potassium, and sodium sulfates are the most common sulfates that attack concrete. Sulfate ions penetrate concrete structures and react with cement components as part of the sulfate attack process. (Al-Anbori, 2013)

Ettringite formation is mostly responsible for the expansion and disruption in concrete structures. Ettringite formation typically happens in two phases. The first stage is termed "Early Ettringite Formation" (EEF), and it occurs homogenously during the first few hours of concrete casting. This sort of Ettringite does not provide any warning to the concrete structure. Gypsum and tri-calcium aluminate's interaction implicated in the early Ettringite production process as in Eq.1. (Alam et al., 2012)

$$C_3A + 3(CaSO_4.2H_2O) + 26H_2O\ C_3A.3CS.H_{32} \qquad \text{Eq.(1)}$$

This kind of Ettringite slows the setting of hydrated cement mixes without having a significant, all-encompassing disruptive impact. The creation of a layer immediately surrounding the surface of the cement grains after mixing the cement and water causes the retardation effect. "Primary" Ettringite refers to this type of Ettringite formation. (Al-Obaidy, 2017)

After several, months or perhaps years the "secondary" Ettringite formation stage known as "Delay Ettringite Formation" (DEF) takes place. After the temperatures for heat curing reach an excessive level, DEF is too responsible for the cracking of concrete structures. Since Ettringite expands and is thermodynamically unstable, it will break down into hydrated calcium mono-sulphoaluminate and release sulphates into solution when the concrete reaches a setting temperature of more than 158°F. These sulphates will then physically absorb onto the hydrated calcium silicate (gel) surface. The C-S-H gel begins to release the sulphates that had adhered to its surface during storage or use at ambient temperature and moisture environment, reintroducing them into the solution. When sulfate ions penetrate small cracks and interact with C_3A there, they create Ettringite, an expanding substance that expands and destroy the concrete members. (Shah and Ahmad, 2014)

In the 1960s, concrete was made with polypropylene (PP), glass, natural **(Azevedo et al., 2021),** and steel fibers **(Zollo, 1997).** According to numerous research, concrete fibers have little to no effect on Compressive St. **(Zhang et al., 2021).** Significant study has demonstrated that fibers added to concrete increase both the flexural and tensile strengths of the concrete **(Ahmed et al., 2021).**When fibers are added to other supplemental cementitious materials, the durability of concrete is greatly increased **(Zhang et al., 2021).**

According to **(Fawzi and Weli, 2016)**, this research objectives to examine the impact of additional polymer materials on the hardened properties of SCC and evaluate the impact of petroleum produce (kerosene and gas oil) after various exposure times of 30, 60, 90, and 180 days. For SCC and PMSCC, a total of 2 days on the water and 26 days in the air are employed as the healing methods. According to the test results, reference concrete saw a greater decline in Compressive St. than PMSCC (15% P/C ratio), which is open to oil produces. In comparison the same mixture submerged in water, the Compressive St. values of PMSCC (15% P/C ratio) decreased by percentages of (6.03%) and (9.61%) up to 180 days of contact to kerosene and gas oil, correspondingly, while the Compressive St. values of SCC (reference concrete) decreased by percentages of (21.18%) and (25.19%) up to the same time period.

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Results for flexural strength show an improvement across all age groups and Concrete mixtures with varying amounts of polymer. When exposed to oil products, values for the full absorption of PMSCC (15% P/C ratio) performed superior to the reference concrete mix. With models submerged in water, kerosene, and gas oil, correspondingly, it was (1.34, 2.21, 2.17%) up to 180 days, with reduction percentages of (23.86%), (33.83%), and (31.33%) in comparison to the SCC (reference concrete).

According (**Al-galawi and Hassooni, 2016),** this investigation examines the impact of cement types, especially OPC and SRPC, which are the main cement types produced in Iraq. Study how HRM and SF, two mineral admixtures, affect high performance concrete's (HPC) resistance to ISA. For both types, SF is utilized at (8 and 10)% and HRM at (10%) as a partial substitute for cement by weight. By adding NG as a partial replacement, by weight, for Sand. , the percentages of sulphate under investigation are (1, 2, and 3%). Compressive St., flexural st. , and density experiments were conducted at ages 7, 28, 90, and 120 days for this study. The findings demonstrated that, at all test ages, SRPC mixes exhibited less concrete property reduction than OPC mixes. For OPC mixes and SRPC mixes, the greatest loss in Compressive St. occurred at ages of (90) and (28) days, respectively. After that, all sulphate in Sand. percentages showed a reduced reduction in the concrete. The outcomes also showed that HRM performed better than SF, and that replacing 10% of SF with 8% of SF produces superior outcomes for both types of cement. In mixes with 10% HRM and SF at (8 and 10)%, the sulphate-resistant Portland cement exhibits a lesser decrease in strength than regular Portland cement. At all test ages, the decrease in strength testing rises with the addition of (SO_3%) in FA; however, the reduction decreases as test ages go on because pozzolanic reactions may be the reason why OPC and SRPC mixes' strengths improve. For SRPC and OPC mixes, the strength recovery after 28 and 90 days, respectively, has improved. The chemical composition of cement has a major impact on HPC's resistance to internal sulphate attack.

The This study's objective is to produce structural LWSCC with lightweight aggregate (LECA) and then expose it to internal sulfate attack in different percentages (2%, 4%, 6%) in fine aggregate, finally studying the best enhancement by the adding of 0.5% (V_f) polypropylene fiber on sulfate exposed mixes.

2. MATERIAL CHARACTERISTICS

2.1 Cement:

This work created lightweight self-compacting concrete mixes using common type Al Mass that is manufactured in Iraq. The cement characteristics are shown in **Tables 1 and 2**. **(IQS. No.5, 2019)**

Table 1. Main ingredients and chemical composition.

Oxide	%	IQS-5-2019)
CaO	61.54	-
SiO_2	21.61	-
Al_2O_3	5.93	-

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Fe_2O_3	3.31	-
MgO	2.84	> 5
SO_3	2.24	≤ 2.8 If C_3A > 3.5
I.R	0.72	>1.5
L.O.I	0.93	>4.0
L.S.F	0.75	0.66-1.02
Main Compounds(Bogue's equations)		
C_3S	35.17	-
C_2S	35.50	-
C_3A	10.11	-
C_4AF	10.09	-

Table 2. Characteristics of cement physically.

Physical characteristics	Results	(IQS 5-2019)
Specific surface area (Blaine method), m^2/kg	375	≥230
Setting time (Vicate apparatus) Initial setting time, hrs: min Final setting time, hrs: min	1:45 4.51	≥45 min. ≤ 10 hrs
Compressive St.(MPa) 2 days 28 days	13 36	> 10 > 32.5

2.2 Light Expanded Clay Aggregates (LECA)

LECA degree ranges from 4 to 10 mm, and **Table 3** lists the LECA characteristic.

Table 3. LECA characteristic

characteristic	findings	IQS No.45/1984
Sp.gr	0.66	---
Abs. %	21	---
density Kg/m^3	317	---
SO_3	0.07	Max. 0.1

2.3 Fine aggregate:

Natural sand for the investigation came from the Al-Ukhaider district. Sand complied with IQS NO. 45/1984 zone 2. Its sieve analysis is explained in **Table 4**, while **Table 5** provides an explanation of the sulfate concentration and physical properties of the employed Sand. **(IQS No.45, 1984)**

Table 4. Sieves analysis of fine aggregate.

Sieve Size	%	IQS NO.45/1984 (Zone 2)

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10mm	100	100
4.75mm	95.2	90-100
2.36mm	80.6	75-100
1.18mm	72.9	55-90
600µm	45.6	35-59
300µm	24.6	8-30
150µm	4.9	0-10

Table 5. Physical properties of sand.

characteristics	Outcomes	IQS NO.45/1984
Sp. g	2.57	
Abs. ,%	1.3	
sieve size 75µm%	2.4	Max. 5%
(SO_3), %	0.34	Max. 0.5%

2.4 Natural gypsum:

The natural gypsum NG crush and pulverized with a hammer, then put through the exact same sieve set that was used for the Sand.in the ISA mix. The mass of sand partially replaces gypsum as a small percentage. The chemical characteristic of the NG shown in Table 6.

Table 6. The chemical characteristic of NG.

Content	**%**
SiO_2	8.34
R_2O_3	2.2
CaO	32.0
MgO	0.9
SO_3	40.41
I.R	6.9

2.5 Mixing Water:

Tap water was utilized through this investigation for mixing and curing. (IQS NO.1703, 1992)

2.6 Admixture:

High range water decrease additive as a super-plasticizer is BETONAC-1030-3 SR. Table 7 displays some of its typical properties. (ASTM C494/C494M)

Table 7. Superplasticizer description *

Properties	
Color	Light yellow
Den.	1.07±0.02 gm/ml
Chloride	Non

2.7 Silica fume:

As a mineral additive, SF is provided by the Iraqi Branch of the SICA Company. **Table 8** lists the silica fume's physical and chemical properties under the requirement. **(ASTM C 1240, 2015)**

Table 8. Chemical and physical properties of Silica Fume

Chemical properties			Physical properties		
Oxide	%	(ASTM-C1240,2015)	characteristic	SF	(ASTM-C1240,2015)
SiO_2%, Min.	93.05	85	retained on 45mm (No. 325) sieve, max.%	6.3	10
L.O.I%, Max.	0.45	6.0	Strength Activity Index at 7 days, min. %	120.3	105
Moisture%, Max.	0.5	3.0	Specific surface, min, (m^2/g)	21	15

2.8 Polypropylene fibers (PP):

PP is safe and easy to use, improves ductility and reduces the tendency for plastic and drying shrinkage cracking, plastic settlement, permeability, spalling at high temperatures and slap curling. **Table 9** show the properties of polypropylene fiber.

Table 9. Characteristic of Polypropylene fiber*.

Description	L (mm)	D (µm)	Den. (g/cm^3)	Melting point ℃	(L/D)	Tensile st. MPa	Elastic modulus GPa
polypropylene fiber	12	32	0.91	160	375	310	4.3

*Manufacturer Properties

3. CONCRETE SAMPLE PREPAREMENT:

3.1 Combination Ratio:

EFNARC (2005) states that the LWSCC mixes in employment in this search was appropriate. According to EFNARC, 2005, multiple trial mixes created once acceptable self-compatibility were determined by assessing the fresh properties of the concrete used. The water-to-cementitious ratio for each mix utilized in this search is 0.34, and the ideal amount of superplasticizer (Sp) to add is 1.4% of the cement weight in the form of BETONAC-1030-3 SR. The mix component is shown in **Table 10**. **(EFNARC, 2005)**

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

Mix.	Cement Kg/m³	LECA Kg/m³	Sand Kg/m³	SO_3 % in	Lime Stone powde	Silica Fum	W/Cm	Superplasticizer %	Volume fraction

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				san d	r Kg/m³	e %			%
CM	481	151	799	0.34	29	14.1	0.34	1.4	--
CG2	481	151	799	2	29	14.1	0.34	1.4	--
CG4	481	151	799	4	29	14.1	0.34	1.4	--
CG6	481	151	799	6	29	14.1	0.34	1.4	--
CGP 2	481	151	799	2	29	14.1	0.34	1.4	0.5
CGP 4	481	151	799	4	29	14.1	0.34	1.4	0.5
CGP 6	481	151	799	6	29	14.1	0.34	1.4	0.5

3.2 Mixing, Casting and Curing of Concrete:

Cement lumps were removed by putting it through a sieve with a No. 14 opening (1.18mm). The components are combined using a mixer. Cube molds measuring 100x100x100mm, cylinders measuring 100*200mm and 150*300mm, and prism measuring 80*80*380mm are prepared, cleaned, and lubricated before the concrete mixing process starts. The molds are covered with nylon sheets for approximately 24 hours after casting. After that, they were placed in a water tank for curing till testing (7, 28, 90, 120, and 180 days). **(ASTM C192, 2006)**

4. TEST RESULTS:

4.1 Fresh concrete tests:

4.1.1 Slump flow test and T500 mm test:

The test calculated the horizontal free flow of the SCC. According to EFNARK, 2002, This widely used test measures followability and resistance to segregation. **(EFNARC, 2002)**

4.1.2 L-Box test:

SCC must move through tiny openings, like those between supporting bars, without segregating or clogging in order to pass this test. The method of EFNARK (2002) for calculating the L-box test's passing ratio for self-compacting concrete. **(EFNARC 2002)**

4.1.3 Sieve segregation resistance test:

The segregation test used to assess the SCCs resistance to segregation. **Table 11** show the category used in the SCC standard. **(EFNARC, 2005)**

Table 11. Segregation category according to EFNARC 2005

Class	Segregation resistance in %
SR_1	≤ 20
SR_2	≤ 15

4.2 Hardened concrete tests:

4.2.1 Compressive strength test:

According to BS EN12390-3, 2019, the test conducted in this search. The cubes (100x100x100 mm) were examined at ages 7, 28, 90, 120, and 180 days. After recording the

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load at failure, the Compressive St. was computed by averaging the three cubes for each age. **(BS EN 12390-3, 2019)**

4.2.2 Splitting St.:

Samples of 100 mm by 200 mm were used. This check was conducted at 7, 28, 90, 120, and 180 days of age. **(ASTM C496-04, 2007)**

4.2.3 Flexural strength test:

This standard evaluates concrete's flexural St. utilizing prism samples with dimensions of (80*80*380) mm and center point loading. A calculation was made using three prisms at ages 7, 28, 90, 120, and 180 days. **(ASTM C293, 2006)**

4.2.4 Oven Dried Density Test:

The dried density used specimens that were 100*100*100 mm cubes. The samples were cured for 72 hours at 110 C in an oven. The mass of each specimen was then determined after it had cooled in dry air for no more than 30 minutes on each. Every 24 hours, repeat the oven drying, chilling, and mass recording procedures until the mass is determined and the mass change is less than 0.5%. **(ASTM C567/ C567M-19, 2019)**

4.2.6 Water Absorption:

According to ASTM C 642 - 13, the absorption after immersion in water was showed. The cube samples (100*100*100 mm) were dried for 24 hours at temperatures between 100 and 110°C to dry them. Each sample was then taken out of the oven and allowable to cool in dry air to a temperature of 20 to 25 °C, and its mass was calculated. The sample was submerged in water for 48 hours. Its mass is once more measured after being surface-dried by wiping away surface moisture with a damp cloth. **(ASTM C642, 2013)**

5. RESULTS AND DISCUSSION

5.1 Workability:

All cases of the workability results for mixes are presented in **Table 12** and dramatically reduced, when the SO_3% contented in sand was increased. **Table 12** displays that the Slump flow values for LWSCC decreased from (750 to 562) mm and this decreases in the slump flow is shown in **Fig.1** which shows the flowability of the mixes which decreased as the percentage of SO_3 in sand increased. This is because ettringite forms in larger amounts in the early stages of hydration when the sulphate content is higher. As a result, a large amount of water is used in the reaction that makes ettringite **(Mehta at el., 2006).**

T_{500} mm values for LWSCC ranged from (2.31 to 4.9) sec which displays in **Table 12** and the increased in the T_{500} is shown in **Fig.2** which shows the viscosity of the mixes were increased as the percentage of SO_3 in sand increased . The $T_{500\,mm}$ was raised by the addition of 0.5% V_f PP, which also reduced the slump flow due to their small diameter, (PP) require a large quantity of water to become saturated. This causes the mixing water to become unbalanced **(Ghernouti et al., 2015).**

Table 12 displays that the L-box values for LWSCC ranged from 0.89 to 0.80 and the decreased in the L-box is shown in **Fig.3,** which shows the passing ability of the mixes, were decreased as the SO_3% in sand increased. Results show that the ratio (H2/H1) went down as the amount of sulphates in the concrete grew up. This drop is probably because the amount of sulphates has gone up, which has caused by yield stress and viscosity to rise up. And also the adding of fibers led to decreased in L-box. This can be attributed to the friction that exists between the fibers and the aggregate as well as between the fibers.

Table 12 displays that the Sieve Segregation values for LWSCC ranged from 19.7 to 15.49 and the reduced in the Sieve Segregation is shown in **Fig.4** which shows the segregation of the mixes were decreased as the percentage of SO_3 in sand improved. This decreased was because the formation of Ettringate.

The Sieve Segregation was reduced by the inclusion of 0.5% V_f polypropylene fiber. This is attributed to the dispersion of fibers in concrete, which leads to the formation of a network that effectively prevents the separation of aggregate particles from the mixture. This may explain why LWSCC with fibers has a higher resistance to segregation, which is consistent with the findings of **(Almawla et al., 2019).**

Table 12. Fresh concrete test results

Concrete Mix.	Tests				
	Slump flow (mm)	T_{500} Slump Flow (sec)	L-box (h_2/h_1)	Segregation %	EFNARC 2005
CM	750	2.31	0.89	19.7	SR_1
CG2	720	3.12	0.88	18.8	SR_1
CG4	685	3.87	0.86	17.9	SR_1
CG6	650	4.67	0.85	17.01	SR_1
CGS2	650	4.0	0.85	17.54	SR_1
CGS4	607	4.55	0.83	16.04	SR_1
CGS6	562	4.9	0.80	15.49	SR_1

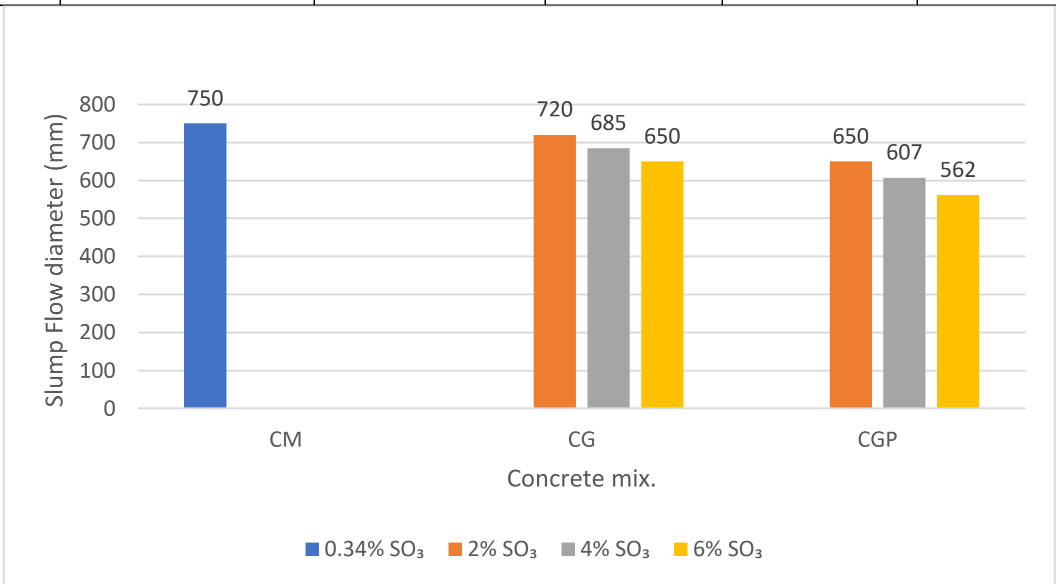

Figure 1: Effect of SO_3% and fibers on the slump flow diameter for LWSCC

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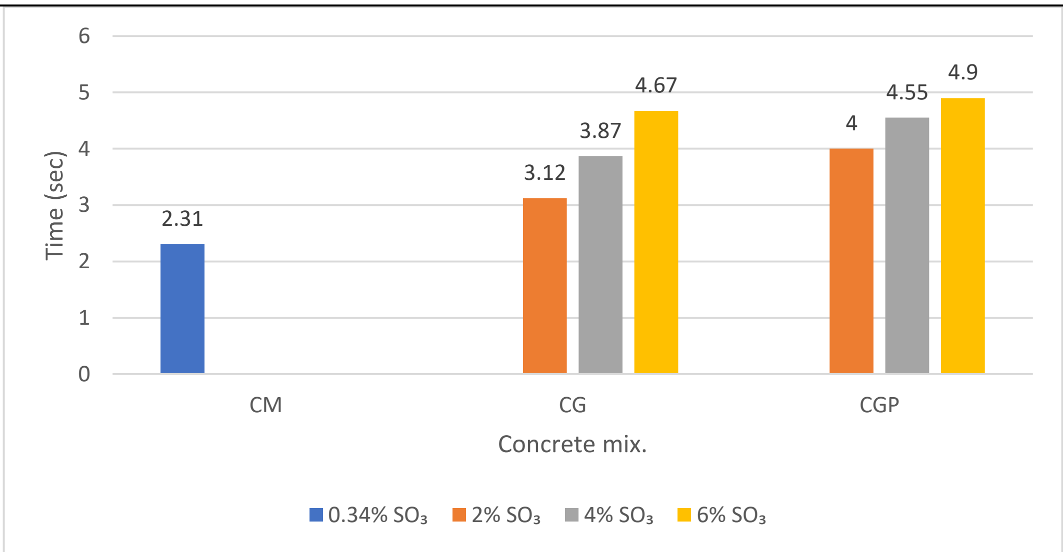

Figure 2: Effect of SO_3% and fibers on the $T_{500\ mm}$ for LWSCC

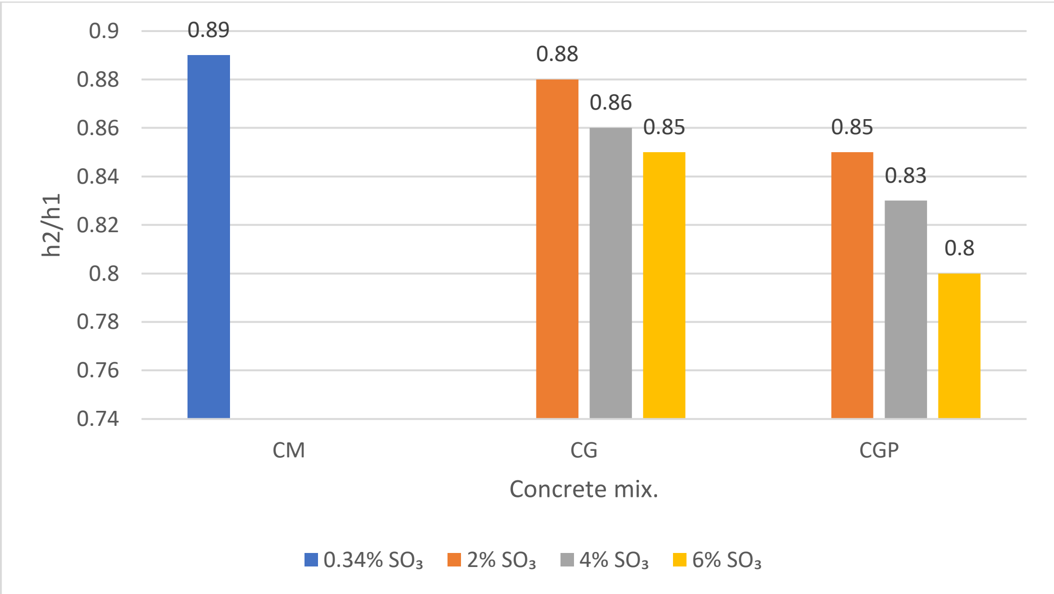

Figure 3: Effect of SO_3% and fibers on the L-box for LWSCC

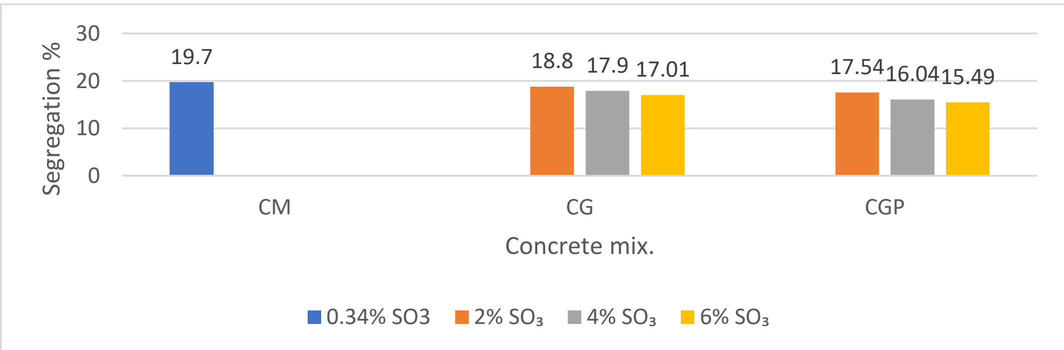

Figure 4: Effect of SO_3% and fibers on the Sieve segregation resistance for LWSCC

5.2 Hardened Concrete:

5.2.1 Compressive st. and Density test:

The production of Ettringate, which weakens the concrete, is to blame for the reduction in Compressive St. This suggests that as the proportion of SO_3 in Sand. rises, the compressive St.% decreases. The Compressive St. values for different mixes and the reference mix utilized on days 7, 28, 90, 120, and 180 are shown in **Table 13**. **Fig.5** demonstrates how the Compressive St. has reduced as curing age and SO_3% have risen. When the sulfate percentage in Sand. increased from 0.34% to 2%, the Compressive St. decreased by 16.15% and 16.53% at 90 and 120 days, respectively. The decrease in Compressive St. was 21.96% and 22.45% at 90 and 120 days, respectively, when the sulfate percentage increased to 4%. Compressive St. decreased by 25.4% and 26.47% at 90 and 120 days, respectively, as sulfate climbed to 6%. This decrease in Compressive St. may have been caused by the formation of ettringite, which then diffused through the voids present in LECA and between LECA and mortar, resulting in micro cracking and splitting of concrete structures. These micro cracks are the consequence of volumetric differences between cement paste and LECA **(Lawrence, 1990).**

For concrete mixes with %SO_3 at 28 days, adding 0.5% V_f of PP increased the Compressive St. by (5.30%, 4.11%, and 3.35%) from the reference mix. At 90 days and 120 days, the Compressive St. increased by percentages of (4.55%, 3.22%, and 2.40%) and by (3.75%, 2.31%, and 1.40%) respectively. As the improvement in Compressive St.by using 2% SO_3 with the addition of PP was higher than that by using 4% and 6% SO_3, the development in Compressive St. increases with the decrease in the percentage of SO_3 **(Al-Musawee, 2011).** While, strength reductions result from polypropylene fiber inclusion and air entrainment. **(Miao et al., 2003).** In addition, the steel and polypropylene fibers would indirectly add to the increase in strength by slowing down the deterioration caused by sulfate action, while the CG2, CG4 and CG6 would continue to get deteriorate. This would be a clear difference between plain and fiber strengthened LWSCC with sulfate.

The values of oven-dried density for the CM and various mixes utilized at 28 days are shown in **Table 13**. **Fig.6** shows how density decreases as SO_3% increases. Density decreased by 1.31 % at 28 when sulfate percentage in sand increased from 0.34% to 2%. The density reduced by 2.35% at 28 when the sulfate percentage increased to 4%. Sulfate concentration rose to 6%, and after 28 days, density decreased by 3.28%. The production of Ettringate, which weakens the concrete, is to blame for the decrease in density. This suggests that when the percentage of SO_3 in sand rises, the density percentage decreases.

The density was decreased by 0.27% for mix CG2 by 0.33% in CG4 and 0.39% in CG6 by adding 0.5% V_f of PP.

Table 13. Effect of SO_3% and fibers on the Compressive Strength and density for LWSCC

Concrete mix.	Compressive strength (MPa)					Density Kg/m^3
	7d	28d	90d	120d	180d	28d

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CM	19.6	27.31	34.61	39.5	41.0	1831
CG2	16.7	23.21	29.0	33.0	34.1	1805
CG4	15.9	21.8	27.0	30.6	31.7	1786
CG6	15.4	20.8	25.8	29.0	30.0	1771
CGP2	17.8	24.43	30.33	34.26	35.13	1800
CGP4	16.75	22.75	27.87	31.39	32.15	1780
CGP6	16.05	21.58	26.43	29.5	30.3	1762

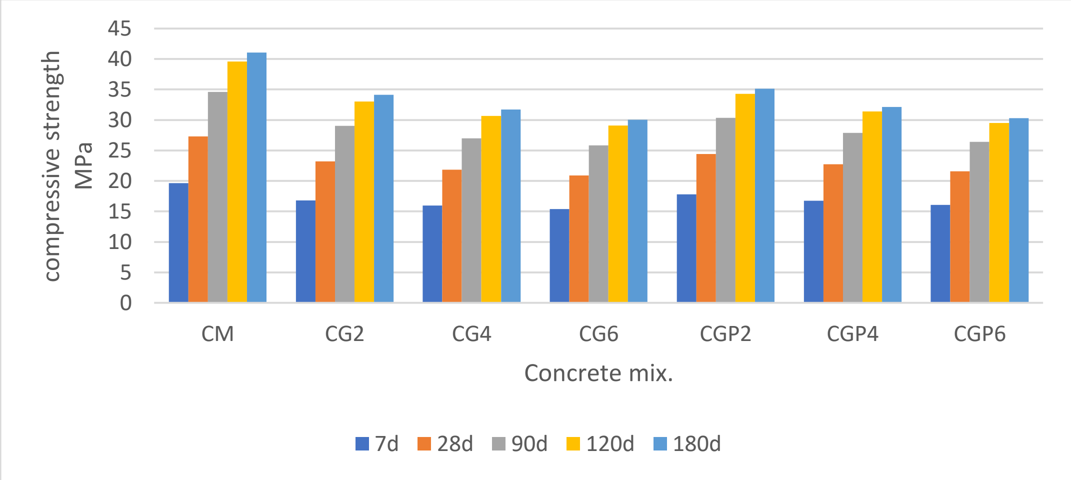

Figure 5: Effect of SO_3% and fibers on the Compressive Strength for LWSCC

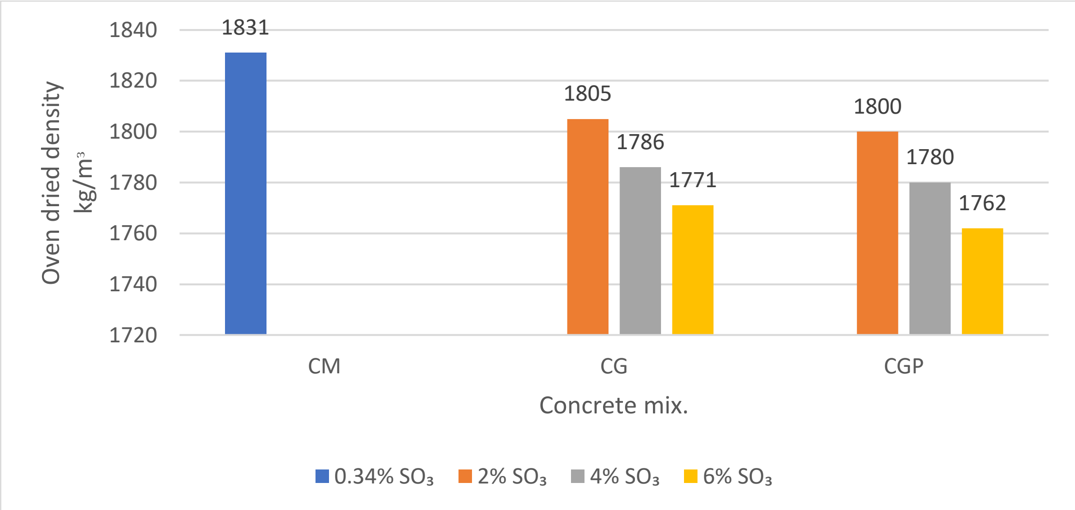

Figure 6: Effect of SO_3% and fibers on the oven dry density for LWSCC

5.2.2 Splitting tensile strength and Flexural test:

The values of splitting St. for CM and various mixes utilized at 7, 28, 90, 120, and 180 days are shown in **Table 14**. **Fig.7** showed how adding SO_3% at various curing ages decreased splitting tensile St. When sulphate percentage in Sand. rose from 0.34% to 2%, splitting tensile strength decreased by 16.12% and 16.25% at 90 and 120 days, respectively. When the sulfate percentage increased to 4%, the splitting st. decreased by 25.8% and 26.38%, respectively, at 90 and 120 days. While the lower splitting st. was 30.64% at 90 days and 31.59% at 120 days when the sulphate content increased to 6%. The production of Ettringate, which weakens the concrete, is the cause of this drop in splitting st.. This suggests that as the amount of SO_3 in Sand. increases, the percentage of splitting st. decreases.

Adding 0.5% V_f of PP improved the splitting tensile strength by (14.54%, 13.77%, and 13.11%) from the CM for mixes with SO_3% at 28 days. The splitting tensile strength is also increased by a percentage in concrete mixes at 90 days by (14.23%, 13.04%, and 12.09%). As the development in splitting St. by using 2% SO_3 with the addition of PP was higher than that by using 4% and 6% SO_3, the development in splitting tensile St. Increases with the decrease in the %SO_3.

Table 14 displays the flexural St. Values for the CM and various mixes used at days 7, 28, 90, 120, and 180. **Fig.8** shows how the reduction in flexural St. occurred with an increase in SO% and for various curing ages. When the sulfate percentage in sand increased from 0.34% to 2%, there was a 26.61% and 27.06% reduction in flexural st. at 90 and 120 days, consecutive. At 90 and 120 days after increasing the sulphate percentage to 4%, flexural St. decreased 37.84% and 38.27%, respectively. While at 90 and 120 days, respectively, the decrease in flexural St. was 46.10% and 47.15% when the sulfate concentration increased to 6%. The fine voids that develop on the aggregate surface represent structural breaks in continuity and provide an opportunity for ettringite accumulation, Ettringite forms in fine voids and micro cracks with less surface energy than it does when forming in bulk paste **(Fu and Beaudoin, 1996).** Many researchers**(Fu and Beaudoin, 1996), (McMullen, 2004), (Taylor et al., 2001)** have observed in damaged concretes that ettringite crystals usually exist in cracks, voids, and the transition zone at the aggregate-binder interface if concrete is subjected to expansion due to ettringite. This leads to additional stress on the aggregate-matrix interface and, consequently, to micro cracks. In addition, ettringite formed in micro cracks will grow due to expansion pressure. Under low applied stresses, these processes will result in the debonding of aggregates and matrix, leading to prompt failure. Because polypropylene fibres prevent further microcracking and slow the growth of existing ones, their presence delays these processes. Consequently, the deleterious impact of sulfates on concrete is diminished.

When 0.5% SO3 of polypropylene fiber was added to concrete mixes containing (2% to 6%) of SO3 at 28 days, the flexural St. increased by (21.55%, 21.07%, and 20.38% from the reference mix. The flexural St. rose at 90, 60, and 120 days by 21.25%, 20.66%, and 19.57%, respectively. Because using 2% SO3 with polypropylene fiber improved flexural st. more than using 4% and 6% SO3, the improvement in flexural st. rises as the percentage of SO3 falls.

Table 14. Effect of SO_3% and fibers on the splitting tensile strength and flexural strength for LWSCC

Concrete mix.	Splitting tensile (MPa)					Flexural strength (MPa)				
	7d	28d	90d	120d	180d	7d	28d	90d	120d	180d
CM	1.71	2.62	3.12	3.4	3.5	2.6	3.8	4.3	4.7	4.8
CG2	1.4	2.2	2.62	2.8	2.9	1.9	2.8	3.21	3.4	3.5
CG4	1.31	1.91	2.31	2.5	2.6	1.6	2.4	2.7	2.91	3.0
CG6	1.2	1.81	2.11	2.31	2.41	1.41	2.01	2.32	2.5	2.5

CGP2	1.67	2.52	2.97	3.28	3.39	2.41	3.44	3.88	4.18	4.24
CGP4	1.49	2.23	2.6	2.86	2.95	2.05	2.93	3.27	3.51	3.59
CGP6	1.38	2.07	2.41	2.63	2.71	1.74	2.48	2.81	2.98	3.03

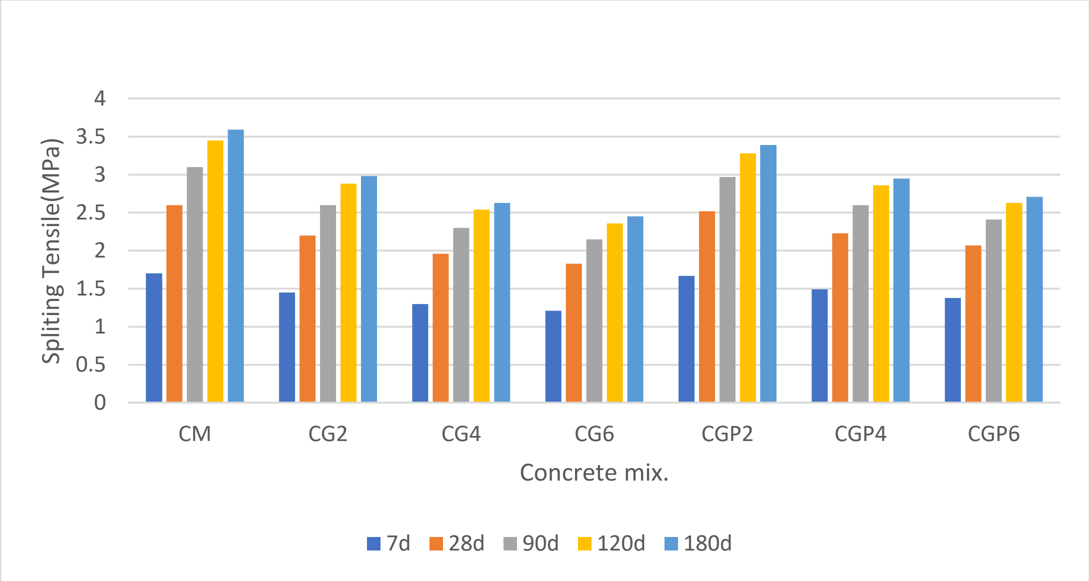

Figure 7: Effect of SO_3% and fibers on the splitting tensile strength for LWSCC

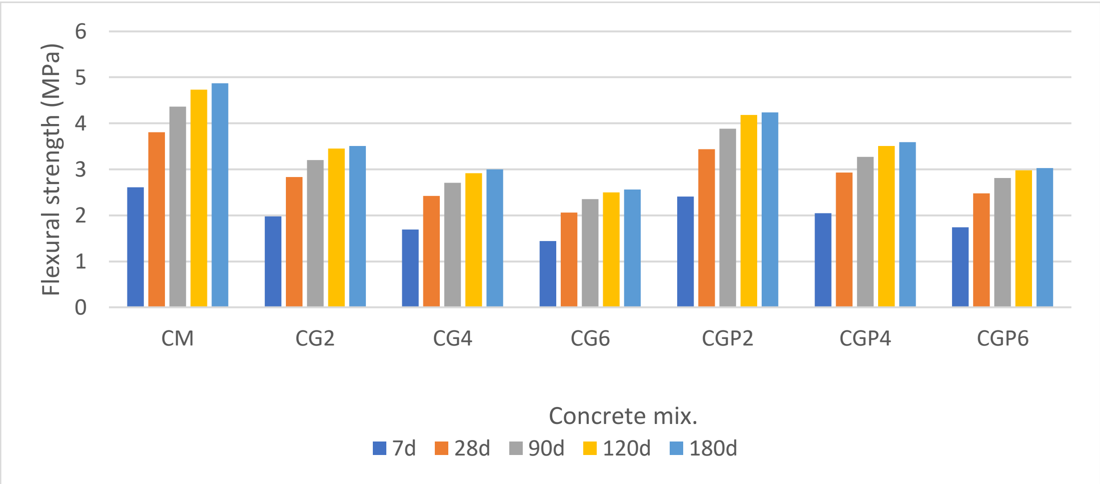

Figure 8: Effect of SO_3% and fibers on the Flexural strength for LWSCC

5.2.3 Modules of elasticity test:

The values of the modulus of elasticity (ME) for the CM and various mixes utilized at 28 days are shown in **Table 15**. **Fig.9** shows how the reduction in ME is caused by the addition of SO_3% in sand, the drop in ME was (12.69%, 16.45%, and 19.85%) when the sulfate percentage increased from (0.34% to 6%). Because Ettringate forms and weakens concrete, the modulus of elasticity has declined. This suggests that as the proportion of SO_3 in sand rises, so does the percentage of reduction in ME. This indicates the reduction in ME increases as the %SO_3 in sand increases. In other words, the rise in SO_3 caused in a drop in the specimens' ME as a consequence of a drop in the matrix's ME due to decrease in bulk cement paste and aggregate interfacial bond strength **(Al-Ameeri and Issa, 2014).**

Compared to the CM for mixes with SO_3%, adding 0.5% V_f of PP increased the ME by (21.70%, 20.54%, and 19.70%) at 28 days. As the development in ME by using 2% SO_3 with polypropylene was higher than that by using 4% and 6% SO_3, the development in ME rises with the reduction in the %SO_3.

Table 15. Effect of SO_3% and fibers on the Modules of Elasticity for LWSCC

Concrete Name.	Modules of Elasticity GPa at 28 days
CM	16.7
CG2	14.6
CG4	14.0
CG6	13.4
CGP2	17.83
CGP4	16.9
CGP6	16.1

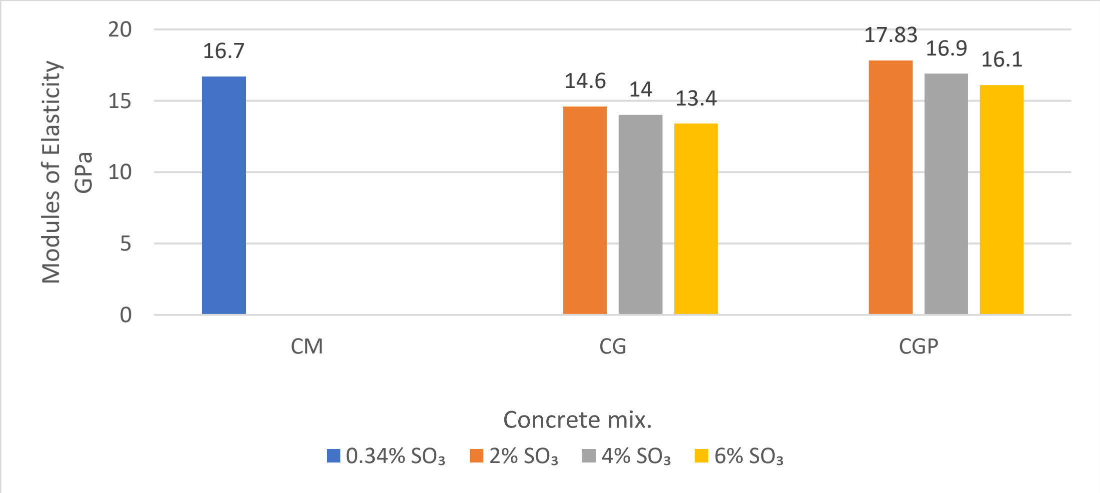

Figure 9: Effect of SO_3% and fibers on the Modules of Elasticity for LWSCC

5.2.4 Water Absorption:

The values of water absorption for the CM and various mixes utilized at 28 days are shown in **Table 16**. **Fig.10** shows how the rise in SO_3% improved water absorption. In fine aggregate, as sulfate percentage increased from (0.34% to 2%, 4%, and 6%), water absorption increased by (5.88%, 10.9%, and 15.3%), respectively. The production of Ettringite, which deteriorates the concrete, is the cause of the increased water absorption. This indicates that as the proportion of SO_3 in Sand. increases, so does the percentage of increase in Water Absorption.

Compared to the reference mix for concrete mixes with SO_3, adding 0.5% V_f of PP increased the water absorption by (1.93%, 2.99%, and 3.54%) at 28 days.

Table 16. Effect of SO_3% and fibers on the water absorption for LWSCC

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Concrete mix.	Water absorption % 28 days
CM	3.91
CG2	4.14
CG4	4.34
CG6	4.51
CGP2	4.22
CGP4	4.47
CGP6	4.67

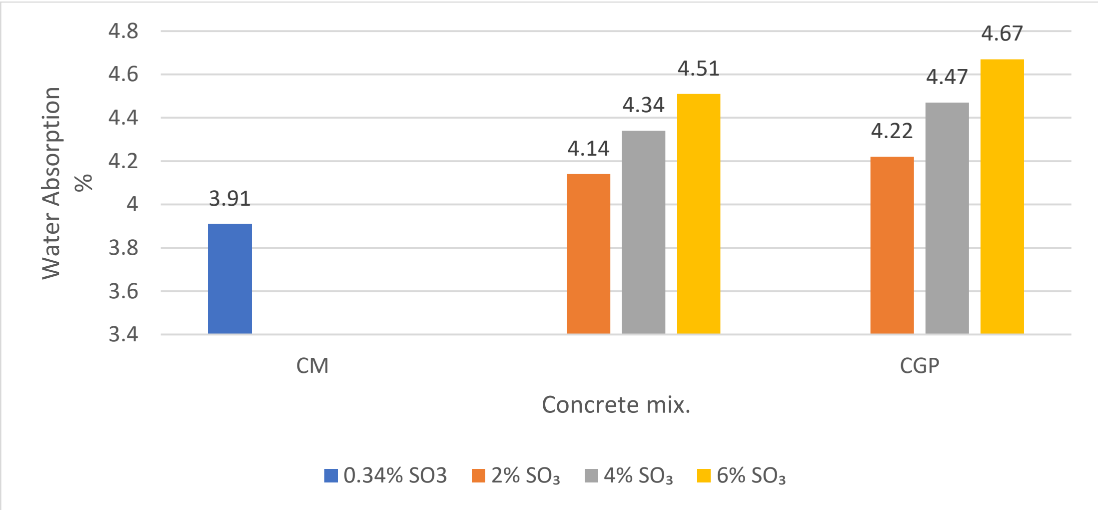

Figure 10: Effect of SO_3% and fibers on the water absorption for LWSCC

6. Conclusions:

1- A reduction in the properties of workability were found for all LWSCC mixed when the SO_3% content in sand was excessed. And the adding of PP made a more reduction in the workability.

2- With the growth in the %SO_3 in the mixes, the values of the mechanical characteristic decrease and the water absorption increase. Moreover, with the progressing age, the influence of sulphate on mechanical properties is greater than before.

3- The addition of PP led to an development in the reduction produced by the sulphate, so it enhanced Compressive St. and den. with a slight enhancement. However, splitting St., flexural St. and ME with a significant enhancement. Moreover, adding polypropylene fiber led to a worse decline produced by the sulphate, so it decreased water absorption. Compared to the CM.

4- The addition of PP enhanced the characteristic by using 2% SO_3 better than 4% and 6% SO_3. Moreover, addition polypropylene fiber increased water absorption by using 6% SO_3 better than 4% and 2%.

7. References:

De Azevedo.A.R.G., Marvila .M. T., Tayeh .B. A., Cecchin .D., Pereira.A. C., and Monteiro.S. N., 2021. Technological performance of açaʹı natural fibre reinforced cement-based mortars. Journal of Building Engineering, 33, p. 101675.

Almawla, S. A., Mohammed, M. K., & Al-hadithi, A. I., 2019. Production and Properties of Self-Compacting Lightweight Concrete Containing Waste Plastic Fibers. Master thesis university of Anbar.

ASTM C 1240, 2015 May. Standard Specification for the Use of Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete, Mortar, and Grout, 4(2) ,pp.1-7.

ASTM C192, 2006. Standard Practice for Making and Curing Concrete Test Specimens in The Laboratory.

ASTM C293, 2006. Standard Test Method for Flexural Strength of Concrete, Using Simple Beam With Center-Point Loading.

ASTM C469-02, 2009. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.

ASTM C494/C494M – 05. Standard specification for chemical admixtures for concrete. American Society for Testing and Materials.

ASTM C496-04, 2006. Standard Test Method for Splitting Tensile of Cylindrical Concrete Specimens. Annual Book of ASTM Standards, American Society for Testing and Materials, 04(02), pp.1-6.

ASTM C567/ C567M-19, 2019. Standard Test Method for Determining Density of Structural Lightweight Concrete.

ASTM C642-13, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete‖", ASTM International.

Alam .B, Ashraf .M, Shahazard .K, Afzal .S and Khan .K, July 2012. Sulphate Attack in High-Performance Concrete-A Review. International Journal of Advanced Structures and Geotechnical Engineering, 01 (01), pp.15-18.

Vakhshouri .B and Nejadi .S, 2016. Mix design of light-weight self-compacting concrete. University of Technology Sydney, 4,pp.1-14. http://dx.doi.org/10.1016/j.cscm.2015.10.002

BS EN 12390-3, 2019. Compressive strength of test specimens. British Standard Institution.
C. J. M. o. c. R. Lawrence, 1990. Sulphate attack on concrete. 42 (153), pp.249-264.

Zhang .D, Shahin .M.A, Yang .Y, Liu .H, and Cheng .L, 2021. Effect of microbially induced calcite precipitation treatment on the bonding properties of steel fiber in ultra-high performance concrete. Journal of Building Engineering, 50, p. 104132.

Zhang .D, Liu .Y, and Tan .K.H, 2021. Spalling resistance and mechanical properties of strain-hardening ultra-high performance concrete at elevated temperature. Construction and Building Materials, 266, p. 120961.

Al-Anbori .Z.K.A, 2013. Effect of External Sulfate Attack on Self Compacted Concrete. Eng. & Tech. Journal, 31 (6), pp.1093. doi: www.pdffactory.com

EFNARC, 2005. The European Guidelines for Self-Compacting Concrete Specification, Production and Use. www.efranice.org

Ali .E.M, 2013. Internal Sulphate Attack On Self Compacting Concrete. Journal of Babylon University, Engineering Sciences, 21(5), pp.1622.

Fu Y., and Beaudoin J.J., 1996. Microcracking as a precursor to delayed ettringite formation in cement systems. Cement and Concrete Research, pp.1493-1498. https://doi.org/10.1016/0008-8846(96)00134-2

Taylor .H.F.W , Famy .C, Scrivener .K.L , 2001. Delayed ettringite formation in concrete. Bauhaus-University Weimar., Germany. Cement and Concrete Research, 31(5), pp.683-693. https://doi.org/10.1016/S0008-8846(01)00466-5

Al-Obaidy .H.K.A, May 2017. Influence of Internal Sulfate Attack on Some Properties of Self Compacted Concrete. Journal of Engineering, 23(5), pp.27-46.

IQS NO.1703, 1992. Iraq standard specification for Water used in concrete.

Iraqi Specification, No.5, 2019. Portland Cement. Ministry of Planning. Central Organization for Standardization and Quality Control.

Iraqi Specifications, IQS No.45, 1984. The Used Aggregate from Natural Sources in Concrete and Building. Central Apparatus for Standardization and Quality Control. (Translated from Arabic).

McMullen T.M, 2004. The St. Francis Dam Collapse and Its Impact on the Construction Of the Hoover Dam. M.Sc. thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park.

Mehta, P.K. and Monteiro P.J., 2006. Concrete: microstructure, properties and materials. Third Edition, McGraw-Hill, USA, pp.659.

Miao B., Chern J.C., and Yang C.A., 2003. Influence of fiber content on properties of self compacting steel fiber reinforced concrete. Journal of Chinese Institute of Engineers, 26(4), pp.523-530. doi:0.1080/02533839.2003.9670805

Al-galawi .N.M, Hassooni .S.A, February 2016. The Effect of Cement and Admixture Types on the Resistance of High Performance Concrete to Internal Sulphate Attack. Journal of Engineering, 22(2), pp.74-92.

Fawzi .N.M, Weli .A.K, January 2016. Some Properties of Polymer Modified Self-Compacting Concrete Exposed to Kerosene and Gas Oil. Journal of Engineering, 22(1), pp.31-48.

Zollo .R.F,1997. Fiber-reinforced concrete: an overview after 30 years of development. Cement and Concrete Composites, 19(2), pp. 107–122.

S. Ahmed, A. Hussain, Z. Hussain, Z. Pu, K. A. Ostrowski, and R. Walczak, 2021. Effect of carbon black and hybrid steel-polypropylene fiber on the mechanical and self-sensing characteristics of concrete considering different coarse aggregates' sizes. Materials, 14(23), p. 7455.

Shah .S and Ahmad .S, 2014. High performance concretes and applications. CRC Press.

Ghernouti .Y, Rabehi .B, Bouziani .T, Ghezraoui .H, Makhloufi .A, 2015. Fresh and hardened properties of selfcompacting concrete containing plastic bag waste fibers (WFSCC). Construction and Building Materials, 82 (1), pp.89-100. https://doi.org/10.1016/j.conbuildmat.2015.02.059