Effect of External Sulfate Attack on Self Compacted Concrete

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Received on: 1/4/2012 & Accepted on: 8/11/2012

ABSTRACT

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The effect of external sulfate attack was studied-Es (very sever exposure SO_4>10000ppm) according to ACI 318-11.

The mix design method of SCC used is according to EFNARC 2002, and then must satisfy the criteria of filling ability, passing ability and segregation resistance. The experimental program focuses to study two different chemical composition of sulfate resistance Portland cement with different percentage of silica fume replacement by weight of cement and W/cm (0.3 and 0.35). The SCC mixes with cement type 1(C_3S= 46.39 and C_3S/C_2S = 1.78) shows more resistance to Es than mixes with cement type 2 (C_3S= 61.22 and C_3S/C_2S =4.44). The SCC mixes containing 10% SF as replacement of cement shows more resistance to external sulfate attack. The percentage of increase is 17.95% for SCC mixes with type 1 cement and W/cm =0.3 and 17.88% for SCC mixes with type 2 cement and W/cm =0.3 compared to reference concrete mixes.

Keywords: External sulfate attack (ES), self compacted concrete (SCC), silica fume.

تأثير مهاجمة الاملاح الخارجية على الخرسانة ذاتية الرص

الخلاصة

الخرسانة ذاتية الرص هي خرسانة غير تقليدية لا تحتاج الى عملية أهتزاز أو رص في التنفيذ. تكون لها القابلية على الانسياب تحت تأثير وزنها, ولها القابلية على ملئ القالب كاملاً حتى في

https://doi.org/10.30684/etj.31.6A6
2412-0758/University of Technology-Iraq, Baghdad, Iraq

وجود تسليح كثيف . تم دراسة تأثير مهاجمة الاملاح الخارجية القاسية (SO_4 < ١٠٠٠ppm)
وحسب متطلبات الجمعية الامريكية ٣١٨ لعام ٢٠١١ .

الخلطات الخرسانية مصممة حسب متطلبات EFNARC لعام ٢٠٠٢ والتي يجب ان تتوافق مع قابليتها على الملئ , الانسياب و مقاومتها للانعزال. البرنامج العملي يركز على دراسة تأثير التركيب الكيماوي للسمنت البورتلاندي المقاوم ,أضافة نسب من ابخرة السيلكا كأستبدال من وزن السمنت و بنسب وزن ماء الى سمنت ٠،٣ و ٠،٣٥.الخلطات الخرسانية ذاتية الرص الحاوية على النوع ١ من السمنت (C_3S=٤٦،٣٩ وC_3S/C_2S =١،٧٨) أظهرت مقاومة أعلى لمهاجمة الاملاح الخارجية من الخلطات الحاوية على النوع ٢ (C_3S=٦١،٢٢ و C_3S/C_2S=٤،٤٤).الخطات الخرسانية ذاتية الرص الحاوية على ١٠% من أبخرة السيليكا كانت أكثر مقاومة لمهاجمة الاملاح الخارجية و كانت نسبة الزيادة قد وصلت الى ١٧،٩٥ للنوع ١ من السمنت و ١٧،٨٨ للنوع ٢ من السمنت لنسبة ماء الى سمنت (٠،٣).

INTRODUCTION

Self compacted is a concrete which can be placed and compacted under its own weight with little or no vibration effort, while cohesive enough to be handled without segregation or bleeding at the same time. SCC was developed in Japan in the late 1980s to be mainly used for highly congested reinforced structures in seismic regions. The main advantages reported in using SCC are reduced the construction time and labor cost, eliminating the need for vibration, reduced noise pollution and a better construction ensuring good structural performance. Durability was the main concern and the purpose was to develop a concrete mix that would reduce or eliminate the effect of external sulfate attack.

Sulfates are found in the soil and in the underground water. Mainly sulfates of calcium, sodium, potassium and magnesium. Calcium sulfates attack only hydrated C_3A, forming calcium sulfoaluminate, known as ettringite $3CaO.Al_2O_3.3CaSO_4.31\text{-}32H_2O$), Magnesium sulfate attack calcium silicate hydrates [Neville, 2005] as will as $Ca(OH)_2$ and calcium aluminates hydrate. This reaction results in an increase of solid volume phase 227%, thus a gradual disintegration of concrete results [1].

LITERATURE REVIEW

Rehman (2008) [2] has studied the properties of SCC. Sixteen mixes are adopted to investigate the properties of SCC and conventional concrete (CC). Limestone powder was used in SCC and high performance superplasticizer (Glinume 51) as chemical admixture. Results indicate that the value of bulk density for both types of concrete SCC and CC exhibits an increase with the increase of compressive strength and time of curing for the same w/cm ratio. Moreover the results show that the compressive strength is slightly higher for SCC than CC.

Monterio and Kurts, (2003)[3], analyzing test results made by US the Bureau of Reclamation for the 1940s concrete exposed to sodium sulfate, concluded that cements containing high amounts of C_3S may lead to premature failure of concrete. They recommended that additional research be performed to assess specifically the influence of high C_3S content on sulfate resistance, particularly as C_3S content is known to be increased in modern cement manufacture. Zanqun et al, (2012) [4] study the effect of severe exposure condition on cement and cement + fly ash (25% dosage) pastes were immersed in 5%, 15% and 30% at 30 °C and 15% at 40 °C

Na_2SO_4 solutions. They concluded that the chemical sulfate attack occurring in the high concentration sulfate pore solutions of upper part of concrete in contact with air is likely the cause for the worse deterioration of the upper part, both in case of traditional and fly ash paste.

In order to improve the resistance of a concrete structure to the external sulfate attack, sulfate resisting cement is used in severe exposure. Pozzolana as reported in the ACI-318-2011[5] is blended with the cement type V for the very severe conditions, it will react with $Ca(OH)_2$ form C-S-H similar to the Portland cement. But at a slower rate, and it will thus decrease the free $Ca(OH)_2$ with time. When properly employed as an ingredient of Portland – Pozzolana cement or as an admixture to the Portland cement concrete, pozzolana can improve the performance of both fresh and hardened concrete [6]. The use of the blended cement made with a fly ash, a silica fume and a blast furnace slag is recommended [7]. Nabil [8] founds that metakaolin replacement of cement was found effective in improving the resistance of concrete to sulfate attack. The sulfate resistance of MK concrete increased with increasing the MK replacement level. Concrete containing 10% and 15% MK replacements showed excellent durability to sulfate attack.

Zhang et al (2003) [9] concluded from results of their experimental study confirmed that the autogenous shrinkage increased with the decreasing of W/C ratio and the silica fume was developed rapidly at an early age. Laboratory studies on paste, mortar or concrete specimens exposed to Na_2SO_4 and $MgSO_4$ solutions in a wide range of concentrations at different temperatures as well as mixtures with different compositions, cement compositions and limestone proportions are considered in a conceptual analysis as for the resistance to external sulfate attack and, especially, thaumasite sulfate attack. Regardless of limestone filler content, paste, mortar and concrete made with low-C_3A cements (<5%) and using a low effective w/c ratio (<0.50), which complies with the ACI 2011 recommendation for moderate sulfate environments, no early damage at low temperatures resulted **[10].** Salih and Salman (2011) [11] results show that SCC mixes containing silica fume required higher superplastizer content to 9% by weight of cement compared with 8% by weight of cement for mixes without pozzolanic materials to maintain the self compatibility of mixes. A significant improvement was observed in the mechanical properties of mixes including compressive and splitting tensile strength, Modulus of rupture, static modulus of elasticity, and impact resistance. The improvement percentages at 28 days were (6.74%, 5.37%, 4.5%, 3.2%, and 6.07%) respectively for SCC with silica fume mixes.

EXPERIMENTAL PROGRAM

Materials

Cement

Sulfate resistance Portland cements conforming to the **IQS 5/1984[12]** were used the Iraqi –Al Jasser (Type 1) and the Saudi Arabia –Al Shamalia (Type 2). The chemical analysis and physical properties is listed in Tables (1 and 2) respectively.

Table (1)Chemical composition of cement used.

Oxide Content %	Type 1	Type 2
SiO_2	21.25	20.8
Al_2O_3	3.10	3.78
Fe_2O_3	4.00	3.89
CaO	59.08	63.1
SO_3	2.11	2.30
MgO	2.02	3.30
L.O.I	3.10	2.45
I.R	1.74	1.56
L.S.F	0.86	0.85
Compound Composition (Bogue` s Equation)		
C_3S	46.39	61.22
C_2S	26.01	1
C_3A	1.45	3.44
C_4AF	12.16	11.82

- Chemical tests were conducted by Central Organization for Standardization and Quality Control, Ministry of Planning

Table (2) Physical properties of cements used.

Properties	Type 1	Type 2
Specific surface (Air permeability test),m^2/kg	360	350
Autoclave expansion,%	0.04	0.04
Setting time (vicate apparatus), a. Initial - hr:min b. Final - hr:min	 1:40 4:40	 2:25 4:30
Compressive strength MPa(N/mm^2): a. 3-days b. 7-days	 18.1 28.3	 16.5 25.6

- Physical tests are conducted by the Central Organization for Standardization and Quality Control, Ministry of Planning

Fine Aggregate

Fine aggregate from Al-Ukhaider region was used. The grading satisfy the Iraqi specification IQS 45/1984[13] and confirm to the zone two. The sieve analysis is shown in Table (3). The sulfate content and the physical properties of fine aggregate are shown in Table (4).

Table (3)Sieves analysis of fine aggregate.

Sieve size	% passing by weight	Limits of IQS 45/1984 (Zone 2)
10mm	100	100
4.75mm	95	90-100

2.36mm	85	75-100
1.18mm	72	55-90
600µm	48	35-59
300µm	25	8-30
150µm	5	0-10

Table (4)Physicals properties and sulfate content of fine aggregate used in experimental work.

Properties	results	IQS 45/1984
Fineness modulus	2.7	
Specific gravity	2.6	
Absorption ,%	1.5	
Moisture content,%	0.3	
Passing sieve size 75µm%	2.2	Max. 5% for natural fine aggregate
Sulfate content (SO_3), %	0.2	Max. 0.5%

-Tests are carried out in the Material Laboratory of the College of Engineering-Baghdad University

Coarse Aggregate

The maximum size of 10mm of natural coarse aggregate from Al-Niba`ee quarry (crushed) was used. The aggregate satisfies the Iraqi specification **IQS 45/1984[13]**. The sieve analysis for the crushed aggregate is shown in Table 5. The sulfate content and the physical properties are shown in Table 6.

Table (5) Sieves analysis of coarse aggregate with 10mm maximum size.

Sieve size	% passing by weight	Limits of IQS 45/1984
20mm	100	100
10mm	78	50-85
5mm	2	0-10

Table(6) Physical properties and sulfate content of coarse aggregate.

Properties	results	IQS 45/1984
Specific gravity (SSD)	2.67	--
Absorption ,%	0.8	--
Moisture content ,%	0.2	--
Material passing sieve size 75µm,%	0.9	Max. 3%
Sulfate content (SO_3),%	0.02	Max. 0.1%

- Tests are carried out in the Material Laboratory of the College of Engineering-Baghdad University

Mixing Water

Water is used for mixing and curing of the concrete, according to the IQS 1703/1992[14]. The PH equal to 7.4 and the TDS (total dissolve solids means the sum of all the minerals, metals, salts dissolved in the water) equal to 389ppm.

Silica Fume

The silica fume used in the study was Elkem micro silica fume from Egypt in powder form satisfying the ASTM C1240-03[15] and the accelerated pozzolanic strength activity index with Portland cement at 7-days was 115% (min 105% according to ASTM C1240-03[15]). The chemical analysis is given in Table 7. The specific gravity and the material retained on sieve number 45 micrometer were 2.45 and 4.5% respectively.

Chemical Admixture

A superplasticizer based on modified polycarboxylic ether Glinume 51 (G51) was used in this research as chemical admixture .G51 is free from chlorides and complies with **ASTM C494-05 [16]** Types A and F. The typical properties of Glinume 51 are shown in Table 8.

Table (7) Chemical analysis of silica fume*.

Oxides %	Content (%)	ASTM C 1240 -03
SiO_2	95.1	Min. 85%
Fe_2O_3	1.32	-
Al_2O_3	2.32	-
CaO	0.03	-
SO_3	< 0.07	-
L.O.I	0.7	Max. 6.0%
Moisture content	0.82	Max. 3.0%

*The chemical analysis done by Geological Survey and Mining

Table (8) Typical properties of Glinume 51(MBT 2004).

Form	Viscous liquid
Color	Light brown
Relative density	1.1at 20°C
pH	6.6
Viscosity	128+/-30cps at 20°C

Mix Proportion

The mix design method of SCC used in the study is according to EFNARC 2002[17**]** as presented in Table (9)**,** and then the proportions of materials are modified after obtaining a satisfactory self-compatibility by evaluating fresh concrete tests. Two w/cm ratios (0.30 and 0.35) are adjusted for each mix and the optimum dosage of Glinume 51 (1.5 liter per 100 kg of cement) is obtained from several trial mixes incorporating G51,by increasing the dosage of the admixture gradually ,and fixed the w/cm ratios (0.3 and 0.35) to ensure the self-compatibility.

Mixing and Curing of Concrete

The cement was passed through the sieve No.14 (1.18mm) and the lumps were removed. The mixing of ingredients is done by hand in a plastic pan for five minnts. Mixing of dry constituent cast iron cube moulds, with dimensions of 150x150x150mm are prepared, cleaned and oiled before starting mixing of concrete. The molds were covered with nylon bag and polyethylene sheets for nearly 24hr after casting, and then placed in the curing tank filled with water until the time of testing (7, 28, 90 and 180-day) –normal curing. The effect of a very severe external sulfate attack –ES (SO_4 in water > 10000 ppm) on the strength for the age (7, 28, 90 and 180 day) was investigated with the solution of pure (0.2%$CaSO_4.2H_2O$ and 2.3%$MgSO_4.7H_2O$).

Table (9) The mix proportions for self compacted concrete.

Mixes symbol	Silica fume (%)	W/Cm	Cement (kg/m^3)	Silica fume (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
Ref. (MR1)*,(MR3)**	0	0.3	500	0	550	650
MR1-5%SF*, MR3-5%SF **	5		475	25	550	650
MR1-10%SF*,MR3-10%SF**	10		450	50	550	650
Ref. (MR2)*, (MR4)**	0	0.35	500	0	550	650
MR2-5%SF*,MR4-5%SF**	5		475	25	550	650
MR2-10%SF*,MR4-10%SF**	10		450	50	550	650

* Cement Type 1
** Cement Type 2

Tests Performed

The following are the standard tests that were carried out on the fresh concrete, and hardened concrete.

Testing of Fresh Concrete

Slump Flow Test and T50cm Test

The slump flow test is used to assess the horizontal free flow of self-compacting concrete. It is the most commonly used test, and gives a good assessment of filling ability. It may give some indication of resistance to segregation. T50cm test is also the measure of the speed of flow and hence the viscosity of SCC **[17].**

V-Funnel test

The V-funnel test is used to assess the viscosity and filling ability of self-compacting concrete. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction **[17]**.

L-Box Test

This test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section **[17]**.

Testing of Hardened Concrete- Compressive Strength Test

The compressive strength test of concrete cubes of (150x150x150) mm was carried out in the present work according to the **BS 1881: Part 116: 1983[18]**, because it is the most suitable test for the compressive strength used in Iraq. The cubes of concrete were tested at the 7, 28, 90, 180-day, at each test age three cubes of concrete are taken from the curing tank and were placed in the testing machine.

The load at failure was recorded and calculates the average of compressive strength for the 3-cubes at each age test.

RESULTS AND DISCUSSION

Fresh Concrete

Fresh concrete tests results presented in Table (11). These results are within the acceptable criteria for SCC **[17]** and indicate also excellent deformability and filling ability without any segregation, bleeding and blocking as presented in the Figures (1) to (4).

Table (11) Fresh concrete test results (slump flow, T 50cm slump flow, V-funnel and L-box).

Mixes No.	Cement typ	W/Cm	Tests			
			Slump flow (mm)	T 50cm slump flow (sec)	V-funnel (sec)	L-box (h_2/h_1)
			650-800*	2-5*	6-12*	0.8-1.0*
MR1	Type 1	0.3	755	2.5	7.5	0.91
MR1-5%SF			720	4.1	8.5	0.82
MR1-10%SF			695	4.3	10	0.8
MR2		0.35	786	2.4	6.5	0.96
MR2-5%SF			762	3.9	8	0.84
MR2-10%SF			735	4.1	9.5	0.82
MR3	Type 2	0.3	760	2.7	7	0.92
MR3-5%SF			723	4.2	8.5	0.81
MR3-10%SF			700	4.5	10.5	0.8
MR4		0.35	784	2.4	6.5	0.95
MR4-5%SF			765	4	7.5	0.83
MR4-10%SF			738	4.2	9	0.82

*Permissible limits according to **EFNARK 2002** [17] guidelines.

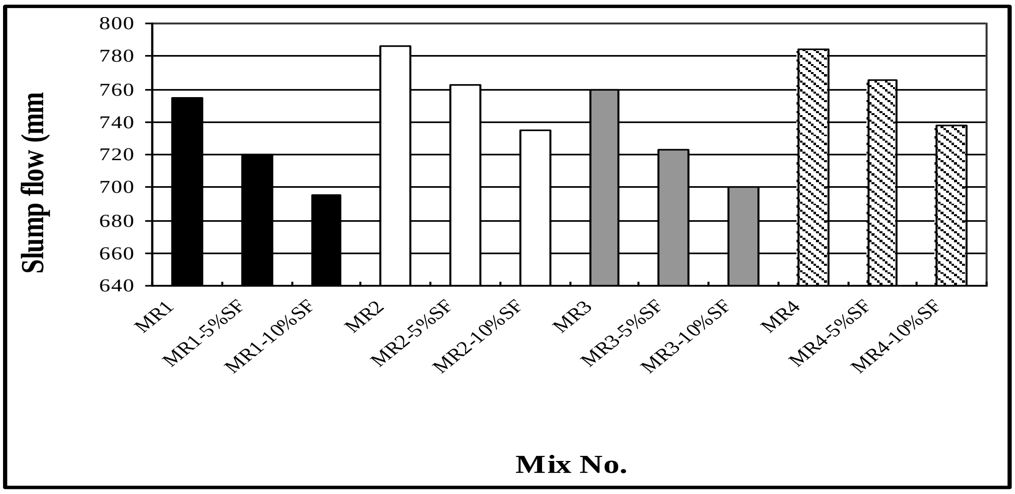

Figure (1) Slump flow for all mixes.

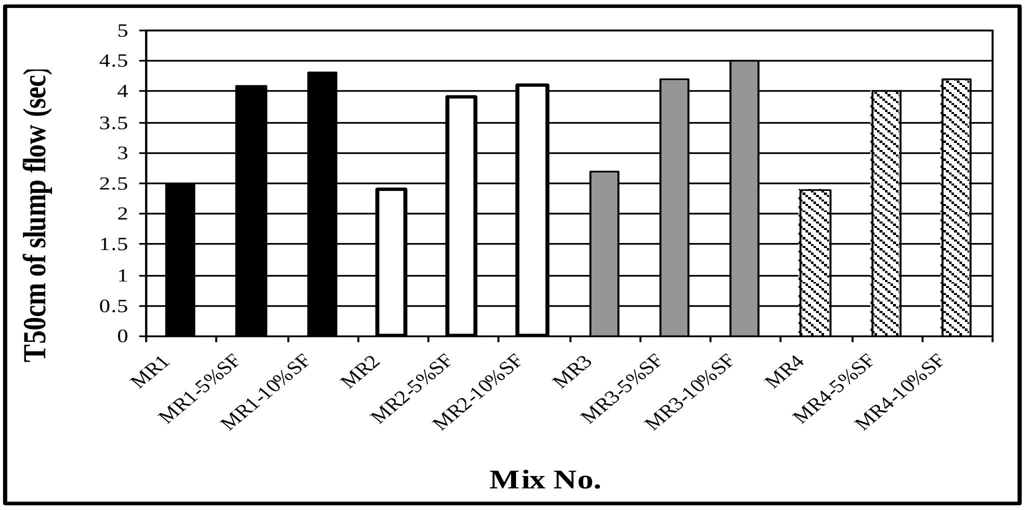

Figure (2) T50 cm of slump flow for all mixes.

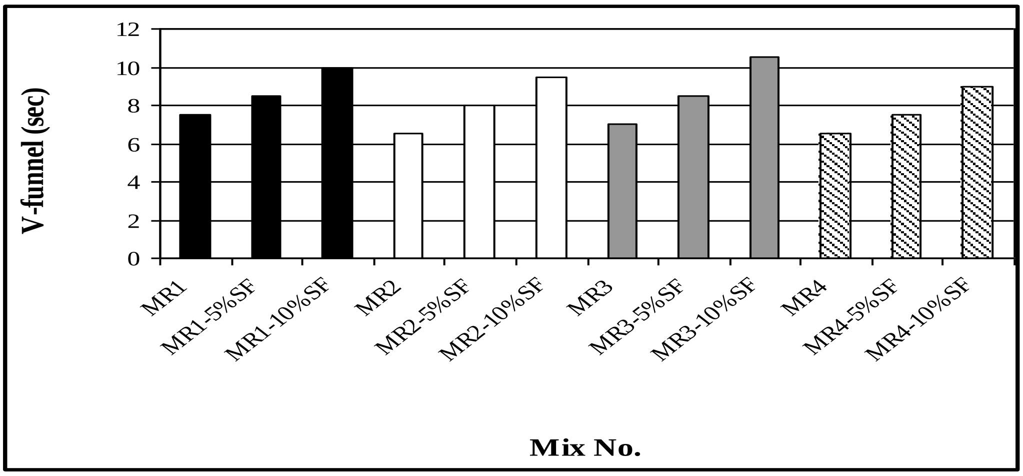

Figure (3) V-Funnel for all mixes.

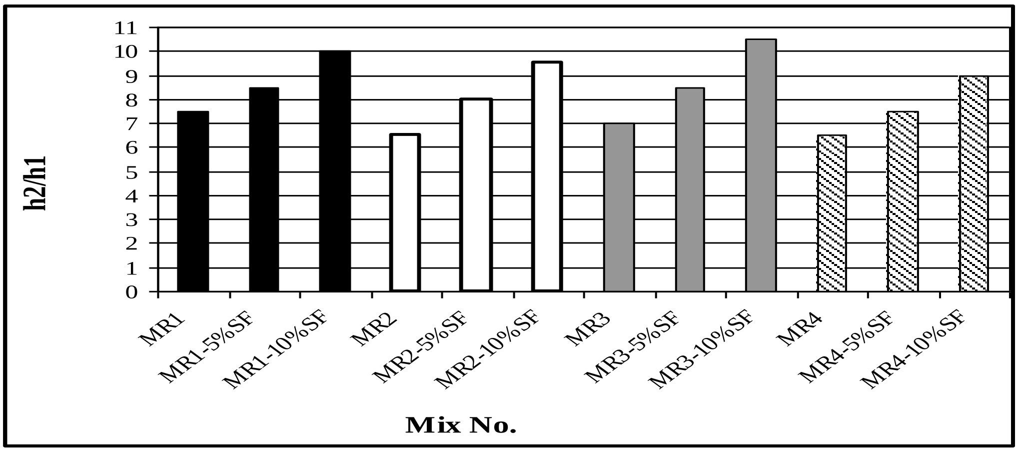

Figure (4) L – Box (h2/h1) for all mixes.

Hardened Concrete -Compressive Strength Test

The results of the compressive strength for reference mix, mixes containing 5 and 10% silica fume as a replacement of cement with 1.5% of the weight of cement superplasticizer for the both type of cement 1 and 2 are presented in Table (12).

Figures (5) to (8) shows the compressive strength before and after exposure to external sulfate attack (ES) for SCC mixes containing cement type 1 and 2 cements with w/cm (0.3 and 0.35) respectively. For normal curing the development gain of strength is for all the ages , although for the mixes immersed in sulfate solution there is a gain of strength till 90 days , and then a reduction of the compressive strength in 180-day for both concrete mixes containing cement type 1 and 2 with w/cm (0.3 and 0.35) respectively**.** The sulfate attack is generally attributed to the reaction of sulfate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The gypsum and ettringite formed as a result of a sulfate attack are significantly more voluminous (1.2–2.2 times) than the initial reactants. The formation of gypsum and ettringite leads to expansion, cracking, deterioration, and disruption of concrete structures [19]. In the long term, these reactions result in deterioration of concrete stability [20].

For concrete with type 1 and 2 cements the compressive strength increases with the increase of silica fume replacement by weight of cement from 5% and 10% for all ages compared to reference mixes for both the normal curing and the external sulfate attack as presented in Table (13) and the increase is more clear at later ages . This is due to high pozzolanic activity of SF [6]. The pozzolanic reaction take place between the silica (SiO_2) from SF and calcium hydroxide CH formed during the hydration process. This leads to form the cementations compound leads to densification of the concrete matrix resulting in a considerable increase in strength, and reduction in permeability. Besides, the pore-size and grain-size refinement processes associated with pozzolanic reaction can effectively reduce the microcraking and strengthen the transition zone [21] [22][23].

The increment gain in compressive strength for normal cured strength and compressive strength for the immersed mixes in sulfate solution at 90-days and 180-days compared to 28-day are presented in Table (14). The table shows that the SRPC type 1 (C_3S= 46.39 and C_3S/C_2S = 1.78) is more resistance than type 2 (C_3S= 61.22 and C_3S/C_2S =4.44) , this is may be due to the increase of the CH released during the silicate hydration then, the CH reacts with sulfate ions to form gypsum. The gypsum formation creates the required environment conditions to form an expansive ettringite derives from the aluminate or ferroaluminate hydrates. According to Mehta et al (2006)[21], the ettringite formation is expansive when the gypsum and CH dominate the paste environment. In the ordinary Portland cements, a secondary ettringite depends principally on the C_3A content of the cement. But, it also depends on the amount of CH produced during the early stage of hydration, which is closely related to the C_3S content of cement and that is agree with Rasheeduzzafar et al, (1990)[24] and Irassar et al (2000)[25] for normal concrete.

Table (12) Compressive strength results for all mixes and different ages for normal condition and external sulfate attack.

Mixes No.	Cement ype (Sr.)	W/C	Compressive strength (MPa)					
			7-day	28 day	90-day		180-day	
					Normal	ES	Normal	ES
MR1	Type 1 (1.78)	0.3	33.7	45.9	54.5	48.8	58.2	46.8
MR1-5%SF			35.8	49.7	63.5	57.7	65.8	53.1
MR1-10%SF			36.9	51	67.8	59.5	70.1	55.2
MR2		0.35	32.8	41.5	50.6	44.8	53.8	42.8
MR2-5%SF			33.7	45.1	57.2	50.6	61.2	47.2
MR2-10%SF			34.5	45.9	62.4	56.1	65.8	50.1
MR3	Type 2 (4.44)	0.3	36.6	47.2	56.3	51	60.9	47.1
MR3-5%SF			37.9	50.8	64.9	57.6		53.8
MR3-10%SF			39.2	53.5	68.8	61.2		57.2
MR4		0.35	34.3	42.9	52.5	46.2	68.6	42.5
MR4-5%SF			35.9	46.8	58.2	51.8	72.7	46.9
MR4-10%SF			37.2	48.6	64	55.2	67.2	50.1

Table (13) Development of compressive strength relative to reference mixes for all ages.

Mixes No.	W/C	Percentage of increment relative to reference mixes					
		7-day	28-day	90-day		180-day	
				Normal	ES	Normal	ES
MR1-5%SF	0.3	6.23	8.28	16.51	18.23	13.06	13.46
MR1-10%SF	0.3	9.49	11.11	24.4	21.9	22.16	17.95
MR2-5%SF	0.35	4.16	8.67	13.04	12.95	13.75	10.28

MR2-10%SF	0.35	5.2	10.6	23.3	25.22	22.3	17.06
MR3-5%SF	0.3	3.55	7.6	15.27	12.94	12.64	16.3
MR3-10%SF	0.3	7.1	13.3	22.2	20.0	19.37	21.44
MR4-5%SF	0.35	4.66	9.32	10.85	12.12	15.97	10.82
MR4-10%SF	0.35	8.45	13.28	21.9	19.48	20.6	17.88

Table (14) Development of compressive strength for 90 and 180 days compared to 28-day for normal strength and external sulfate attack.

Mixes No.	Cement Type	90-day		180-day	
		Normal	ES	Normal	ES
MR1	Type 1	18.74	6.3	26.79	1.96
MR1-5%SF		27.76	16.1	32.39	6.8
MR1-10%SF		32.94	16.67	37.45	8.2
MR2		21.6	7.9	29.64	3.13
MR2-5%SF		26.83	12.19	35.69	4.66
MR2-10%SF		35.95	22.22	43.35	9.15

Continued Table (14).

Mixes No.	Cement Type	90-day		180-day	
		Normal	ES	Normal	ES
MR3	Type 2	19.28	8.05	29.03	-0.1
MR3-5%SF		27.76	13.38	35.04	5.91
MR3-10%SF		28.6	14.39	35.88	6.9
MR4		22.38	7.69	29.84	-0.9
MR4-5%SF		24.36	10.68	35.89	2.13
MR4-10%SF		31.68	13.58	38.27	3.08

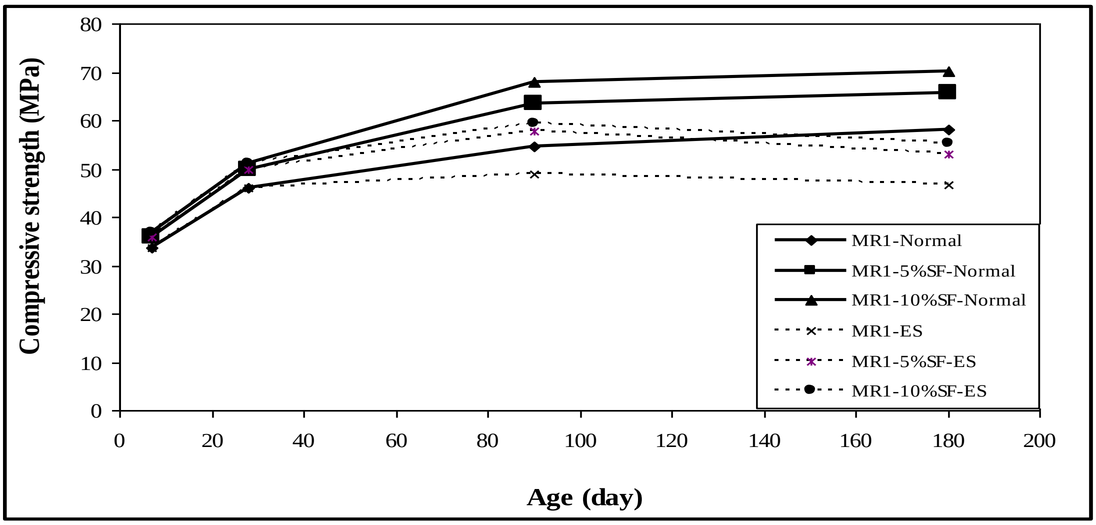

Figure (5) Compressive strength with ages for concrete mixes before and after exposure (Es) for cement type and W/Cm =0.3.

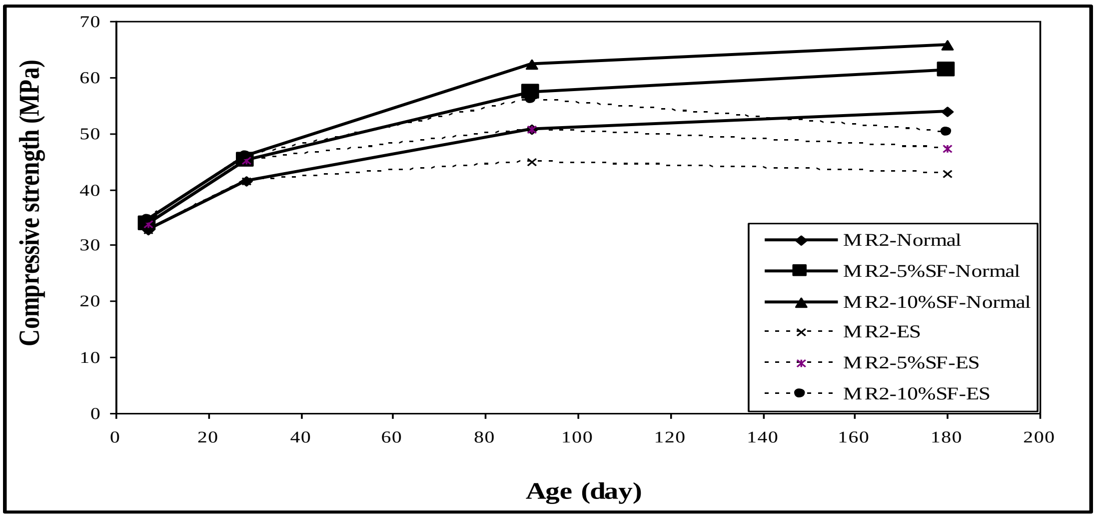

Figure (6) Compressive strength with ages for concrete mixes before and after exposure (Es) for cement type 1and W/Cm =0.35.

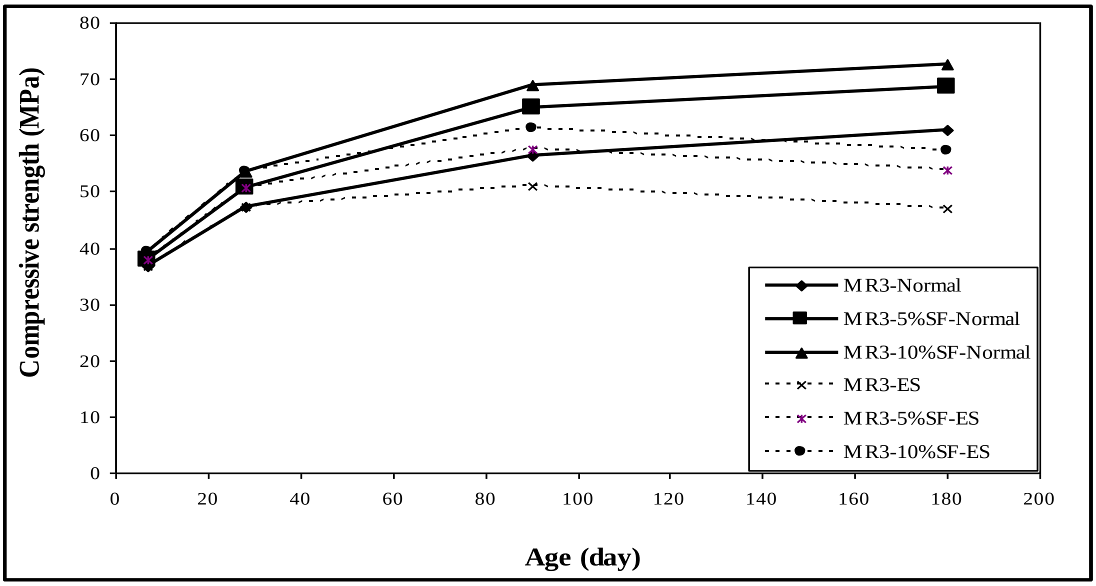

Figure (7) Compressive strength with ages for concrete mixes before and after exposure (Es) for cement type 2and W/Cm =0.3.

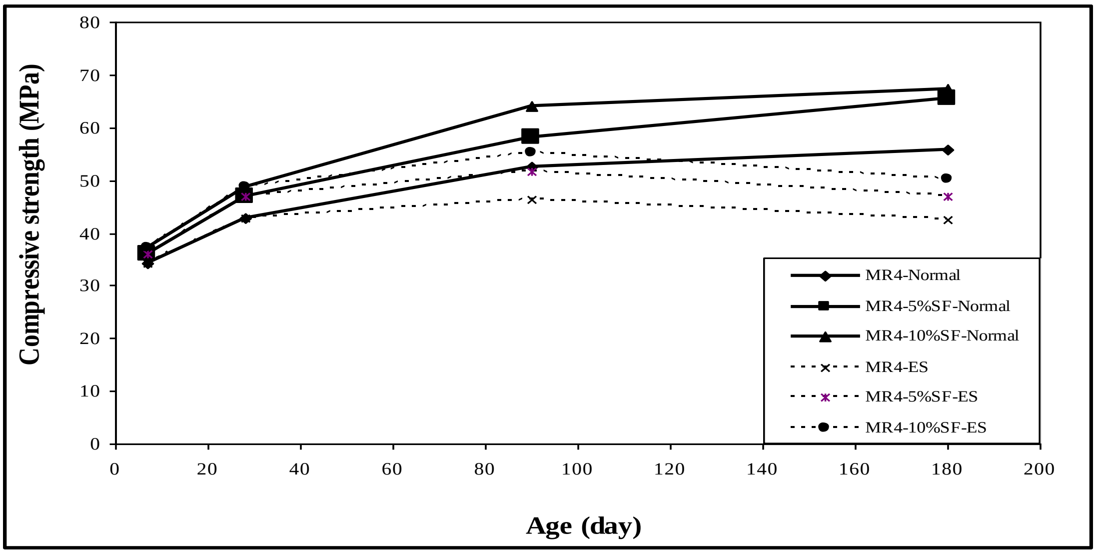

Figure (8) Compressive strength with ages for concrete mixes before and after exposure (Es) for cement type 2 and W/Cm =0.35.

CONCLUSIONS

1 The SCC mixes with high performance superplasticizer (Glinume 51) and highly active pozzolanic materials SF (5 and 10%) shows good workability requirements of slump flow ranges between (695- 760) mm and (735-786) and T50 cm values range between (2.5-4.5) sec and (2.4-4.2) sec. The time of the concrete to pass through the V–funnel time range between (7.0-10.5) sec and 6.5-9.5 sec for w/cm

ratio 0.3 and 0.35 respectively and L-box results ranges (0.80-0.91) and (0.82-0.96).

2. The development gain of strength for SCC is for all the ages at normal curing condition, although for the mixes immersed in sulfate solution there is a gain of strength till 90 days, and then a reduction of the compressive strength in 180-day for both concrete mixes containing cement type 1 and 2 with w/cm (0.3 and 0.35) respectively.

3. Self compacted concrete mixes with type 1 and 2 cements, the compressive strength increases with the increase of silica fume replacement by weight of cement from 5% and 10% for all ages compared to reference mixes for both the normal curing and the external sulfate attack.

4. The SCC mixes containing 10% SF as replacement of cement shows more resistance to external sulfate attack. The percentage of increase is 17.95% for SCC mixes with type 1 cement and W/cm =0.3 and 17.88% for SCC mixes with type 2 cement and W/cm =0.3 compared to reference concrete mixes.

5. Self compacted concrete mixes with cement type 1(C_3S= 46.39 and C_3S/C_2S = 1.78) shows more resistance to Es than mixes with cement type 2 (C_3S= 61.22 and C_3S/C_2S =4.44).

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