Effect of Gypsum Content in Fine Aggregate on Mechanical Properties of Self-Compacting Concrete

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Abstract

The research deals with the effect internal sulfates (as gypsum) present in fine aggregate (sand) on the mechanical properties of self-compacting concrete made using a local filler. A mix of self-compacting concrete was designed according special specifications and trials. This mix was tested by various fresh concrete workability tests as **Slump-flow, T50cm, L-box, U-box,** and **V-funnel** tests to evaluate the **passing ability, filling ability, stability** and **segregation resistance** of the fresh mix.

The gypsum content (as **SO_3**) was varied in sand as (**0.4%, 1.0%, 1.5%, 2.5%, and 3.5%**) by wt. of sand which yield a total **SO_3** content in concrete as (**3.77%, 4.74%, 5.55%, 7.15%,** and **8.77%**) by wt. of cement respectively.

The experimental results show that there is an **Optimum Gypsum Content** in fine aggregate (SO_3=1.0%) by wt. of fine aggregate which gives the highest results in **compressive strength, splitting tensile strength, flexural strength** and **Young's modulus of elasticity** of **SCC**. As gypsum content increases beyond this limit the above mechanical properties will be decreased remarkably and also SCC reveals **softer stiffness mechanical behavior**.

الخلاصة

يتناول هذا البحث دراسة تأثير محتوى أملاح الكبريتات الداخلية (الجبس) الموجودة في الركام الناعم (الرمل) على الخواص الميكانيكية للخرسانة ذاتية الرص الحاوية على مادة مالئة متوفرة محليا. تم تصميم خلطة خرسانة ذاتية الرص استنادا لمواصفات خاصة مع التجريب. هذه الخلطة الخرسانية الطرية جرى فحصها بفحوص متعددة لقابلية التشغيل مثل: انسياب المخروط وزمن الانسياب والصندوق على شكل **L** والصندوق على شكل **U** والقمع على شكل **V** وذلك لتقييم هذه الخلطة من ناحية قابليتها للمرور وقابليتها للإملاء ومقاومتها للانعزال.

محتوى الجبس (على شكل نسبة **SO_3**) جرى تغيره في الرمل كالأتي: (0.4%,1.0%,1.5%,2.5%, 3.5%) من وزن الرمل والتي تقابل محتوى **SO_3** كلي في الخرسانة مقداره (3.77%, 4.74%, 5.55%, 7.16%, 8.77%) من وزن السمنت بالتتابع.

أظهرت النتائج انه توجد نسبة مثلى لمحتوى الجبس في الركام الناعم للخرسانة ذاتية الرص مقدارها (1.0%) من وزن الركام الناعم والتي تعطي أعلى النتائج **لمقاومة الانضغاط ومقاومة شد الانشطار ومقاومة الانثناء ومعمل مرونة يونك.** وإذا تعدت نسبة الجبس في الركام الناعم عن هذه النسبة فان النتائج أظهرت انخفاضا في **الخصائص الميكانيكية أعلاه وكذلك أظهرت سلوكا ميكانيكيا اقل جساءة.**

Introduction

Most quarries of sand prevailing in Iraq are contaminated with high gypsum contents which have adverse effect on the mechanical properties and durability of concrete when such sands are used as fine aggregate *(Rauf 1965)*.

Self-compacting concrete is a new type of concrete which has the property of consolidating itself without the need of compaction by vibrators. This concrete possesses fascinating workability and strength properties. Yet there is a need for studying the effect of gypsum present widely in Iraqi sand and used as fine aggregate on strength and mechanical properties of Self-compacting Concrete (**SCC**).

Research Significance

The main purpose of this research is exploring the effect of internal sulfate attack by gypsum present in fine aggregate on Self-compacting concrete made using local materials. This effect includes strength and mechanical properties.

Literature Review

Self-compacting Concrete:

SCC is defined so that no additional inner or outer vibration is necessary for compaction. It is compacting itself due to its own weight and is de-aerated almost completely while flowing in the formwork *(Noguchi et al. 2002)*. In structural members with high percentage of reinforcement it also fills completely all voids and gaps.

Studies to develop **SCC**, including a fundamental study on the workability of concrete have been carried out by **Okamura**, **Ozawa**, and **Ouchi** *(Ozawa and Okamura 1989), (Okamura 1998), (Okamura and Ouchi 1999).*

SCC consists of the same components as conventionally normal concrete, which are hydraulic cement, fine and coarse aggregates plus appreciable amount of additives and/or admixtures (fillers and superplasticizers). The high amount of superplasticizer is for reducing the water demand and highly enhancing flowability and overall workability. The high powder content, as well as the use of viscosity modifying agents are to increase plasticity and viscosity of the SCC mix *(Campion and Jost 2000), (Frank and Fritz 2001).*

Dirch H. et al. 2000, studied the effect of sand grading, particle shape and surface texture on the rheology of SCC. They found that increasing the fineness of sand particles and the (fine aggregate / total aggregate) ratio lead to increase the yield stress and plastic viscosity.

Su K. et al. 2002, studied the effect of sand ratio (S/A = fine aggr. volume to total aggr. volume) on the elastic modulus of SCC. They found that the flowability of SCC increases with the increase in S/A ratio, meanwhile the modulus of elasticity of SCC is not significantly affected by this ratio when the total aggregate volume is kept constant.

Several test methods are used to evaluate filling ability (flowability), passing ability (passibility), and segregation resistance (stability) of fresh SCC. Among these test methods are the followings:

- **Slump flow** and $\mathbf{T_{50cm}}$ test to evaluate *flowability* and *stability*.
- **L-box** test to assess *flowability* and *passing ability*.
- **U-box** test to measure the *filling ability*.
- **V-funnel** test to determine the *filling ability*.

All these tests were cited from references and conducted by *(Ali 2006).*

Internal Sulfate Attack:

This attack is one of the vigorous problems in Iraq due to the presence of sulfates in aggregate of the concrete mix especially fine aggregate. Many researchers have studied the effect of sulfate contaminated aggregate on properties of hardened concrete *(Al-Damirchi and Al-Rawi 1973), (Al-Samarai 1976), (Al-Kadhimi and Hamid 1983), (Al-Qaisi 1989), and (Al-Rawi et al. 1997).*

It is believed that the formation of Calcium-sulfoaluminate in early stage, when concrete is still plastic, expansion does not cause any appreciable disruption or reduction in strength because the formation of Sulfoaluminates is not associated with a development of internal stresses as fresh concrete possesses plastic rheology. But internal stresses will develop due to the formation of Calcium-sulfoaluminate in the hardened concrete stage. *(Lea 1976),* and *(Neville 1995)* stated that gypsum from different interior source (cement, fine aggregate, coarse aggregate) reacts with some components of cement as Tricalcium Aluminate $\boldsymbol{C_3A}$. Such reaction produces Calcium-sulfoaluminate (Ettringite) $3CaO.Al_2O_3.3CaSO_4.31H_2O$. The volume of this product is 227% of the volume of reactants. The hydration process of Calcium Silicate (C_3S , C_2S) yields Calcium hydroxide [$Ca(OH)_2$] which reacts with Sulfates to produce gypsum. The volume of gypsum is 124% of the volume of reactants. These volumetric changes are accompanied by interior stresses which cause strength reduction and disintegration.

Al-Qaisi 1989 found that the activity of Sulfates present in sand depends on its grain size and fineness. Fine gypsum grains are more active in sulfate attack than coarse grains gypsum.

Abdul-Latif 1997 concluded that each type of cement has a certain behavior in relation to the (SO_3) content of sand. This behavior depends on number of factors; one of them is SO_3 content in cement.

Experimental Work

Materials and Mixes

Cement

Ordinary Portland cement (OPC) brought from Kufa cement plant was used throughout the present study. This cement conforms to the Iraqi standard specification (**IQS No.5-1984**). The chemical composition and physical properties of this cement are presented in Table (1).

Table (1): Chemical composition and physical properties of Ordinary Portland cement used

Oxides	% by weight	Limits of Iraqi Specification IQS No.5/1984
CaO	61.94	_
SiO_2	20.80	_
Al_2O_3	5.52	_
Fe_2O_3	4.00	_
MgO	1.85	≤ 5.00
SO_3	2.5	≤ 2.8
$Na_2O + K_2O$	0.85	_
Free lime	0.97	_
Loss on Ignition	3.3	≤ 4.00
Insoluble Residue	0.90	≤ 1.50
Lime Saturation Factor	0.88	0.66 -1.02
Main compounds (Bogue equations)	**% by weight of cement**	**Limits of Iraqi Specification IQS No.5/1984**
C_3S	41.48	_
C_2S	28.34	_
C_3A	7.86	_
C_4AF	12.17	_

Physical Properties	Test Result	Limits of Iraqi Specification IQS No.5/1984
Specific surface area (Blaine method), cm^2/gm	3300	≥ 2300

Setting time (Vicate apparatus), Initial setting, h:min Final setting, h:min	**2:10 3:30**	**≥ 00:45 ≤ 10:00**
Compressive strength, N/mm² 3-days 7-days	**27.5 38.0**	**≥ 15.00 ≥ 23.00**
Soundness (Autoclave expansion), %	**0.27**	**< 0.8**

Fine Aggregate (Sand):
Kerbala sand brought from Al-Akhaidher region was used as fine aggregate in the present study. Sieve analysis and other properties of this sand are listed in table (2).

Table (2): Grading and other properties of fine aggregate.

Sieve size	**Cumulative Passing %**	**Limits of Iraqi Specification IQS No.45/1984 for zone (2)**
9.5 mm	**100**	**100**
4.75 mm	**97**	**90 – 100**
2.36 mm	**82**	**75 – 100**
1.18 mm	**71**	**55 – 90**
0.6 mm	**55**	**35 - 59**
0.3 mm	**27**	**8 – 30**
0.15 mm	**4.0**	**0 – 10**
Physical properties	**Test results**	**Limits of Iraqi Specification IQS No.45/1984**
Specific gravity G	**2.55**	**—**
Sulfate content as SO_3	**0.4 %**	**≤ 0.5 %**
Absorption	**1.5 %**	**—**
Fine materials	**0.95 %**	**≤ 5 %**
Fineness modulus FM	**2.64**	

Gypsum:
Variable SO_3 contents in the sand were achieved by adding gypsum obtained from crushing natural gypsum rocks to a grain size identical to the gradation of sand. The

chemical composition of the gypsum used is listed in table (3). The achieved contents of SO_3 by wt. of sand were: **0.4%, 1.0%, 1.5%, and 2.5%.**

Table (3): Chemical composition of the gypsum used.

Compound composition	Content %
SiO_2	8.74
CaO	31.88
Al_2O_3	1.42
Fe_2O_3	0.70
MgO	0.97
SO_3	41.10
L.O.I	15.19

Coarse Aggregate (Gravel):

Rounded river gravel brought from Al-Nebaee region was used as coarse aggregate in the present work. Its gradation and other properties are listed in table (4). The maximum size of gravel was **12.5mm** which is preferred for **SCC** *(Ali 2006)*.

Table (4): Grading and other properties of coarse aggregate.

Sieve size	Cumulative Passing %	Limits of Iraqi Specification No.45/1984 5-20mm size
20 mm	100	100
12.5 mm	100	90 – 100
9.5 mm	69	50 – 85
4.75 mm	6.45	0 – 10

Physical properties	Test result	Limits of Iraqi Specification No.45/1984
Specific gravity G	2.63	—
Sulfate content as SO_3	0.09 %	$\leq$ 0.1 %
Absorption	0.5 %	—
Fine materials	0.0 %	$\leq$ 3 %

Superplasticizer:

A liquid superplasticizer (high range water reducing admixture) commercially known as [*Ura-plast SP]* was added to the concrete mix to obtain high workability and fluidity. This superplasticizer can be classified as class **F** and **G** according to *ASTM C494-86* as it has the capability of obtaining more than **12%** reduction in mixing water for a given consistency, besides it has a retarding effect to setting. According to trials it was found that the most suitable dose of *Ura-plast SP* is (**4** liters per 100kg of cement). The typical properties of this superplasticizer are listed in table (5).

Table (5): Properties of *Ura-plast* superplasticizer.

Subsidiary effect	setting and hardening retarder
Form	viscous liquid
Color	dark brown
Relative density	1.1 at 20 C
Viscosity	128 + 3 cps at 20 C
pH value	6.6
Transport	not classified as dangerous

Filler:

Limestone powder named locally as "Ghobra" was used filler to increase the amount of powder content (cement+filler) to produce *SCC* mixes in the present work. The fineness of limestone powder was measured by *Blaine method* and found to be **150 m^2/kg**. The particle size which is less than 0.125mm acts to increase workability and density of the *SCC*. This filler conforms to ***BS 8500-2, 4.4*** specification. The chemical composition of the used limestone powder is given in table (6).

Table (6): Chemical composition of limestone powder.

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	L.O.I
%	52.76	1.40	0.70	0.17	0.10	2.91	40.60

Mix Design and Proportions

The Japanese mix design procedure (cited by *EFNARC 2002*) was followed to design the mix proportions of *SCC*. Many trials were made to fix the proportions so as to obtain *SCC* mix maintaining the ranges and limits of fresh *SCC*. Table (7) shows the mix proportions of the *SCC* mix used in the present study.

Table (7): Mix proportions of the *SCC* mix.

Cement (kg/m^3)	Limestone Powder (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)	W/C ratio	SP %by wt. of cement
450	75	725	750	180	0.40	4.0

Hence, the mix proportion by weight of cement is (1 : 1.61 : 1.66 : 0.40) (cement : sand : gravel : water).

The weight of the ground gypsum rock which was added to the sand was calculated using the following equation:

W = (R-P)*S / N

Where: W = weight of ground gypsum to be added to the mix in kg.

R = percentage SO_3 required in sand %.

P = percentage SO_3 present originally in sand %.

S = weight of sand in the mix kg.

N = percentage SO_3 in the gypsum rock = 0.411.

Four mixes were produced for casting specimens of the present study:

M1 (Reference mix): No ground gypsum was added to the mix (only with the originally present SO_3 content in sand = 0.40%), total SO_3 in conc. =3.77% by wt. of cement.

M2: SO_3=1.0% by wt. of sand, total SO_3 in conc. =4.74% by wt. of cement.
M3: SO_3=1.5% by wt. of sand, total SO_3 in conc. =5.55% by wt. of cement.
M4: SO_3=2.5% by wt. of sand, total SO_3 in conc. =7.16% by wt. of cement.
M5: SO_3=3.5% by wt. of sand, total SO_3 in conc. =8.77% by wt. of cement.

Mixing, Casting and Curing

To acquire *SCC* mix maintaining its properties during the fresh state, the procedure of mixing the four mixes with the proportions mentioned above is as follows:

1. The total amount of fine aggregate (sand with the added gypsum) and 1/3 of the mixing water were poured in the mixer and mixed for 1 minute.
2. The amounts of cement, filler (limestone powder) and 1/3 (water+SP) were added to the mixer and mixed for 30 seconds.
3. 1/2 of the gravel and 1/3 (water+SP) were added and mixed for another 30 seconds.
4. The remaining 1/2 of the gravel and the remaining 1/3 of SP were added and mixed for a final 1 minute.

Testing of fresh concrete was conducted on the produced *SCC* mix. Then, from the same mix the following samples were cast for mechanical properties testing of the hardened concrete:

- **18** cubes of (150mm) were cast for compressive strength determination; each 6 cubes were tested at 7 days age, 28 days age and 60 days age.
- **9** cylinders of (100*200mm) were cast for splitting tensile strength determination; each 3 cylinders were tested at 7 days age, 28 days age and 60 days age.
- **9** prisms of (100*100*400mm) were cast for flexural strength determination; each 3 prisms were tested at 7 days age, 28 days age and 60 days age.
- **3** cylinders of (150*300mm) were cast for measuring modulus of elasticity at 28 days age.

No vibration or compaction, neither externally nor internally had been applied to consolidate the specimens.

The specimens were covered with polyethylene sheets immediately after casting for 24 hours. Then, they are moist cured until the date of testing.

Fresh Concrete Testing

The fresh concrete tests below are specially devised to assess *filling ability* (**flowability**), *passing ability* (**passibility**) and *segregation resistance* (**stability**) of *SCC*. But, there is no unique test so far devised to measure the three properties together. It is important to mention that none of the fresh *SCC* test methods has yet been standardized, and the tests described below are not yet perfected or definitive (*EFNARC 2002*). These tests are:

1. **Slump flow and T_{50cm} test**

   The same steel hollow cone with the steel base plate, which are used to measure slump of normal concrete, are used to measure *flowability* of *SCC* by measuring the time required for the diameter of the concrete mix to spread (after raising the steel cone vertically) to reach a diameter of 50cm (**T_{50cm}**). Then, measuring the final diameter reached of the free flowing mix (**slump**

flow). This test can also indicate the resistance of the mix to segregation. Fig.(1) shows the mold, base plate and details of this test.

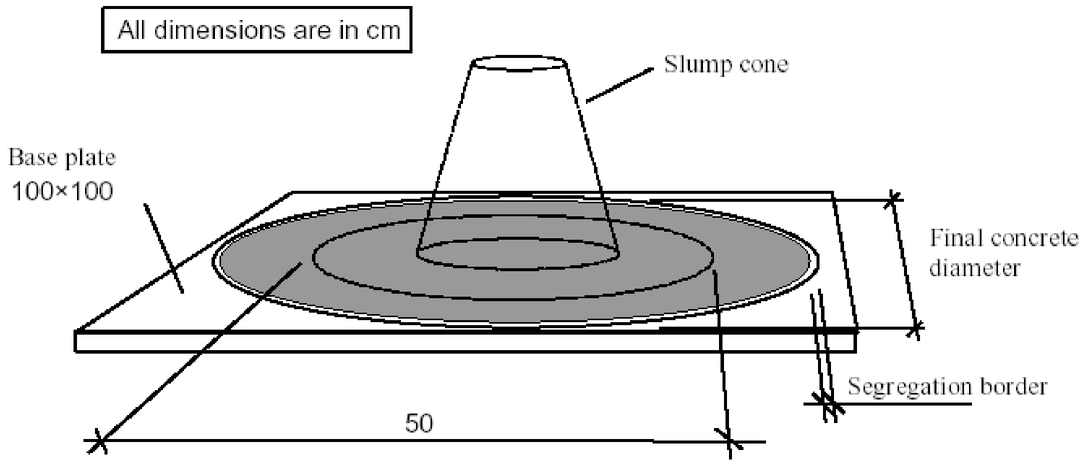

Fig. (1): Apparatus for slump flow and T50cm test.

2. **L-box test**

This test estimates the *passibility* of concrete and indicates the degree to which the passage of concrete through the reinforcing bars is restricted. The apparatus of this test is made according to the Japanese experience for under water concrete described by *Petersson et al. 1996.* The **L-box** apparatus is shown in Fig.(2). When the sliding gate is closed the vertical leg of the apparatus is filled with (12.7 liters) of concrete. Then, the sliding gate is lifted and the concrete is allowed to flow out into the horizontal leg passing through the gaps between the bars and when concrete stops flowing, the initial H_1 and the final height H_2 are measured and the ratio of H_2/H_1 is calculated.

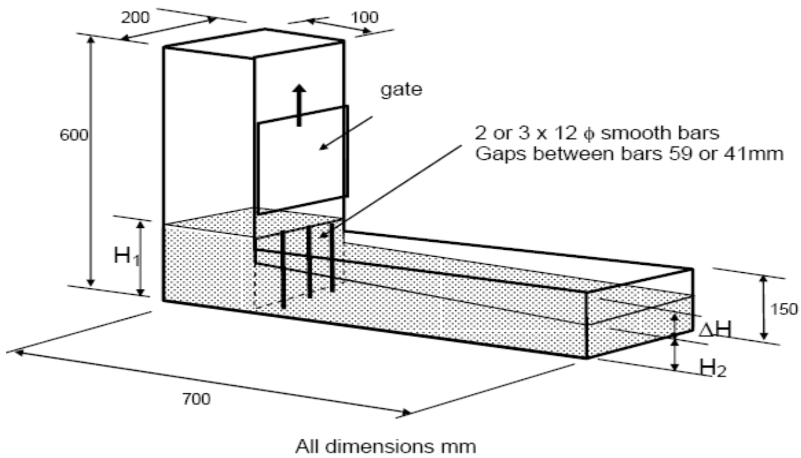

Figure (2): L-box test

3. U-box test

This test is devised to indicate the *filling ability (flowability)* of *SCC*. Fig.(3) shows the **U-box** apparatus. This apparatus consists of steel U shaped box with the two legs adjacent together and opened upward. There is a passage for concrete to flow through downward. The passage opening is restricted by steel bars and controlled by a sliding gate. When the sliding gate is closed one leg of the **U**-box is filled with about (20 liters) of *SCC***.** Then, the sliding gate is lifted and the concrete is allowed to flow out to the other leg passing through the gaps between the bars and when concrete rests and stops moving, the height of concrete in the two legs R_1 and R_2 are measured and the difference between them R_1-R_2 is calculated.

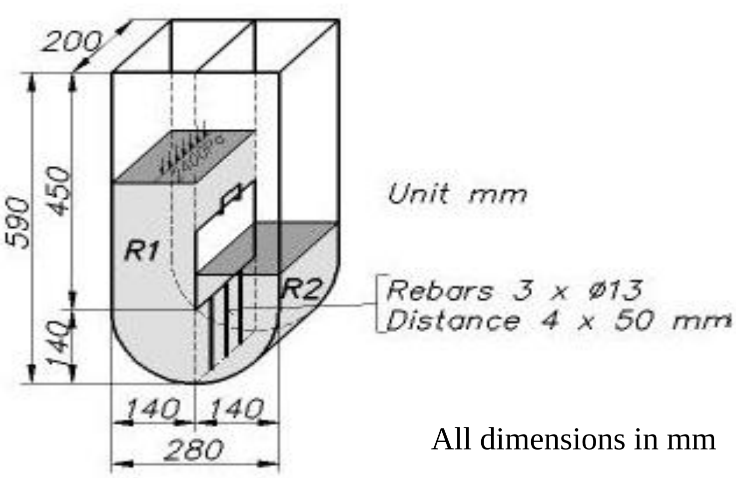

Figure (**3**): The U-box test.

4. V-funnel test

This test is used to determine the *filling ability (flowability)* of concrete with a maximum size of coarse aggregate not exceeding (20mm). This apparatus was devised according to *Okamura 1998* efforts. The test is performed by filling the funnel with about (12 liters) of *SCC* without any tamping or compaction, then opening the trap door (below the funnel) and allowing concrete to flow from the funnel by gravity and recording the time required for flowing all the concrete out of the funnel. Fig.(4) shows the apparatus of the **V**-funnel test.

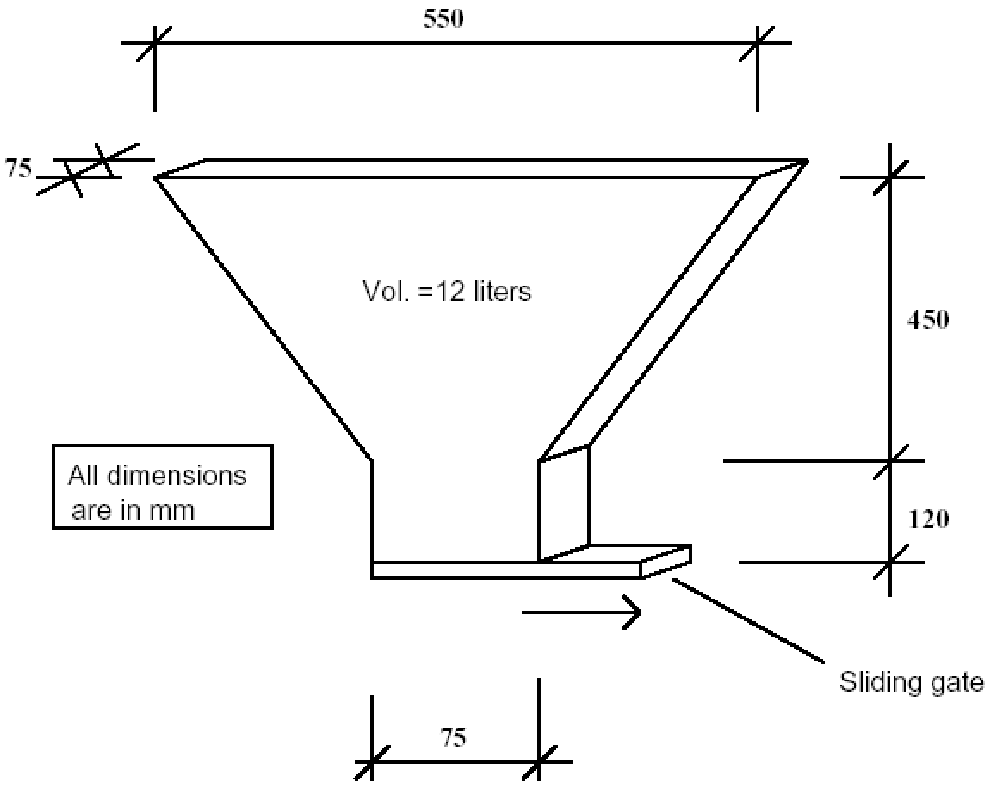

Fig. (4): V-funnel test.

Hardened Concrete Testing

The following tests are performed to measure some of the mechanical properties of the hardened *SCC* containing different percentages of sulfates in fine aggregate:

1. ***Compressive Strength:***

Concrete cubes of (150mm) were used to measure the compressive strength of *SCC* at the ages of (7, 28 and 60) days. This test was performed according to *"BS 1881:part116:1983"* specification with the exception that there is no compaction by tamping or vibration performed to consolidate the concrete in moulds but only the upper surface of cube is struck by a trowel and the concrete surplus is cutoff and removed. The cubes were moist cured until the age of testing. A total number of (**90** cubes) were cast and tested throughout the research.

2. ***Splitting Tensile Strength:***

Concrete cylinders of (100*200mm) were used to measure the splitting tensile strength of *SCC* at the ages of (7, 28 and 60) days. This test was conducted according to *"BS 1881:part117:1983"* specification but without any compaction or vibration. The cylinders were moist cured until the age of testing. A total number of (**45** cylinders) were cast and tested throughout the research. The splitting tensile strength ($\mathbf{f}_{sp}$) is calculated from the following equation:

$\mathbf{f}_{sp} = 2P/\prod LD$ ………………. (1)

where: P = the maximum resisted load, N

L = the cylinder height = 200mm

D = the cylinder diameter = 100mm

3. Flexural Strength (Modulus of Rupture):

SCC prisms of dimensions (100*100*400mm) were cast and tested for flexural strength determination. This test was performed according to *"BS*

5328:part4:1990" specification but without any compaction or vibration to the fresh concrete. The concrete prisms were moist cured until the age of testing (7, 28 and 60) days. This test was performed using *two-point load*. A total number of (**45** prisms) were cast and tested throughout this work. Modulus of rupture (**R**) is calculated from the following equation:

$\mathbf{R} = P\, l / b\, d^2$ ……………….. (2)

Where: P = maximum resisted load, N
l = span length = 340mm
b = specimen width = 100mm
d = specimen depth = 100mm

This equation is applied when the location of failure crack is between the two applied point loads.

***4. Static Modulus of Elasticity*:**

Concrete cylinders of dimensions (150*300mm) were used to determine *Static Modulus of Elasticity*. This test was performed according to *"BS 1881:part121:1983"* specification but without any compaction or vibration. The cylinders were moist cured until the age of testing (28) days. Capping of the upper and lower bases of the cylinder was then accomplished by a layer of gypsum. The test was conducted by subjecting the cylinder to a compression load until failure. Two steel proving rings clamped to the cylinder leaving 200mm gauge length between each other. A dial gauge of (0.01 mm/div.) accuracy was fixed between the proving rings to measure contraction strain in the concrete cylinders due to the applied compression. The modulus of elasticity $\mathbf{E}_c$ is calculated using the following equation:

$\mathbf{E}_c = (S_2 - S_1) / (\varepsilon_2 - \varepsilon_1)$ ……………… (3)

Where: $\mathbf{E}_c$ = static modulus of elasticity, GPa
S_2 = stress corresponding to 40% of ultimate load, MPa
S_1 = stress corresponding to a longitudinal strain of $50*10^{-6}$, MPa
ε_2 = longitudinal strain produced by S_2
$\varepsilon_1 = 50*10^{-6}$

Results And Discussion

Fresh Concrete Test Results

Table (8) gives the experimental results obtained from *Slump flow*, ***T**50cm*, ***L**-box*, ***U**-box*, and ***V**-funnel* tests that were conducted throughout the present work. It can be seen that the test results are within the limits of *Self-compacting Concrete* results established in *EFNARC 2002* which means that the designed concrete mix in the present work conforms to the specifications of *SCC*. Also, it can be noticed that the percentage of gypsum in fine aggregate has no effect on any of the results of the above workability tests i.e. has no interference with the *flowability*, *passibility*, nor *stability* of the *SCC* mix.

Table (8): Fresh concrete test results

Test	**SO_3 % by wt. of sand**					***EFNARC SCC limits***
	0.4	**1.0**	**1.5**	**2.5**	**3.5**	
Flow, mm	810	810	810	805	805	600-900
***T** 50cm, sec*	3.5	3.5	3.5	3.5	3.5	2-5
H_2/H_1, %	90	90	90	90	90	80-100
R_1-R_2, mm	15	15	15	15	15	0-30
***V**-time, sec*	8	7	8	8	8	6-15

Hardened Concrete Test Results

1. Compressive Strength Results:

Table (9) presents *cube compressive strength* test results for the *SCC* mixes with different SO_3 content in fine aggregate. Each test result represents the mean value of the compressive strength of six cubes.

It can be seen that the *Optimum Gypsum Content of fine aggregate* which gives the highest values in compressive strength of SCC is at (SO_3=1.0%) by wt. of fine aggregate and the total gypsum content in concrete is (SO_3=4.74%) by wt. of cement. This limit of gypsum content yields maximum compressive strength at 7, 28 and 60 days age with a percentage of ***increase*** in compressive strength (13.3%, 15.0% and 12.5%) respectively. Then, increasing sulfate content in fine aggregate beyond this limit *yields remarkable decrease in the compressive strength of SCC* at the three ages of testing. The percentage of ***decrease*** was about (0.0%, 6.6%, 10.0%) at 7 days age, (5,0%, 17.5%, 25.0%) at 28 days age and (4.1%, 27.1%, 35.4%) at 60 days age when SO_3 content in fine aggregate was increased from 0.4% to (1.5%, 2.5% and 3.5%) respectively. This reflects an intensive deleterious effect of sulfates on compressive strength of *SCC*. It can be seen also that this deleterious effect is more pronounced with age development. It can also be pointed out that at the high percentages of SO_3 in fine aggregate (2.5% and 3.5%) the development of compressive strength almost vanishes and leveled.

This behavior indicates that the deleterious effect of sulfates in fine aggregate of *SCC* is identical to that in normal concrete in spite of the higher content of cement in *SCC as this concrete includes also high content of fine aggregate*. This leads to conclude that: ***"The limitation of SO_3 content in fine aggregate of IQS No.45-1988 specification can fairly be modified to be not exceeding 1.0% by wt. of fine aggregate in SCC to avoid the adverse effect of internal sulfate attack"***.

Table (9): Relationship between cube compressive strength and SO_3 content in fine aggregate of *SCC*

Mix designation	***SO_3* content in fine aggregate %**	**Total *SO_3* content in concrete %**	**Cube compressive strength MPa**		
			7 days	**28 days**	**60 days**
M1	**0.4**	**3.77**	**30**	**40**	**48**
M2	**1.0**	**4.74**	**34**	**46**	**54**
M3	**1.5**	**5.55**	**30**	**38**	**46**
M4	**2.5**	**7.16**	**28**	**33**	**35**
M5	**3.5**	**8.77**	**27**	**30**	**31**

2. **Splitting Tesile Strength:**

Table (10) presents the values of *splitting tensile strength* at (7, 28 and 60) days age for *SCC* specimens with different percentages of SO_3 in fine aggregate. Each value of test results represents the mean value for three *SCC* cylinders. It can be seen that with increasing of the SO_3 content in fine aggregate from 0.4% to 1.0% the splitting tensile strength ***increases*** by about (10.5%, 10.4%, 9.1%) at (7, 28, 60) days age respectively. This limit of SO_3 seems to be the same ***OGC*** in fine aggregate of SCC found from compressive strength results. Then, as the gypsum content in fine aggregate increases beyond this limit, splitting tensile strength decreases appreciably. The percentage decrease was (5.2%, 21.0%, and 26.3%) at 7 days age, (2.0%, 18.7%, and 33.3%) at 28 days age and (7.2%, 18.2%, and 40.0%) at 60 days age when the SO_3 content in fine aggregate was increased from 0.4% to (1.5%, 2.5% and 3.5%) respectively. It can be indicated that the deleterious effect of sulfates in fine aggregate is more pronounced compared with their effect on compressive strength.

Table (10): Relationship between splitting tensile strength and SO_3 content in fine aggregate of *SCC*

Mix designation	SO_3 content in fine aggregate %	Total SO_3 content in concrete %	Splitting tensile strength MPa		
			7 days	28 days	60 days
M1	0.4	3.77	3.8	4.8	5.5
M2	1.0	4.74	4.2	5.3	6.0
M3	1.5	5.55	3.6	4.7	5.1
M4	2.5	7.16	3.0	3.9	4.5
M5	3.5	8.77	2.8	3.2	3.3

3. **Flexural Strength:**

Table (11) gives test results of *flexural strength* at (7, 28 and 60) days age for *SCC* specimens with variable percentages of SO_3 in fine aggregate. Each value of the test results represents the mean value for three *SCC* prisms tested by two-point load until fracturing. It can be seen that as the SO_3 content in fine aggregate increases from 0.4% to 1.0%, flexural strength also increases at about (8.0%, 10%, 6.0%) at (7, 28, 60) days respectively. Then, when increasing of SO_3 content in fine aggregate beyond 1.0% optimum limit, flexural strength decreases remarkably at the three ages of testing. The percentage decrease was (4.0%, 16.0%, and 28.0%) at 7 days age, (0.0%, 13.3%, and 33.3%) at 28 days age and (3.0%, 12.1%, 36.3%) at 60 days age when SO_3 content in fine aggregate was increased from 0.4% to (1.5%, 2.5% and 3.5%) respectively.

It can be pointed out that the adverse effect of sulfates in fine aggregate is more intensive than their effect on compressive strength. This mechanical behavior can be explained by the intensive micro-cracking due to the delayed ettringite formation and the following progressive pronounced expansion when internal sulfate attack is acting by the continuous supplement of sulfates from sand (*Collepardi 1999*) and (*Collepardi 2001*).

Table (11): Relationship between flexural strength and SO_3 content in fine aggregate of *SCC*

Mix designation	*SO_3* content in fine aggregate %	Total *SO_3* content in concrete %	Flexural strength MPa		
			7 days	28 days	60 days
M1	0.4	3.77	5.0	6.0	6.6
M2	1.0	4.74	5.4	6.6	7.0
M3	1.5	5.55	4.8	6.0	6.4
M4	2.5	7.16	4.2	5.2	5.8
M5	3.5	8.77	3.6	4.0	4.2

4. Young's (Static) Modulus of Elasticity:

Table (12) demonstrates the experimental values of *Young's (static) modulus of elasticity* $\boldsymbol{E_c}$ at 28 days age for *SCC* specimens with different *SO_3* content in fine aggregate. Each value of modulus of elasticity $\boldsymbol{E_c}$ represents the mean value for two test cylinders.

From results it can be deduced that the same Optimum Gypsum content in fine aggregate (SO_3=1.0%) which gives the highest value of E_c can be recognized. It can be seen also that increasing the *SO_3* content in fine aggregate of *SCC* beyond this limit affects adversely the modulus of elasticity. This indicates that with the increase of sulfates, *SCC* responds to equal stresses by higher strains i.e. shows softer stiffness behavior. Hence, based on the preceding finding, it can be expected that with the increase of *SO_3* content in fine aggregate of *SCC*, ***Poisson's ratio*** increases also.

Table (12): Young's (static) modulus of elasticity of *SCC* at 28days age with different SO_3 content in fine aggregate

SO_3 content in fine aggregate %	0.4	1.0	1.5	2.5	3.5
E_c GPa	32.6	34.8	32.4	29.9	26.8

Conclusions

1- Percentage of sulfates in fine aggregate of *SCC* doesn't affect any of the fresh concrete properties tested by *flow test, T_{50cm}, L-box, U-box, and V-funnel* tests.

2- There is an *Optimum Gypsum Content* in fine aggregate of SCC which gives highest compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity. This limit was found to be (SO_3=1.0%) by wt. of fine aggregate.

2- The presence of sulfates in fine aggregate of *SCC* (higher than 1.0% *SO_3* by wt. of fine aggregate) decreases remarkably *compressive strength, splitting tensile strength, flexural strength and static modulus of elasticity.*

3- The adverse effect of sulfates present in fine aggregate is more intensive on flexural strength and splitting tensile strength compared with their deleterious effect on compressive strength.

4- Increasing sulfates content in fine aggregate of *SCC* beyond the optimum limit decreases static modulus of elasticity leading to a softer stiffness behavior.

5- The current study recommends that the present Iraqi specification *IQS No.45-1988* which limits the *SO_3* content in fine aggregate "not to exceed 0.5%" can fairly be modified to "not to exceed 1.0%" for the requirements of producing *Self-compacting Concrete*.

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