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HIGH STRENGTH SELF-COMPACTED CONCRETE MIX DESIGN

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ABSTRACT

High strength Self-compacted Concrete (HSSCC) is a highly flow able high strength concrete that can spread into place under its own weight and achieve good consolidation in the absence of vibration and without exhibiting defects due to segregation and bleeding. Development of HSSCC required a balance between the flow ability and the stability of the concrete mix. While, achieving good consolidation in the absence of vibration and satisfying the requirement of high strength concrete is affected by the characteristics of materials and the mix proportions. Therefore, it becomes necessary to evolve a procedure for mix design of HSSCC. This paper describes a procedure specifically developed to achieve high strength self-compacting concrete. In addition, the test results for acceptance characteristics for self-compacting concrete such as slump flow, J-ring, V-funnel and L-Box are presented. Further, the strength characteristics in terms of compressive strength for 7-days, 28-days and 56-days are also presented.

KEYWORDS: High Strength Concrete (HSC), Self-Compacted (SCC), Flow Ability, Passing Ability

INTRODUCTION

Producing High strength concrete is always one of the major goals of concrete technology. For more than 30 years high strength concretes with compressive strength ranging from 45 N/mm² up to 140 N/mm² have been used worldwide in large buildings, towers and long span bridges buildings. Building elements made of high strength concrete are usually densely reinforced with small spacing between reinforcing bars this may lead to defects in concrete(1).

Commonly high strength concrete has low (W/C) ratio which means low workability and inability to fill the forms corners without external actions.

On the other hand Self-compacted concrete (SCC) is a highly flowable concrete that can spread into place under its own weight and achieve good consolidation in the absence of vibration without exhibiting defects due to segregation and bleeding.

So if high strength concrete is a self-compacting one, the production of densely reinforced building element from high strength concrete with high homogeneity would be an easy work. Self-compacting concrete is a concrete that flows and compacts only under gravity. It fills the whole mould completely without any defects.

The new type of concrete was proposed by Okamura (1997). In 1986, he started a research project on the flowing ability and workability of this special type of concrete, later called self-compacted concrete.

Self-compatibility is largely affected by the characteristics of materials and the mix proportions; it becomes necessary to evolve a procedure for mix design of SCC. Okamura and Ozawa have proposed a mix proportioning system for SCC(2). In this system, the coarse aggregate and fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the (water/powder) ratio and superplasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume and the (water/powder) ratio is assumed to be 0.9-1.0 by volume depending on the properties of the powder and the super plasticizer dosage. The required (water/powder) ratio is determined by conducting a number of trials. One of the limitations of SCC is that there is no established mix design procedure yet.

Requirements for Self-Compacted Concrete

SCC must possess the following three characteristics to meet its stated workability requirements [3, 4]:

- **Filling Ability:** The ability of SCC to flow into and fill completely all spaces within the formwork under its own weight.
- **Passing Ability:** The ability of SCC to flow through tight openings such as between reinforcing bars without segregation and blocking.
- **Segregation Resistance:** The ability of SCC to remain homogeneous during transportation and placing.

The test results for acceptance characteristics for self-compacting concrete such as slump flow, J-ring, V-funnel and L-Box are presented.

MATERIALS

The materials used in the high strength self-compacted concretemixesare:

Cement

The cement was ordinary Portland cement, conforming to the requirements of ASTM C 150[5]. Its Storage was in airtight containers to ensure minimum exposure to humidity. The physical properties of the cement are shown in Table (1) and chemical analysis in Table (3).

Table 1: Physical Properties of the Cement

Physical Tests	Results*	ASTMC150
Initialsettingtime	140min.	Notlessthan 45min.
Finalsettingtime	190min.	Notmorethan 375 min.
Fineness, Specific Surface	240m^2/Kg	160m^2/Kg,lowerlimit
3-daycompressivestrength	43.2MPa	12.0MPa,lowerlimit
7-daycompressivestrength	52.4MPa	19.0MPa,lowerlimit
Expansion (Autoclave)	0.32%	0.80%,upperlimit

*Tested by Directory of Construction Laboratory-Hawler

Table 2: Physical Properties of the Silica Fume

Physical Properties	Results**	ASTMC1240
Max.particlesize(µm)	0.40	<10%retainon45µm
Averageparticlesize(µm)	0.15	
Specificsurfacearea(m²/Kg)	22000	15000min.
Specificgravity	2.24	
Pozzolanicactivity(%)	105	85min.

** Downloaded from manufacturer web site:www.afrisam.com

Table 3: Chemical Analysis of Cement and Silica Fume

Material	Cement		Silica Fume	
Contents(%)	Results*	ASTMC150	Results**	ASTMC1240
SiO_2	20.00		92.50	85.00min.
CaO	63.50		0.54	

Table 3: Contd.,

Al_2O_3	4.00		1.47	
Fe_2O_3	4.50		2.20	
MgO	2.15	6.00max.	1.29	
SO_3	2.10	3.00max.	0.40	
Na_2O			1.41	
C			1.90	
H2O			0.83	3.00max.
C_3A	3.00			
C_3S	67.20			
C_2S	6.90			
C_4AF	13.70			
L.S.F	0.90	(0.66-1.02)		
pH			6.74	
Insoluble material	0.50	0.75max.		1.00max.
Loss of ignition	2.22	3.00max.	4.20	6.00max.

* Tested by Directory of Construction Laboratory-Hawler.
** Downloaded from manufacturer web site:www.afrisam.com

Silica Fume

It is a by-product of the ferrosilicon industry, highly pozzolanic material that is used to enhance mechanical and durability properties of SCC. It may be added directly to concrete as an individual ingredient or in a blend of Portland cement and silica fume, ACI 234R-96(6). The presence of this substance imparts greatly improved internal cohesion and water retention. The concrete mix becomes extremely soft and pumping properties are substantially improved. In the set concrete the latently reactive silica fume forms a chemical bond with the free lime. The additional crystal formation produces a significantly more dense set cement matrix. Silica fume of type CSF-90, was used in the present study, the physical properties of the silica fume are in Table (2), compared with ASTM C1240(7) limitations and the chemical analysis shown in Table (3).

Stone Powder (Filler)

Lime-stone as a powder filler was us edontrial mixes with particle size of (150-250) μm, to investigating there place mentability with an amount of cement or silica fume.

Aggregates

Locally available natural Aggregates (in Erbil) with maximum size of 4.75 mm was used as fine aggregate, and normal rounded Aggregates with maximum size of 12.5mm was used as coarse aggregate, as follow:

Fine Aggregate

The fine aggregate (Normal Sand) was obtained from Aski-Kalak quarry, well washed and dried before sieve analysis to satisfy ASTM C33(8) limitations. The grading of fine aggregate satisfies ASTM limitations, as shown in Table (4).

Coarse Aggregates

The normal coarse aggregate was obtained from Aski-Kalak quarry, coarse aggregate was used in high strength self-compacted concrete (HSSCC) mixes, after well washing. Gravel with maximum size of 12.50 mm was used. The grading of coarse aggregates and the limits of ASTM C33(8) are shown in Table (4).

Table 4: The Grading of Sand, Gravel and the Limits of ASTM C33[8]

Aggregates	Sieve Size mm	12.5	9.50	4.75	2.36	1.18	0.60	0.30	0.15
Normal Sand	upperlimit		100	100	100	85	60	30	10
	%Passing		**100**	**99.7**	**92.6**	**76.3**	**46.3**	**18.8**	**4.3**
	lowerlimit		100	95	80	50	25	10	2
Gravel	upperlimit	100	100	30	10	5			
	%Passing	**100**	**91.7**	**18.4**	**5.4**	**1.4**			
	lowerlimit	100	85	10	0	0			

Admixtures

Sika® ViscoCrete®-PC 15 is a third generation super plasticizer for concrete and mortar. It is especially suitable for the production of concrete mixes which require high early strength development, powerful water reduction and excellent flow ability.

Water

Normal Potable water (Erbil) was used for washing, mixing, and curing of HSSCC.

HSSCC Trial Mixes

Twenty trial mixes were prepared by varying the cement content, fine to coarse aggregate ratio, free water content, silica fume and stone powder ratio, and superplasticizer (Sika® ViscoCrete®-PC 15) content. Five levels of the cement content 250, 300, 380, 440 and 480 Kg/m3, varicose levels of sand to total aggregate ratio from (46%) to (56%) by mass, Superplasticizer (Sika® ViscoCrete®-PC 15) were taken in variable doses, were used for preparing the twenty trial mixes, so as the mixes satisfy the SCC requirements.

For each trial group mixes, different (water/binder) ratios and a constant amount of silica fume and stone powder were taken. Proportions of the trial mixes are shown in Table (5).

Table 5: SCC Trial Mixes Proportions

Mix No.	Cement Kg/m3	Gravel Kg/m3	Sand Kg/m3	S.F Kg/m3	Stone Powder Kg/m3	Pc-15%	Free Water Kg/m3	W/B* Ratio %
TR P-1	250	871	943	0	0	1.4	155	0.62
TR P-2	250	871	943	0	50	1.4	155	0.62
TR P-3	250	871	943	30	50	1.4	155	0.55
TR P-4	250	871	943	45	100	1.4	155	0.52
TR P-F	250	871	943	45	152	1.4	155	0.52
TR W-1	440	800	900	44	66	0	145	0.30
TR W-2	440	800	900	44	66	0.5	145	0.30
TR W-3	440	800	900	44	66	1.5	154	0.32
TR W-F	440	800	900	44	66	1.14	165	0.34
TR S-1	440	900	780	44	66	1.82	135	0.28
TR S-2	480	850	820	48	72	1.7	154	0.29
TR S-3	480	800	850	48	72	1.25	200	0.38
TR 1	300	940	880	45	45.0	1.20	157	0.46
TR 2	300	900	920	45	45.0	1.20	168	0.49
TR 3	300	880	950	45	45.0	1.00	176	0.51
TR 4	380	935	850	38	57.0	1.63	121	0.29
TR 5	380	850	900	38	57.0	1.32	155	0.37
TR 6	380	750	950	38	57.0	0.53	193	0.46
TR 7	440	840	840	44	66.0	1.36	152	0.31
TR 8	480	900	720	48	72.0	2.07	139	0.26

*B is Binder (Cement + Silica Fume)

HSSCC Mixing Procedure

A special mixing procedure was used to mix the compounds of the concrete mix. Aggregates were stored in laboratory conditions at (18-22) ^{o}C the mixing steps were as follow:

- Mixing two third of coarse aggregate and the fine aggregate for 1 minute.
- Mixing the cement, silica fume and the stone powder using a special hand mixer for at least 1.5 minute until it is fully homogenous.
- Adding the mixing in step two to the mixing in step one with further mixing for 2 minute.
- The superplasticizer is added to the water and is mixed well.
- Adding two third of the water and mixing it for 4-5 minute.
- The rest of coarse aggregate is added and mixed for 2 minute
- Leaving the mix resting for 2-3 minutes without mixing.
- Adding the rest of the water and further mixing for 4 minute.

CHARACTERISTIC TEST METHODS

The filling ability and stability of high strength self-compacting concrete in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by one or more test methods, as given in table (6).

Table 6: SCC Characteristic Test Methods

Characteristic	Preferred Test Method(s)
Flow ability	Slump-flow test
Viscosity (assessed by rate of flow)	T_{500} Slump-flow test or V-funnel test
Passing ability	L-box test, J-Ring test
Segregation	Segregation resistance (sieve) test

Slump-Flow Test (ASTM C 143/C 143M)[9]

Slump-flow value describes the flow ability of a fresh mix in unconfined condition. It is a sensitive test that will normally be specified for all SCC, as the primary check that the fresh concrete consistence meets the specification (lifting the slump cone, filled with concrete, the concrete flows, then the average diameter of the concrete circle is a measure for the filling and flowing ability of the concrete). Visual observations during the test and/or measurement of the T_{500} time can give additional information on the segregation resistance and uniformity of each delivery. Figure (1) shows typical slump-flow test.

Figure 1: Slump-Flow Test

T_{500} Slump-Flow Test and V-Funnel Test

Viscosity can be assessed by the T_{500} time (The time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm) during the slump-flow test or assessed by the V-funnel flow time. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured. Further, T_{5min} is also measured with V-funnel, which indicates the tendency for segregation, whereas in the funnel can be refilled with concrete and left for 5 minutes to settle. The time value obtained does not measure the viscosity of SCC but is related to it by describing the rate of flow. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time. Figure (2) shows typical V-funnel test.

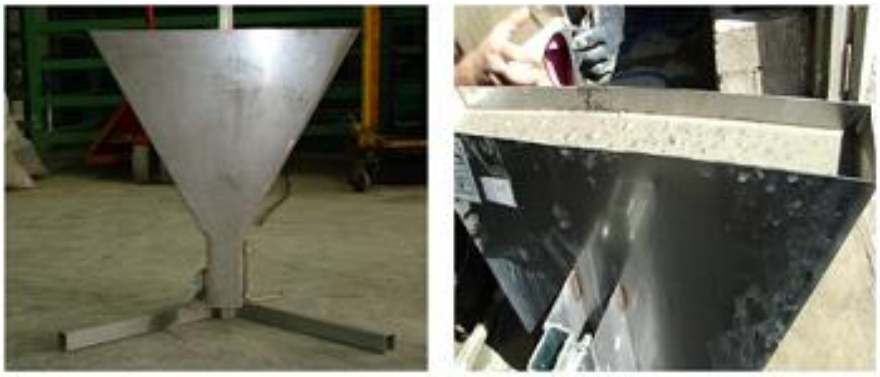

Figure 2: V-Funnel Test

L-Box Test

The passing ability is determined using the L-box test. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability. The specified ratio between the height soft he concrete at each ends must be ≥(0.8). Figure (3) show L-Box test.

Figure 3: L-Box Test

J-Ring Test

The principle of the J-Ring test may be Japanese, but no references are known. The J-Ring test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals, in accordance with normal reinforcement considerations, 3 times the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is 300mm, and the height 100 mm. The J-Ring can be used in conjunction with the Slump flow, or V-funnel. These combinations test the flowing ability and the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the J-Ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. Figure (4) show typical J-Ring test.

Figure 4: J-Ring Test

EXPERIMENTAL RESULTS AND DISCUSSIONS

HSSCC properties for all trial mixes were shown in Table (5) in order to compare them and to insure which mix satisfied SCC requirements. Slump by Abrama cone, T_{50cm} slump flow, J-ring, V-funnel and L-box SCC are required tests which were done and all the results are shown in the table (7).

Mixes (TR P-1, TR P-2, TR P-3 and TR P-4) were trial mixes with cement content of 250 kg/m3 and coarse aggregate and fine aggregate contents were kept as 871 kg/m3 and 943 kg/m3, respectively. Free water content was 155 kg/m3. The super plasticizer content was taken as 1.4 % of cement content. The silica fume and stone powder content were taken (0, 1), (0, 50), (30, 50), (45, 100) and (45, 152) kg respectively, until the mix satisfied the requirement of SCC on mix SCC 1 (TR P-F).

Mixes (TR W-1, TR W-2 and TR W-3) were trial mixes with cement content of 440 kg/m3 and coarse aggregate and fine aggregate contents were kept as 800 kg/m3 and 900 kg/m3, respectively. The silica fume and stone powder content were taken 44 and 66 kg/m3 respectively. Free water content was taken 145, 145, 154 and 165 kg/m3 and the super plasticizer content was taken as 0, 0.5, 1.0 and 1.14 % of cement content, until the mix satisfied the requirement of SCC on mix SCC 2 (TR W-F).

Mixes (TR S-1, TR S-2 and TR S-3) were trial mixes with cement content of 440, 480 and 480 kg/m3 respectively. The fine aggregate to total aggregate contents (fine + course) were varied from 0.46 to 0.52. All mixes satisfied the requirement of SCC (SCC 3, SCC 4 and SCC5) as shown in table (7). Incase of further trials, the fine to total aggregate ratio was between 0.46 to 0.55, the silica fume and stone powder content, were varied with further variation in(water/binder) ratio. Similarly, different trials were carried out untilmix characterizing all the properties of SCC were obtained, mixes (TR 1 to TR 9) or (SCC 6 to SCC 13) table (7).

Mixes (SCC 1, SCC 6, SCC 7 and SCC 8) have passed all the tests of SCC but they have compressive strength within the normal concrete strength. The rest of mixes can be considered as HSSCC. The mixes SCC 3, SCC 12 and SCC13 reach or just pass the upper limits of some SCC requirements as given in Table (8), T_{500} max time (5 sec.) and V-funnel max. Time (12 sec.). These limits are for normal strength SCC but for HSSCC there are some exceed in limits. The results of trial mixes show that SCC can give compressive strength two or three times higher than normal strength concrete.

Table 7: Trial Mixes Results for SCC

Mix No.	Slump Flow (mm)	$T_{50(sec)}$	J Ring (mm)	V-Funnel $F_{t.\ (sec)}$	L-Box (H1/H2)	Compressive Strength for 150x150x150 Cube MPa		
						7 day	28 day	56 day
TR P-1	----	----	----	----	----	----	----	----
TR P-2	----	----	----	----	----	----	----	----
TR P-3	----	----	----	----	----	----	----	----
TR P-4	----	----	----	----	----	----	----	----
SCC 1 (TRP-F)	810	3.18	4.8	5.12	0.99	20.5	34.8	38.9
TR W-1	----	----	----	----	----	----	----	----
TR W-2	----	----	----	----	----	----	----	----
TR W-3	----	----	----	----	----	----	----	----
SCC 2 (TRW-F)	650	3.54	4.56	8.45	0.90	64.20	88.32	93.22
SCC 3 (TRS-1)	640	6.10	6.24	12.75	0.85	78.20	98.8	110.75
SCC 4 (TRS-2)	610	6.54	6.33	9.94	0.84	62.41	92.21	110.40
SCC 5 (TRS-3)	630	5.42	4.21	7.54	0.92	60.05	84.22	98.24
SCC 6 (TR1)	640	5.24	9.00	7.15	0.97	24.52	43.51	46.67
SCC 7 (TR2)	765	4.35	8.50	5.40	1.00	23.53	34.25	38.54
SCC 8 (TR3)	800	3.07	6.50	5.15	1.00	21.25	31.25	36.54
SCC 9 (TR4)	635	6.09	7.89	11.81	0.81	57.25	66.45	78.38
SCC 10 (TR5)	640	5.14	5.21	10.12	0.85	54.21	60.89	70.14
SCC 11 (TR6)	690	3.35	4.90	9.55	0.95	46.52	52.43	61.28
SCC 12 (TR7)	680	7.25	7.21	13.54	0.79	67.50	93.45	103.85
SCC 13 (TR8)	550	7.85	8.54	14.35	0.75	78.54	100.68	118.45

Table 8: Limits for SCC Requirements[3]

No.	Test Method	Unit	Typical Range of Values	
			Minimum	Maximum
1	Slump flow by Abrams cone	mm	550	800
2	T50cm slump flow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
6	L-box	(h2/h1)	0.8	1.0

CONCLUSIONS

- In producing high strength self-compacting concrete, a stone powder could be used as a partially replacement of fine and coarse aggregates with sufficient flow property and low segregation potential without affecting the early age strength, the best ratio was 13% of cement content.
- Adding of silica fume develops filling and passing ability of SCC. Silica fume provides mechanical strength to HSSCC. Best ratio for silica fume as a replacement of cement was 9% which is give best effect on compressive strength of concrete.
- At the water/binder ratio from 26% to 51%, slump flow test, V-funnel test and L-box test results were found to be satisfactory; i.e. filling ability segregation resistance, and passing ability.
- At the fine to total aggregate ratio of 0.46 to 0.55 many different HSSCC mixes can be prepared and satisfy the requirement of SCC.
- HSSCC could be developed without using Viscosity Modifying Admixture (VMA) as was done in this study.
- HSSCC having different compressive strength can be prepared by using different combinations of cement, stone powder and silica fume.

ABBREVIATIONS

HSSCC	High Strength Self-Compacted Concrete
SCC	Self-Compacted Concrete
W/B	Water/ Binder Ratio
W/C	Water / Cement Ratio
W/P	Water to Powder Ratio

REFERENCES

1. Jianxin Ma1; Jorg Dietz1 “Ultra High Performance Self Compacting Concrete”, Diplng Institution, University of Leipzig Lacer No. 7, 2002.
2. H. Okamura and M. Ouchi, “Self-Compacting Concrete”, Journal of Advanced Concrete Technology, 1(1) (2003), PP. 5–15.
3. EFNARC, “Specifications And Guidelines For Self-Compacting Concrete”, EFNARC, Uk (Www.Efnarc.Org), February 2002, PP. 1-32.
4. ACI 237r-07, "Self Consolidating Concrete", ACI Committee 237, American Concrete Institute (ACI), April 2007.
5. American Society for Testing and Material, ASTM C150, "Standard Specification for Portland Cement", 2000.
6. ACI 234R-96, Guide for the Use of Silica Fume in Concrete "Reported By American Concrete Institute", May 1, 1996.
7. American Society for Testing and Material, ASTM C1240, "Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout", July, 2000.
8. American Society for Testing and Material, ASTM C33, "Standard Specification for Concrete Aggregates", 2001.
9. American Society for Testing and Material, ASTM C143M, “Standard Test Method for Slump of Hydraulic-Cement Concrete", 2010.