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Research Article

Experimental Analysis of Self Compacting Concrete Incorporating different range of High-Volumes of Class F 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. 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 of hardened concretes such as compressive strength .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, Fly Ash SCC, Plasticizer, Ultimate Load.

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, earlier demoulding and faster use of elements and structures. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. 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.

In 2002 EFNARC [1] 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 specifies and purchasers.

Goodie CI [2] studied SCC is not expected to ever completely replace conventionally vibrated concrete, the use of the material in both the precast and ready-mix markets in the UK, Europe and the rest of the world is expected to continue to increase as the experience and technology improves, the clients demand a higher- quality finished product and the availability of skilled labour continues to decrease.

By employing self-compacting concrete, the cost of chemical and mineral admixtures is compensated by the elimination of vibrating compaction and work done to the surface of the normal concrete [3]. [Khayat et al 1999].

The concept of self-compacting concrete was proposed in 1986 by professor Hajime okamura [4], but the prototype was first development in 1988 in Japan, by professor Ozawa [5] 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. Investigations for establishing a rational mix-design method and self-compactability testing methods have been carried out from the viewpoint of making it a standard concrete.

Okamura et al [4] and proposed a mix design method for SCC based on paste and mortar studies for super plasticizer compatibility followed by trial mixes. However, it is emphasized that the need to test the final product for passing ability, filling ability, and flow and segregation resistance is more relevant. Prashant Bhuva et al[6] gives in their studies development of Self Compacting Concrete no Specific Method of Mix Design is Available. In this paper an attempt is made to develop SCC of Different Strength by Using various ranges of cements and Fly Ash, with appropriate quantity of Super plasticizer and VMA.

EXPERIMENTAL PROGRAMME

Batching Procedure

A total of 10 (ten) batches based on the above mix designs have been prepared in this research. The procedure used for the batches was 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 according to ASTM C 192-95 ‘’Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory’’.
- Compressive strengths of concretes were performed according to ASTM C 39-94 “Standard Test Method for Compressive Strength of Cube Concrete Specimens’’.

Table 1: Proportions of the concrete mixtures

Mix . No	W (C+FA)	Water	Cement	Fly ash		Fine aggregate, kg/m³	Coarse aggregate, kg/m³	AEA, ml/m³	SP, L/m³
			Kg/m³	%	Kg/m³				
1	0.5	163	326	-	-	650	905	67	0
2	0.45	188	251	40	167	831	842	338	1.2
3	0.4	159	238		159	844	844	355	2.9
4	0.35	136	232		155	846	847	345	3.8
5	0.45	188	207	50	207	845	843	356	0.4
6	0.4	161	200		200	842	843	372	1.7
7	0.35	138	197		197	856	856	338	2.8
8	0.45	190	169	60	254	853	853	483	0
9	0.4	164	163		245	851	851	394	2
10	0.35	141	161		241	866	864	345	3

The experimental program is based on the powder type self compacting concrete. Nine SCC mixtures and one control concrete mix design were prepared. From each concrete mixture, three 150x150x150-mm cubes specimens were made were used for the determination of compressive strength after 28 days of standard curing. The content of the cementitious materials was maintained constant (400 kg/m³). While the water/cementitious material ratios ranged from 0.35, 0.4 & 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 mixtures to obtain the properties of fresh concrete in terms of viscosity and stability

The total number of cast specimens was 30. However, before the actual batching and testing started, a few preliminary mixes were batched and four specimens were cast and tested after three days of curing. These specimens were tested to see if they would yield reasonable results and to ensure that the research was valid and the continuation of any further research was feasible. Also, for self-compacting concrete, slump flow and U-type tests were carried out in order to evaluate the filling ability and the self-compactability of the concrete.

Figure 1: Concrete Cubes Specimens

Figure 2: Compression Test

CHARACTERISTICS OF MATERIALS USED

Cement

Cement ordinary port land cement of 53 grade confirming to IS-12269 having specific gravity of 3.15 was used [7].

Fine aggregate

All normal concreting sands are suitable for SCC. Both crushed and rounded sands can be used .Natural river sand confirming to IS-383 zone π having specific gravity 2.63.

Table 2: 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
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	-

Table 3 : Grading of fine aggregate

IS sieve	Cumulative %		Specification as per IS: 383[8]. % Passing		
	Retained	Passing	Zone 1	Zone 2	Zone 3
4.75	3.5	96.5	90-100	90 to 100	90 to 100
2.36	13.65	86.4	60-95	75-100	85-100
1.18	47.3	52.7	30-70	55-90	75-100
600 microns	73.2	26.8	15-34	35-59	60-79
300 microns	93.7	6.3	5-20	8-30	12-40
150 microns	98.8	1.2	0-15	0-10	0-10

Coarse aggregate

All types of aggregate are suitable. The normal maximum size is generally 16-20mm; however particle sizes up to 40mm or more have been used in SCC.. Crushed granite angular aggregate of size 12.5 mm passing confirming to IS-383 having specific gravity 2.63.

Table 4: Grading of coarse aggregate

IS sieve	Cumulative %		Specification as per IS: 383 [8] % passing	
	Retained	Passing	Graded	Single sized
40.00 mm	0	100	100	90-100
20.00 mm	9.8	90.2	95-100	85-100
12.5 mm	84.8	15.2	-	-
10.00 mm	95.6	4.4	25-55	0-20
04.75 mm	100	0	0-10	0-5

Table 5: Physical properties of fine aggregate and coarse aggregate

	Bulk density (kg/m3)	Specific gravity	Absorption	Fineness modulus
Fine Aggregate	1625	2.53	1.65	2.62
Coarse Aggregate	1540	2.64	1.07	-

Mineral admixtures fly ash confirming to is 3812-1981

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. Fly ash with high lime and sulphate content is not suitable for producing SCC as it decreases the flow and increases the viscosity; non-cohesiveness of the mortar is also increased significantly. Fly ash with higher LOI, i.e. the higher carbon content, is not a suitable mineral admixture for SCC mortar. It affects the theology adversely making the mix highly viscose as well as non-cohesive.

Table 6: Physical properties of fly ash

SL.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 7: Chemical properties of fly ash

SL.No	Constituents	Percent by weight
1.	Loss on ignition	4.17
2.	Silica (Sio_2)	58.55
3.	Iron oxide (Fe_2O_3)	3.44
4.	Alumina (Al_2O_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

Water confirming to IS 456.

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

Super plasticizer

Super plasticizer Glenium B233 PCE (polycarboxylic ether) is used as admixture for all

SCC mix proportion expect for control concrete.A good PCE based admixture may be required in the dosage of 0.6% to 1.2% of the cementitious material in the mix. VMA 's are normally required from 0.2% to 0.4% of the cementitious material. GLENIUM B233 is an admixture of a new generation based on modified polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. GLENIUM B233 is free of chloride & low alkali. It is compatible with all types of cements.

Typical properties

Aspect : Yellowish free flowing liquid
Relative Density: 1.09 ± 0.01 at 25 ℃
Ph: 7 ±1, Chloride ion content: < 0.2%
Standards
ASTM C494 Types F
EN 934-2 T 3.1/3.2
IS 9130; 1999
BASF Construction Chemicals (India) Private Limited

Air entraining agents

A synthetic resin type air-entraining admixture (AEA) was used in all the SCC concrete mixtures. They are chemicals that introduce small air bubbles of size less than 45 microns in concrete. These air bubbles disperse uniformly in concrete and work like ball bearings to increase the workability of the concrete. Most of this entrained air is not expelled during compaction and becomes a permanent part of concrete. This is unlike plasticizers whose effect ceases after the setting of concrete. The entrained air has following advantages,

- Helps to lower the water/cement ratio hence reduces permeability of concrete.
- Make concrete mixes cohesive and increases compactability of concrete.
- Reduces bleeding in concrete.

RESULTS AND DISCUSSION

Based on the scientific evaluation of results from laboratory within the European standardization ''TESTING-SCC'', the slump flow & V-funnel tests have been selected as priority test methods for filling ability and passing ability of self compacting concrete.

Slump Flow Test

The slump flow test is the most widely used method for evaluating concrete consistency in the laboratory and at construction sites. In this study, the diameter of the concrete flowing out of the slump cone was obtained by calculating the average of two perpendicularly measured diameters for determining the above mentioned properties of concrete- 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 3: Slump flow test result

Figure 4:V.Funnel Test

V.Funnel Test

The flow ability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured. Shorter flow time indicate greater flow ability. 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.

The slump of the control concrete was about 110mm, and those of fly ash self-compacting concretes were approximately 240mm. The slump flow of the self-compacting concretes was in the range of 450 to 650mm, and the funnel test flow times were in the range of 3 to 7 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 (expect 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.

Table 8 : Properties of fresh concrete

Mix. No	W/(C+FA)	% of fly ash	Slump, mm	Slump flow, mm	Funnel test flow time, sec
1	0.5	-	110	-	-
2	0.45	40	240	625	3
3	0.4		240	625	4
4	0.35		240	650	7
5	0.45	50	230	520	3
6	0.4		240	570	5
7	0.35		240	540	6
8	0.45	60	230	450	3
9	0.4		240	600	3
10	0.35		240	650	4

This demonstrates the potential of high-volume fly ash self compacting concrete system for reducing the temperature rise in large concrete members due to its low cement content and the slow reaction process of fly ashes.

COMPRESSIVE STRENGTH

The compressive strength of the different concretes is shown in Table. The control concrete developed compressive strengths of 16.7, 27.3 and 34.6MPa, at 1.7, and 28 days, respectively. The self compacting concretes developed compressive strengths ranging from 4.9 to 16.6, 14.7 to31.3 and from 26.2 to 48.3 MPa at 1.7 and 28 days.

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 9: Compressive strength of concrete

Mix.No	W/(C+FA)	% of fly ash	Compressive Strength, MPa		
			1^{st} day	7^{th} day	28^{th} day
1	0.5	-	16.7	27.3	34.6
2	0.45	40	8.7	21.2	34.6
3	0.4		10.7	25.8	37.8
4	0.35		16.6	31.3	48.3
5	0.45	50	6.1	17.4	33.2
6	0.4		7	19.3	34.9
7	0.35		7.8	22.6	38.9
8	0.45	60	5.2	15.6	30.2
9	0.4		4.9	14.7	26.2
10	0.35		7.3	20.6	35.8

COST ANALYSIS

Cost analysis of the concrete mixtures based on the cost of the materials only, and it has been analyzed as per the purchased price from the market (as of February 2011). The mixes selected for calculation and analysis were those which could pass maximum properties of freshly mixed concrete. The table shows that the cheapest concrete mixture that achieved the targeted 28-day compressive strength of approximately 35MPa is the control concrete followed by the self compacting concrete made with 50% of fly ash and with a water-to-cementations materials ratio of 0.45. the costs of the above two mixtures are Rs 3025 and 2964 per 1 m³ of concrete, respectively. This shows that a concrete with a 28days compressive strength of 35MPa can be replaced by a self-compacting concrete with no significant extra cost. Such self-compacting concrete would be flow able with a slump flow and flow time of approximately 500mm and 3 seconds, respectively; the concrete is likely to be resistant to segregation and to thermal cracking caused by the heat of hydration of the cement. However, such self-compacting concrete might exhibit high bleeding water and long setting times.

Table 10 :Cost Analysis of control concrete and self compact concrete

Mix. No			1	2	3	4	5	6	7	8	9	10
W/(C+A)			0.5	0.45	0.4	0.35	0.45	0.4	0.35	0.45	0.4	0.35
Mix Design	Cement-kg/m³		326	251	238	232	207	200	197	169	163	161
	Fly Ash	%	-	40			50			60		
		Kg/m³	-	167	159	155	207	200	197	254	245	241
	Fine Aggregate-kg/m³		650	845	844	846	845	842	856	853	851	866
	Coarse Aggregate-kg/m³		905	846	844	847	843	843	856	853	851	864
	AEA –ml/m³			0.34	0.36	0.35	0.36	0.37	0.34	0.48	0.39	0.35
	SP L/m³		0	1.2	2.9	3.8	0.4	1.7	2.8	0	2	3
Mix pricing	Cement at Rs 5500/T		1793	1380	1309	1276	1138	1100	918	929	896	885
	Fly Ash at Rs 1500/T		-	248	239	233	311	300	296	381	368	362
	F.A at Rs1100/m³		715	929	928	930	929	926	938	938	936	953
	C.A at Rs 880/m³		517	484	484	484	484	484	484	487	486	494
	AEA at Rs 150/L		-	51	54	53	54	56	51	72	59	52
	SP at Rs120/L		-	144	348	456	48	204	336	-	240	360
Total Cost Rs/m³			3025	3236	3362	3432	2964	3070	3023	2807	2985	3106

CONCLUSIONS

Taking into account the finding from this study, the following conclusions can be drawn. By using the slump flow and V-funnel tests, that self-compacting concrete (SCC) achieved consistency and self- compactability under its own weight, without any external vibration or compaction.

The self-compacting concrete developed compressive strengths ranging from 15 to 31 MPa and from 26 to 38 MPa, at 7 to 28 days with no extra cost . The present investigation has shown that it is possible to design a self-compacting concrete incorporating high-volume of Class F fly ash.

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

Its advantages related to the SCC does not require compaction, it can be considered environmentally friendly, because of no vibration is applied no noise is made.

Savings in labor costs might offset the increased cost related to the use of more cement and super plasticizer, and the mineral admixtures, could also increase the fluidity of the concrete, without any increase in the cost.

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