



Self Compacting Concrete – an Analysis of Properties using Fly Ash

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Abstract

Self compacting concrete has ability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars. Several researchers have employed the different methods to achieve self- compactability. In recent years, self-compacting concrete (SCC) has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness. The initial results of an experimental program aimed at producing and evaluating SCC made with high volumes of fly ash are presented and discussed. Nine SCC mixtures and one control concrete were investigated in this study. The content of the cementitious materials was maintained constant (400 kg/m³), while the water / cementitious material ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40,50 and 60% by Class F fly ash. Tests were carried out on all mechanical properties of hardened concretes such as compressive strength were also determined. The self-compacting concretes developed a 28- day compressive strengths ranging from 26 to 48 MPa. The results show that an economical self-compacting concrete could be successfully developed by incorporating high-volumes of Class F fly ash. The present project investigates the making of self-compacting concrete more affordable for the construction market by replacing high volumes of Portland cement by fly ash. The study focuses on comparison of fresh properties of SCC containing varying amounts of fly ash with that containing commercially available admixture. Test result substantiate the feasibility to develop low cost SCC using Class F fly ash.

Keywords: Self Compacting Concrete, Flyash, Admixture, Plasticizer, Funnel Test

1. Introduction

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction. The concept of self-compacting concrete was proposed [1], but the prototype was first development in 1988

in Japan, by professor Ozawa [2] at the university of Tokyo. Self-compacting Concrete was development at that time to improve the durability of concrete structures. Since then, various investigations have been carried out and SCC has been used in practical structures in Japan, mainly by large construction companies.

In 2002 EFNARC published their “Specification & Guidelines for Self-Compacting concrete” which, at that time, provided state of the art information for producers and users. Since then, much additional technical information on SCC has been published but European design, product and construction standards do not yet specifically refer to SCC and for site applications this has limited its wider acceptance, especially by specifiers and purchasers.

In 2004 five European organisations BIBM, CEMBUREAU, ERMCO, EFCA and EFNARC, all dedicated to the promotion of advanced materials and systems for the supply and use of concrete, created a “European Project Group” to review current best practice and produce a new document covering all aspects of SCC. This document “The European Guidelines for Self Compacting Concrete” serves to particularly address those issues related to the absence of European specifications, standards and agreed test methods[3].

1.1 Necessity of Self-Compacting Concrete

The previous studies found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, they At almost the same time, "High performance concrete" was defined as a concrete with high durability due to low water-cement ratio [4] Since then , the term high performance concrete has been used around the world to refer to high durability concrete .Therefore, [1] has changed the term for the proposed concrete to Self-compacting High Performance Concrete".

1.2 Benefits due to Self compacting concrete

The main reasons for the using self-compacting concrete is as follows and it has proved beneficial because of factors mentioned below[5].

- Faster construction
- Reduction in site manpower
- Easier placing Uniform and complete consolidation
- Better surface finishes
- Improved durability
- Increased bond strength Greater freedom in design
- Reduced noise levels, due to absence of vibration
- Safe working environment

1.3 Engineering properties

Self-compacting concrete and traditional vibrated concrete of similar compressive strength have comparable properties and if there are differences, these are usually covered by the safe assumptions on which the design codes are based. However, SCC composition does differ from that of traditional concrete so information on any small differences that may be observed is presented in the subsequent sections [3].

Durability, the capability of a concrete structure to withstand environmental aggressive situations during its design working life without impairing the required performance, is usually taken into account by specifying environmental classes. This leads to limiting values of concrete composition and minimum concrete covers to reinforcement.

In the design of concrete structures, engineers may refer to a number of concrete properties, which are not always part of the concrete specification. The most relevant are:

- Compressive strength
- Tensile strength
- Modulus of elasticity
- Creep
- Shrinkage
- Coefficient of thermal expansion
- Bond to reinforcement
- Shear force capacity in cold joints
- Fire resistance

Where the value and/or the development of a specific concrete property with time is critical, tests should be carried out taking into account the exposure conditions and the dimensions of the structural member. But the self compaction concrete is differ from the fresh conventional concrete the following properties and their testing procedure are tabulated in Table no 1.

Table 1: Showing the SCC Property and the Test to be carried

Property	Test methods	
	Laboratory [For Mix Design]	Field [For quality control]
Filling ability	Slump flow T _{50cm} slump flow V-funnel Orimet	Slump Flow T _{50cm} Slump Flow V-funnel Orimet
Passing ability	L-box U-box Fill-box	J-ring
Segregation Resistance	GTM test V -Funnel at T 5 minutes	GTM Test V-Funnel at T 5 minutes

2. Objectives of the Present Study

- ✓ To assess workable properties of SCC containing various amount of Class F fly ash and compressive strength of SCC.
- ✓ To develop medium strength Self compacting concrete.
- ✓ To achieve an economical SCC that can replace the control concrete with similar 28th day compressive strength (35MPa).
- ✓ To encourage the use of self-compacting concrete in general construction and to realize the potential economic and environmental benefits of this technology.

The proposed study is being carried out to develop self compacting concrete using fly ash in varying combinations for use in the Indian conditions satisfying European standards for rheological properties of concrete in fresh state using OPC 53 grade cement and class F fly ash from ENNORE Thermal Power Station. Fly ash used in concrete is available free of cost in large quantities which can actually bring the cost down even though two different concrete mixes may have similar strengths.

3. Material Used and its Properties

3.1 Cement

Cement ordinary port land cement of 53 grade confirming to IS-12269 [6] having specific gravity of 3.15 was used and are presented in Table no 2.

Table 2: Physical properties of cement

Physical property	Results obtained	As per IS
Fineness (retained on 90-µm Sieve)	8.0	10mm
Normal consistency	28%	-
Vicat initial setting time (minutes)	75	30 min
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 28 days(MPa)	45	43.0 min m
Specific gravity	3.15	-

3.2 Fine Aggregate

The amount of fines less than 0.125 mm is to be considered as powder and is very important for the Theology of the SCC. A minimum amount of fines (arising from the binders and the sand) must be achieved to avoid segregation. Natural river sand confirming to IS-383[7] zone π having specific gravity 2.63 are used in this work.

3.2 Coarse Aggregate

Gap graded aggregates are frequently better than those continuously graded, which might experience greater internal friction and give reduced flow. Crushed granite angular aggregate of size 12.5 mm passing confirming to IS-383[7] having specific gravity 2.63 were adopted in this paper. Consolidated properties are presented in table 3

Table 3: Physical Properties of Fine Aggregate and Coarse Aggregate

	Bulk density (kg/m ³)	Specific gravity	Absorption	Fineness modulus
Fine Aggregate	1625	2.53	1.65	2.62
Coarse Aggregate	1540	2.64	1.07	-

3.3 Mineral Admixtures Fly Ash confirming to is 3812-1981[8]

The mineral admixtures, which have been used for this project, as cement replacement comprises of class F fly ash obtained from Ennore Thermal Power Station and their properties are presented table 4 and table 5

Table 4: Physical properties of fly ash

S.No	PHYSICAL PROPERTIES	TEST RESULT
1.	Color	Grey (blackish)
2.	Specific Gravity	2.13
3.	Lime Reactivity – average Compressive strength after 28 Days of mixture 'A'	4.90 MPa

Table 5: 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 ₂ O) b)Potassium Oxide(K ₂ O)	0.58 1.26

3.4 Water Confirming to IS 456[9]

Ordinary potable water as specified in IS code was used for mixing and curing concrete specimen.

3.5 Super plasticizer

Super plasticizer Glenium B233 PCE (polycarboxylic ether) is used as admixture for all SCC mix proportion expect for control concrete.

Typical properties are as follows

Aspect : Yellowish free flowing liquid

Relative Density: 1.09 ± 0.01 at 25 °C

Ph: 7 ± 1, Chloride ion content: < 0.2%

Standards

ASTM C494 Types F

EN 934-2 T 3.1/3.2

IS 9130; 1999 [10]

BASF Construction Chemicals (India) Private Limited

3.6 Air Entraining Agents

A synthetic resin type air-entraining admixture (AEA) was used in all the SCC concrete mixtures.

4. Mix Design

The requirements which form the basis of selection and proportioning of mix ingredients are[11]

- The minimum compressive strength required from structural consideration
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

4.1 Normal mix design and proportions

The Mix design is based on as per IS 10262-1982 [11]

The summarized requirements are presented in table 6

Table 6: Showing Normal Concrete Mix Proportions

Cem	W/C	Water	Sand	20mm	10mm	Admix
326	0.5	163	650	504	446	1.2
1		0.5	1.9	1.55	1.37	0.033

Cement: Sand: Coarse Aggregates = 1: 1.9: 2.92

4.2 Self-Compacting Concrete Mix Design [1]

This method was suggested by [1] used for calculating the proportions

The process is defines as follows

Designation of desired air content (mostly 2%)

Determination of coarse aggregate volume

Determination of sand content Design of paste composition

Determination of optimum water : powder ratio and super plasticizer dosage in mortar

Finally the concrete properties are assessed by standard tests.

Here the coarse aggregate and the fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the water / powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50percent of the total solid volume; the fine aggregate content is fixed at 40 percent of the mortar volume.

A water-to-powder ratio in volume between 0.9 and 1.0 is a typical starting point, which corresponds to a 0.29 and 0.32 water-to-powder ratio in mass respectively. A 0.32 water-to-cement ratio is ideal. The required water/powder ratio and admixture ratio is determined by conducting a number of trial batches until we reach the SCC properties such as resist segregation and excessive bleeding; the combined proportions are presented in table 7

Table 7: Showing The Complete Mix Proportions And The Required Aggregate

Mix No	W	Cement	Fly ash		Fine aggregate, kg/m ³	Coarse aggregate, kg/m ³	AEA, ml/m ³	SP, L/m ³	
	(C+FA)		Water	Kg/m ³					%
1	0.5	160	322	-	-	648	900	57	0
2	0.45	180	247		166	829	840	330	1.2
3	0.4	155	235	40	158	823	834	345	2.9
4	0.35	132	228		154	840	837	335	3.8
5	0.45	185	203		206	840	833	340	0.4
6	0.4	158	197	50	199	841	833	362	1.7
7	0.35	135	194		196	855	846	318	2.8
8	0.45	187	166		252	851	833	466	0
9	0.4	160	160	60	241	849	831	384	2
10	0.35	137	157		237	856	844	335	3

4.3 Mixing Procedure

A total of 10 (ten) mix proportions have been prepared in this paper. The procedure used for the mixes is as follows:

- ❖ Predetermined quantities of fine and coarse aggregate were added to the mixer and mixed for 30 seconds;
- ❖ Predetermined quantities of cement, fly ash, slag cement and silica fume were added to the mixer and mixed together with the aggregates for 1 minute;
- ❖ Various amounts of water, super plasticizer and viscosity admixture were added and mixed thoroughly;
- ❖ Different mixtures obtained were used to carry out the slump flow test, the U-type test, and to cast cylindrical specimens.

No vibration or compaction has been applied to the self-compacting concrete specimens, whereas compaction on normal concrete specimens was applied, for approximately 30 seconds, using a tamping rod. All concrete specimens have been cast and cured [12].

5. Results and Discussion

The results are arrived based on properties such as slump test, V funnel test, compressive test and the results are tabulated in table no 8.

The slump of the control concrete was about 115mm, and those of fly ash self-compacting concretes were approximately 235mm. The slump flow of the self-compacting concretes was in the range of 440 to 645mm, and the funnel test flow times were in the range of 3 to 6 seconds. All self-compacting mixtures (except mixture # 8) presented a slump flow between 500 and 700mm which is an indication of a good deformability. The different SCCs performed well in term of stability since all mixtures (except one) exhibited a flow time below 6 seconds.

The slump flow seems to be more related to the dosage of super plasticizer than to the percentage of the fly ash or to the water-to-cementitious materials ratio used. However, the dosage of the super plasticizer of the self-compacting concrete that ranged from 0 to 3.8 L/m³ of concrete seems to increase with a decrease in both the water-to-cementitious materials ratio and the

percentage of fly ash used. For all SCC mixtures, the flow time increased with a decrease in the water content.

The dosage of the air-entraining admixture (AEA) required for obtaining an air content of 5 to 7 % was about 67m L/m³ for the control concrete, and ranged from 338 to 483 mL/m³ for the self-compacting concrete materials did not significantly influence the bleeding water of the self-compacting concrete.

The compressive strength of the different concretes are 25.3 and 33.6 MPa, at 7 and 28 day testing. The self compacting concretes developed compressive strengths ranging from 13.8 to 31.10 and 19.5 to 33.8 Mpa at 7 and 28 day testing.

The compressive strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. Apart from mixtures 8 and 9 made with 60% of fly ash and a water-to-cementitious materials ratio of 0.40 and 0.45, all the remaining concrete mixtures achieved the targeted 28-day compressive strength of approximately 35MPa.

Table 8: Showing the Combined Results

Mix No	W/ (C+FA)	% of fly ash	Slump, mm	Slump flow, mm	Funnel test flow time, sec	Compressive Strength, MPa	
						7 day	28 day
1	0.5	-	115	-	-	25.3	33.6
2	0.45		235	620	3	20.2	33.6
3	0.4	40	235	620	3	24.2	35.8
4	0.35		235	645	6	30.3	47.2
5	0.45		225	510	3	15.2	32.2
6	0.4	50	235	560	5	17.2	33.9
7	0.35		235	530	6	20.5	37.8
8	0.45		225	440	3	14.6	29.2
9	0.4	60	235	600	3	13.8	25.1
10	0.35		235	640	4	19.5	33.8

5.1 Conclusions

The results show that it is possible to design a self-compacting concrete incorporating high-volume of Class F fly ash. The high-volume fly ash self compacting concretes have a slump flow in the range of 500 to 700mm, a flow time ranging from 3 to 6 seconds, and the setting times of the self compacting concrete were 3 to 4 hours longer than those of the control concrete. The self-compacting concrete developed compressive strengths ranging from 13 to 31 MPa and from 23 to 34 MPa, at 7 to 28 days, respectively.

By considering the results the conclusions are as follows.

✓ Under its own weight, without any external vibration or compaction, SCC attained consistency and self compatibility.

✓ The construction time, which in most of the cases is shorter than the time when normal concrete is used, due to the fact that no time is wasted with the compaction through vibration.

✓ As long as SCC does not require compaction, it can be considered environmentally friendly, because of no vibration is applied no noise is made.

✓ The utilization of fly ash in SCC solves the problem of its disposal thus keeping the environment free from pollution.

As SCC technology is now being adopted in many countries throughout the world, in the absence of suitable standardized test methods it is necessary to examine the existing test methods and identify or, when necessary, 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, the testing equipment should be reliable, easily portable and inexpensive. The test procedure should be carried out by a single operator and the test results have to be interpreted with a minimum of training. Also, the results have to define 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 could be manufactured in large quantities.

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