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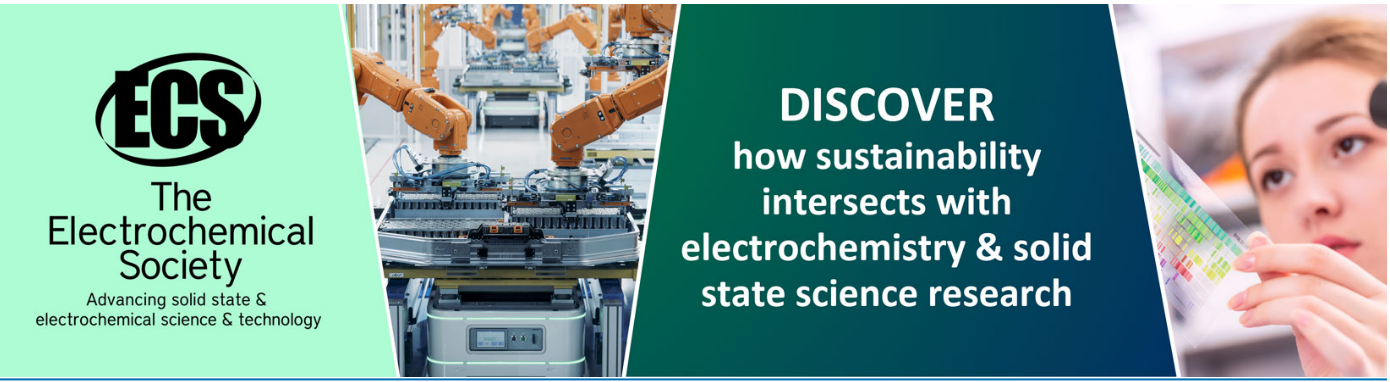

Studying The Effect of Internal Sulfates on Normal and Lightweight Concrete

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Abstract. The current research includes study the effect of internal sulfate (Calcium sulfate) on mechanical properties of normal and light weight concrete. The mechanical properties included compressive, splitting tensile, and flexural strength. The experimental work consists of casting and testing 216 cubes (150×150×150) mm, 216 cylinders (200×100) mm, and 144 prisms (400×100×100) mm having different condition including: ratio of the sulfate, the age test, type of concrete, and type of cement. This research consists of two part normal and light weight concrete, each part divided to three groups according to type of cement (type I cement, type V cement, and type I cement with 15% silica fume replacing from weight of cement). Each group consisting of four set with different ratio of sulfate (0.28% (reference SO3), 0.5%, 1% and 1.5%) by weight of fine aggregate where these ratios approximate the actual reality of the sulfates present in internal concrete components such as sand, each set having nine cubes tested in a different age (28, 60, and 90) days. The experimental results show that the harmful effect of internal sulfate in concrete on mechanical properties was decreased by using type I cement with 15% silica fume replacement whether normal and light weight concrete. Using of silica fume concrete is more effective to enhance the concrete resistance to internal sulfate attack.

Keywords: Internal Sulfate, Normal Concrete, Light Weight Concrete.

1. Introduction

The aggregates located in Iraq for concrete are sea deposits, which have become contaminated with sulfates due to the tropical dry climate. These sulfates are the source of the problem of internal sulfate in concrete [1]. When amount of sulfates exceeds a certain limit, internal stresses will develop due to the formation of calcium sulphoaluminate and gypsum. The effect of sulfate attack has not only destructive cracking and expansion, but as well lack of the adhesion between cement paste and the aggregate particle and loss of the cohesion in the hydrated cement paste lead to damage of strength of concrete [2]. Sulfate salts in sand is a great issue in the Southern and Middle region of Iraq. the sulfate salts in sand are consist of magnesium, calcium, sodium and potassium sulfates. calcium sulfate is the most salt found in Iraqi sand as gypsum. The sulfates in sand are about 95% as calcium sulfates because of the low solubility of this type of sulfate [3].

During the process of sulfate attack, sulfate ions resulting from sand in the presence of water can spread and interact with cement components (calcium hydroxide and CSH gel) to form gypsum, which in turn interacts with the calcium aluminate present in the cement paste, mainly (C3A) and to a lesser extent (C4AF). A secondary ettringite is the end product of these reactions that can generate stress states within the concrete [4]. These chemical reactions lead to the mechanical effects composed of a gradual decrease in the strength and stiffness of the concrete. This causes two different phenomena: mechanical damage caused by stress due to the expansion of ettringite in the pores, and chemical damage resulting from the filtering of silicate hydrates and calcium hydroxide [5]. The resistance to concrete sulfate has been improved in several studies. One of methods used to improve the resistance of concrete sulfate is the use of pozzolans such as silica fume, fly ash, and natural pozolan [6].

Many researchers studied the effect of internal sulfate on concrete. They believed the formation of calcium sulphoaluminates in an early stage does not cause any appreciable disruption or reduction in strength because the formation of the sulphoaluminates is not associated with the development of the internal stresses, due to fresh concrete plasticity, but internal stresses will develop due to the formation of calcium sulphoaluminates in the hardened cement mix. Abdul Latif (1997) [7], concluded that each type of cement has certain behavior in relation to the increase of (SO3) percent in sand and this behavior depends on number of factors such as SO3% in cement, fineness, C3A content and soundness that specifies optimum gypsum content for each case. Since this would not agree with the limits specified in 1QS 45-1984.

Al-Rawi and Abdul-Latif (1998) [8] proposed a new test named "Compatibility test" to study the possibility of using relatively high content of (SO3) in sand with suitable cement without damaging the concrete. The study was achieved on 7 types of cement: one white cement, three sulfate-resistant cement, and three ordinary Portland cement. From the conclusions it was found that the effect of content of SO_3 in the sand varies from cement to another depending on the fineness and the chemical composition of the cement. Khudair J. A. and Faleh S. Kh. (2013) presented study about the durability of silica concrete from various concrete mixtures subject to sulfate attack. This study was carried out on concrete cubes with and without silica fume with the percentage of replacing (5 and 10) % SF from weight of cement. The solutions used in test to equip sulfate ions and cations were 10260 ppm groundwater sulfate, 5% magnesium sulfate solution, and 5% sodium sulfate solution. The reference solution used a tap water. Test results found that the replacement of silica fumes (5%) showed good resistance to sulfate in all test solutions. While replacing (10%) silica fume showed poor resistance to exposure to magnesium sulfate solution, on the other hand, it showed good durability with respect to groundwater and sodium sulfate solution [9].

Abbas (2016) [10], This study aims to obtain the influence of adding Nano metakaolin on some mechanical properties of hardened concrete. Three levels of SO3 in sand were investigated, these levels were (0.27 (reference SO3), 0.5 and 1% by weight of fine aggregate). One level of Nano metakaolin replacements (1 % by weight of cement) was used in this work. The results show that the optimum content of gypsum in sand (SO_3 = 0.5% from weight of sand) which gives highest results in modulus of elasticity, splitting strength and compressive strength of normal concrete (NC).

In this study, attempts to address some of the concerns related to sulfate resistance for concrete by replace cement type or replace 15% from cement by silica fume. Tests were selected to investigate and compare the variations in mechanical properties for both types of concretes (normal & light weight concrete). Internal sulfate attack is a long term function, therefore, tests were done for a long period up to the age of (90) days.

2. Objectives

The purpose of this research is to study the effect of internal sulfates in sand on compressive, splitting tensile, flexural strength tests for normal concrete (NC) and light weigh concrete (LWC). The main aims of this study are as follows:

1. Studying the effect of difference in percentage of sulfate (0.28%, 0.5%, 1% and 1.5%) by weight of fine aggregate on mechanical properties for normal and light weight concrete.
2. Studying effect of age test (28, 60, 90 days) on behavior of concrete subjected to internal sulfate.

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3. Investigating the effect of cement type (ordinary Portland cement (OPC), sulfate-resisting Portland cement (SRPC), and OPC with 15% SF as replacing from weight of cement) for normal and light weight concrete subjected to internal sulfate.

3. Experimental program

3.1. Materials

3.1.1. Cement. In this research, ordinary Portland cement, known as KAR Cement (Type I) and sulfate resistant Portland cement, known as AL-JESR Cement (Type V) were used. The physical properties and the chemical analysis of it meet the requirements of Iraqi Standards (IQS No. 5 / 1984) [11].

3.1.2. Sand. In this work, Sand brought from Al-Akhaidur region is used. The sulfate content and the grading conformed to the IQS limits of (IQS No. 45 / 1984) [12].

3.1.3. Normal Coarse Aggregate. Natural crushed gravel brought from Al-Nebai quarry with 12 mm maximum size was used. This aggregate was cleaned with water and then left in air to dry. The physical properties and the grading of this gravel agreed with the IQS limits (IQS No. 45 / 1984) [12].

3.1.4. Light Weight Coarse Aggregate. The coarse lightweight aggregate used in this study for producing lightweight concrete (LWC) is Crushed bricks where the brick was available in the market for the purpose of achieving the appropriate dry loose bulk density of lightweight aggregates comply to which must not exceed 880 kg/m3. It was obtained by crushing manually bricks as shown in figure 1. It was separated by sieve analysis and recombined it to meet the grading according to (ASTM C 330-05) [13].

Figure 1. Graded Crushed Bricks

So as to avoid the absorption of mixed water by light weight aggregate, this aggregates must be saturated in water for one day, and then dispersed inside the laboratory to obtain a saturated surface dry condition (SSD). Light coarse aggregate is used in the same nominal size as natural coarse aggregate (12 mm). Table 1 explained some physical properties of all coarse aggregate types.

Table 1. Some of Physical Properties of Aggregate

Aggregate Type	Dry Loose Bulk Density kg/m^3	Absorption (%)
Natural Gravel	1635	0.88
Bricks	874	26.9

3.1.5. Natural Gypsum. The gypsum used in this study was obtained from Kufa cement factory, which crushed, sifted and graded. The percentages of sulfate in concrete ingredients are obtained by adding natural gypsum to the sand as a partial replacement from weight of sand.

3.1.6. Silica Fume. In this study, silica fume is used meeting the requirements according to ASTM C 1240-05 [14].

3.1.7. Superplasticizer. To produce LWC, SikaViscocrete-5930 (SP) is a high range water reducing admixture (HRWRA) was used. It is used in present study by adding to mix water. Also, it conformed with ASTM C494-05 [15].

3.1.8. Water. For mixing concrete and for curing of it tap water was used.

3.2. Mix Proportion

3.2.1. Mix Design of Normal Concrete. According to ACI Committee 211.1-91[16], normal concrete was designed with some modifications in order to select mixing ratio for normal concrete to obtain cubes strength at 28 days about 30 MPa. So as to achieve scopes of this study, 12 mixtures were made with W/C (water/ cement) or W/P (water/ powder (cement and SF)) was 0.45 to give slump 85 ±10 mm.

The w/p and mixing ratio remained fixed in all mixes, the difference in the mix were sulfate contents in sand, type of cement and silica fume contents as replace from cement content. So as to investigate the effect of sulfates on NC in hardened state and compared its properties with properties of reference NC. Table 2 shows mixing design of normal concrete.

Table 2. Normal Concrete Mix Specification

Group	Mix Symbol	Type of cement	Amount (kg/m^3)					Sulfate (%) kg/m3
			Cement content	Silica Fume	Sand	Gravel	Water	
1	MN1	OPC	400	0	600	920	180	(0.28%) 1.68
	MN2	OPC	400	0	600	920	180	(0.5%) 3
	MN3	OPC	400	0	600	920	180	(1%) 6
	MN4	OPC	400	0	600	920	180	(1.5%) 9
2	MN5	OPC+SF	340	60	600	920	180	(0.28%) 1.68
	MN6	OPC+SF	340	60	600	920	180	(0.5%) 3
	MN7	OPC+SF	340	60	600	920	180	(1%) 6
	MN8	OPC+SF	340	60	600	920	180	(1.5%) 9
3	MN9	SRPC	400	0	600	920	180	(0.28%) 1.68
	MN10	SRPC	400	0	600	920	180	(0.5%) 3
	MN11	SRPC	400	0	600	920	180	(1%) 6
	MN12	SRPC	400	0	600	920	180	(1.5%) 9

3.2.2. Mix Design of Light Weight Concrete. Structural light weight concrete was defined as a concrete having density no more than 2000 kg/m3 and having compressive strength at 28 days more than 17 MPa, while normal weight concrete having density between 2200 -2600 kg/m3. Light weight concrete is based on their density therefore the target air dry density must not more than 2000 kg/m3. For comparison purposes, the target compressive strength for light weight concrete at 28 days were 30 MPa which is the same compressive strength for normal concrete.

Several trail mixing were made conformed to ACI committee 211.2-98 [17] and conforming to previous researches with some changes to satisfy the compressive strength and required density for LWC. The mixing ratios for light weight concrete is shown in table 3. The ratio of W/C or W/P was 0.35 and SP was 1.5% weight of cement to give slump 85 ±10 mm.

Table 3. Light Weight Concrete Mix Specification

Group	Mix Symbol	Type of cement	Amount (kg/m^3)						Sulfate (%) kg/m^3
			Cement content	Silica Fume	Sand	Brick	Water	SP.	
4	MLW1	OPC	400	0	600	920	180	6.48	(0.28%) 1.68
	MLW2	OPC	400	0	600	920	180	6.48	(0.5%) 3
	MLW3	OPC	400	0	600	920	180	6.48	(1%) 6
	MLW4	OPC	400	0	600	920	180	6.48	(1.5%) 9
5	MLW5	OPC+SF	340	60	600	920	180	6.48	(0.28%) 1.68
	MLW6	OPC+SF	340	60	600	920	180	6.48	(0.5%) 3
	MLW7	OPC+SF	340	60	600	920	180	6.48	(1%) 6
	MLW8	OPC+SF	340	60	600	920	180	6.48	(1.5%) 9
6	MLW9	SRPC	400	0	600	920	180	6.48	(0.28%) 1.68
	MLW10	SRPC	400	0	600	920	180	6.48	(0.5%) 3
	MLW11	SRPC	400	0	600	920	180	6.48	(1%) 6
	MLW12	SRPC	400	0	600	920	180	6.48	(1.5%) 9

3.3. Hardened Concrete Tests

The experimental program consists of testing 216 cubes (150×150×150) mm, 216 cylinders (200×100) mm, and 144 prisms (400×100×100) mm having different condition including: ratio of the sulfate, the age test, type of cement, and type of concrete. For this, the compressive strength test is calculated conformed to BS 1881-part 116:2000 [18], splitting tensile strength test is calculated conformed to ASTM C496/C 496M-04 [19], and flexural strength test is calculated conformed to ASTM C 78-02 [20]. Each result of splitting tensile and compressive strength was determined by averaging of the three specimens but flexural strength was determined from average two specimens for NC and LWC.

4. Results and Discussion

4.1. Normal Concrete

Value of compressive, flexural, and splitting strength at 28, 60, and 90 days for normal concrete with different ratios sulfate content in sand are explained in table 4 and figures (2 to 4) for different types of cement. For all mixtures it can be observed that there is an ideal sulfate content gives maximum compression, splitting and flexural strength, along with this optimum value, the compressive strength decreases with increasing sulfate content at all test ages. Current data indicate that the optimum sulfate content for these mixtures is about (0.5%) by weight of sand for normal concrete with OPC and (1.0%) by weight of sand for normal concrete with SRPC or OPC with replacing 15% silica fume.

Also, it was found that the specimens in group 2 and 3 made with high internal sulfate exhibit higher strength development than specimens made with standard sand, this conduct may be due to the reaction of sulfate of sand with C3A compound of cement. This reaction produces a suitable amount of primary Calcium Sulfoaluminate hydrates (Ettringite) which has a good mechanical properties and fill the pores inside the microstructure of the specimen if it was the number of Ettringite less than the pores [10].

Table 4. Compressive, Splitting, and Flexural Strength for Normal Concrete

Group	Mix Symbol	So3%by Weight of Sand	Compressive Strength MPa			Splitting Tensile Strength MPa			Flexural Strength MPa		
			28 days	60 days	90 days	28 days	60 days	90 days	28 days	60 days	90 days
1	MN1	0.28%	27.1	39.5	43.4	3.50	3.75	3.85	3.69	4.00	4.13
	MN2	0.5%	29.1	40.3	44.3	3.65	4.02	4.19	3.82	4.04	4.28
	MN3	1.0%	26.8	37.9	42.8	3.40	3.67	3.81	3.62	3.95	4.10
	MN4	1.5%	23.4	34.2	41	3.35	3.55	3.73	3.34	3.64	4.02
2	MN5	0.28%	34.5	42.4	44.8	3.82	4.05	4.11	4.65	4.64	4.60
	MN6	0.5%	36.8	46.7	51.0	3.92	4.10	4.21	5.05	4.96	4.72
	MN7	1.0%	37.7	48.2	54.0	3.93	4.16	4.28	5.09	5.16	5.25
	MN8	1.5%	31.8	38.7	42.0	3.71	3.92	4.09	4.05	4.11	4.32
3	MN9	0.28%	28.4	40.4	44.2	3.7	3.94	4.04	3.76	4.18	4.23
	MN10	0.5%	32.7	42.9	45.3	3.71	4.00	4.10	3.79	4.24	4.43
	MN11	1.0%	33.8	43.3	47.0	3.75	4.01	4.12	3.83	4.27	4.48
	MN12	1.5%	24.4	37.4	43.5	3.22	3.45	3.51	3.32	3.97	4.22

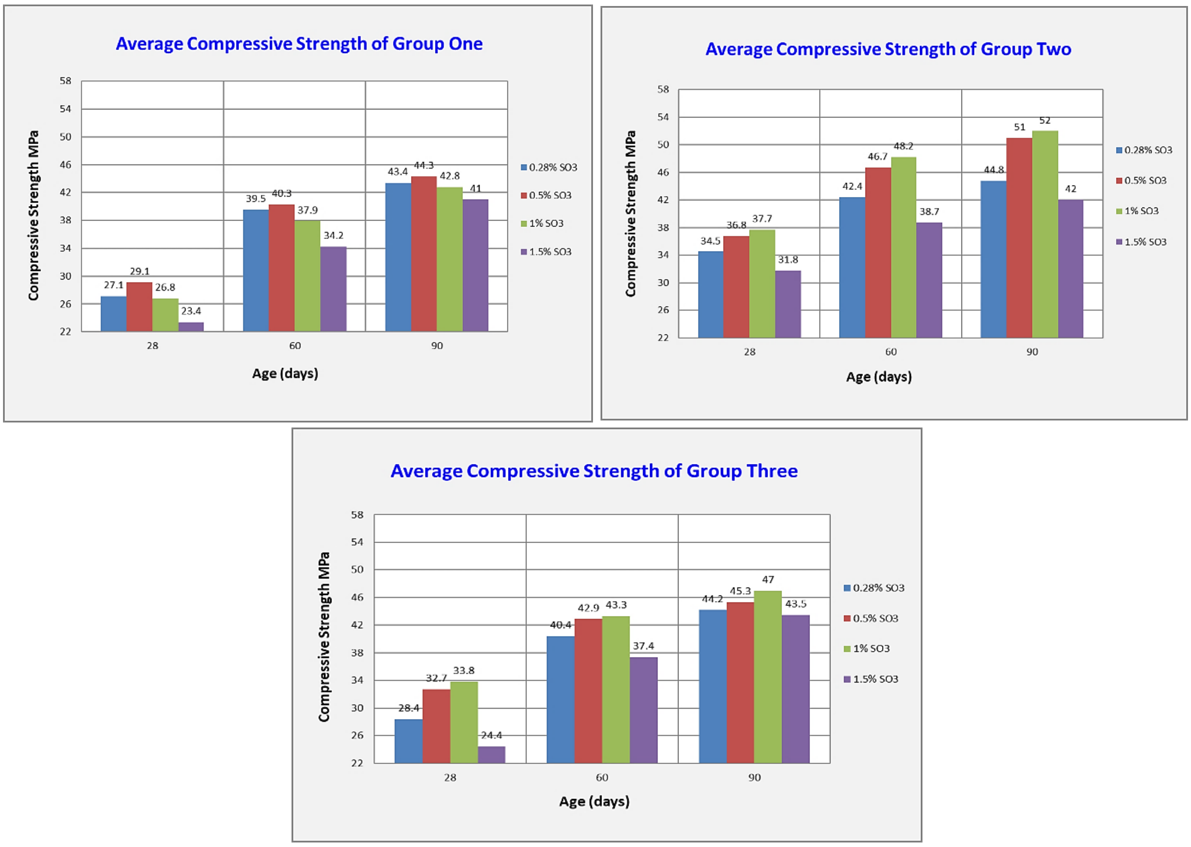

Figure 2. Compressive Strength Development for Normal Concrete

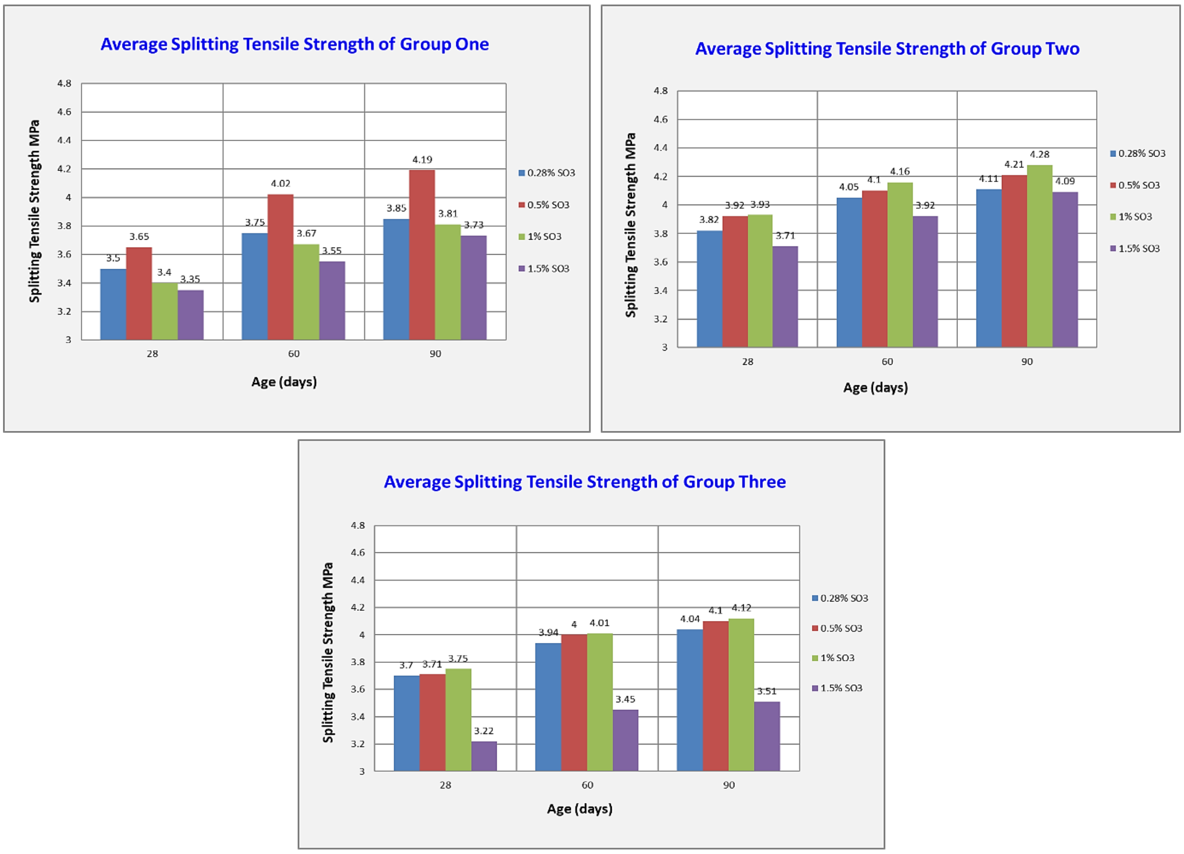

Figure 3. Splitting Tensile Strength Development for Normal Concrete

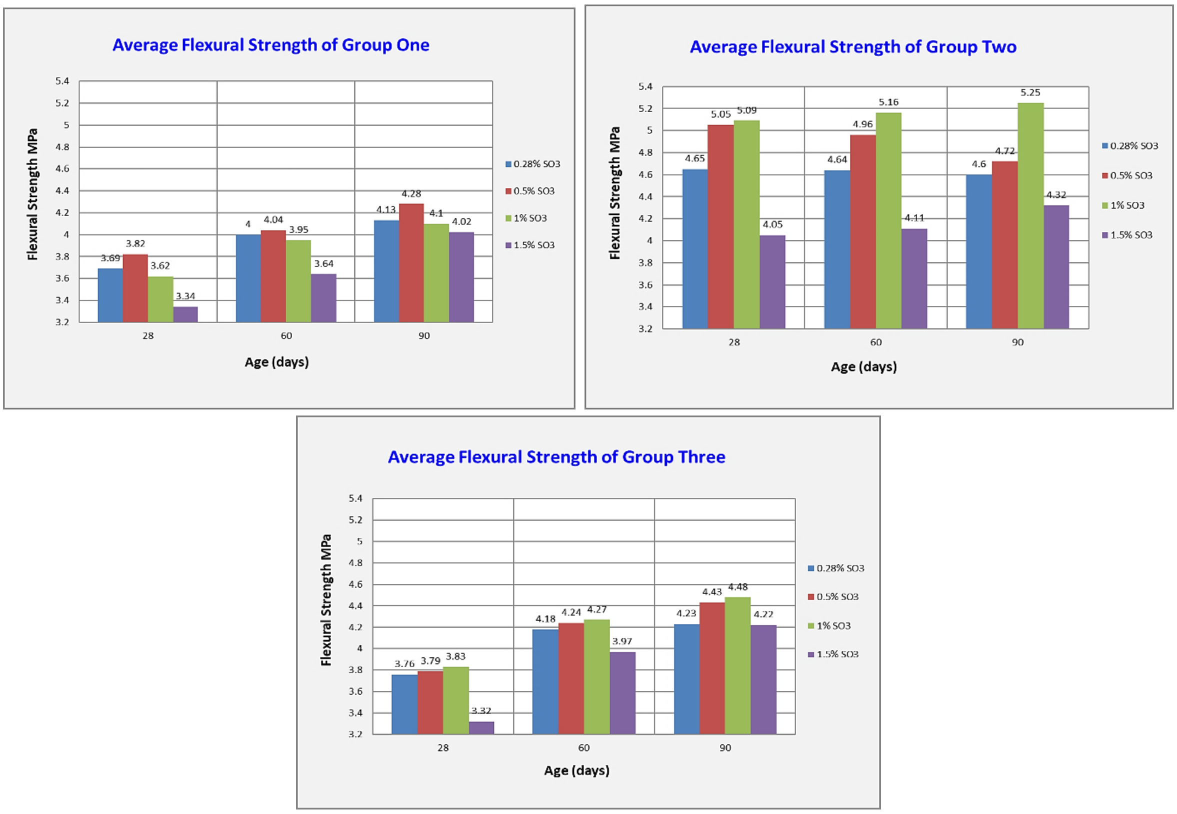

Figure 4. Flexural Strength Development for Normal Concrete

The results show that compressive, splitting tensile, and flexure strength increased for normal concrete with OPC and 15% SF as replacing from weight of cement at all mixes and at all ages compared to other types of cement.

4.2. Light Weight Concrete

Table 5 shows the results for Light weight concrete of compressive, splitting tensile, and flexural strength at 28, 60, and 90 days with various percentages sulfate content in sand. The optimal gypsum content for these mixtures is around (1.0% from weight of sand) for mixes which contain OPC and SRPC and about (1.5% from weight of sand) for mixes which contain 15% silica fume as replacing of OPC. But it was found that the decreasing in development of mechanical properties when sulfate in sand increases from (0.28 to 1.5) % for OPC was more than SRPC.

The light weight concrete which contains 15% silica fume as replacing of OPC gives improve in compressive, flexural, and splitting tensile strength with increasing sulfate content and curing time when compared with mixes that contain OPC and SRPC. This may be due to the cementation materials that are present in concrete which give more cohesion between the ingredients in the concrete mix.

Table 5. Compressive, Splitting, and Flexural Strength for Light Weight Concrete

Group	Mix Symbol	SO_3%by Weight of Sand	Density kg/m^3	Compressive Strength MPa			Splitting Tensile Strength MPa			Flexural Strength MPa		
				28 days	60 days	90 days	28 days	60 days	90 days	28 days	60 days	90 days
4	MLW1	0.28%	1894	27.6	38.8	40.3	2.92	3.72	3.81	3.29	3.75	4.0
	MLW2	0.5%	1896	30.0	40.0	41.5	2.98	3.78	3.87	3.34	3.89	4.07
	MLW3	1.0%	1905	30.8	41.7	43.1	2.97	3.88	3.96	3.35	3.9	4.16
	MLW4	1.5%	1911	23.7	36.5	38.9	2.45	3.57	3.64	3.25	3.7	3.76
5	MLW5	0.28%	1913	28.9	39.0	42.4	2.95	3.73	3.82	3.31	3.82	4.05
	MLW6	0.5%	1815	32.0	41.0	44.5	2.98	3.78	3.87	3.34	3.92	4.1
	MLW7	1.0%	1921	33.3	42.4	45.0	3.00	3.8	3.90	3.35	3.93	4.16
	MLW8	1.5%	1926	33.5	43.6	46.1	3.01	3.84	3.94	3.39	3.96	4.18
6	MLW9	0.28%	1893	29.5	39.6	41.2	2.94	3.77	3.87	3.32	3.76	4.0
	MLW10	0.5%	1896	32.3	41.3	43.2	2.96	3.86	3.97	3.33	3.79	4.04
	MLW11	1.0%	1906	33.0	42.0	43.8	2.98	3.9	4.04	3.34	3.90	4.11
	MLW12	1.5%	1910	29.3	39.4	40.4	2.92	3.74	3.85	3.30	3.73	3.98

Figures 5, 6, and 7 show results of compressive, splitting and flexural strength at age 28, 60, and 90 days for light weight concrete with various percentages sulfate content in sand.

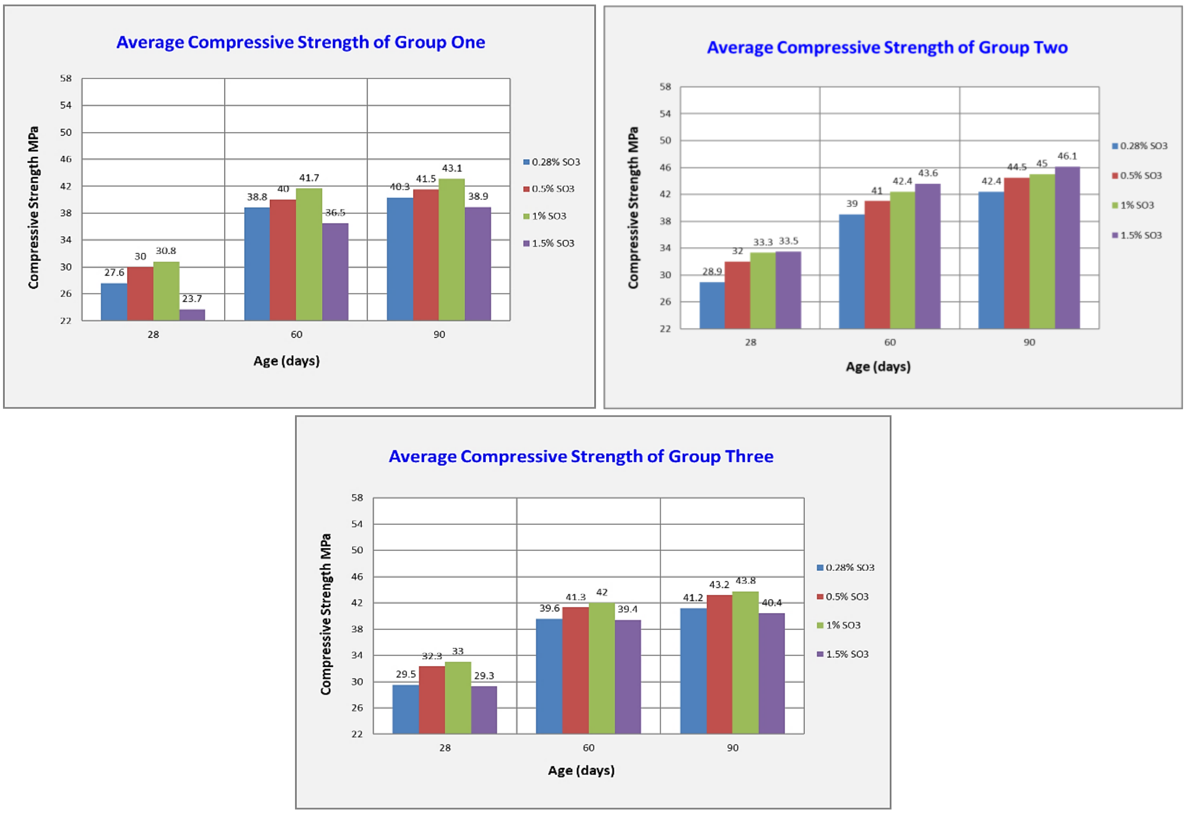

Figure 5. Compressive Strength Development for Light Weight Concrete

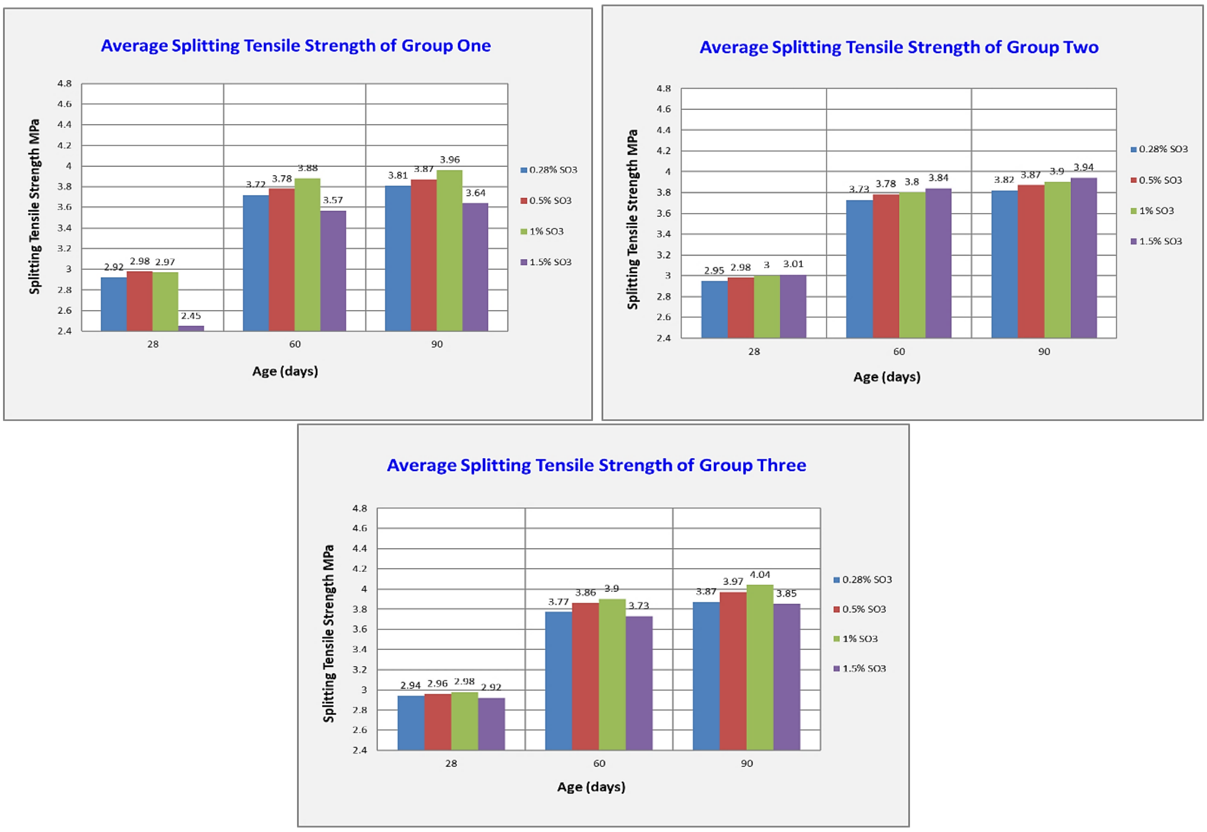

Figure 6. Splitting Tensile Strength Development for Light Weight Concrete

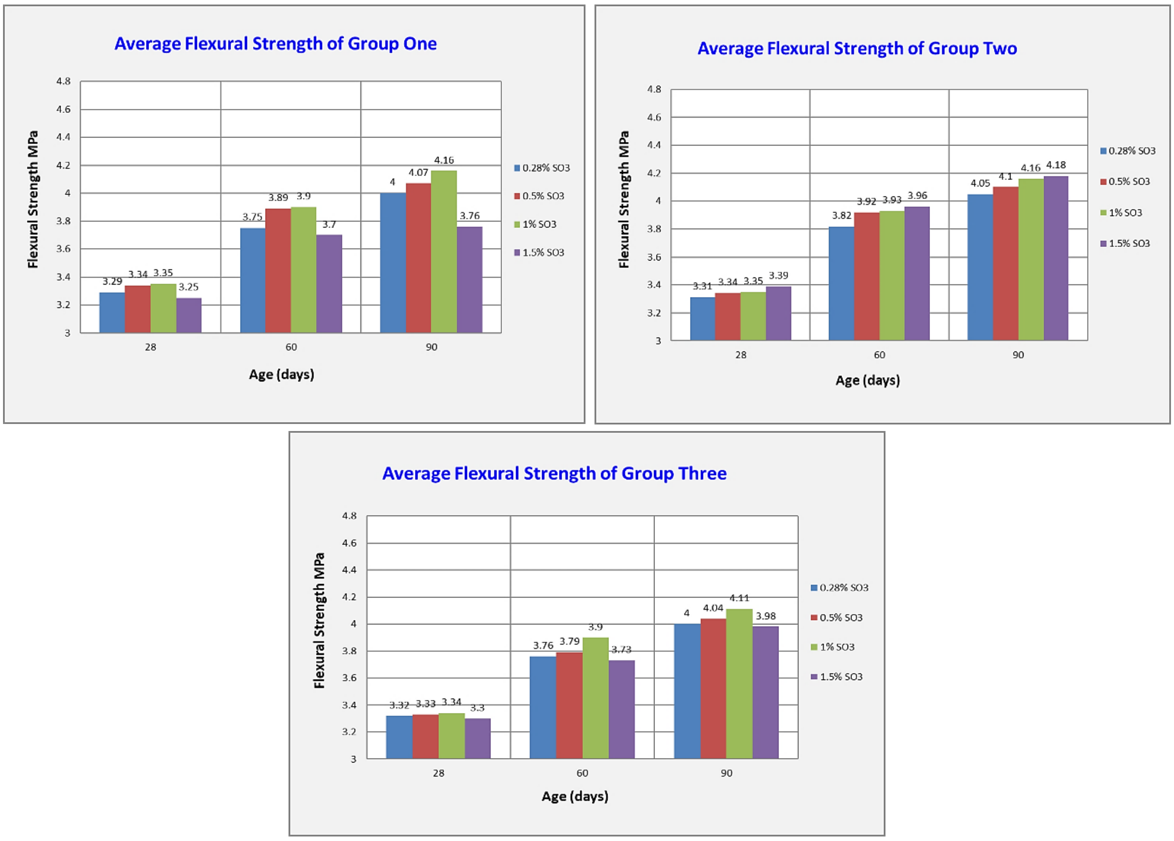

Figure 7. Flexural Strength Development for Light Weight Concrete

4.3. Comparison Between Normal and Light Weight Concrete

The results show that the mechanical properties increasing with replacing 15% silica fume at all mixes and at all ages for LWC and until 1% SO3 for NC. The enhancement of the strength of concrete with silica fume due to a decrease in the calcium hydroxide content that does not have any cementing property and thus reduce the formation of sulfate and the output of hydrated calcium silicate (CSH) which plays a vital role in concrete properties [9]. It was found that concrete with reference sand (0.28% SO3) gave compressive, flexural, and splitting tensile strength less than concrete with artificial sand until 0.5% SO_3 for NC and 1% SO_3 for LWC when concrete using OPC. Also, it was noted improve for all results when concrete using SRPC instead of OPC as shows in table 4 and 5.

In general, Results indicated that light weight concrete is more strength for internal sulfate than normal concrete.

5. Conclusions

Based on the experimental data, the following results can be stated within the scope of this study:

1. It was found that the optimal sulfate content for all mixture of normal concrete is around (0.5%) from weight of sand when concrete using OPC and (1.0%) by weight of sand when concrete using SRPC or OPC with replacing 15% silica fume.

2. It was concluded that The optimum gypsum content for all mixes of light weight concrete is about (1.0% by weight of fine aggregate) when concrete using OPC or SRPC and about (1.5% by weight of fine aggregate) when concrete using 15% silica fume as replacing of OPC.

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3. It was shown that results of compressive, splitting tensile, and flexure strength for NC and LWC increased with replacing 15% SF from weight of OPC at all mixes and at all ages compared to other types of cement.

4. It was found that the results that mixes with reference sand (0.28% SO3) gave compressive, flexural, and splitting tensile strength less than mixture with artificial sand until 0.5% SO3 for NC and 1% SO3 for LWC when concrete using OPC.

5. It was noted improve for all results when using concrete made from SRPC instead of OPC.

6. The effect of sulfates on the flexural, and splitting tensile strength have the same tendency of compressive strength.

6. References

[1] Jabir, J. A, Influence of Internal Sulphate Attack on Some of Properties for Concrete Containing Recycled Aggregate, Foundation of technical education, AL- Taqani, Vol. 25, No. 3, (2012) 69-87.

[2] Lei M., Peng L., Shi C., Wang S, Experimental Study on the Damage Mechanism of Tunnel Structure Suffering from Sulfate Attack, Tunnelling and Underground Space Technology, Civil Engineering, Central South University, China, 36, (2013) 5–13.

[3] Hassan, J.J, Effect of Sulphates in Fine Aggregate On Drying Shrinkage Cracking in End Restrained Concrete Members, M.Sc. Thesis, University of Babylon, College of Engineering, Civil Engineering (2005).

[4] Neville A, The confused world of sulfate attack on concrete, Cement and Concrete Research London, 34, (2004) 1275–1296.

[5] Chindaprasirt P., Kanchanda P., Sathonsaowaphak A., Cao H.T, Sulfate Resistance of Blended Cements Containing Fly Ash and Rice Husk Ash, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Australia, Construction and Building Materials, 21, (2007) 1356–1361.

[6] Jaturapitakkul C., Kiattikomol K., Tangchirapat W.t, Saeting T, Evaluation of The Sulfate Resistance of Concrete Containing Palm Oil Fuel Ash, Department of Civil Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Thailand, Construction and Building Materials, 21, (2007) 1399–1405.

[7] Abdul-Latif, A.M, Compatibility of Sulphate Content in Concrete Ingredients, M.Sc. Thesis, University of Baghdad, College of Engineering, (1997).

[8] Al-Rawi, R.S, and Abdul-Latif, A. M, Compatibility of Sulphate Contents in Concrete Ingredients, Fourth Scientific Conference, University of Baghdad, College of Engineering, (1998).

[9] Khudair J. A. and Faleh S. Kh, Sulphate Resistance of Concrete Containing Silica – Fume, Proceedings of the First Basrah International Civil Engineering Conference (BICCE-01), Iraq, (2013) 109-117.

[10] Abbas, Z. H, Effect of Sulfate in Sand on Some Mechanical Properties of Nano Metakaolin Normal Concrete, Civil Engineering, Al-Mustaqbal University College, Iraq, Journal of Babylon University, Engineering Sciences, No. 1, Vol. 24, (2016) 107-116.

[11] Iraqi Specification Standards IQS No.5, 1984, Portland Cement, Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ, (in Arabic).

[12] Iraqi Specification Standards IQS No.45, 1984, Aggregate from Natural Sources for Concrete and Construction, Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ, (in Arabic).

IOP Conf. Series: Materials Science and Engineering **888** (2020) 012054 doi:10.1088/1757-899X/888/1/012054

[13] ASTM C 330-05, Standard Specification for Lightweight Aggregates for Structural Concrete, Annual Book of ASTM Standards, Concrete and Aggregates, West Conshohocken, PA, United States, Vol. 04. 02, (2005).
[14] ASTM C 1240-05, Standard Specification for Silica Fume Used in Cementitious Mixtures, (2005) 1-7.
[15] ASTM C 494/C 494M-05, Standard Specification for Chemical Admixtures for Concrete, Annual Book of ASTM Standards, American Society for Testing and Materials, Vol. 04. 02, (2005).
[16] ACI Committee 211.1-98, Standard Practice for Selecting Proportions for Normal Heavyweight, and Mass Concrete, Manual of Concrete Practices, American Concrete Institute, (1998) 1-38.
[17] ACI 211.2-98, (Reapproved 2004), Standard Practice for Selecting Proportions for Structural Lightweight, ACI Manual of concrete practice, Part1, (1998) 1-17.
[18] BS 1881-Part 116, Method for Determination of Compressive Strength of Concrete Cubes, British Standards Institute BSI, London, (2000).
[19] ASTM C 496/C 496M-04, Standard Test Method for Splitting Tensile Strength of Cylinder Concrete Specimens, Annual Book of ASTM Standards, American Society for Testing and Materials, (2004).
[20] ASTM C 78-02, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), Annual Book of ASTM Standards, American Society for Testing and Materials, (2002).