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Effect of External and Internal Sulphate on Compressive Strength of Concrete

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Abstract

In this paper, the influence of external and internal effect of sulphate on normal and high performance concrete was studied. The aim of this experimental study is to evaluate the effect of external severe sulphate solution on compressive strength of concrete mixes containing two different internal sulphate. The experimental work included of casting and testing of 360 concrete cubes, half of them fully immersed in ground water solution with sulphate SO_4 =6965 ppm. The other half of cubes was immersed in tap water to be references. Sulphate resistance cement and ordinary Portland cement with 10% silica – fume used in mixes. Two types of locally available sand were used (standard SO_3= 0.2% and non-standard SO_3= 1.13%). The results showed that the compressive strength development continuously increases in specimens immersed in tap water and the development rate decreases when the w/c ratio decreases. The harmful effect of internal sulphate in concrete was decreased by using type I cement with 10% silica –fume replacement and low w/c ratio. The effect of internal sulphate was clearly appeared at early ages till 90 days when using non-standard sand in mixture with low w/c ratio 0.31. Using of silica fume concrete with w/c ratio of 0.45 is more effective to enhance the concrete resistance to external sulphate attack.

Keyword: Compressive Strength Loss, Sulphate exposure, Silica Fume Concrete, Internal Sulphate, Durability

INTRODUCTION

Excessive amount of sulphates in soil or water can attack and destroy a concrete that is not properly designed. Sulphates (calcium sulphate, sodium sulphate and magnesium sulphate) can attack concrete by reacting with hydrated compounds in the hardened cement paste. These reactions can induce sufficient pressure to disrupt the cement paste, resulting in disintegration of the concrete (loss of paste cohesion and strength) [1]. Sulphate attack can manifest in the form of expansion and cracking of concrete. When concrete cracks have been occur, its permeability increases and the aggressive water penetrates more easily into the interior, thus accelerating the process of deterioration. Sometimes the expansion of concrete may cause serious structural problems, such as the displacement of building walls due to horizontal thrust by an expanding slab. Sulphate attack can also take the form of a progressive decrease in the strength and loss of mass due to loss of cohesiveness of the cement hydration products [2].

Porous concrete is susceptible to weathering caused by salt crystallization, these salts may or may not contain sulphate and they may or may not react with the hydrated compounds in concrete. The greatest damage occurs with drying of saturated solutions of these salts, often in an environment with specific cyclic changes in relative humidity and temperature that later mineralogical phases. In permeable concrete exposed to drying conditions, salts solutions can rise to the surface by capillary action and subsequently – as results the solution phase becomes supersaturated and salt crystallization occurs, sometimes generating pressures large enough to cause cracking. If the rate of migration of the salt solution through the pores is lower than the rate of evaporation, a drying zone forms beneath the surface and salt crystallization occurs in the pores causing expansion and scaling [1].

Many experimental studies have been carried out to explain the sulphate attack and the role of silica fume (Micro Silica) in resisting concrete deteriorations. All these investigations emphasize that in order to understand the deterioration of concrete due to sulphate attack, it is necessary consider the type of the accompanying cation as well as the degree of concentration of the sulphate solution [3].

Troxell, et al reported the effect of sulphate water on concrete. Sulphate present in alkali soils and waters are known to cause deterioration of many concrete structures. The effect of such salts is more severe in structures in dry seasons. This is mainly due to the increase in the concentration of salts. The stronger concentrations cause more rapid disintegration [4].

Khudair J. A. and Faleh S. Kh. Investigated the durability of silica fume concrete of different concrete mixtures exposed to sulphate attack. This experimental study was conducted on concrete cubes with and without silica fume with replacement ratio of silica fumes (5 and 10%) by weight of cement. The test solutions used to supply the sulphate ions and cations were 5% sodium sulphate solution, 5% magnesium sulphate solution and 10260ppm sulphate of ground water. Tap water was used as the reference solution. The test results showed that the silica fume concrete (10%) silica fume replacement exhibit good durability with respect to sodium sulphate and ground water solutions, on the other hand it exhibit bad resisting in magnesium sulphate solution exposure. While silica fume concrete (5%) silica fume replacement showed good sulphate resisting in all test solutions [5]

Touma H.N. studied the effect of internal sulphate (SO_4^{-2}) which is present in the concrete raw materials. Natural calcium sulphate hydrate (Gypsum ($CaSO_4 .2 H_2O$)) was used as a source of internal sulphate (SO_4^{-2}). Results have shown that the compressive strength of concrete at 28 days after curing decreases by 50.9%, 65.5% and 66.73% when added calcium sulphate was 3%, 5% and 7% by weight of sand to concrete mixes, respectively. Also, results had shown that when increasing the percentage of cement content by 3%, 9% and 11% in concrete mixes, which contain calcium sulphates in 3%, 5% and 7% by weight of sand [6].

The aim of this paper is to study the effect of external and internal sulphate on the strength of normal and high performance concrete made with silica fume. The experimental study was developed to evaluate the effect of high concentration sulphate solution as an external exposure on compressive strength of different concrete mixes along 360 days of severe exposure duration. Furthermore, the influence of medium concentration sulphate in local sand was investigated.

EXPERIMENTAL PROGRAM

The experimental program consists of casting and testing of 360 cubes. 100 x100 x 100mm cubes according to BS1881 116-83[7] were prepared and casted in the Construction Materials Laboratory of the College of Engineering, University of Basrah**.** Half of these cubes were fully immersed in severe sulphate ground water. The other half of cubes was immersed in tap water.

Materials

All materials used in this work are locally available.

Cement

Two types of cement were used, Ordinary Portland cement (OPC), and sulphate resisting cement (SRC) produced by Tasloga Factory, North of Iraq. It is stored in airtight plastic bags to avoid exposure to different atmospheric conditions. Test results indicated that the adopted cement conformed to the ASTM C150-04[8]. The chemical composition and physical properties of cement used in this study are shown in Table 1 and Table 2.

Table 1: Chemical composition of the Cement

Compound composition (Oxides)	Chemical composition	Type I Content (%)	Type V Content (%)	Type I Limits of ASTM C150-04[8]	Type V Limits of ASTM C150-04[8]
Calcium oxide	CaO	54.37	50.31	-	-
Iron oxide	Fe_2O_3	3.44	3.86	-	-
Aluminum oxide	Al_2O_3	5.88	3.646	-	-
Silicon dioxide	SiO_2	16.68	16.96	-	-
Magnesium oxide	MgO	1.92	1.59	6*	6*
Sulphur trioxide	SO_3	2.29	2.18	3*	2.3*
Lime saturation factor	L.S.F	1.00	0.92	-	-
Loss on ignition	L.O.I	8.179	3.9	3.0*	3.0*
Insoluble residue	I.R	1.47	1.35	0.75*	0.75*
Tricalicum silicate	C_3S	43.3	39.6	-	-
Dicalicum silicate	C_2S	20.7	29.4	-	-
Tricalicium Aluminates	C_3A	9.8	3.1	-	5*
Tetracalicum aluminates ferrite	C_4AF	10.5	11.7	-	-
Tetracalcium Aluminoferrite Plus twice the Tricalcium Aluminate	(C_4AF+2(C_3A))	-	17.9	-	25*

Table 2: Physical properties of cement

Physical properties	Type I Cement Test	Type V Cement Test	Type I ASTM C150-04 Limit [8]	Type V ASTM C150-04 Limit [8]
Fineness using Blain air permeability apparatus (m^2/kg)	300	310	280**	280**
Setting time using Vicat's instrument Initial (min.) Final (min.)	190 285	180 270	45** 375*	45** 375*
Compressive strength at: 3days (MPa) 7days (MPa) 28days (MPa)	18.0 24.1 --	20.3 23.6 26.0	12** 19** 5** 23**	8** 15** 21**
7 days(Mpa)				5** 23**

* Maximum limit. ** Minimum limit

Fine Aggregate

Natural sand from (Sanam Hill) and (Zubair – Alajooza borrow pit) regions, south of Iraq were used for concrete mixes. The fine aggregate was 4.75mm maximum size with rounded-shape particles with smooth texture, and yellowish-brown in colour. The grading of the two types of fine aggregates is shown in Table (3). The obtained results indicated that the fine aggregates grading were within the limits of ASTM C33-03[9]. Table (4) shows the specific gravity, sulphate content and absorption of the two types of fine aggregates.

Table 3: Grading of (Sanam Hill and Zaubair-Alajooza) Fine Aggregate

No.	Sieve size	Passing (%)		
		C33-03[11]		
		Test results Sanam Hill	Test results Zubair- Alajooza Borrow Pit	ASTM C33-03[9] Limit
1	9.50 mm	100	100	100
2	4.75 mm	98	99	95-100
3	2.36 mm	93	93	80-100
4	1.18 mm	79	78	50-85
5	600 μm	57	55	25-60
6	300 μm	15	23	5-30
7	150 μm	1	3	0-10
8	pan	-	0	-

Table 4: Physical and Chemical Properties of (Sanam Hill and Zaubair-Alajooza) Fine Aggregate

Properties	Sanam Hill Sand	Zubair-Alajooza Borrow Pit Sand	Iraqi specification No. 45/1984[10] Limit
Specific gravity	2.61	2.6	-
Sulphate content (SO_3) %	0.2	1.13	≤ 0.5
Chloride content (Cl) %	0.01	0.02	≤ 0.1
Absorption %	1.50	1.52	-

Coarse Aggregate

Crushed gravel from (Sanam Hill) south of Iraq region with maximum size of 19 mm was used in mixes. The coarse aggregate was washed before using. The grading of the coarse aggregate is shown in Table (5). The results indicate that, the coarse aggregate grading is within the limits of ASTM C33-03[9]. Specific gravity, sulphate content and absorption of the coarse aggregate are illustrated in Table (6).

Table 5: Grading of (Sanam Hill) Coarse Aggregate

No.	Sieve size	Passing (%)	
		Coarse Aggregate	ASTM C33-03[9]
1	25 mm	100	100
2	19 mm	95	90-100
3	9.5 mm	31	20-55
4	4.75mm	1	0-10
5	2.36 mm	0	0-5
6	pan	-	-

Table 6: Properties of (Sanam Hill) Coarse Aggregate

Physical properties	Test results	Iraqi specification No. 45/1984[10] Limit
Specific gravity	2.63	-
Sulphate content (SO_3) %	0.062	≤ 0.1
Chloride content (Cl) %	0.087	≤ 0.1
Absorption %	0.85	-

Silica Fume

The condensed silica fume used in this study is SikaFume®-HR [11], which is a concrete additive of a new generation in Gray powder form ready to use, Silica fume is a highly active pozzolanic material and is a by-product from the manufacture of Silicon or Ferro-silicon metal. It is collected from the flue gases from electric arc furnaces. Silica fume is an extremely fine powder, with particles about 100 times smaller than an average cement grain. It is generally used at 5 to 12% by mass of cementitious materials as a partial replacement for concrete structure that need high strength or significantly reduced permeability to water [12]. The silica fume used in this work conforms to the chemical and physical requirements of ASTM C1240-03[13] as shown in Tables (7) and Table (8).

Table 7: Chemical Properties of SikaFume®-HR*

Oxide composition	SikaFume®-HR Test results	ASTM C 1240[13] Limits
SiO_2 (%)	94.0	≥ 85.0
Moisture content (%)	1.0	≤ 3.0
Loss on ignition	3.0	≤ 6.0

* According to the manufacturer editors

Table 8: Physical Properties of SikaFume®-HR

Oxide composition	SikaFume®-HR Test results	ASTM C 1240[13] Limits
Percent retained on 45-µm (No.325) sieve	8	≤ 10
Accelerated pozzolanic Strength Activity Index with Portland cement at 7 days	113	≥ 105
Specific surface (m^2/g)	22	≥ 15
Percent retained on 45-µm (No.325) sieve	6	≤ 10

Water

Tap water was used for mixing and curing of all concrete specimens.

Superplasticizer

For the production of high strength concrete, superplasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. One of a new generation of copolymer-based superplasticizer is the Glenium 51. It complies with ASTM C494, type A and type F [14]. The typical properties of Glenium 51 are shown in Table (9).

Table 9: Technical properties of Glenium 51*

Structure of the Material	Polycarboxylic ether based
Density (kg/liter)	1.082 - 1.142
Chloride content. Max %	0.1
Alkaline Content. Max %	3
Colour	Amber

* According to the manufacturer editors

CONCRETE MIXES

To study the external and internal effect of sulphate attack, three types of concrete mixes designed by weight were prepared to obtain three types of compressive strength 30, 40 and 60 MPa. Half of these mixes, Ordinary Portland cement with silica-fume used and the other half, Sulphate resisting Portland cement used. Two types of sand were used in mixing, pass in chemical (standard sand) properties and fail in chemical properties (non-standard sand). The details of concrete mixtures are shown in Tables (10). Slump was kept between (120 - 140) mm for all mixtures.

Table 10: Details of Concrete Mixtures

Mixture number	Symbol	Cementitious materials	Type of sand	w/cm
Mix Proportion 1:2.1:3.2				
1	1VS30	Type V	Standard	0.55
2	2VN30	Type V	Non-standard	0.55
3	3IS30	90%Type I + 10%SF	Standard	0.55
4	4IN30	90%Type I + 10%SF	Non-Standard	0.55
Mix Proportion 1 : 1.78 : 2.78				
5	5VS40	Type V	Standard	0.45
6	6VN40	Type V	Non-standard	0.45
7	7IS40	90%Type I + 10%SF	Standard	0.45
8	8IN40	90%Type I + 10%SF	Non-standard	0.45
Mix Proportion 1 : 1.31 : 2.3				
9	9VS60	Type V	Standard	0.31
10	10VN60	Type V	Non-standard	0.31
11	11IS60	90%Type I + 10%SF	Standard	0.31
12	12IN60	90%Type I + 10%SF	Non-standard	0.31

CURING

The moulds of concrete specimens were covered with damp canvas cloth and nylon sheets to prevent evaporation of water from fresh concrete. The cubes left in the laboratory for about 24 hours then demoulded carefully and stored in tap water concrete tank in wetted room along 7 days after casting. After that, half of the specimens were moved to the plastic cylindrical tanks with water tight cover of capacity 60 litter containing severe sulphate ground water. The second half of the specimens was stilled in tap water tank to be used as reference specimens.

SULPHATE SOLUTION

Ground water was used as test solution to supply the sulphate ions and cations. Ground water had been supplied from Garmat Ali region. Chemical properties of solution illustrated in Table (11). Tap water was used as the reference solution. Half of the total number of specimens was immersed in the test severe sulphate solution, the other half were immersed in tap water. Compressive strength was used to assess the changes in the mechanical properties of concrete specimens exposed to sulphate attack along 360 days duration.

Table 11: Chemical Properties of Ground Water (Sulphate Solution)

Properties	Test Result
TDS (ppm)	10120
SO_4^{-2} (ppm)	6965
CL^{-1} (ppm)	4075

TEST PROCEDURE

A (100 x 100 x 100) mm concrete cubes according to BS1881 116-83[7] were used. The cubes were casted, compacted, and cured for seven days, and then immersed in the test solutions for 360 days, the average compressive strength of three cubes was determined at 28, 90, 180, 270, and 360 day by using hydraulic machine type of 2000kN capacity. Two types of cement were used; sulphate resistance cement and ordinary Portland cement with 10% silica fume as a replacement of cement weight. Standard and non-standard sand were used as a fine aggregate. Ground water of severe sulphate was used to study the external sulphate effect on specimens. Tap water was used as the reference solution. Also, internal sulphate effect was studied by using sand having different sulphate content. Twelve water tight plastic cylindrical tanks of capacity (60) litter were used to store the cube specimens in solutions. The specimens and tanks were marked and stored at 25$\pm$ 5°C room. The deterioration of the concrete cube specimens was investigated by thorough visual examination of damage and by determining the compressive strength loss (CSL), which was calculated as follows:

$$CSL\ (\%) = \left[\frac{(A-B)}{A}\right] x100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:-

A: average compressive strength of cubes cured in tap water (MPa).

B: average compressive strength of cubes cured in test solutions (MPa).

RESULTS AND DISCUSSION

Visual Examination

It is carried out to evaluate the visible signs of continuously fully immersed concrete deterioration in ground water sulphate solution. Concrete attacked by sulphate has a characteristic whitish appearance on the surfaces of cubes of concrete specimens. The damage of concrete specimens through the test period was negligible. At 360 days, the specimens showed significant white salts accumulation on faces of specimens as shown in Plate (1). It is clear that the specimens with w/c ratio 0.55 reveal a significant deterioration of surface white salt deposition as compared with specimens of w/c ratio 0.45 and 0.31. This is attributed to the high absorption of specimens with high percentage of w/c ratio.

Compressive Strength

As mentioned earlier, the compressive strength of all concrete test specimens were determined from 100 mm cubes. Table (12) summarizes the results for mix proportion (1:2.1:3.2) of a w/c ratio 0.55 at the ages of 28, 90, 180, 270 and 360 days and fully immersion in tap water and sulphate ground water solution. Referring to Fig. (1), the development of compressive strength of all concrete specimens in tap water was continuing till age 360 days. The specimens 1VS30 and 3IS30 showed 14% strength increase after 360 days as compared with strength results of 90 days. While 33% and 31% strength increases in 2VN30 and 4IN30 after 360 days compared to its 90 days strength respectively. The specimens made with non-standard sand with high internal sulphate exhibit higher strength development than specimens made with standard sand, This behaviour may be attributed to the reaction of internal sulphate of sand with C_3A compound of cement, this reaction produce 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 [15].

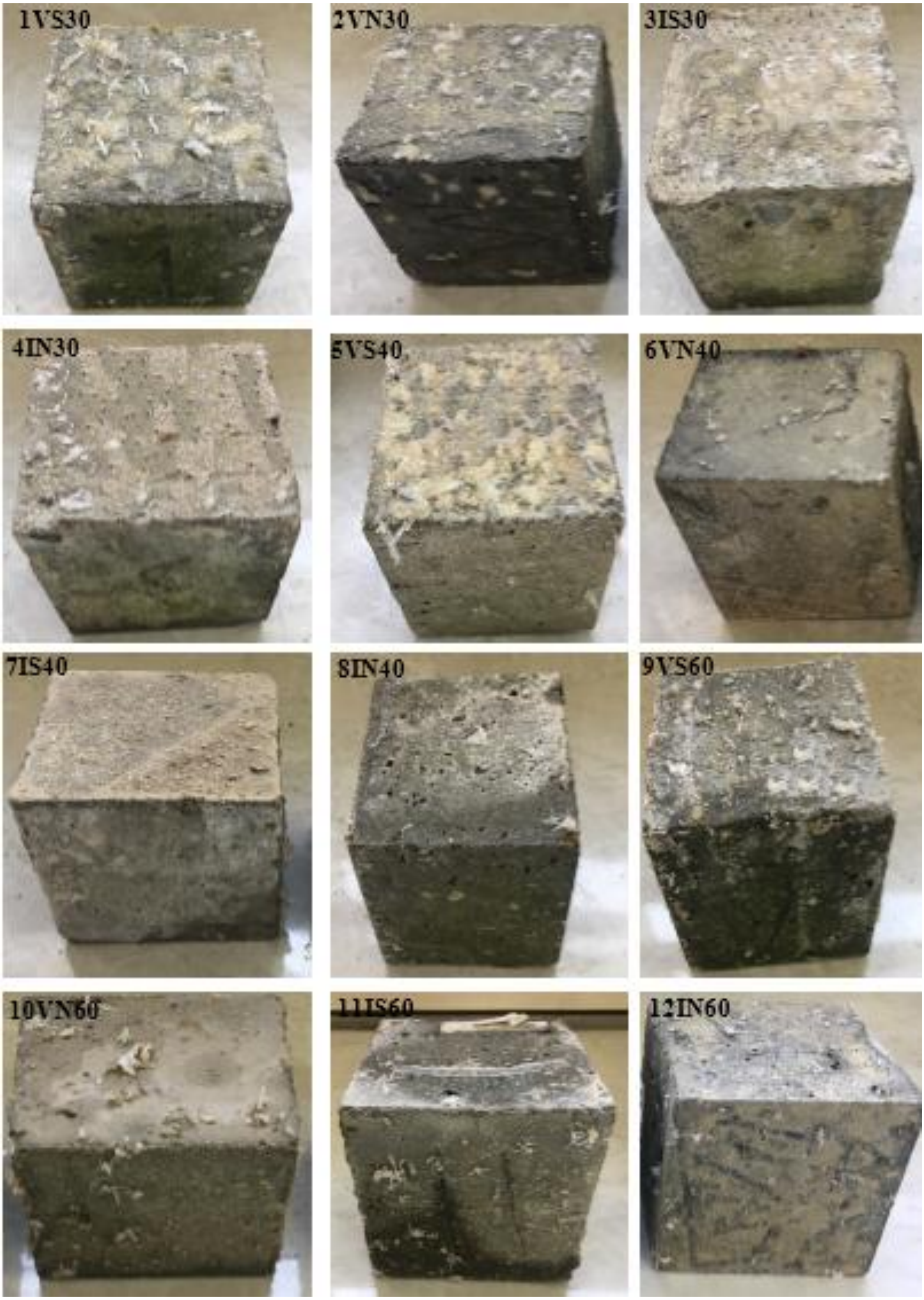

Plate (1) Visual Damage of specimens in ground water solution at age 360 days

Table 12: Compressive strength (N/mm^2) of specimens in test solutions and CSL for mix proportion 1:2.1:3.2

Age	Mix. number	Symbol	Tap water	Ground Water SO_4= 6965 ppm	CSL (%)
28	1	1VS30	32.37	29.73	8.16
	2	2VN30	30.53	29.83	2.29
	3	3IS30	31.55	28.79	8.75
	4	4IN30	32.86	29.66	9.74
90	1	1VS30	35.58	31.55	11.33
	2	2VN30	33.31	30.00	9.94
	3	3IS30	35.20	26.00	26.14
	4	4IN30	33.07	29.57	10.58
180	1	1VS30	35.87	32.63	9.03
	2	2VN30	40.27	31.67	21.36
	3	3IS30	38.00	30.94	18.58
	4	4IN30	35.83	30.87	13.84
270	1	1VS30	37.93	33.03	12.92
	2	2VN30	41.17	31.50	23.49
	3	3IS30	38.53	28.50	26.03
	4	4IN30	38.67	30.60	20.87
360	1	1VS30	40.73	33.07	18.81
	2	2VN30	44.37	33.87	23.66
	3	3IS30	40.10	28.33	29.35
	4	4IN30	43.47	34.03	21.72

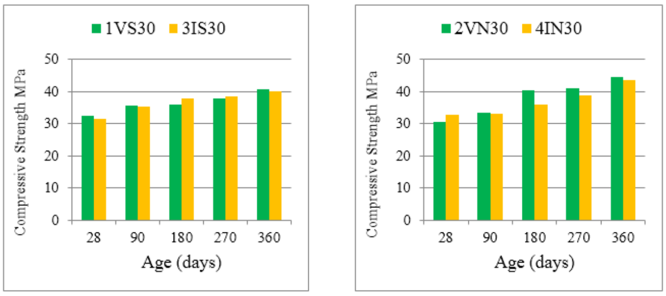

Figure 1: Compressive Strength Development for Mix Proportion 1:2.1:3.2 and w/c 0.55

The compressive strength loss (CSL) of concrete specimens made with sulphate resisting cement (Type V) and ordinary Portland cement (Type I) with silica –fume (SF) and immersed in ground water solution (6965 ppm sulphate content) is shown in Fig. (2). The relative strength loss of specimens 3IS30 is greater than those of 1VS30 during the time of exposure at all ages. This has been probably due to the absence of C_3A in specimens 3IS30 is more than 1VS30 and the presence of high amount of water in mixture, and then permeable sulphate ions through the pores of concrete microstructure after several months and cause delay of ettringite formation (DEF) which leads to expansion and cracks in the paste and at the aggregate –cement paste interface (interfacial transition zone) [2]. However, as illustrated in Fig. (2), the CSL of specimens 4IN30 is smaller than 2VN30 after ages over 90 days. The good resistance of concrete containing SF and non-standard sand (SO_3 =1.13 %) is due to immediate homogenous formation ettringite resulting from the rapid reaction of internal sulphates and C_3A, this type of stable ettringite (cubic ettringite) form an almost impervious ettringite shell around C_3A which prevents its further hydration[16]. Furthermore, the filler action of SF which has fine particle size and the pore refinement process occurring due to the conversion of calcium hydroxide (protlandite) in to secondary C-S-H gel through strong pozzolanic reaction [17].

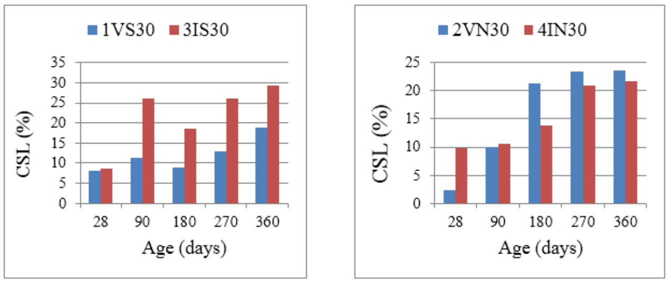

Figure 2: CSL for Mix Proportion 1:2.1:3.2 and w/c 0.55

The compressive strength development and CSL for concrete mixture of proportion (1: 1.78: 2.78) and w/c of 0.45 are shown in Table (13). Fig. (3) illustrates the compressive strength development of all specimens in tap water along 360 days. For concrete specimens made with standard sand, the strength development rate increased by 22% in specimen 5VS40 after 360 days relative to 90 days, and 6% strength increasing rate in specimen 7IS40 after 360 days compared to its 90 days. Concrete specimens made with non-standard sand, the specimen 6VN40 reveals 14% strength increase at age 360 days than those of 90 days. 9% strength increasing rate in specimen 8IN40 was recorded at the same period. These results may be related to the difference in chemical composition of the two types of cement due to the content of C_3S and C_2S compound which mainly affects on strength development rate, because of the hydration of C_2S is slow intrinsic rate of reaction.

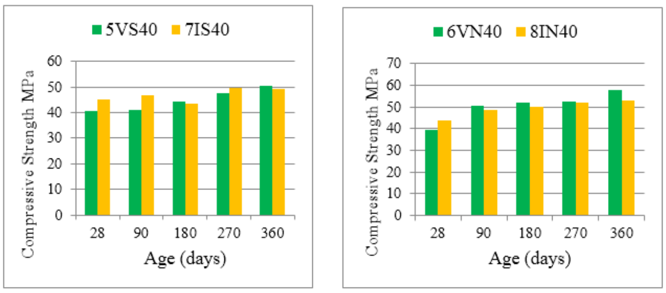

Figure 3: Compressive Strength Development for Mix Proportion 1:1.78:2.78 and w/c 0.45

Table 13: Compressive strength (N/mm^2) of specimens in test solutions and CSL for mix proportion 1:1.78:2.78

Mix Proportion 1 : 1.78 : 2.78					
Age	Mix.	Symbol	Tap water	Ground Water SO4=	CSL (%)
28	5	5VS40	40.50	39.63	2.15
	6	6VN40	39.60	39.97	-0.93
	7	7IS40	45.17	39.90	11.67
	8	8IN40	43.63	42.70	2.13
90	5	5VS40	41.20	38.73	6.00
	6	6VN40	50.60	44.43	12.19
	7	7IS40	46.60	40.87	12.30
	8	8IN40	48.63	43.53	10.49
180	5	5VS40	44.33	37.63	15.11
	6	6VN40	51.8	39.40	23.94
	7	7IS40	43.53	44.77	-2.85
	8	8IN40	50.13	47.90	4.45
270	5	5VS40	47.77	36.33	23.95
	6	6VN40	52.37	41.07	21.58
	7	7IS40	49.67	42.97	13.49
	8	8IN40	51.87	46.03	11.26
360	5	5VS40	50.33	38.8	22.91
	6	6VN40	57.90	47.43	18.08
	7	7IS40	49.27	44.70	9.28
	8	8IN40	52.93	44.37	16.17

Fig. (4) Shows that CSL is lower for concrete specimens made with ordinary Portland cement and silica fume as compared to concrete specimens made with sulphate resisting cement for standard and non – standard sand. At age 360 days of exposure to sulphate solution, the CSL of Specimens 7IS40 and 5VS40 was about 9% and 23% respectively, however, 16% and 18% CSL values were obtained for specimens 8IN40 and 6VN40 respectively as shown in Table (13). This is because of that silica fume reduce the quantity of Portlandite $Ca(OH)_2$ in hydrated cement paste of the concrete, silica fume reacts with $Ca(OH)_2$ so that $Ca(OH)_2$ is no longer available for reaction with sulphate and C_3A [18]. The compressive strength loss values at age 90 days were approximately one half of those at age 360 days. This is attributed to the external sulphate effect at late ages.

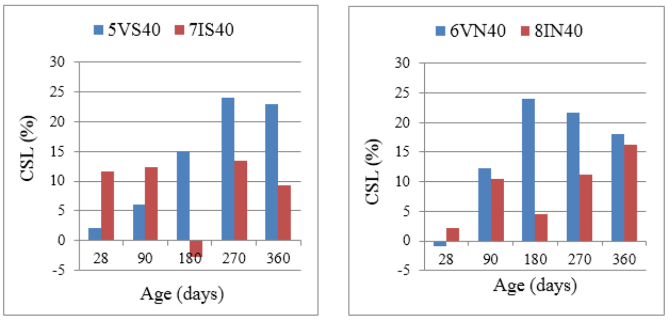

Figure 4: CSL for Mix Proportion 1:1.78:2.78 and w/c 0.45

The compressive strength development of high performance concrete mixes are illustrate in Table (14) and Fig. (5). The obtained results reveal that the compressive strength continuing increasing until age of 360 days. All specimens showed about 10% strength increase at 360 days refer to those at 90 days.

Table 14: Compressive strength (N/mm^2) of specimens in test solutions and CSL for mix proportion 1:1.31:2.3

Mix Proportion 1 : 1.31 : 2.3					
Age	Mix.	Symbol	Tap water	Ground Water SO4=	CSL (%)
28	9	9VS60	59.39	46.47	21.75
	10	10VN60	56.43	46.63	17.37
	11	11IS60	59.37	48.47	18.36
	12	12IN60	59.80	48.50	18.90
90	9	9VS60	62.13	57.67	7.18
	10	10VN60	62.30	46.40	25.52
	11	11IS60	60.73	55.08	9.30
	12	12IN60	62.00	44.87	27.63
180	9	9VS60	62.83	56.00	10.87
	10	10VN60	65.40	56.89	13.01
	11	11IS60	61.70	54.03	12.43
	12	12IN60	63.13	53.07	15.94
270	9	9VS60	65.03	52.27	19.62
	10	10VN60	68.00	49.92	26.59
	11	11IS60	64.20	55.07	14.22
	12	12IN60	67.80	54.90	19.03
360	9	9VS60	67.37	53.67	20.34
	10	10VN60	70.97	48.67	31.42
	11	11IS60	66.73	52.97	20.62
	12	12IN60	68.20	55.38	18.80

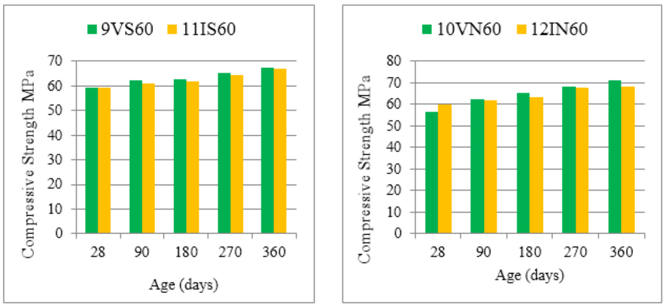

Figure 5: Compressive Strength Development for Mix Proportion 1:1.31:2.3 and w/c 0.31

Fig. (6) Shows the CSL of high strength concrete specimens at all ages. The CSL of concrete samples made with type I cement + SF and non-standard sand at age 360 days were less than those of concrete samples made with type V cement and non-standard sand, the CSL value for specimen 12IN60 was 19% while 31% for specimen 10VN60. This because of the filler action of fine particle size of silica fume and the pore refinement process occurring due to conversion of portlandite $Ca(OH)_2$ in to C-S-H gel so that, $Ca(OH)_2$ is no longer available for reaction with sulphates and avoid the formation of a large amount of gypsum crystals . Moreover, at the same age, specimens 9VS60 and 11IS60 gave same values of CSL of 20%. This may be attributed to the low permeability and absorption, and this lead to decrease the external sulphate solution attack.

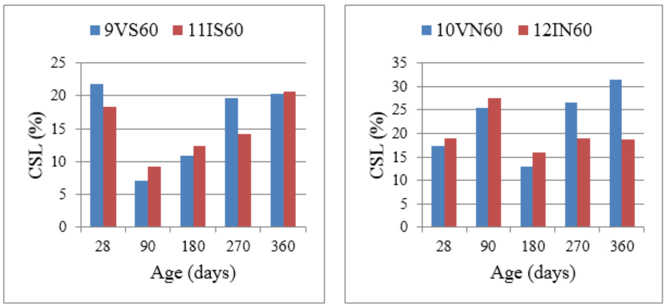

Figure 4: CSL for Mix Proportion 1:1.31:2.3 and w/c 0.31

CONCLUSIONS

Based on the experimental results in this investigation, the following conclusions can be drawn:

1. The compressive strength continuously increases in specimens immersed in tap water. The rate of development decreases when the w/c ratio decreases also.
2. Maximum CSL occurred in concrete prepared with type V cement, non-standard sand and w/c ratio 0.31. The value of CSL is 31% at age 360 days of exposure to Sulphate solution.
3. To decrease the harmful effect of internal sulphate come from the use of non-standard sand (SO_3=1.13%) in concrete, type I cement with 10% of silica –fume replacement with low w/c ratio is preferred to resist the internal and external effect of sulphate.
4. Concrete made with silica –fume plus type I cement and standard sand exhibits a much better resistance to sulphate solution attack than concrete made with type V cement and standard sand when w/c ratio 0.45.
5. Using non - standard sand (SO_3 =1.13%) in mixtures with low w/c ratio 0.31, the effect of internal sulphate is clearly appear at early ages until 90 days. This is observed by the loss in strength of the specimens, the amount of CSL is about 25%.
6. The best resistance to external sulphate attack is obtained when the silica – fume added to mixtures prepared with ordinary Portland cement and w/c ratio of 0.45.

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