Development and Study of Behaviour of Self Compacting Concrete Mixes using Fly Ash

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Abstract— SCC is a high performance concrete that can flow under its own weight to completely fill the form work and self-consolidates without any mechanical vibration. Such concrete can accelerate the placement, reduce the labor requirements needed for consolidation, finishing and eliminate environmental pollution. The process of selecting suitable ingredients of concrete and determining their relative amounts with an objective of producing a concrete of required strength, durability and workability as economically as possible is termed as concrete mix design. The experimental procedure consists of fixing the optimum mix for SCC taking into account the criteria for SCC and design mix calculated as per Nan Su method. The mix ratio obtained from Nan Su method is made to satisfy the EFNARC Guidelines by trial mix method. Further the cement is replaced in the range of 5- 30% with an interval of 5% by FA for the optimum mix and finally fresh and hardened properties of developed mixes have been studied.

Key words: Self Compacting Concrete (SCC), Fly Ash (FA), Rheology, Compressive and Splitting Tensile Strength

I. Introduction

Developments in Japan, beginning in 1983, had been focused on the elimination of poor compaction which was identified as a major cause of poor durability of concrete structures by Ouchi (1998). Motivated by a lack of skilled workers and a substantial number of durability damages due to insufficient compaction, Okamura announced in 1986 the necessity to employ a SCC, which can be compacted into every corner of formwork, purely by means of its own weight and without the need for vibrating compaction by Okamura and Ozawa (1995).

SCC is highly engineered concrete with much higher fluidity without segregation and is capable of filling every corner of form work under its self weight only by Okamura (1997). Thus SCC eliminates the needs of vibration either external or internal for the compaction of the concrete without compromising its engineering properties. SCC is a fluid mixture, which is suitable for placing difficult conditions and also in congested reinforcement, without vibration. In order to meet the performance requirements the following three types of SCC are available.

- Powder type of SCC: This is proportioned to give the required self-compactibility by reducing the water-powder (material<0.1mm) ratio and provide adequate segregation resistance. Super plasticizer and air entraining admixtures give the required deformability.
- Viscosity agent type SCC: This type is proportioned to provide self-compaction by the use of viscosity modifying admixture to provide segregation resistance. Super plasticizers and air entraining admixtures are used for obtaining the desired deformability.
- Combination type SCC: This type is proportioned so as to obtain self-compatibility mainly by reducing the water powder ratio, as in the powder type, and a viscosity modifying admixture is added to reduce the quality fluctuations of the fresh concrete due to the variation of the surface moisture content of the aggregates and their gradations during the production.

II. Materials and Methods

A. Materials used

1) Cement

Portland cement is one of the most widely used additives for all types of constructional activity. The cement used for the investigation was Pozzolana Portland cement (PPC-33grade). It confirmed to the requirements of Indian Standard Specification (IS: 8112-1989).

2) Sand

Good river sand in absence of any earthy matter and organic matter. Particles are angular in shape passing 4.75mm and retaining on 150 micron sieve. Sample is washed in water to get free from earthy and silt content and dried over a period of 48 hours in sunlight.

3) Coarse Aggregates

The maximum size of aggregate is generally limited to 20mm.Coarse aggregate which passed through 12mm sieve but retained on 6mm sieve are used for the SCC mix. Well graded cubical or rounded aggregate are desirable. Aggregates should be of uniform quality with respect to shape and grading.

4) Mixing Water

Ordinary potable water of normally pH 7 is used for mixing and curing the concrete specimen.

5) Admixtures for SCC

a) Superplasticizer

Glenium B233 is used because it is essential components of SCC to provide necessary workability.

b) Fly Ash

FA is industrial waste from thermal power station. FA is one of the residues generated in combustion and comprises the fine particles that rise with the flue gases. In an industrial context, FA usually refers to ash produced during combustion of coal. It is important to increase the amount of pastry in SCC because it is an agent to carry the aggregates. As a consequence, FA has been used in order to increase the amount of pastry.

III. METHODOLOGY DETAILS

The present investigation is to design M_{30} grade SCC by using Nan Su method of mix design and as per EFNARC guide lines. The proportion is chosen in the range of 0-30% by weight of cement and is partially replaced at an interval of 5% respectively. Further developed mixes are studied both for rheology as well as hardened properties to use in Indian conditions. Other than this superplasticizer is also used to modify the fresh properties of SCC.

A. *Mixture Proportions*

The method of mix design for SCC proposed and used in this study is based on a method developed in Taiwan by Nan Su. The main objectives of this method are to determine the amount of paste required to fill the opening between loosely piled aggregate. The design mix ratio is calculated by Nan-Su method is then used to develop SCC by trial mixes and they should satisfy the fresh property as per EFNARC guidelines. The ratios which satisfy all criteria of EFNARC is a final developed ratio in which the cement is replaced with 0-30% of FA with an interval of 5% for the optimum mix to study the fresh and hardened properties of SCC.

The usage of FA is detrimental for compressive strength of SCC. Thus, these contents were chosen to attempt keeping increase in compressive strength similar to ordinary SCC. Thus, this paper would contribute the limited studies about the FA replacement. After then, seven different types of mixtures have been obtained including control and FA based mixtures. These are indicated as: (NSCC) for normal SCC, FA based Mix-1 (SCC_FA5%), FA based Mix-2 (SCC_FA10%), FA based Mix-3 (SCC_FA15%), FAbasedMix-4 (SCC_FA20%), FA based Mix-5 (SCC_FA25%), FA based Mix-6 (SCC_FA30%). During the production of fresh SCC, all ingredients have been mixed in dry state. After a homogeneous dry mixture has been obtained, the 80% of mixture water by volume has been added to the mixture. Afterwards, chemical admixture has been dissolved in the rest of mixing water and this solution has been added to the mixture. Mixing process has been continued until the mixture has the consistency of self-compactibility. This duration was not less than 5min.

B. *Mix design for SCC*

The method of mix design for SCC proposed and used in this study is based on a method developed in Taiwan by Nan Su. The main objective of this method is to determine the amount of paste required to fill the opening between loosely piled aggregate. This method consists of following steps.

1) *Mix Design Method*

a) Estimation of coarse and fine aggregates content:

The content of fine and coarse aggregates can be calculated as follows:

The parameter considered in the mix design.

- S/a ratio: It is a ratio of fine aggregate to total mass of aggregate, which ranges usually from 50 to 57%, (S/a) is been taken as 50%.

b) Pf-Packing Factor

It is defined as a ratio of mass aggregate of tightly packed state to that loosely packed state. The volume ratio of aggregate in air is about 52-58%. Further void in the loose aggregate is about 42-48% according to ASTM C 29. On the other hand, the value ratio of aggregate after lubrication and compaction in SCC is about 59-68%. In this study the PF value is selected as 1.16.

Wfa = Mass of the fine aggregate
Wca = Mass of the coarse aggregate
Wfal = Bulk density of fine aggregate
Wcal = Bulk density of coarse aggregate
f_c = Grade of Concrete
CF = Correction factor

1) Step 1: Calculation of fine aggregates

$$Wfa = PF \text{ X } Wfal \times S/a = 1.16 \text{ X } 1088 \times 50/100)$$
$$Wfa = 631.04 \text{ Kg/m}^3.$$

2) Step2: Calculation of coarse aggregates

$$Wca = PF \text{ X } Wcal \times S/a = 1.16 \text{ X } 1148 \times (1\text{-}50/100)$$
$$Wca = 665.84 \text{ Kg/m}^3.$$

3) Step3: Calculation of cement Content

$$C = (f_c/0.14) \times CF = (30/0.14) \times 1.535 = 328.92 \text{ Kg/m}^3.$$

4) Step4: Calculation of Mixing Water Content Required by Cement

The content of mixing water required by cement can be obtained by using equation by choosing water/binder ratio as 0.70

$$Wwc = [w/c] \times C = [0.7] \times 328.92$$
$$Wwc = 230.24 \text{ Kg/m}^3.$$

5) Step 5: Final quantities

Cement = 328.92 Kg/m^3
Fine aggregate = 631.04 Kg/m^3.
Coarse aggregate = 665.84 Kg/m^3.
Water content = 230.24 Kg/m^3.
Ratio = 1:1.92:2.02

Mix proportion obtained by Nan-Su, Method is 1:1.92:2.02 and w/p ratio as 0.70.

IV. RESULTS AND DISCUSSION

The basic materials used in the present work are tested in the laboratory in order to ascertain the properties of different materials to satisfy the codal provisions. Further, tested the cement, fine aggregate and coarse aggregates used in the investigation and the properties of those materials evaluated in the laboratory are tabulated in Tables 1 and 2 respectively.

Sl. No	Material	Test	Result
1	Cement	Specific gravity	2.80
		Initial setting time (min)	68
		Final setting time (min)	346
		Fineness (%)	9
		Compressive strength at 7-days (MPa) 28-days (MPa)	24.20 35.10
2	FA(Flyash)	Specific gravity	2.10
		Fineness (%)	8.30

Table 1: Test results of cement and Flyash(FA)

Sl. No	Material	Test	Result
1	Fine Aggregate	Specific gravity	2.70
		Bulk density (Kg/m^3)	1088
		Water absorption (%)	1.80
		Fineness Modulus	2.30
2	Coarse Aggregate	Specific gravity	2.70
		Bulk density (Kg/m^3)	1148
		Water absorption (%)	0.46%

Table 2: Test results of sand and coarse aggregate

The test results of cement, flyash (FA), fine aggregate and coarse aggregates obtained in the laboratory satisfies the BIS Code requirements.

A. Properties of Fresh Concrete

The properties of fresh concrete for different trial mixes considered in the present investigation are as shown in Table 3.

Slno	Mix ratio	SP (%)	W/P(ratio)	Slump flow	U-Box	V-Funnel	Remarks
1	1:1.92:2.02	-	0.70	-	-	-	Not satisfied
2	1:1.92:2.02	-	0.75	-	-	-	Not satisfied
3	1:1.92:2.02	-	0.80	-	-	-	Not satisfied
4	1:1.92:2.02	0.98	0.60	-	-	-	Not satisfied
5	1:1.92:2.02	1.57	0.60	-	-	-	Not satisfied
6	1:1.92:2.02	1.75	0.60	-	-	-	Not satisfied
7	1:1.92:2.02	2.10	0.60	-	-	-	Not satisfied
8	1:1.92:2.02	2.10	0.50	583	47	46.43	Not satisfied
9	1:2.08:1.98	2.10	0.50	610	38	37.35	Control mix
10	1:1.43:1.64	1.73	0.45	630	29	23.30	Not satisfied
11	1:1.43:1.64	1.93	0.45	630	18	19.45	Not satisfied
12	1:1.51:1.52	1.35	0.45	659	16	17.42	Not satisfied
13	1:1.51:1.52	1.46	0.45	684	14	17.35	Bleeding
14	1:1.48:1.52	1.27	0.44	689	11	17.46	Bleeding
15	1:1.48:1.52	1.27	0.43	682	15	16.18	Bleeding
16	1:1.48:1.52	1.27	0.42	665	13	16.15	SATISFIED

Table 3: Trial mixes to develop SCC

From the Table 3, all relevant details of a trial mixes are considered. Mixes 1 to 3 were initial trials obtained from Nan-Su method of design mix to achieve slump flow. With Mix 4, Super plasticizer is used to modify the flow properties. Mix 4 to 7 was kept constant but w/p ratio and SP is varied. Although this mix achieved a slump flow of 455mm, therefore in the next mix with reference to previous mix, dosage of SP and material proportions is kept constant and w/p ratio is varied. The mix 9 is taken as control mix or reference mix. Finally the slump flow of 600 was achieved from the w/p ratio of 0.50.further the replacement of cement is done with FA with the obtained trial mixes (1:1.48:1.52) and w/p ratio of 0.42.

Further results of rheological properties of SCC mixes with various percentages of Flyash replacement levels is as shown in Table 4.

Specifications	Slump flow	T_{50cm} Slump flow	V-funnel	V-funnel T_{5min}	J-ring	U-box
NSCC	665	4.3	12	14	10	07
SCC_FA05%	706	4.8	9	14.6	10	11
SCC_FA10%	684	4.65	11.5	14.2	10	18
SCC_FA15%	700	4.7	10	15.2	10	21
SCC_FA20%	681	4.50	11	15.5	11	23
SCC_FA25%	689	4.90	11.5	15.6	11	24
SCC_FA30%	695	5.60	12	15.9	11	25

Table 4: Fresh properties of SCC

B. Hardened properties of SCC

The important hardened properties of SCC are compressive and splitting tensile strengths. However in the present investigation they are evaluated by replacing cement by Fly ash (FA).The compressive strength results of SCC, when cement is partially replaced by Fly ash (FA) for different ages is reported in Table 5.

Specifications	7-day (MPa)	28-day (MPa)
NSCC	26.30	39.90
SCC_FA05%	29.10	41.70
SCC_FA10%	28.60	45.40
SCC_FA15%	28.20	38.10
SCC_FA20%	25.50	37.90
SCC_FA25%	25.30	36.10
SCC_FA30%	22.90	36.40

Table 5: Compressive strength results of SCC for various replacement levels of FA (%).

A graph of compressive strength of SCC with different ages is as shown in Fig. 1.

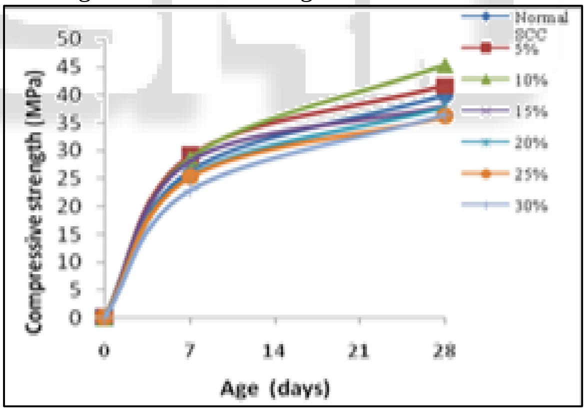

Fig. 1: Graph of compressive strength of SCC with Flyash at 7 and 28-days

It can be seen from the graph the optimum strength gained after 28 days of curing period is at 10% replacement levels and the lowest strength is at 25% replacement of levels of FA with cement. At 7days curing optimum strength gained is at 5% replacement levels and lowest at 30% replacement levels of FA with cement.

Splitting tensile strength results of SCC, when cement is partially replaced by FA for different ages is as shown in Table 6.

Specifications	7-day (MPa)	28- day (MPa)
NSCC	2.3	3.0
SCC_FA05%	2.3	3.1
SCC_FA10%	2.4	3.1
SCC_FA15%	2.3	2.8

SCC_FA20%	2.0	2.6
SCC_FA25%	1.6	2.4
SCC_FA30%	1.7	2.7

Table 6: Splitting tensile strength results for various replacement levels of FA (%).

A graph of splitting tensile strength of SCC with different ages is as shown in Fig. 2

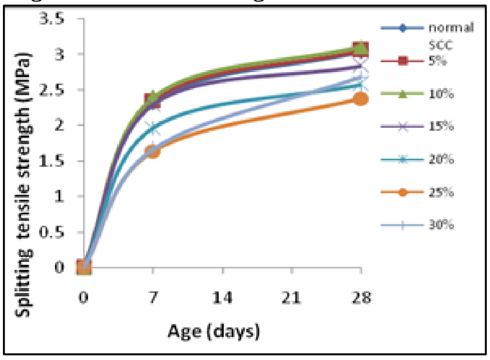

Fig. 2: Graph of splitting tensile strength of SCC with Flyash at 7 and 28-days

It can be seen from the graph the splitting tensile strength of 28days is more than that of 7days. The optimum strength gained after 28days curing period is at 10% and lowest at 25% replacement levels of FA with cement. At 7days curing the optimum strength gained is at 10% replacement levels and lowest at 30% replacement levels of FA with cement.

V. CONCLUSIONS

On the basis of laboratory results evaluated the following important conclusions are arrived.

– SCC mixes requires high powder content and high range of super plasticizer dosage to achieve good rheological properties.
– The time of addition of super plasticizer is very important and it is generally added after the addition of 50-70% of water.
– SCC fills the formwork and encapsulates the reinforcements without vibration, to achieve compaction by its own weight and gives an excellent surface finish.
– On the basis of test results, cement can be replaced by FA up to 15% without affecting strength of the mixes.
– It is observed that compressive strength increases up to10% replacement levels of cement by FA and decreased strength trend beyond 10% replacement levels of cement by FA.
– It is also observed that more reduction in strength for higher replacement levels of 25 and 30% of cement by FA.

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