Self-Compacting Concrete - Procedure and Mix Design

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Abstract - *An Self-compacting concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration. Self-compacting concrete development must ensure a good balance between deformability and stability. Also, compactibility is affected by the characteristics of materials and the mix proportions; it becomes necessary to evolve a procedure for mix design of SCC. The paper presents an experimental procedure for the design of self-compacting concrete mixes. The test results for acceptance characteristics of self-compacting concrete such as slump flow; J-ring, V-funnel and L-Box are presented. Further, compressive strength at the ages of 7, 28, and 90 days was also determined and results are included here.*

Key Words: **Self-compacting Concrete; Fly Ash; Mix Design; Fresh Properties; Hardened Concrete Properties; Compressive Strength.**

1. INTRODUCTION

This document is template. Self-Compacting Concrete (SCC), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. SCC, was first introduced in the late 1980's by Japanese researchers [1], is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding, and must maintain its homogeneity during transportation, placing and curing to ensure adequate structural performance and long term durability. The successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mixture proportioning of SCC, which include

i) reducing the volume ratio of aggregate to cementitious material [1-2]

(ii) increasing the paste volume and water-cement ratio (w/c) carefully controlling the maximum coarse aggregate particle size and total volume; and using various viscosity enhancing admixtures (VEA).

For SCC, it is generally necessary to use superplasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are fly ash, silica fume, lime stone powder, glass filler and quartzite filler.

Since, self-compactibility 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 . In this system, the coarse aggregate and fine aggregate contents are fixed and self-compactibility is to be achieved by adjusting the water /powder ratio and super plasticizer 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 /cement ratio is assumed to be 0.4-0.5 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.

This paper describes a procedure specifically developed to achieve 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 90-days are also presented.

2 Materials Used

2.1 Cement

Ordinary Portland cement (Grade 53) was used. Its physical properties are as given in Table 1.

Table 1. Physical Properties of Cement

PROPERTY	VALUE	IS CODE IS : 8112 - 1989
Specific Gravity	3.15	3.10-3.15
Consistency	28%	30-35
Initial setting time	35min	30min minimum
Final setting time	178min	600min maximum
Compressive strength at 7 days N/mm2	38.49 N/mm2	43 N/mm2
Compressive strength at 28 days N/mm2	52.31 N/mm2	53 N/mm2

2.2 Fly ash

Class C Fly ash obtained from "Panipat Thermal Power Station, Haryana, India. The physical and chemical properties of fly ash are given in the Table 2 and Table 3, respectively

Table 2. Physical Properties of Fly Ash

Sr.no	Physical Properties	Test Result
1	Colour	Grey
2	Specific Gravity	2.13

TABLE 3 Chemical Properties of fly ash "CLASS C"

Sr. No	Constituents	Weight % by
1	Loss on ignition	4.17
2	Silica (SiO2)	69.40
3	Iron Oxide (Fe2O3)	3.44
4	Alumina (Al2O3)	28.20
5	Calcium Oxide (CaO)	2.23
6	Magnesium Oxide (MgO)	1.45
7	Total Sulphur (SO3)	0.165
8	Insoluble residue	-
9 ALKALIES	Sodium Oxide (Na2O) Potassium Oxide (K2O)	0.58 1.26

The properties of fly ash conform to IS: 3812-2003

2.3 Aggregates

Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, having specific gravity, fineness modulus and unit weight as given in Table 4 and crushed stone with 16mm maximum size having specific gravity, fineness modulus and unit weight as given in Table 4 was used as coarse aggregate. Both fine aggregate and coarse aggregate conformed to Indian Standard Specifications IS: 383-1970 [6]. Table 4 gives the physical properties of the coarse and fine aggregates.

Table 4. Physical Properties of Coarse and Fine Aggregates

Physical tests	Coarse aggregate	Fine aggregate
Specific gravity	2.67	2.66
Fineness modulus	6.86	2.32
Bulk density (kg/m3)	1540	1780

3. Test Methods

3.1Parameters of test

Self- Compacting Concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Table 5 gives the recommended values for different tests given by different researchers for mix to be characterized as SCC mix.

Table 5. Recommended Limits for Different Properties

Sr. No.	Property	Range
1.	Slump Flow Diameter	500-700 mm [7]
2.	T50cm	2-5 sec [7]
3.	V-funnel	6-12 sec [8]
4.	L-Box H2/H1	≥ 0.8 [9]

3.2 SLUMP FLOW TEST AND T50cm TEST

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Fig:-1 Slump Flow Test

3.3 V-Funnel test

About 12 litre of concrete is needed to perform the test, sampled normally.Set the V-funnel on firm ground.Moisten the inside surfaces of the funnel. Keep the trap door open to allow any surplus water to drain. Close the trap door and place a bucket underneath. Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concretelevel with the top with the trowel. Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity. Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (theflow time). This is taken to be when light is seen from above through the funnel. The whole test has to be performed within 5 minutes.

Fig:-2 V-funnel TEST

3.4 L BOX TEST METHOD

About 14 litre of concrete is needed to perform the test, sampled normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus waterFill the vertical section of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400mm marks. When the concrete stops flowing, the distances "H1" and "H2" are measured. Calculate H2/H1, the blocking ratio. The whole test has to be performed within 5 minutes.

Interpretation of result If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1. Therefore the nearerthis test value, the 'blocking ratio', is to unity, the better the flow of the concrete. The EU research teamsuggested a minimum acceptable value of 0.8. T20 and T40 times can give some indication of ease offlow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

Fig:-1 L BOX TEST

3.5 COMPRESSIVE STRENGTH TEST

150 mm × 150 mm × 150 mm concrete cubes are cast. Specimens with ordinary Portland cement (OPC) and OPC replaced with and fly ash. The specimens is remove from the mould and subjected to water curing for up to 90 days. After curing, the specimens are tested for compressive strength using a calibrated compression testing machine of 2,000 KN capacities.

Fig:-2 COMPRESSIVE STRENGTH TEST

4. Experimental Procedure

The procedure adopted in the study is as follows

1. Using Japanese method of mix design, initial mix design was carried out at coarse aggregate content of 46 percent by volume of concrete and fine aggregate content of 44 percent by volume of mortar in concrete, the water/cement ratio was kept at 0.40. These Trial mixes were designed with superplasticizer content of 0%, 0.56% and 2.60% for mixes TM1, TM2, TM3 respectively.

2. To proceed towards achieving SCC, the coarse aggregate content was reduced to 46% by volume of concrete and thereby kept constant. Fine aggregate content was kept constant at 44% by volume of mortar in concrete and superplasticizer content at 1.15 percent of powder content i.e. cement and fly ash. The water-cement ratio was varied from 0.40 to 0.52 for trial mixes TR1 to TR5.

3. Coarse aggregate content was further reduced and fine aggregate content was increased, until a slump flow of 500-700 mm is achieved by slump flow test. For each trial, tests are carried out in order that the mix satisfies slump flow test, V-funnel test and L-box passing ability test.

Table 6. Mix Proportions

Sr.No	Mix	Cement (Kg/m^3)	Fly ash (Kg/m^3)	F.A (Kg/m^3)	C.A (Kg/m^3)	Water (Kg/m^3)	S.P. (%)	W/c ratio
1	TM1	490	150	740	763	200	0.00	0.40
2	TM2	490	150	740	763	200	0.56	0.40
3	TM3	490	150	740	763	240	2.60	0.49
4	TM4	510	145	780	690	265	1.15	0.52
5	TM5	510	145	780	690	253	1.15	0.50
6	SCC1	480	140	965	573	255	1.15	0.53
7	SCC2	480	140	965	573	254	1.15	0.53
8	SCC3	480	140	965	573	253	1.15	0.53
9	SCC4	480	140	965	573	252	1.15	0.52
10	SCC5	480	140	965	573	251	1.15	0.52

By reducing contents of coarse aggregate from 46% to 34% and increasing fine aggregate contents from 44.75% to 57%, required results in all the tests i.e., slump flow, V-funnel and L-Box were obtained.

Mixes TR1 to TR5 were considered as trial mixes, as these mixes do not fulfil all the requirements of the SCC mix. SCC1 to SCC5 are the SCC mixes that satisfy all the properties of SCC mixes and determination of optimum water-powder ratio was carried out for these mixes. Mix proportions for various mixes are given in Table 6.

Table 7. Workability and compressive strength results

Sr. No	Mix	Slump flow (mm)	T50cm (sec)	V-funnel Tf b (sec)	V-funnel T5min c (sec)	L-box Blocking ratio(H2/H1)d	7 Days (MPa)	28 Days (MPa)	90 Days (MPa)
1	TM1	590	15.0	46	-	-	12.64		
2	TM2	600	-	28	-	-	12.60		
3	TM3	640	11.0	22	-	-	20.06	38.53	70.06
4	TM4	400	-	-	-	-	21.36	34.45	68.96
5	TM5	680	5.0	36			18.31	24.51	70.18
6	SCC1	696.7	3.0	14	16.0	0.35	18.72	25.41	52.34
7	SCC2	676.7	3.5	11	12	0.85	20.71	25.40	52.32
8	SCC3	713.33	2.5	9	11.5	0.90	20.35	26.37	54.33
9	SCC4	660	4.0	8.0	9.0	0.85	23.05	31.99	65.90
10	SCC5	670	5.0	8.0	9.0	0.65	17.99	27.34	56.32

T50cm : time taken for concrete to reach the 500 mm spread circle

Tf : V-funnel flow time after keeping the concrete in funnel for 10 sec

T5min : V-funnel flow time after keeping the concrete in funnel for 5 min

H1,H2: Heights of the concrete at both ends of horizontal section of L-box after allowing the concrete to flow .

5. Results and Discussion

Table 7 presents the results of workability tests, conducted to achieve self-compacting concrete. The trials were started at 46 percent volume of total concrete as content of coarse aggregates and 44 percent by volume of mortar in concrete as contents of fine aggregates and variation in w/p ratio and super plasticizer was carried out to achieve SCC mixes. In case of further trials, the coarse aggregate content and fine aggregate content were varied with further variation in water/cement ratio. Similarly, different trials were carried out until mix characterizing all the properties of SCC was obtained. Mixes TM1 to TM5 were initial trials to obtain an

SCC mix. TM1, TM2 were trial mixes with cement content of 490 kg/m3 and fly ash content as 150 kg/m3 .The coarse aggregate and fine aggregate contents were kept as 740 kg/m3 and 763 kg/m3, which amounted to 46 % of total concrete and 44% by volume of mortar in concrete, respectively and w/c ratio of 0.40. The super plasticizer content was taken as 0, 0.56 and 2.60 respectively. None of the SCC characteristics was found in the mixes. Thus, the contents of cement, fly ash, coarse aggregates and fine aggregate was varied to 510 kg/m3, 140.0 kg/m3, 780 kg/m3 and 660 kg/m3 respectively, for mixes TM3, TM4 and TM5. In addition, the super plasticizer content was kept constant at 1.15% of powder content. The quantity of water was changed for all mixes from 240 to 265 kg /m3 from TM3 to TM5. Some of the workability characteristics were obtained in TR5, but not all values were within recommended limits. The consistency and workability of SCC1 to SCC5 satisfied slump flow property but SCC3 was the only mix to have T50 cm as 2.5 sec, thus satisfying both slump flow and time property. In addition, all the mixes SCC1 to SCC5 have the V-funnel time Tf between 8-14 sec and V-funnel time T 5min within the range of Tf +3. The L-Box blocking ratio H2/H1 could not be satisfied for SCC1 and SCC5.

Conclusions

1. At the water/Cement ratio of 0.52 to 0.53, slump flow test, V-funnel test and L-box test results were found to be satisfactory, i.e. passing ability, filling ability and segregation resistance are well within the limits.

2. SCC could be developed without using VMA as was done in this study.

3. The SCC1 to SCC5 mixes can be easily used as medium strength SCC mixes, which are useful for most of the constructions; the proportions for SCC3 mix satisfying all the properties of Self-Compacting Concrete can be easily used for the development of medium strength self-compacting and for further study.

4. By using the OPC 53 grade, normal strength of 38 MPa to 53 MPa at 28-days was obtained, keeping the cement content around 340 kg/m3 to 415 kg/m3.

As SCC technology is now being adopted in many countries throughout the world, in absence of suitable standardized test methods it is necessary to examine the existing test methods and identify or, when necessary to develop test methods suitable for acceptance as International Standards. Such test methods have to be capable of a rapid and reliable assessment of key properties of fresh SCC on a construction site. At the same time, testing equipment should be reliable, easily portable and inexpensive. A single operator should carry out the test procedure and the test results have to be interpreted with a minimum of training. In addition, the results have to be defined and specify different SCC mixes. One primary application of these test methods would be in verification of compliance on sites and in concrete production plants, if self-compacting concrete is to be manufactured in large quantities.

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