Self-Compacting Concrete - Procedure for Mix Design

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Abstract

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.

Keywords

Self-compacting Concrete; Fly Ash; Mix Design; Fresh Properties; Hardened Concrete Properties; Compressive Strength.

Introduction

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); (iii) carefully controlling the maximum coarse aggregate particle size and total volume; and (iv) using various viscosity enhancing admixtures (VEA) [1].

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 [3]. 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 /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.

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.

Materials Used

Cement

Ordinary Portland cement (Grade 43) was used. Its physical properties are as given in Table 1.

Fly ash

Class F 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 1. Physical Properties of Cement

Physical property	Results obtained	IS: 8112-1989 [4] specifications
Fineness (retained on 90-µm sieve)	8.0	10mm
Normal Consistency	28%	-
Vicat initial setting time (minutes)	75	30 min^{m}
Vicat final setting time (minutes)	215	600 max^{m}
Compressive strength 3-days (MPa)	23	22.0 min^{m}
Compressive strength 7-days (MPa)	36	33.0 min^{m}
Compressive strength 28days(MPa)	45	43.0 min^{m}
Specific gravity	3.15	-

Table 2. Physical Properties of Fly Ash

Sr. No.	Physical Properties	Test Results
1.	Colour	Grey (Blackish)
2.	Specific Gravity	2.13
3.	Lime Reactivity -average compressive strength after 28 days of mixture ‘A’	4.90 MPa

Table 3. Chemical Properties of Fly Ash

Sr. No.	Constituents	Percent by Weight
1.	Loss on ignition	4.17
2.	Silica (SiO_2)	58.55
3.	Iron Oxide ($Fe_2 O_3$)	3.44
4.	Alumina ($Al_2 O_3$)	28.20
5.	Calcium Oxide (CaO)	2.23
6.	Magnesium Oxide (MgO)	0.32
7.	Total Sulphur (SO_3)	0.07
8.	Insoluble residue	-
9.	Alkalies a) Sodium Oxide (Na_2O) b) Potassium Oxide (K_2O)	0.58 1.26

The properties of fly ash conform to IS: 3812-2003 [5].

Admixtures

A polycarboxylic ether based superplasticizer complying with ASTM C-494 type F, was used.

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/m^3)	1540	1780

Test Methods

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.	T_{50cm}	2-5 sec [7]
3.	V-funnel	6-12 sec [8]
4.	L-Box H2/H1	≥ 0.8 [9]

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T_{50cm} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm.

Figure 1. Slump Flow Test

The flowability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured, figure 2.The funnel is filled with about 12 litres 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, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. According to Khayat and Manai, a funnel test flow time less than 6s is recommended for a concrete to qualify for an SCC [9].

The passing ability is determined using the L- box test [10] as shown in Fig 3. 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 requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.8.

Figure 2. V-funnel test

Figure 3. L-Box test

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 50 percent by volume of concrete and fine aggregate content of 40

percent by volume of mortar in concrete, the water/powder ratio was kept at 0.90. These Trial mixes were designed with superplasticizer content of 0%, 0.76% and 3.80% for mixes TR1, TR2, TR3 respectively.

2) To proceed towards achieving SCC, the coarse aggregate content was reduced to 45% by volume of concrete and thereby kept constant. Fine aggregate content was kept constant at 40% by volume of mortar in concrete and superplasticizer content at 1.14 percent of powder content i.e. cement and fly ash. The water-powder ratio was varied from 1.06 to 1.19 for trial mixes TR4 to TR6.
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/p ratio
1	TR1	499	141	743	759	198	-	0.90
2	TR2	499	141	743	759	198	0.76	0.90
3	TR3	499	141	743	759	198	3.80	0.90
4	TR4	520	146	775	684	243	1.14	1.06
5	TR5	520	146	775	684	252	1.14	1.09
6	TR6	520	146	775	684	273	1.14	1.19
7	TR7	520	146	775	684	249	1.14	1.08
8	TR8	520	146	775	684	270	1.14	1.17
9	TR9	520	146	775	684	252	1.14	1.09
10	SCC1	485	135	977	561	257	1.14	1.21
11	SCC2	485	135	977	561	256	1.14	1.20
12	SCC3	485	135	977	561	254	1.14	1.19
13	SCC4	485	135	977	561	253	1.14	1.18
14	SCC5	485	135	977	561	252	1.14	1.18

By reducing contents of coarse aggregate from 45% to 37% and increasing fine aggregate contents from 40% to 47.5%, required results in all the tests i.e., slump flow, V-funnel and L-Box were obtained.

Mixes TR1 to TR9 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)	T_{50cm} [a] (sec)	V-funnel T_f [b] (sec)	V-funnel T_{5min} [c] (sec)	L-box Blocking ratio(H2/H1)[d]	7-days (MPa)	28-days (MPa)	90-days (MPa)
1	TR1	-	-	-	-	-	-	-	-
2	TR2	-	-	-	-	-	-	-	-
3	TR3	-	-	-	-	-	-	-	-
4	TR4	-	-	-	-	-	10.03	22.24	-
5	TR5	590	15.0	46	-	-	12.64	22.67	-
6	TR6	-	-	-	-	-	12.60	22.00	29.65
7	TR7	-	11.0	-	-	-	20.06	37.93	71.56
8	TR8	400	-	-	-	-	21.36	34.45	69.76
9	TR9	670	5.0	39	70.0	0.10	18.31	22.67	68.48
10	SCC1	696.7	3.0	12	15.0	0.30	17.00	25.36	50.14
11	SCC2	676.7	3.5	11	12.5	0.90	17.00	26.90	52.32
12	SCC3	713.33	2.0	10	11.0	0.95	16.13	27.57	55.39
13	SCC4	660	4.5	8.0	9.0	0.90	16.15	31.54	66.27
14	SCC5	670	5.0	8.0	9.0	0.67	12.21	29.21	49.27

[a] T_{50cm} : time taken for concrete to reach the 500 mm spread circle
[b] T_f : V-funnel flow time after keeping the concrete in funnel for 10 sec
[c] T_{5min} : V-funnel flow time after keeping the concrete in funnel for 5 min
[d] H1,H2: Heights of the concrete at both ends of horizontal section of L-box after allowing the concrete to flow .

Results and Discussion

Table 7 presents the results of workability tests, conducted to achieve self-compacting concrete. The trials were started at 50 percent volume of total concrete as content of coarse aggregates and 40 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 TR1 to TR9 were initial trials to obtain an SCC mix. TR1, TR2, TR3 were trial mixes with cement content of 499 kg/m^3 and fly ash content as 111 kg/m^3 .The coarse aggregate and fine aggregate contents were kept as 759 kg/m^3 and 743 kg/$m^{3,}$ which amounted to 50 % of total concrete and 40% by volume of mortar in concrete, respectively and w/p ratio of 0.90. The super plasticizer content was taken as 0, 0.76 and 3.80 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 520 kg/m^3, 146.0 kg/m^3, 684 kg/m^3 and 775 kg/m^3 respectively, for mixes TR4, TR5, TR6, TR7, TR8 and TR9. In addition, the super plasticizer content was kept constant at 1.14% of powder content. The quantity of water was changed for all mixes from 243 to 273 kg /m^3 from TR4 to

TR9. Some of the workability characteristics were obtained in TR9, 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 sec, thus satisfying both slump flow and time property. In addition, all the mixes SCC1 to SCC5 have the V-funnel time T_f between 6-12 sec and V-funnel time T_{5min} within the range of T_f +3. The L-Box blocking ratio H2/H1 could not be satisfied for SCC1 and SCC5.

Conclusions

1. At the water/powder ratio of 1.180 to 1.215, 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 43 grade, normal strength of 25 MPa to 33 MPa at 28-days was obtained, keeping the cement content around 350 kg/m^3 to 414 kg/m^3.

   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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