Effect of additives' ratios on workability and strength of self-compacting concrete

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ABSTRACT

Self-compacting concrete (SCC) is a new and an emerging technology in the construction industry. SCC is highly workable concrete that can flow through congested reinforced structural elements under its own weight without the need for vibration, and adequately fill voids without segregation or excessive bleeding. This type of concrete must have excellent flow ability and, at the same time, adequate segregation resistance independently of the casting method (pouring or pumping). In the present work, several proportions of the constituent materials of the Self-Compacting Concrete mix, which are the cement, sand, gravel, water, silica fume, and superplasticizer are attempted and tested. Three types of flow test are implemented to evaluate the workability of the fresh mixes while the compression test is used to measure the strength of the hardened concrete. It was found that adding silica fume contributes significantly in increasing the compressive strength and enhancing the self- leveling status of concrete. Also, it was found that self-compactability can be achieved by optimizing the plasticizing additive dose.

Keywords: self-compacting concrete, superplasticizer, cementatious materials, silica fume and workability

الملخص باللغة العربية

تعتبر الخرسانة الذاتية الرص تكنولوجيا حديثة في الصناعة الإنشائية، وهي خرسانة ذات قابلية تشغيل عالية للغاية، بحيث تستطيع الانسياب خلال الأعضاء الإنشائية الكثيفة التسليح تحت تأثير وزنها الذاتي دون الحاجة إلى استعمال الهزاز، وتملأ بدرجة كافية الفجوات دون حصول الانعزال أو النضح . يجب أن يكون لهذا النوع من الخرسانة قابلية تدفق ممتازة، وفي في نفس الوقت، مقاومة انعزال كافية، بغض النظر عن طريقة الصب (السكب أو النضح). في هذا البحث، تم داسة عدةَ نسب من المكونات الأساسية للخرسانة الذاتية الرص: الإسمنت، الرمل، الحصى، الماء، غبار السيليكا والملدنات. أجريت ثلاثة أنواع من فحوصات التدفق لتقييم قابلية التشغيل للخرسانة الطرية، بينما اسُتخدم فحص الانضغاط لقياس مقاومة الخرسانة المتصلبة. وُجد بأن إضافة غبار السيليكا يسهم بشكل كبير في زيادة مقاومة الانضغاط وتحسين حالة الرص الذاتي للخرسانة. كذلك وُجد بأن قابلية الرص الذاتي يمكن أن تحقق بإضافة الجرعة المثلى للملدن.

INTRODUCTION

Self-compacting concrete (SCC) is a new type of concrete. It fills all sections of forms without mechanical vibration, and has reasonable flow-ability, homogeneity, resistance against segregation and mechanical strengths (1,2). The first completed prototype of self-compacting concrete was in 1988 using materials available on the market (3,4). Several articles dealing with the SCC were published round-world; in Western Europe, Canada, Sweden and Netherlands. SCC showed good performance in compressive strength test and could fulfill other construction needs because its production has taken into consideration the requirements in the structural design (5).
The SCC has now been taken up with enthusiasm throughout the world for both site and precast work (6). Self-compacting concrete has been described as "the most revolutionary development in concrete construction for several decades" (7-9). In this study, self-compacting concrete was produced by using specific super plasticizer available in markets widely.

METHODS AND EXPERIMENTS

Linear optimization mix. Proportion

The optimum mix design method is based on the rational mix design method of Okamura and Ozawa (3), but was modified by using the mathematical approach of linear optimization to produce an optimum mixture of water, powders and aggregate (10). The mix design procedure undergoes the following steps:

Step 1: A typical air content is chosen (1- 1.5 % for non-air-entrained).
Step 2: The coarse aggregate content is fixed (table 1).
Step 3: A binder composition is chosen using the guidelines in table (1) or from past experience.
Step 4: The maximum water/binder ratio is chosen to ensure that the following three conditions are satisfied:
1-The paste has sufficient plastic viscosity (before addition of superplasticizer to provide adequate segregation resistance. This is estimated by means of the specific gravity of the binder, retained water ratio and deformation coefficient.
2- The concrete has sufficient compressive strength.
3- The durability requirements were met.
The minimum value of water/binder ratio from 1, 2 and 3 was chosen.
Step 5: The volume of sand in the mortar was chosen.
Step 6: The paste content is calculated and adjusted if outside the limits (table 1).
Step 7: The water and binder contents were calculated with the water being a limiting factor and set before step 5 if greater than 200 kg/ m^3.
Step 8: The superplasticizer dosage was then estimated from tests on the mortar component of the mix using the V-funnel test.
Step 9: The concrete mix was then made and tested for fresh concrete properties.

Table (1): Limiting mix proportions for successful self –compacting concrete (10)

	Maximum aggregate size 20 mm	Maximum aggregate size 20 mm
Coarse aggregate content (kg/m^3)	0.5*dry rodded unit wt	0.5-0.54*dry rodded unit wt
Max water content (kg/m^3)	200	
water/powder ratio by wt (w/p)	0.28-0.40	0.28-0.50
water/(powder+fine aggregate) ratio by wt	0.12-0.14	0.12-0.17
Paste volume	0.38-0.42	

Experimental investigation

The experimental work was carried out in the Materials laboratory of civil engineering department at University of Basra. The following steps were achieved in this phase.

1- Concrete mix design: Until now a days, there is no standard method for mix design of SCC and many academic institutions had begun to develop their own mix proportioning methods. The most important thing in laboratory trials is that they should be used to verify properties of the initial mix composition with respect to the specified characteristics and classes. If necessary, modifications to the mix composition should then be made.
Self- compactability can be largely affected by the characteristics of materials and the mix proportion. Linear Optimization Mix. Proportion for self-compacting concrete using a variety of materials is necessary. This method is modified on Rational Mix-Design Method (Okamura and Ozawa method) (3,4).

2- Concrete mix: Mixing procedure is important to obtain the required workability and homogeneity of the concrete mix. Concrete was mixed in drum laboratory mixer, with a capacity of 0.1m^3. Before starting to mix, it is necessary to keep the mixer clean, moist and free from water. Based on Jin's work (11), the mixing procedure is shown in figure (1).

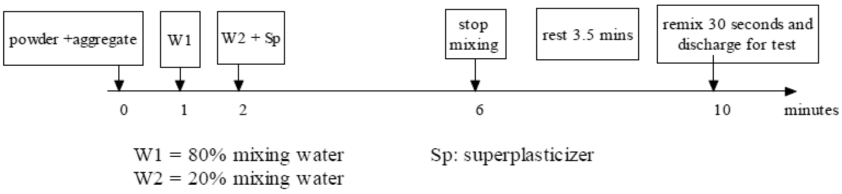

Figure (1): The mixing procedure for concrete (11).

3- Preparation of specimens: Standard cubes (150*150*150 mm) were used according to BS1881: part 116 (12).
Mold of cubes have been cleaned and oiled. After pouring the concrete into the molds, there is no need to compact the concrete either by using vibrators or hand compaction. Even the concrete did not require any finishing operation. After 24 hours of casting the specimens were demolded and were transferred to the curing tank. After the curing period of 7 and 28 days specimen removed from curing tank and screed off the all face of specimen and taken for testing.

4- Fresh and harden properties of self-compacting concrete: In the fresh state, many different test methods have been developed to characterize the properties of SCC. Hence, each mix design should be tested by more than one test method for the different workability parameters. The flow characteristics of self-compacting concrete are measured from slump flow test tool, V-funnel test tool and L-box test tool. Also the strength characteristics of self-compacting concrete like compressive strength.
A test result is the average of at least three standard cured strength specimens made from the same concrete sample and tested at the same age. In most cases strength requirements for concrete are at an age of 7 and 28 days of curing. The concrete cubes, after 28 days were tested for their compressive strength.

Materials

Satisfactory SCC is obtained by selecting suitable materials, and good quality control.

Cement: Cement particles in SCC are highly dispersed by the superplasticizer, which gives available in local markets was used in this work. The cement used in this study is Iraqi Portland cement (sulfate resistant cement) (Al-Muthena). It had satisfied the requirements of Iraqi specifications No. 5/ 1984 (13).

Sands: The fine aggregate used was local sand; the sand that used to SCC is the same that used in conventional concrete (11). It was tested and proved to be satisfying the requirements of Iraqi specifications No.45/1984 (14).
Gravel: The coarse aggregate used was local gravel, the gravel used in conventional concrete can be used in SCC (11). It was tested and proved to be satisfying the requirements of Iraqi specifications No.45/1984 (14).

Water: Normal potable water from reverse osmoses plant was used as mixing water.

Mineral additions: A variety of powder materials have been used in SCC because of the advantages of being able to select the powder composition. Three main types of powder are used (11):

- Cements, such as Portland cement (PC), high Belite cement, etc.
- Cement replacement materials (CRMs), such as pulverised fly ash (PFA), ground granulated blast furnace slag (GGBS), and condensed silica fume (CSF).
- Inert or near-inert materials, such as limestone powder (LSP).

In this study, silica fume is used with cement to produce SCC.

Effect of silica fume on concrete

Silica fume is a very fine non crystalline silica produced in electric arc furnaces as a byproduct of the production of elemental silicon or alloys containing silicon, also known as condensed silica fume or microsilica.
Due to the amorphous nature of the silica with high SiO_2 contain (typically ≥ 85%) and extremely small particle size, makes the silica a highly reactive pozzolan, which effectively improve the concrete in the following manner (10,11):

$$\text{Cement} + H_2O \longrightarrow \underset{65\%}{\text{CSH (Gel)}} + \underset{35\%}{Ca(OH)_2} + \text{Heat}$$

$$\text{Cement} + SiO_2 + H_2O \longrightarrow \underset{(70-97)\%}{\text{CSH (Gel)}} + \underset{(30-0)\%.}{Ca(OH)_2} + \text{Heat}$$

Properties of silica fume concrete can then be listed as:

- Ease of Placement.
- Low Heat of Hydration.
- Increased Compressive Strength.
- Low Permeability.
- Enhanced Durability.
- Abrasion Resistance

Admixtures (Super plasticizer)

All SCC contains a super plasticizer to provide high flowability (10). Super plasticizer enhances deformability and with the reduction of water/powder segregation resistance is increased. High deformability and high segregation resistance is obtained by limiting the amount of coarse aggregate (6,8).

Material added during the mixing process of concrete in small quantities related to the mass of cementitious binder to modify the properties of fresh or hardened concrete (15). The used admixtures are Weber Epsilone HP580 and Tard B, technical description for admixtures respectively are showed in table (2).

Table (2): Technical description of Epsilone HP- 580 and Tard B

Appearance	Liquid (Hp 580)	Liquid (Tard B)
Color	Brown Light	Yellowish
Chloride content	Nil	-
Compatibility	(OPC,MSRC and SRC) Portland *cement *Silica Fume *Fly Ash *Pozzolanic Binders	For all types of cements
Shelf life	Twelve months	Twelve months
Dosage	0.5 liter to 2 liter per 100 kg cementitious content	0.1to 0.6 liters per 100 kg of cement

Tests on fresh self-compacting concrete

In the fresh state, many different test methods have been developed to characterize the properties of SCC. Hence, each mix design should be tested by more than one test method for the different workability parameters. The flow characteristics of self-compacting concrete are measured from slump flow test apparatus, V-funnel test apparatus and L-box test apparatus. Also the strength characteristics of self-compacting concrete like compressive strength. The recommended limits for different fresh properties of SCC by EFNARC are shown in table (3) (16).

1- Slump flow test for measuring flowability: The basic equipment used is the same as for the conventional Slump test (figure 2) (17). The test method differs from the conventional one in the way that the concrete sample placed into the mold has no reinforcement rod and when the slump cone is removed the sample collapses. The diameter of the spread of the sample is measured, ie, a horizontal distance is measured as against the vertical slump measured in the conventional test. While measuring the diameter of the spread, the time that the sample takes to reach a diameter of 500 mm (T_{50}) is also sometimes measured. The Slump Flow test can give an indication about the filling ability of SCC and an experienced operator can also detect an extreme susceptibility of the mix to segregation. However, this information cannot be obtained from numerical results alone, a substantial previous experience in using the test and carrying out construction in SCC is essential.

Table (3): Recommended limits for different fresh properties of SCC by EFNARC (16)

No.	Method	Unit	Typical range of values	
			Min.	Max.
1	Slump flow	mm	650	800
2	T_{50} Slump flow	Sec	2	5
3	V-Funnel	Sec	6	12
4	L-Box	h2/h1	0.8	1

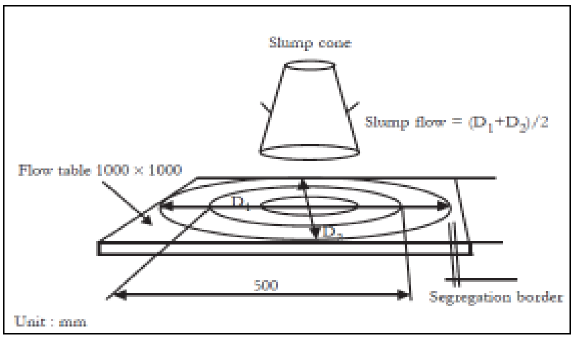

Figure (2): Slump flow test (17)

2- V-funnel test: The V-funnel test was developed in Japan. The equipment consists of a V-shaped funnel (figure 3). The funnel is filled with concrete and the time taken by it to flow through the apparatus measured. This test gives account of the filling capacity (flowability) (17). The inverted cone shape shows any possibility of the concrete to block is reflected in the result.

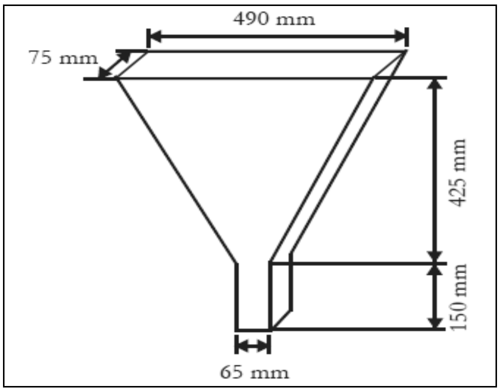

Figure (3): V-funnel (17)

3- L-box test: The L-box test method uses a test apparatus comprising a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door, from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus (figure 4). The concrete ends of the apparatus H1 and H2 measure the height of the concrete at both ends. The L-box test can give an indication as to the filling ability and passing ability (17).

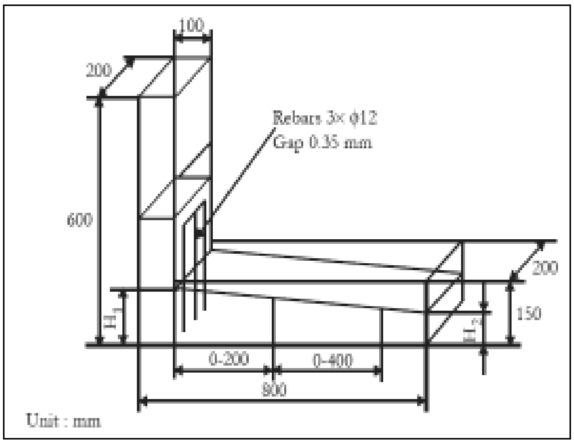

Figure (4): L-box test (17)

RESULTS AND DISCUSSION

In the present study, five trial mixes were attempted and tested both in fresh and hardened states of sulfate resistant cement. The proportions of these mixtures were listed in table (4).

In order to get SCC by using modified rational-mix design (Okawa and Ozawa) method, trial and error and adjustments to concrete ingredients have to be performed to achieve the required workability and strength requirements.

The trail mixes were prepared for five classes of materials to get SCC. There were SCC1, SCC2, SCC3 and SCC4 mixes with admixtures and one control SCC0 mix without any admixture to satisfy compressive strength. The control mix was designed for 28-days characteristic strength of 50 MPa. The effect of superplasticizer dosage on the concrete mix was investigated through mixes SCC1, SCC2 and SCC3 which have different proportions 0.7%, 0.8% and 1% respectively. The fourth mix SCC4 had the same ratio of admixture of SCC3 but with silica fume.

Tests of fresh self-compacting concrete

It is important to select appropriate test methods to qualify the performance of the concrete in the laboratory and later on to control the quality of the concrete at the plant. Basic requirements for self-compacting concrete are those in the fresh state:- flowability, viscosity, passing (flow without blocking). These requirements were evaluated by some tests such as slump flow, V-funnel and L-box. The required tests of SCC were conducted on concrete in fresh state and the results of those tests are presented in table (5).

- SCC1 and SCC2 mix are not satisfy the requirements of EFNARC that required in table (3). On the other hand, mixes SCC3 and SCC4 fulfilled the requirements of slump flow and T_{50}.
- For the V-funnel test, all mixes were found to satisfy requirements EFNARC in table (3), except SCC1 mix.
- For L-box test, all mixes were found to satisfy the requirements EFNARC in table (3).
- This leads to the conclusion that both of SCC3 and SCC4 mixes were noted to satisfy all EFNARC requirements.

Table (4): Mixture proportions

Mix. No.	Cement Kg/m^3	Silica fume Kg/m^3	Coarse aggregate Kg/m^3	Fine Aggregate Kg/m^3	Water Kg/m^3	(HP-580)Kg/m^3	Tard B l/m^3
SCC0	490	-	920	755	205	-	-
SCC1	490	-	875	830	175	3.43	1
SCC2	490	-	925	805	165	3.92	1
SCC3	490	-	970	805	147	4.9	1
SCC4	450	30	970	805	147	4.8	.1

Table (5): Workability tests

Mix. No.	(Hp-580)%	Slump		V–funnel Sec.	L-box H_2/H_1
		Slump flow mm	T_{50} Sec.		
SCC1	0.7%	600	9	15	0.82
SCC2	0.8%	620	7	12	0.88
SCC3	1%	700	5	10	0.92
SCC4	1%	720	4	9	0.98

Tests of hardened self-compacting concrete

The mixes were designed to give a compressive strength of 50 MPa at 28 days. The cube samples were tested in 7 days and 28 days for all mixes. The compressive strength test results are listed in table (6).
The mixtures that contain admixtures have compressive strength greater than control mixture, the strength increase with the decrease of w/c. ratio.
The 28 days compressive strength of SCC1, SCC2 and SCC3 mixes were greater by 2.55%, 5.70 %,9.43 % respectively, compared to SCC0 mix. The mix SCC4 gave the higher compressive strength of 61.63 MPa, because of the effect of silica fume. The high level of fineness and practically spherical shape of silica fume results in good cohesion and improved resistance to segregation. However, silica fume is also very effective in reducing or eliminating bleed and this can give rise to problems of rapid surface crusting.
The increase of CSH (Calcium Silicate Hydrate Gel) caused by adding silica will lead to the increase of the paste and hence increase the compressive strength. Also, the decrease of the production of $Ca(OH)_2$ will result in a reduction in the heat of hydration, which is an important aspect in mass concrete pouring.

Table (6): Compressive Strength MPa

Mix. No.	W/C	7 day	28 day.
SCC0	0.418%	35.12	50.9
SCC1	0.357%	37.69	52.2
SCC2	0.336%	43.30	53.8
SCC3	0.300%	44.50	55.7
SCC4	0.326	55.13	61.63

Physically, adding microsilica to concrete will decrease permeability, since silica fume is 100 times finer than cement, and therefore will fill the voids in the cement paste (18).

CONCLUSION

In this work, the effects of addition of superpalsticizer doses and silica fume on self-compacting concrete sulfate resistant Portland cement were examined. The properties of fresh SCC are studied, such as slump flow, V-funnel and L-box in addition to the compressive strength of hardened cubes at two ages. The following findings were concluded from this study:
1- Adding silica fume contributed synergistically to increase compressive strength.
2- Adding silica fume results in good cohesion and improved resistance to segregation. Thus, produce an excellent concrete with enhanced flow and filing abilities.
3- With low w/c. ratio, and sufficient amount of cementitious materials, self-compactability could be achieved by optimizing the superpalsticizer dose.

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