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Shrinkage Properties of Self-Compacting Concrete with High Volumes of Class F Fly Ash

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Abstract: Self compacting concrete (SCC) is becoming more popular in the present days due to its ability of passing through congested reinforcement without the aid of external vibration effort. To possess self-passing ability fresh concrete should have good cohesiveness. Use of large quantity of fine materials can impart cohesiveness to the SCC. Fly ash (FA) is one of such fine materials which can be used in SCC. In this study effect of class F fly ash on different properties of SCC was studied. Ordinary Portland cement (OPC) was replaced with (30-70) % FA in SCC. Water to binder ratio was maintained 0.325 for all SCC mixes. Slump test, flow ability and filling ability tests were conducted on fresh concrete. Hardened concrete properties such as compressive strength, drying shrinkage, split tensile strength and flexural strength were also studied. SCC mixes developed compressive strength ranging from 26 to 48 MPa at 28 days. Drying shrinkage strain was decreased with increase in FA content.

Keywords: *Self compacting concrete, Fly ash, Drying shrinkage*

1. Introduction

Self-compacting concrete (SCC) was first developed in Japan. SCC is a material which can flow through highly congested reinforced bars without the help of additional compaction and has a capacity to compact on its own weight without segregation [1]. The following reasons have made SCC very advantageous

- Speedy construction
- Manpower reduction
- Superior surface finishing
- Easy to place
- Improves durability
- Gives freedom in design
- Reduction in noise
- Safe working condition [2]

A SCC is a flowing concrete which gives a slump value more than 200 mm and a slump-flow more than 600 mm (diameter of the SCC pat after removal of the slump cone) with high cohesiveness, and can be poured and consolidated without the help of vibration. These flow properties are normally achieved by a high rate of cement paste-to-aggregate ratio than is usually used with normal concrete mixtures. Use of high volume of cement leads to the high rate of drying shrinkage in SCC. The autogenous shrinkage too will be high when the SCC contains a comparatively large quantity of ordinary Portland cement (OPC) and other reactive powders [3].

Drying shrinkage in SCC can be reduced by using high volumes of FA. Many researches have been carried out on SCC with large quantities of fly ash. Cengiz Duran Atis [4] studied the concrete mixes produced with different percentage of replacement (by mass) of OPC with FA. The incorporation of large volume of fly ash in SCC with a low water-binder ratio resulted in a reduction in the drying shrinkage values. Drying shrinkage values were 30% lesser when compared to concrete with OPC. The concrete mixes prepared with superplasticizer exhibited high rate shrinkage values. Shrinkage values were of up to 50% more in comparison with the concrete produced with no superplasticizer. N. Bouzoubaa et al. [5] investigated drying shrinkage strain on SCC mixes with FA by varying the water to binder ratio and air content. Drying shrinkage results observed were very low. Drying shrinkage strain was $600x10^{-6}$ at 224 days. There was no difference found between the drying shrinkage strain of SCC and that of the control concrete. The drying shrinkage strain of the normal concrete was $5.41x10^{-4}$ at 224 days, and while SCC mixes ranged from $5.04x10^{-4}$ to $5.95x10^{-4}$ at 224 days. J.M. Khatib [6] studied the effect of FA and admixture dosage on SCC. The results showed that huge quantity of FA can be used in SCC to obtain high strength and low drying shrinkage. There was a considerable reduction in drying shrinkage as the

FA quantity increases and at 80% FA content, the drying shrinkage at 56 days decreased by 0.66 times compared with the control concrete.

Katherine Kuder et al. [7] studied the effect of high quantities of 2 pozzolana materials namely fly ash and slag on the mechanical properties of SCC mixes. Results showed that drying shrinkage strains of the unsealed specimens were less in comparison with sealed specimens. And also reduction in water absorption was observed in sealed specimens. Mehmet Gesoglu et al.[8] investigated SCC mixes with binary cementitious blends, ternary cementitious blends, and quaternary cementitious blends of PC, fly ash , ground granulated blast furnace slag (GGBS), and silica fume (SF). The SCC mixes with binary cementitious blends of FA or S showed lower drying shrinkage strains than the control concrete mix. This advantageous effect appeared to be more with increase in level of replacing cementitious blends. The concrete having 60% FA showed lowest shrinkage strain. Effect of silica fume was to increase the drying shrinkage strain, when used at replacement levels of 10% and 15%. Using of fly ash and GGBS decreased the free shrinkage of the SCC mixes while the silica fume increased the drying shrinkage when used in binary blends. But combined use of different blends greatly eliminated the adverse effect of the silica fume. Pipat Termkhajornkit et al. [9] studied relation between degree of hydration and autogenous shrinkage of fly ash. The results showed that as the Blaine surface area increased heat of hydration of fly ash also increased. The heat of hydration of fly ash increased with time, and autogenous shrinkage increased with respect to the increase in the heat of hydration of fly ash. It was observed that the total quantity of Al_2O_3 in cement–fly ash samples affected autogenous shrinkage at early ages, but the influence was very small at later ages. Yilmaz Akkaya et al. [10] studied autogenous shrinkage and drying shrinkage of ordinary Portland cement (OPC) concrete, and fly ash and silica fume binder concretes, were investigated and compared. The concrete mixes were formed by replacing part of the OPC with fly ash, very fine fly ash and silica fume.

Table 1: *SCC mix proportions*

Mix	Cement kg/m^3	Fly ash		W/B ratio	Water kg/m^3	Fine aggregates kg/m^3	Coarse aggregates kg/m^3		Superplasticizer kg/m^3
		kg/m^3	%				20mm	12.5mm	
M1	420	180	30	0.325	195	780	420	280	5.7
M2	360	240	40	0.325	195	763	420	280	5.7
M3	300	300	50	0.325	195	745	420	280	5.7
M4	240	360	60	0.325	195	727	420	280	5.7
M5	180	420	70	0.325	195	710	420	280	5.7

The autogenous shrinkage strains were lowered with the use of fly ash and very fine fly ash, the drying shrinkage strains were higher for the mixes with silica fume. From the previous research it is clear that high volumes of FA can be used to achieve different properties SCC.

But it is difficult to interpret the results when water to binder ratio and admixture dosage is varied. In this paper efforts were made to study the effect of FA variation on SCC mixes with same water to binder ratio and admixture dosage.

The objective of this paper is to achieve satisfactory SCC mixtures for high volume fly ash and to measure its strength and shrinkage properties.

2. Materials

2.1. Cement

Ordinary Portland cement (43 grade) having specific gravity 3.006, conforming to IS: 8112-1989 [11] was used in this study.

2.2. Fly ash

Fly ash (class F) produced by Raichur Thermal Power Station (RTPS), Karnataka was used it his study. It has specific gravity of 2.26 and Blaine's surface area of 3225 cm^2/gm. Its specifications were satisfactory as per IS: 3812-1981 [12].

2.3. Aggregates

Coarse aggregates obtained from local source with specific gravity of 2.71 for 20 mm down aggregates and 2.62 for 12.5 mm down aggregates were used. Coarse aggregate fractions used were 60 and 40 for 20 mm and 12.5 mm respectively. Natural sand having specific gravity of 2.65 was used as fine aggregates. Both coarse and fine aggregates were conforming to IS 383:1970 [13].

2.4. Superplasticizer

Superplasticizer used in this study was sulphonated naphthalene polymer type high range water reducing agent conforming to the ASTM C-494 standard [14].

2.5. Curing Membrane

Curing membrane used in this study was low viscosity wax emulsion which incorporates a special alkali reactive emulsion breaking system conforming to ASTM C309-90 standard [15].

3. Mix proportions

A total of 5 SCC mixes were designed at water to binder ratio of 0.325 with total cementitious materials content of 600 kg/m^3. All SCC mixes included OPC and FA as binder. The replacement ratios for FA were 30%, 40%, 50%, 60% and 70% by weight of the total binder. The concrete mix proportions are shown in the Table 1.

Table 2: *Properties of fresh concrete*

Mix	W/B ratio	% of Fly ash	Unit weight, kg/m^3	Slump flow, mm	T_{50}, Sec	V-funnel, Sec	L-box H_2/H_1 ratio	U-box mm
M1	0.325	30	2361	680	2.91	7.66	0.875	20
M2	0.325	40	2353	655	3.69	8.2	0.835	24
M3	0.325	50	2318	694	2.85	7	0.86	22
M4	0.325	60	2285	709	2.6	6.45	0.9	15
M5	0.325	70	2262	715	2.85	6.8	0.89	17

4. Concrete casting and testing of specimens

All the SCC mixes were mixed in mechanical mixer for 5 minutes. Immediately after the mixing tests were conducted to investigate the fresh properties of concrete. From each concrete mixture, nine 150mm x 150mm x 150mm cubes, two 100mm x 100mm x 500mm beams, one cylinder 150mm x 300mm were cast. Cubes were used for determining compressive strength, one beam is used for determination of flexural strength, one more beam is used for determination of drying shrinkage and cylinder was cast to determining the split tensile strength. All the mixes were cast in single layer without using vibrator. All specimens were demoulded after 24 hours, immediately after demoulding specimens were transferred to curing tank.

For monitoring the drying shrinkage one beam 100mm x 100mm x 500mm used. Immediately after demoulding the specimens, curing membrane was applied to all surfaces and the gage length was formed by sticking buttons on the surface of the beams. The initial gage length was measured and consecutive readings were taken at every 5 days. The length change in specimens was measured with the help of demountable mechanical strain gauge with 204 mm gauge length having a capability of measuring strain of 0.002.

5. Results and Discussions

5.1. Fresh Concrete Tests

Fresh properties of SCC mixes were investigated through the slump flow (diameter of SCC pat), T_{50} slump flow time, time for V-funnel flow, height ratio for L-box and U-box height difference as per EFNARC guidelines [16]. Slump flow diameters of all SCC mixes were in the range of 655-715 mm. The slump flow time (T_{50}) for all SCC mixes were less than 4 seconds. The time measured for the V-funnel flow was in the range of 6.4-8.2 seconds. H_2/H_1 ratio in L box were in the range of 0.835-0.9 and the difference in height in U-box were ranged from 15-24 mm. All the mixes showed satisfactory results as per EFNARC. Test results of fresh concrete were shown in the Table 2.

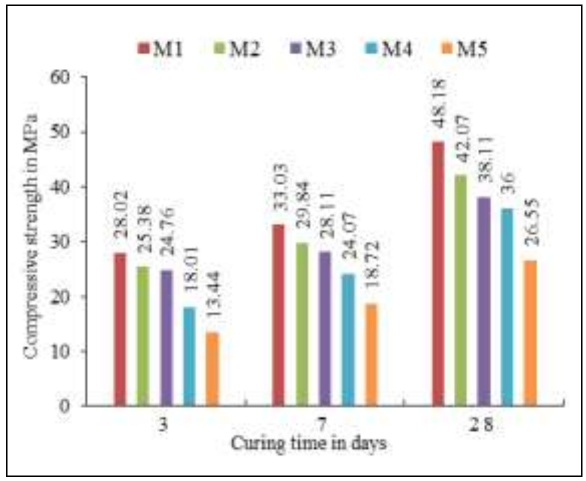

Figure 1 *Compressive strength of SCC mixes at different curing age*

5.2. Compressive Strength

SCC mixes showed compressive strength of 13.44 to 28.02, 18.72 to 33.03 and 26.55 to 48.18 MPa at 3, 7 and 28 days respectively. All the SCC mixes showed lower strength in early age, this is due to delayed setting time and delay in formation of calcium silicate hydrate gel. SCC mixes with 40, 50, 60 and 70 % FA developed 12.6, 20.9, 25 and 44.8 % lesser strength respectively in comparison with SCC mix with 30 % FA at 28 days. Compressive strength for different SCC mixes against curing time is shown in Figure 1.

5.3. Flexural Strength

SCC mixes showed flexural strength ranging from 3.53 to 6.28 MPa at 28 days. Flexural strength for different mixtures at 28 days of curing is shown in Figure 2.

5.4. Split Tensile Strength

SCC mixes developed split tensile strength ranging from 2.01 to 3.19 MPa at 28 days. Split tensile strength for different mixtures at 28 days of curing is shown in Figure 3.

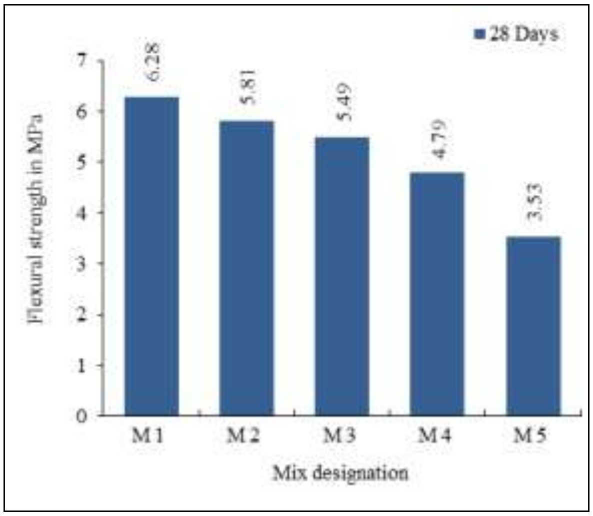

Figure 2 *Flexural strength of SCC mixes at 28 days*

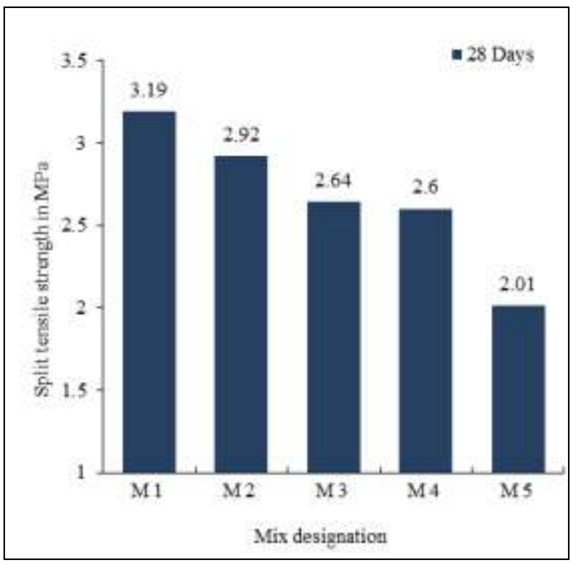

Figure 3 *Split tensile strength of SCC mixes at 28 days*

5.5. Drying Shrinkage

The drying shrinkage strains investigated for SCC mixes were ranging from 2.62 x 10^{-6} to 3.2 x 10^{-6} at 28 days. SCC mix with 30% FA showed higher drying shrinkage strain while mix with 70% FA showed least drying shrinkage strain than other mixes. Drying shrinkage strain for different mixes is shown in Figure 4.

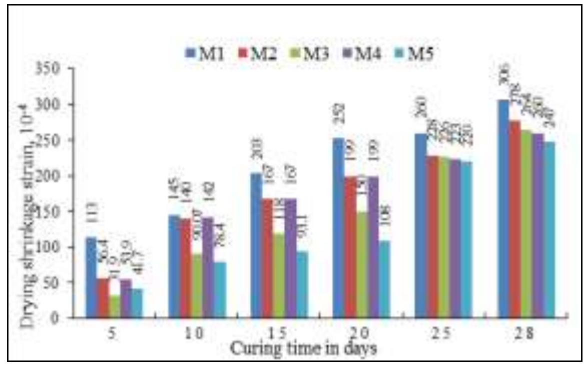

Figure 4 *Drying shrinkage strain of SCC mixes at different curing age*

6. Conclusions

Following observations were drawn from the present study

- Compressive strength decreased with increase in FA.
- Increase in FA content reduced the flexural strength as well as split tensile strength.
- Drying shrinkage in SCC decreased with increase in FA. SCC mix with 70 % FA showed lower drying shrinkage at 28 days.

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