Effect of aggressive soil on self compacting concrete

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Aggressive soil basically means soil which attack the concrete of the earth structures by the chemicals composition of the soil basically sulphate. The conception of self-compacting concrete (SCC) is totally different from ordinary concrete, therefore some changes in durability behavior might occur. The durability aspects investigated here are sulfate attack and permeability, which are of prime importance in almost all concrete structures. Tests were carried out on 6 SCC mixtures and on the corresponding 6 mortar mixtures in addition to the ordinary ones. The SC concrete and mortar mixtures were designed such that they have different paste contents, two types of powder, comprise silica fume or not, and two different gravel to sand ratios. A mineralogical study was conducted at the mortar specimens before and after sulfate exposure to identify the sulfate effects at the microscopic level.

Test results showed that the self-compacting mixtures, owing to their dense microstructure, are severe sulfate resistant in terms of compressive strength, surface scaling, and length change. Also, their permeability are very low compared to the ordinary concrete. These promising results appreciate SCC as suitable for more reliable concrete earth structures.

Keywords: aggressive soil; self-compacting concrete; sulfate attack; durability.

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1 INTRODUCTION

Durability of concrete defines its resistance to the anticipated exposure conditions. The durability response of a concrete structure is shared by both the environmental conditions and the concrete mix design. Self-compacting concrete (SCC) seems to be slightly different in comparison to normal vibrated concrete in that, high amount of super-plasticizer is added for better workability, high powder content is normally employed as "lubricant" for the coarse aggregate, as well as the use of viscosity agent. It seems necessary at this circumstances, to ensure that this new concrete can be utilized to produce high quality, long-lasting concrete earth structures. It was generally found by Billberg et. al.[1] that SCC has a denser microstructure than conventional concrete at the same (w/c) ratio, and also a very dense interfacial transition zone between aggregate and bulk paste. That is, in the opinion of Hansson et. al.[1], why SCC is superior to the conventional concrete in preventing gas (carbon dioxide) and chloride ions from migration inside it.

In the present work, it was tried to check the main durability aspects relevant to the local environmental conditions. The main concerns were sulfate attack and the permeability, which is the property directly affects almost all other durability aspects of concrete. Test results show that SCC in addition to its known benefits in the fresh state, and homogeneity in the hardened state which affect the confidence level in its quality, is more durable than the ordinary one. These benefits render SCC as qualified to replace the ordinary traditional one.

2 EXPERIMENTAL PROGRAM

In the present work, the sulfate attack in the form of swelling of the cementitious mixture was investigated. That was done through 7 mortar mixtures, shown in Table 1. The mortar mixtures were also mineralogical studied at the microscopic level after exposing them to 10% sodium sulfate solution for about one year. Also, the effects of sulfate on the concrete compressive strength, scaling of concrete surface, and permeability of concrete were studied through the corresponding 7 concrete mixtures shown in Table 1.

Table 1: Investigated mortar & concrete mixtures

Mixture		ordinary	SC with silica fume				SC without silica			
		MC	**M1D**	**M1L**	**M2D**	**M2L**	**M3D**	**M3L**		
paste content, litre/m^3		327	350	350	400	400	350	350		
Ingredients*, kg / m^3	cement	400	400	400	400	400	400	400	Mortar	Concrete
	silica fume	_	80	80	80	80	_	_		
	dolomite powder	–	53.3	–	173	–	115	–		
	limestone powder	–	–	53.3	–	173	–	115		
	sand	583	669.3	669.3	617.8	617.8	754	754		
	gravel	1167	1004	1004	926.7	926.7	905	905		
	(superplasticizer/ binder) ratio*	0.03	0.03	0.03	0.03	0.03	0.03	0.03		

*: by weight

2.1 MATERIALS

Ordinary Portland cement and silica fume whose chemical compositions shown in Table 2, were used through this investigation. The aggregates were well-graded natural siliceous sand with a fineness modulus of 2.6, and siliceous gravel whose nominal maximum size is 19 mm. Two kinds of fine powders passing sieve no.200 (75 micron) were employed, i.e. dolomite and limestone powders. High range water reducer (superplasticizer) commercially known as addicrete BVF was used at a dosage of 3.0% from binders weight to accomplish high flowability. It was found in an earlier investigation[2], that there is a specific water content corresponding to the thinnest water film which enables complete bridging of all fine materials. It is the optimum water content corresponding to the maximum possible values of mechanical strengths. For the purpose of this study and to allow for a pronounced effect of sulfate attack, higher water contents were employed for concrete and mortar mixes, shown in Tables 3.

2.2 MIXES FEATURES

Concrete mixtures consist of three main SCC mixtures in beside to the control one. A 400 kg ordinary Portland cement content per cubic meter of concrete was employed for all of them. The predetermined paste volumes were accomplished by varying the powder content. Two types of powders were employed with each main mix, i.e. dolomite and limestone powder. The first two main mixtures were designed such that the gravel to sand ratio is 1.5 based on preliminary blending trials to achieve the highest possible unit weight and therefore the minimum voids and consequently paste volume. Also, silica fume as a pozzolanic material is incorporated within the paste constituents. The third main mixture was designed without pozzolanic admixtures, and its chosen gravel to sand ratio was set to 1.2.

The control ordinary concrete mixture was designed as usually experienced by local practice. A ratio of gravel to sand ratio of 2.0 was adopted. A 400 kg cement content per cubic meter of concrete was chosen like the SCC mixtures. The water to cement ratio was set to 0.5. The same type and dosage of superplasticizer as that used for SCC mixtures was employed. This mixture possessed a relatively high slump value of about 120 mm. Three main self-compacting mortar mixtures in addition to a control one corresponding to the concrete mixtures were cast. Their constituents represent the mortar fraction part of the corresponding concrete mixtures. In other words, the constituents of the mortar mixtures exactly resemble that of the corresponding concrete mixtures but without gravel. Their water contents were determined slightly higher than the optimum water contents that were determined in an earlier investigation [2]. As for concrete mixtures, the two types of powders i.e. limestone and dolomite powders were employed with each main mix.

Table 2: Chemical composition of the employed cemen and silica fume

Oxide, %	O.P. cement	Silica fume
Si O_2	20.61	96.1
Al_2 O_3	5.13	0.7
Fe_2 O_3	3.56	0.52
Ca O	63.75	0.21
Mg O	1.14	0.48
S O_3	1.92	0.1
L.O.I.	2.5	2.2
specific surface area	3400 cm^2/g	20 m^2/g

Table 3: Water contents* of the investigated mortar & concrete mixtures

Mixture	ordinary	SC with silica fume				SC without silica	
	MC	**M1D**	**M1L**	**M2D**	**M2L**	**M3D**	**M3L**
concrete	0.5	0.36	0.36	0.395	0.395	0.39	0.39
mortar	0.4	0.285	0.285	0.31	0.31	0.3	0.3

* : As a ratio of the binders weight

2.3 SPECIMEN PREPARATION

Mixing operations of the concrete mixtures were sequenced as follows: all the powder materials i.e. cement, silica fume, and dolomite or limestone powder were carefully mixed in a pan mixer. Sand was implemented to the dry mixture and mixing further continued to assure complete homogeneity. Gravel was subsequently added to the rotating mixer and mixing was continued for further 120 seconds. Finally water containing the superplasticizer was added and mixing was continued until the mixture became homogenous after about 180 seconds. Then, the concrete was poured into oiled steel molds of the different specimens. After 24 hours the specimens were demolded and cured in water till the age of testing. Details of mixtures, and their proportions are presented in Table 1.

Mixing of the mortar specimens were done in a bowl mixer with rotating paddles. The constituents were supplemented into the mixer in the same sequence as for the corresponding concrete mixes. Mixing water containing the superplasticizer was then added, and mixing continued for about 120 seconds. Having completing the mixing operations, the oiled steel molds of the different specimens were filled in one layer without any tamping nor vibration, except for the control normal mix which was tamped manually. Then the cast specimens were covered by a plastic sheet. The specimens were demolded after 24 hours and cured in water till the age of testing.

3. METHODS OF INVESTIGATION

Hypotheses[3] regarding the mechanisms of sulfate attack include deterioration by magnesium ions from magnesium sulfate, the swelling of already-formed ettringite crystals as they absorb water, the formation of gypsum, and the scaling of concrete as a result of sulfate salt crystallization. The durability aspects investigated here are the following: Sulfate attack in the form of swelling of the cementitious mixtures (length change). Scaling of concrete surface. Compressive strength variations over time with sulfate attack. Permeability of concrete. The different cementitious phases formed due to the sulfate attack were identified by means of a mineralogical investigation.

3.1 SWELLING

The most pronounced effect of sulfate attack on the cementitious mixtures is the formation of the expansive compound “ettringite”. This compound is responsible of the disruption of otherwise sound concrete. This phenomenon was assigned by testing the expansive potential of mortar bars soaked in sodium sulfate solution in accordance with ASTM C1012[4]. In fact, the paste is the concrete fraction highly affected by the aggressive media. Mortar is the second in this effect, and serves to magnify the expansion values of the corresponding concrete. ASTM C1012 requires exposing the mortar bars of this test to sulfate by immersing them into a sulfate solution after the mortar has reached a strength not less than 19.7 MPa. The solution designated by ASTM is a 0.352 molar, 5 percent sodium sulfate ($Na_2 SO_4$) solution. The solution is required to have a pH between 6 and 8. The test criterion requires a maximum expansion limit of 0.1% at 180 days of sulfate solution exposure for moderate sulfate resistance. For severe sulfate resistance, the limit is 0.05%.

Through this work, two sulfate concentrations were adopted, i.e. 5.0%, and 10.0%. The second one is two times that required by ASTM C1012 to accelerate the sulfate effect. 3 mortar bars were cast for each mix. The specimens required for ASTM C1012 are (25*25*286)mm. The specimens were provided with two stud gages at the ends for length change measurements. These stud gages were held in position during casting. Two small demic gages (5 mm diameter) were glued to each of two opposite sides of the specimens with a gage length 25 cm, immediately after demolding. These demic gages served to provide a double check of length changes measurements. Overall length changes were measured by a length comparator apparatus described in ASTM C 490. The specimens were marked with an arrow identifying the direction of placing the specimens during measurements, and the specimens were rotated gently while resting in the apparatus until the reading is no more hesitated. A mechanical extensometer was used to measure length changes between the demic gages on both sides of the specimens with an accuracy 0.002 mm. The specimens were cured in water until the age of 28 days. At this age, the mortar bar specimens were measured for their initial length, as the specified strength was accomplished for all mixes. Then the specimens were soaked into the sulfate solutions for another 11 months. During this period, length change measurements were monitored every other day during the first month, and every other week for the rest of time. The pH of the sulfate solutions was checked after each measurement, and the solution was changed if necessary to adjust its pH value within the specified range.

3.2 SCALING OF CONCRETE SURFACE

Surface scaling is a typical damage mechanism in concrete that may not occur in mortar. Surface scaling occurs when the mortar along the surface of a concrete breaks away from the coarse aggregate as the mortar expands or deteriorate. Evaluating this phenomenon was carried out with guidance of the United States Bureau of Reclamations test, USBR 4908 Method B[5]. The test involved soaking concrete cylinders in a 10% sulfate solution and measuring the length and mass changes of the specimens.

As the swelling potential was evaluated using the mortar bars, it was found sufficient to trace the surface scaling of concrete mixes during this test. For each of the investigated mixes, 21 concrete cube (15*15*15) cm were cast. All the specimens were cured in potable water till 28 days age. At this age, 3 cubes of each mix were tested for compressive strength. Half the remaining cubes were soaked into the 10% sulfate solution, and the second half of specimens were re-soaked in a potable water. The sulfate exposed concrete specimens were weighed every week using a digital scale with an accuracy of 0.1 grams. After two months of sulfate exposure, three cubes corresponding to each of the investigated mixes were tested for compressive strength. Another three cubes of those immersed in potable water were weighed and tested for compressive strength at the same time. Before any measurement, all the specimens were removed from the sulfate solution and the water, and were brought to the saturated-surface dry (SSD) condition. These operations were repeated after three, and eleven months of sulfate exposure, i.e. till about one year age. The solutions were replaced and the containers were cleaned every month to ensure a pH below 9.75 was maintained for the sulfate environment. Visual observations regarding crack development, spalling and surface scaling were also made during the test.

3.3 COMPRESSIVE STRENGTH VARIATIONS

Monitoring of compressive strength variations over time was performed for mortar as well as concrete. Regarding mortar, for each of the investigated mixes, 12 cubes with 5cm side length were cast. All of them were initially cured in water for 28 days. Three specimens were tested for compressive strength at this age. Another three specimens were kept in the curing water for another 11 months. The rest of them were exposed to sulfates in the same containers along with the mortar bar specimens. Three cubes were soaked into a 5% sodium sulfate solution, and the last three into a 10% solution. At the end of test, i.e. after about one year all the cubes were tested for compressive strength, and their results were compared.

The compressive strength of concrete is more valued by engineers than the mortar ones. Therefore, more attention was directed towards concrete testing. As outlined before, the concrete compressive strength was evaluated at 28 days age, i.e. before soaking in sulfate solution. Then the concrete compressive strength was assigned after two, three, and eleven months of sulfate exposure for the two cases. The first one concerning the 10% sodium sulfate solution soaked specimens, and the second one for the water cured specimens. The results of the two cases were compared and interpreted for the effect of sulfates.

3.4 PERMEABILITY OF CONCRETE

It is intuitive to believe that permeability has an effect on the concrete durability. That is because, it measures the ability of deleterious ions and salts to penetrate into the concrete. One should realize that low permeability concrete is not necessarily durable one. Clearly the attack can onset from the concrete surface, like when the concrete comprise within its constituents materials that chemically reactive with the surrounding media. Nevertheless, it is of prime importance as it attributes in resisting the aggressive media. Through the present work, all the concrete mixtures outlined in Table 1 were tested for permeability in accordance with the requirements of DIN1048[6]. For each mix, 3 companion concrete prisms having an overall dimensions of (20*20*12) cm were cast in oiled steel molds prepared especially for this purpose. The concrete prisms were cured in water till they reached 28 days age. Then, they were transferred to the permeability testing machine. In this test the water jet below under a certain pressure against one concrete face (20*20)cm. A central circle, 10 cm in diameter is slightly roughened at this face to ensure that the concrete enface the applied water jet. The roughened area is further enclosed by a rubber seal to prevent water from escape and to keep the water pressure constant at the exposed area. The specimens were firmly fastened to their places in the testing machine. The applied pressure is 1.0 bar for 48 hours, then 3.0 bars for 24 hours, and finally 7.0 bars for another 24 hours. Immediately after completing the water pressure exposing regime, the specimens were released from the testing machine. Then the specimens were divided equally into two halves. The water penetration depth and pattern were recorded for each specimen.

3.5 MINERLOGICAL STUDY

The purpose of this study is to identify the different cementitious phases formed due to sulfate exposure. All the mortar mixes were investigated by the X-ray Diffraction (XRD) and the Differential Thermal Analysis (DTA) Techniques. It worth to mention that the first technique is helpful in tracing the formed crystalline phases, whereas the second one enable identifying the amorphous (non crystalline) as well as the crystalline phases. The mineralogical study was conducted on the mortar mixes at the age of 28 days, i.e. before sulfate exposure, and after exposure for about one year to the 10.0 % sodium sulfate solution. After performing the compressive strength test, the crushed mortar cubes were allowed to air dry for one day. A representative sample from the three cubes of each mix was crushed and ground to a very fine powder that passes (75□m) sieve and was tested immediately after that.

4. TEST RESULTS & DISCUSSION

4.1 LENGTH CHANGE

It was stated before that, the ability of the cementations mixtures to resist the expansive compounds formation due to sulfate attack could be traced through monitoring of the expansive strains. Fig. 1 shows the expansions experienced by the ordinary mortar bars at two sulfate concentrations, i.e. 5%, and 10%. It should be pointed out that the ordinary mortar mix is not actually a control one to the self-compacting mixtures. Nevertheless, it is helpful to clarify the differences between the ordinary and the self-compacting mixtures.

The figure shows that at 5% sulfate concentration the specimens possessed an average strain of 0.05% at 180 days, and a strain of 0.1% at about 230 days. Based on the requirements of ASTM C1012, this mix is regarded as severe sulfate resistant. At 10% sulfate concentration, the expansive strains are of course higher than it at 5% concentration. The strain attained its highest value of about 0.3% at about 300 days, then it is almost stabilized. Anyhow, this relatively high strain is over the tensile capacity of the mortar and therefore hair cracks or flaws are expected to be developed inside it. These results show that although the ordinary mortar mixture is accepted as severe sulfate resistant, it will not long lasting unless it is properly insulated against sulfate attack.

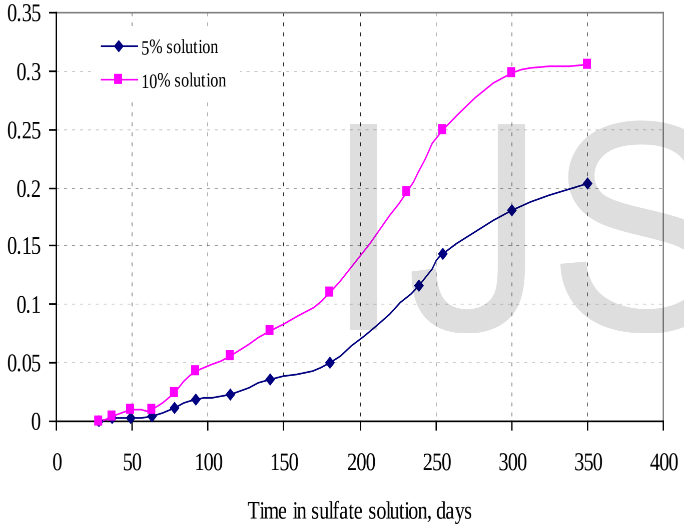


Fig.1: Sulfate expansion of ordinary mortar bars

Self-compacting mixtures provide better solution to this durability problem, as could be realized from Figs. 2, and 3 for the 5% and 10% sulfate concentration, respectively. Clearly, the strain values of the self-compacting mixtures containing silica fume are very low compared to the ordinary mixture' ones. At the 180 days criterion specified be ASTM C1012, the SC mixtures' strain values didn't exceed about one tenth those of the ordinary mixture. Also, the SC mixtures without silica fume exhibited fairly lower expansive strains than those of the ordinary mixture, but their strains were as twice as much the corresponding strains of the silica fume mixtures. The efficiency of silica fume in reducing the expansive strains is evident due to its ability to convert some of the free lime normally generated during cement hydration to the cementing compound CSH. Hence, reducing the formed quantity of the expansive compound named, ettringite. These results held true for both of the employed types of powder, as their results were to a great extent similar to each other and no appreciable difference between them. Test results reveal the efficiency of self compacting mixtures in almost inhabiting sulfate attack in the form of swelling of the cementitious mixtures, but favorably materials of pozzolanic activity should be included within the mixture's constituents to offset sulfate-

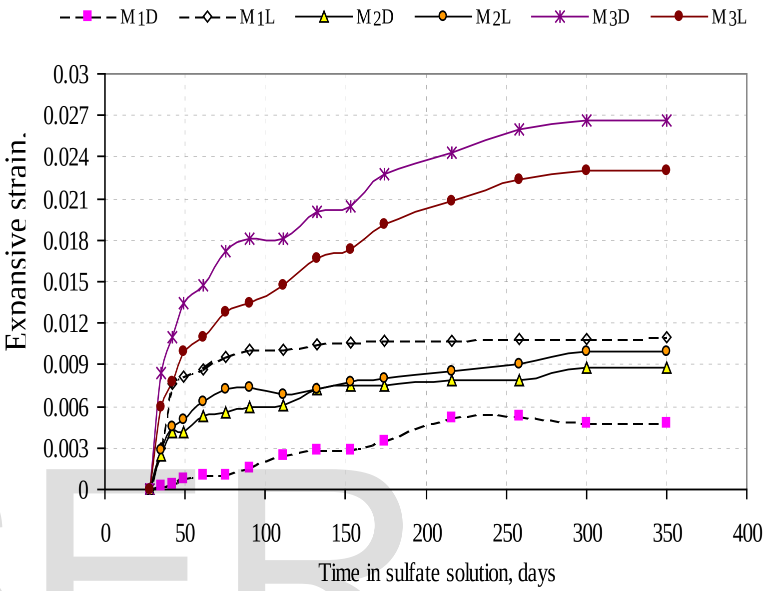


Fig.2: The effect of 5% sod. Sulfate solution on the expansion behavior of SC mortar bars

4.2 SURFACE SCALING

It was outlined before that, if surface scaling takes place, the mortar cover over the coarse aggregate would spall. As a consequence of this spalling, the overall weight will be reduced. In circumstances where there is no spalling, the cubes' weight might be increased as a result of the formation of the expansive compounds which are highly water absorbent. Anyhow, the formation of hydration products is also a possible reason of weight increase (autogenous increase). In all cases, the changes in the specimens' weight whether increase or decrease could be considered a measure of the specimens ability to withstand the sulfate effect.

Results of weight variations over about one year are presented in Figs. 4, for the ordinary as well as the SC concrete mixtures. As could be seen, two distinct patterns are generated. The first one for the mixtures containing silica fume with all paste contents, regardless of the type of powder. Whereby, there was a continuous increase in their weights, although the increases were moderate signalizing marginal effect of sulfates without any sign of cracking or deterioration. The second pattern recorded for the mixtures without silica fume as well as the ordinary (control) mixture. Their weights increase were much higher than those of the first pattern group. Apparently, the effect of sulfates on this group is more pronounced than for the first one. Anyhow, at certain age about 6 months, the weight of the ordinary mixture specimens started to decrease. It was also noted for the ordinary mixture at this age that edge cracks started to form, and shortly after that this edges are no more sharp. These results clearly reveal that SCC mixtures are more resistant to sulfates in the form of surface scaling in comparison with ordinary mixtures. The best results were for the mixtures incorporating pozzolanic materials within its constituents. Also, the two types of powder proved almost the same efficiency.

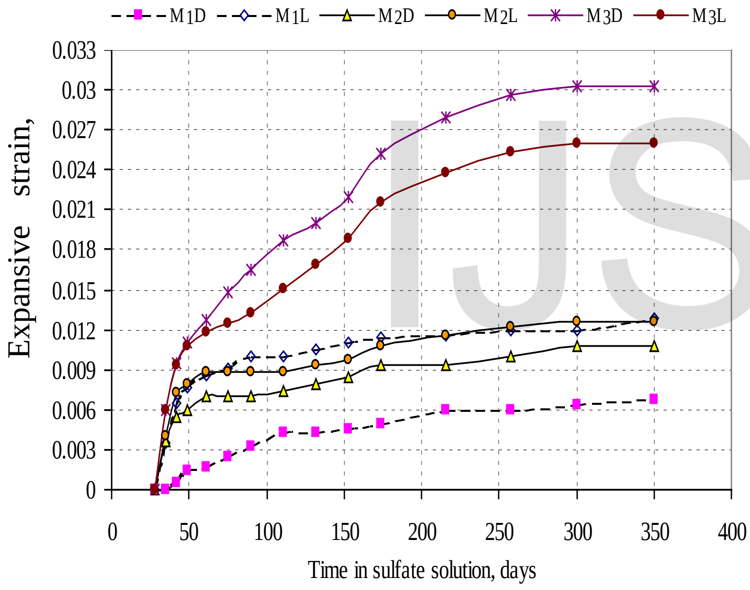


Fig.3: The effect of 10% sod. Sulfate solution on the expansion behavior of SC mortar bars

4.3 COMPRESSIVE STRENGTH RESULTS

Fig.5 illustrates the strength progress over time for the water cured concrete specimens and how these strengths could be affected by the sulfate attack. The rate of strength gain is somewhat affected by the presence of silica fume. The main mixtures M1 and M2 incorporating silica fume within their ingredients achieved almost of their strengths at three months only. At one year age, their strengths were marginally increased over the three months one by an average of 2.5%. That was not the case for the mixtures without pozzolanic materials as a valuable increase in their strengths was monitored till about one year age. Anyhow, the much more important result is the ability of the concrete cubes to withstand the sulfate attack. This ability could be recognized by comparing the strengths of the sulfate exposed specimens with that of the companion specimens soaked in potable water at the same age. Fig.5 shows that the sulfate effect is more recognized after 11 months soaking, thereby the results will be interpreted at this age.

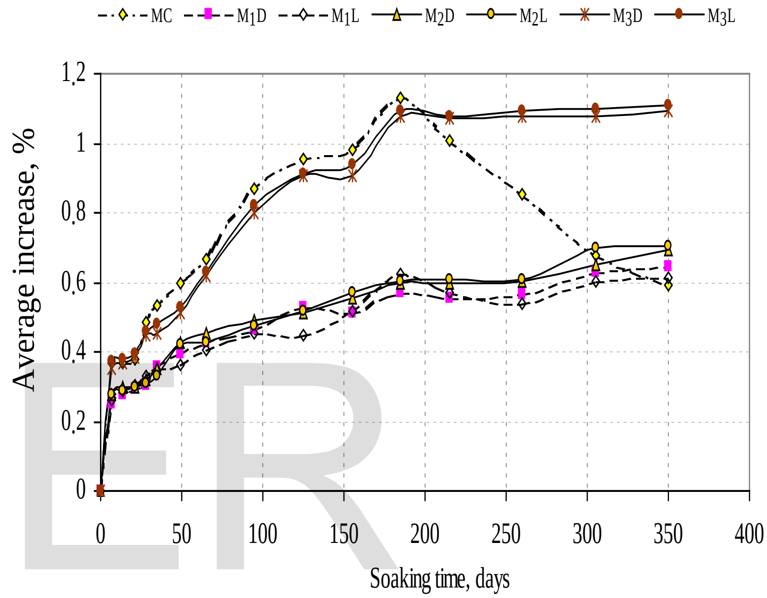


Fig.4: Weight changes of concrete cubes due to soaking in sulfate solution

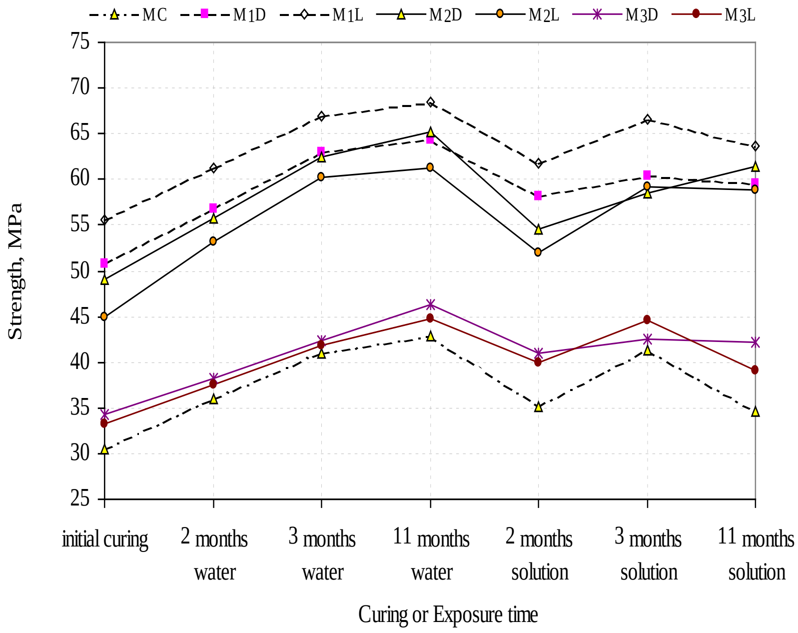


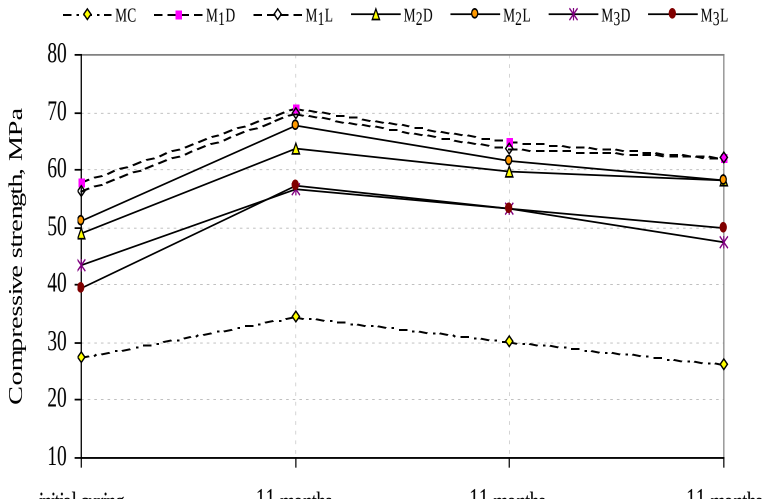
Fig.5:The effect of sulfate exposure on concrete compressive strength over time

As could be seen, the SCC mixtures experienced a marginal reduction in their strengths after 11 months of sulfate exposure, about 7%, and 5% for the main mixtures M1 and M2 containing 350 and 400 liter paste, respectively. The third main mixture M3 without silica fume lost an average strength of 13%. The ordinary mixture MC was the most affected, as the reduction in its strength was about 20%. These results display that SCC mixtures are severe sulfate resistant even when ordinary Portland cement is employed, especially when pozzolanic materials are incorporated within the mixture constituents. The main factors thought to be responsible of increasing the sulfate resistance are:

Dense microstructure due to the physical filling effect of the employed powder. The homogeneity of the mixture due to keeping the viscosity of the mixture at an appropriate level. The homogeneity serves to eliminates the relatively weak zones from a concrete element. The pozzolanic materials are highly contributable because of its known ability to combine with the free lime normally liberated during cement hydration and converting it to a cementitious compound known as CSH. It was stated before that mortar is a concrete fraction much more affected than it by the ambient environmental conditions, which is beneficial in examining the sulfate effect on the different mixtures. The test results of the mortar mixtures, Fig.6, demonstrate that:

The powder type has no or little effect on the strength of the water cured as well as the sulfate exposed SC mixtures.

All the mixtures containing silica fume experienced an equal reduction in their one year strength due to soaking in 10% sulfate solution; about 12%. The SC mixtures without silica fume were more affected by sulfate than other mixtures with silica fume. The ordinary mixture was the most affected by sulfates. It suffered a reduction amounted to about 25% after one year of exposure to the 10% sulfate solution.



All the SC mortar mixtures could be classified as severe sulfate resistant, as their strengths after 11 months of exposure to 10% sulfate solution are still sufficiently higher than their 28-day strengths. On the other hand, the ordinary mixture significantly affected by the 10% solution and its strength dropped to less than the 28-day value. Moreover, the cubes' edges were cracked and spalled.

4.5 PERMEABILITY RESULTS

Table 4 displays the 28-day permeability results for all the concrete mixtures. The permeability test was conducted as described before after the initial curing regime for 28 days. After exposing the specimens to the pressurized water for 4 days, the specimens were divided equally into two halves for the determination of the water penetration depth, Table 4. Dividing the specimens was done using concentric line loading above and under a specimen. The splitting load was recorded and the average splitting tensile strength was recorded and presented in Table 4.

Table 4: Average water penetration depth

Mixture	ordinary	SC with silica fume				SC without silica	
	MC	**M1D**	**M1L**	**M2D**	**M2L**	**M3D**	**M3L**
Average penetration depth, mm	26.5	7	8.5	5.7	4.8	10.6	10
$F_{splitting}$, MPa	1.99	4.1	4.1	3	3	2.7	2.6

The results cited in the table reveal that: The ordinary concrete mixture although has the same cement content as the SCC mixtures and a water content comparable to that of the main mixture M2, but its permeability is much higher than the SCC ones. The difference is attributed to the all of the mixture constituents as well. The impermeability of the SCC mixtures containing silica fume are superior to the others without silica fume. Evidently the use of silica fume has a strong effect on the resulting internal microstructure as much more cementing compounds (CSH) are formed, in beside to the physical filling effect of this very fine powder.

The main mixture M2 exhibited less penetration depth than the main mixture M1. Apparently, increasing the powder content helps to refine the pore structure of the resulting concrete.

The water penetration pattern of the tested samples was almost the same for all samples, and no appreciable difference is found in any of them. Fig. 7 shows that pattern for one of the samples of the mixture M1D. As could be seen, the damp area is somewhat regular, reflecting the homogeneity of the microstructure. While this is logically expected in SCC mixtures, but in ordinary concrete the relatively high cement content may cause a relatively dense microstructure. The recorded splitting tensile strengths of all the mixtures are shown in Table 4. Although it was not intended to produce SCC mixtures with higher strengths than the ordinary one, especially that all mixtures have the same cement content, nevertheless the SCC mixtures M1, M2, and M3 exhibited strengths about 2, 1.5, 1.36 times that of the ordinary concrete respectively. Apparently, the balanced distribution of fines and aggregates through the concrete mass, and consequently the dense microstructure are the causes of this improved strength.

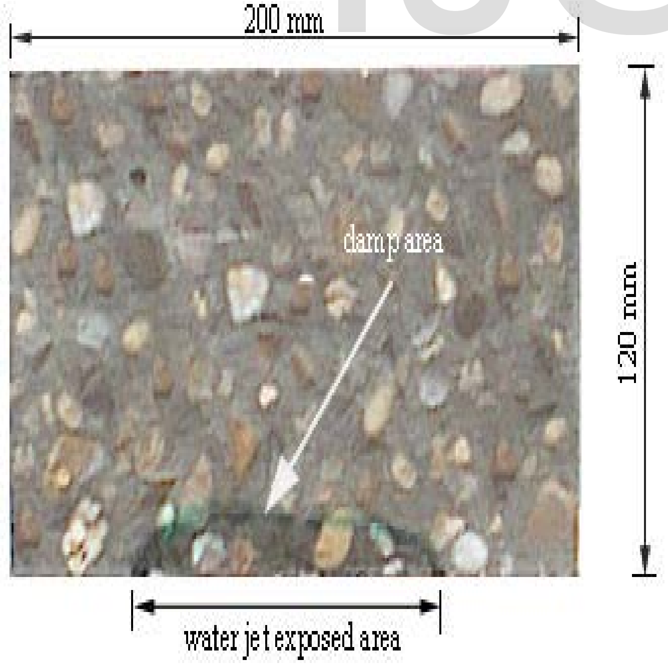


Fig.7: Water penetration patterns-mixture M1D

4.6 MINERALOGICAL COMPOSITION

4.6.1 XRD Analysis

The X-ray diffractograms of the investigated mixtures are shown in Figs. 8, and 9. The first one for the investigated mixtures after completion of the curing regime in water for 28 days, whereas the second one for the same mixtures after soaking them in 10% sodium sulfate solution for one year.

The calcium hydroxide (CH) main peak identified at d spacing 2.628 Å (2□ = 34.1o) and the other confirming peaks demonstrate that the content of CH is pronouncedly reduced in the mixtures containing silica fume, Fig. 8. Also, the added powders, whether dolomite or limestone seem not affecting the CH content as could be seen from the diffractograms of the mixtures M3D, and M3L, respectively. Comparing Fig. 8 with Fig. 9, apparently the CH content of the SC mixtures is little affected by sulfates. On the other hand, the CH of the ordinary mixture (MC) is pronouncedly reduced after sulfate exposure. These results are not surprising, as the SC mixtures proved to have a dense microstructure that able to resist sulfate ions from migration inside it.

Anyhow, the formation of the expansive compound ettringite at d spacing 9.8 Å (2□ = 9o) is an evidence of the sulfate attack extent. Fig. 9 shows that this compound is considerably formed in the ordinary mixture. That might explains the monitored high expansion and also the observed deterioration of the concrete cubes of this mixture. The ettringite compound is hardly noticed in the SCC mixtures without silica fume, while it was not recorded in the SCC mixtures containing silica fume. These results correlate well with the measured free expansions and also confirm the interpreted CH results.

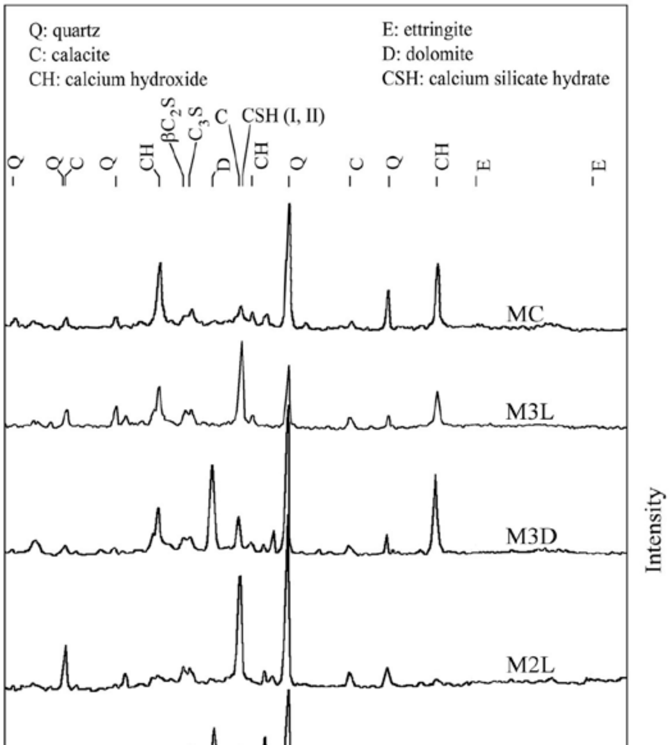
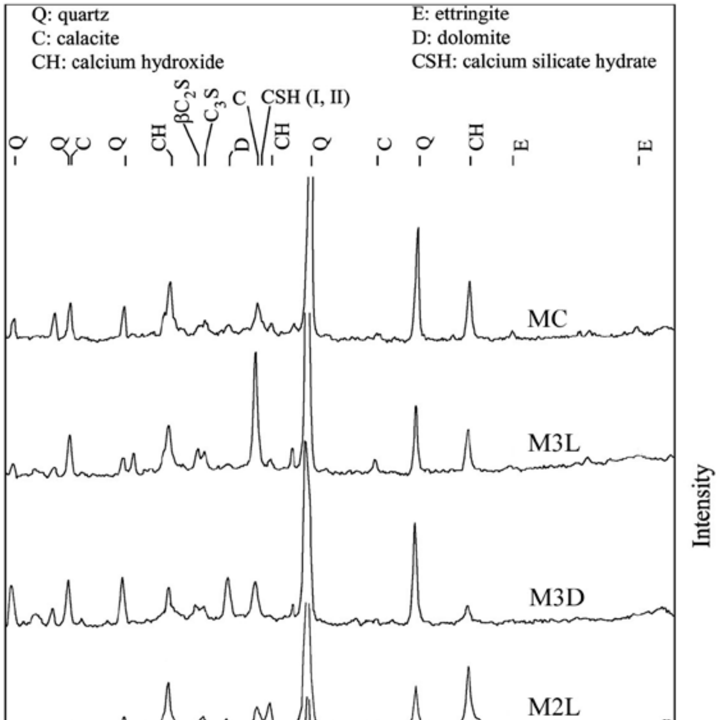


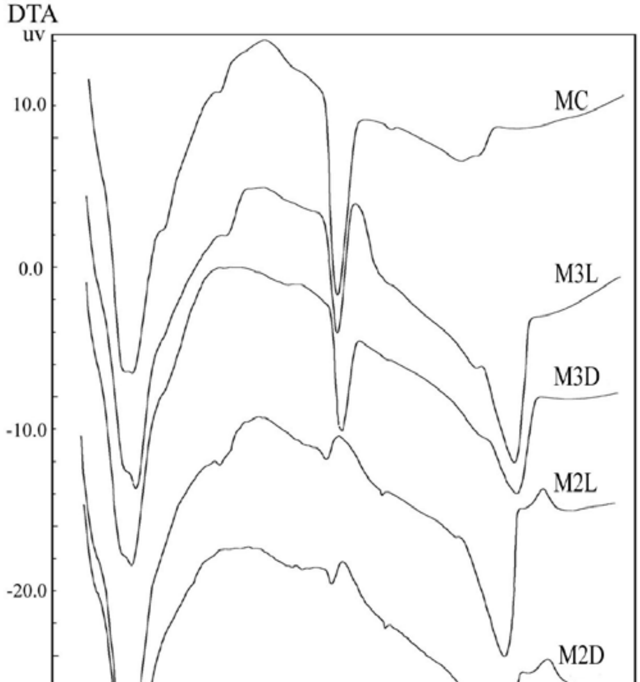
Figure 7. Soil moisture characteristic curve of New Bani sewif shale

The peaks of the added powders; limestone (calcite Ca CO3), and dolomite (Ca Mg (CO3)2) are normally anticipated. Their main peaks are identified at d spacing 3.04 Å (2□ = 29.4o), and d spacing 2.886 Å (2□ = 30.95o) respectively. Unfortunately, the main peaks of the hydration products CSH (I) or tobermorite gel is formed at d spacing 3.06 Å, and CSH (II) at d spacing 3.07 Å, i.e. interfere with the calcite one. Therefore, the cementing compound CSH will be evaluated for the mixtures with dolomite powder only. As could be seen from Fig. 9 a pronounced increase in CSH is achieved for the mixtures containing silica fume. That is why these mixtures are superior in compressive strength to the other mixtures. Anyhow, the densification of the microstructure shares in increasing the compressive strength over that of the ordinary mixtures, which could be realized from the results of the SCC mixtures (M3D, and M3L) without silica fume.



4.6.2 Thermal Analysis

DTA thermograms of the investigated mixes just after 28 days of water curing are shown in Fig. 10, and after exposing to the 10 % sodium sulfate solution for about one year are shown in Fig. 11. The endotherm at about 107 oC is an evidence of the formed cementing compound CSH. Clearly, the amount of the formed CSH or Tobermorite gel is much higher for the SCC mixtures than for the control (ordinary) one, especially for the mixtures containing silica fume. This result demonstrates that increasing the compressive strength of the SCC mixtures over that of the ordinary one is partly due to increasing the amount of the formed CSH compound as a result of the pozzolanic reaction of the employed silica fume. It was reported [7] that the physical filling effect of the pozzolana shares by about 50% in increasing the strength.



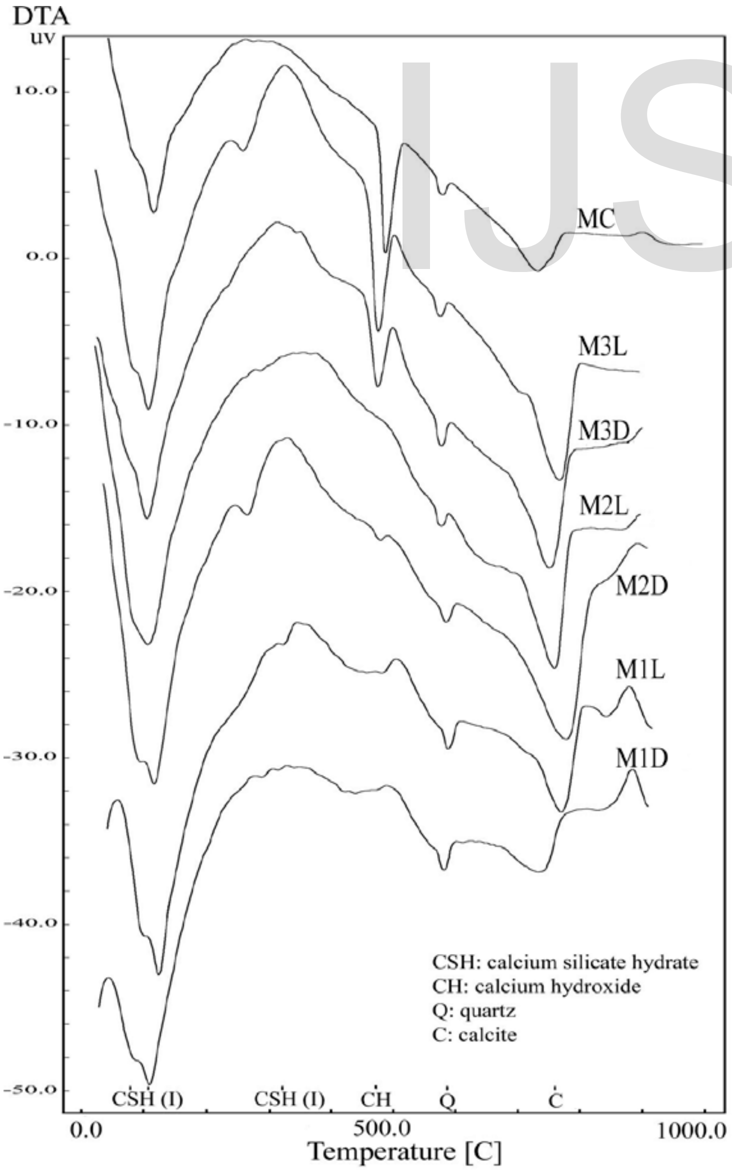


Fig 11: DTA thermograms after sulfate exposure

At about 470 oC, the endotherm of the free CH are observed. Fig. 10 shows that the CH content of the SCC mixtures, especially those containing silica fume, are pronouncedly lower than it for the ordinary one. Decreasing the CH content is normally attributed to the pozzolanic reaction of the employed silica fume. It worth to mention that the added powders, whether pozzolanic or not, owing to their fineness proved to have a catalytic effect on cement hydration [8] which might attribute to decreasing the free lime (CH) content. The extent of sulfate attack could be assessed from the remaining CH content after sulfate exposure. Comparing Fig. 10 with Fig. 11, the consumed CH quantity is much lower for the SCC mixtures as compared to the ordinary one. The present mineralogical investigation confirmed the reliability of SCC mixtures as severe sulfate resistant, especially when a pozzolanic admixture is included within the mixture constituents.

5. CONCLUSIONS

Test results reveal that self-compacting concrete owing to its dense microstructure and interfacial transition zone is efficient in almost inhibiting aggressive soil sulfate attack in the form of swelling, surface scaling, and strength reduction. The permeability test results are another evidence of its superior quality in resisting migration of all deleterious substances inside it. It was also found that the two employed powder types were of comparable contribution to the durability aspects. Thus the self-compacting concrete is more suitable for earth structure in the aggressive soil.

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الملخص العربى

دراسة تاثير التربة العدوانية على الخرسانة ذاتية الدمك

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التربة التى تحتوى على كبريتات تهاجم المنشات الارضية وتسمى تربة عدوانية وتدخل الكبريتات فى مكونها الاساسى و تمثل الخرسانة ذاتية الدمك طفرة كبيرة في مفاهيم صناعة الخرسانة حيث تعتمد بشكل أساسي على توازن مكونات الخلطة لتحقيق الخواص الانسيابية المطلوبة (الأدائية) ومقاومة الكبريتات والكلوريدات الموجودة بالتربة العدوانية , وهي بذلك تختلف في نسب مكوناتها عن الخرسانة التقليدية, وتنعكس هذه الاختلافات على تباين قدرة نوعي الخرسانة على تحمل العوامل البيئية المحيطة مع مرور الزمن (الديمومة). وفي خلال هذا البحث تم دراسة قدرة الخرسانة ذاتية الدمك على مقاومة التدهور بفعل أملاح الكبريتات في كافة صوره: الانتفاش, تقشر السطح, والفقد في المقاومة. كما تم دراسة منفذية الخرسانة لما لها من تأثير ملحوظ على كافة أشكال الديمومة للخرسانة. كما تم أيضا دراسة التركيب المعدني للخلطات الأسمنتية المختلفة قبل تعرضها لأملاح الكبريتات وبعد تعرضها لمحلول 10% كبريتات الصوديوم لمدة عام كامل, وذلك عن طريق اختبار الأشعة السينية المتفرقة, واختبار التباين الحراري. وقد تم إجراء الدراسة على 6 خلطات من الخرسانة ذاتية الدمك وأيضا على 6 خلطات من المونة ذاتية الدمك بالإضافة إلى الخلطات التقليدية, حيث تم تقييم سلوك هذه الخلطات على فترات زمنية امتدت حتى عام كامل.

وقد أظهرت نتائج هذه الدراسة القدرة الفائقة للخرسانة ذاتية الدمك على مقاومة التدهور الناتج عن التعرض لأملاح الكبريتات الموجودة بالتربة في كافة صوره. وتعزى هذه القدرة إلى كثافة البناء الداخلي لهذه النوعية من الخرسانة وأيضا كثافة منطقة اتصال العجينة الأسمنتية مع حبيبات الركام. كما أن نتائج المنفذية أعطت دلالة واضحة على تفوق نوعية الخرسانة ذاتية الدمك وقدرتها العالية على مقاومة نفاذ السوائل الضارة إلى داخل الخرسانة وانها مناسبة للاستخدام فى الاساسات العميقة (الخوازيق) والمنشاءات الارضية.