PROPERTIES OF SCC WITH ALCCOFINE, GGBS AND FLY ASH-PLASTIC VISCOSITY APPROACH

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ABSTRACT. In this paper a study on high strength SCC containing Alccofine is reported. Mix proportioning of SCC is done based on the assumed plastic viscosity of the mix and characteristic compressive strength of concrete after 28 days using micro-mechanical procedure. The study deals with the role of varying Alccofine content on the fresh and hardened properties of SCC. Comparison of the different concrete mixes is done by appropriate tests pertaining to workability like slump flow, V-funnel, and L-box and hardened concrete properties. M40 grade concrete is adopted for the entire course of action of experimental investigations. GGBS and Fly Ash are used in the present study at a constant percentage of 10% by weight of cement while use of Alccofine is varied from 0% to 20% at an interval of 5%. The concrete samples were tested at 28 days for compressive strength. Results indicated that the workability enhanced with the increase in the Alccofine content. Addition of Alccofine also enhanced the compressive and flexural strengths.

Keywords: Alccofine, GGBS, fly ash, plastic viscosity, workability, SCC.

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INTRODUCTION

Self-compacting concrete (SCC) is characterised by its ability to consolidate under its own weight without any means of compaction or vibration. Since the first development of SCC many mix proportions have been proposed which are generally opted for optimization of mineral admixtures used and the reduction of cement content. For a large-scale construction work careful management of available resources and the sustainability of built structure is important. There is no single universal solution but rather a wide range of possibilities for a concrete mix, using locally available materials and reaching a satisfactory outcome in that situation.

The three key fresh properties of SCC are: Filling ability, Passing ability and Resistance to segregation. All these properties must be satisfied in order to design an adequate SCC mix, together with other requirements including those for hardened performance. Better flowability characteristics of concrete will ensure better results for workability and while not compromising on strength parameters the addition of admixtures helps environmental sustainability.

Self-compacting concrete was first developed in 1988 to achieve durable concrete structures. Since then various investigations have been carried out for establishing a rational mix-design method for making self-compacting concrete a standard concrete by means of various self-compactibility testing methods [1]. The science of self-compacting concrete has evolved since. A research aimed at developing medium strength self-compacting concrete by partial replacement of cement with pulverized fly ash and reduced the usage of super plasticizer which reduces the cost of resulting self-compacting concrete. A polynomial regression was fitted into the model. The results obtained showed that a 28-day compressive strength of 30 to 35 MPa was obtained with a cement content of 210 kg/m^3.[2] Cement can be replaced by fly ash as an admixture to obtain better fresh concrete properties. A replacement level of up to 80% of fly ash was tested. To improve the fresh properties of concrete by this replacement water to powder ratio is increased and SP dosage is decreased. It was observed that fly ash content may be restricted to 40% as after that the results obtained were not satisfactory. [3] GGBS has also been used before to replace cement to develop a new mix design methodology of self-compacting concrete. The results indicated that GGBS up to a replacement of 20% to 80% can only be used and concretes up to strength of 30 to 100 MPa can only be developed. The results also indicate that this design methodology can also produce good quality GGBS based SCC mixes. [4] A study of the effect of amount of admixtures used for paste on the properties of self-compacting concrete was performed. The mineral admixtures used in this study were fly ash and GGBS. The results showed that higher the unit weight of concrete, higher the compressive strength and lesser the cement used, lesser will be the early strength and higher the long-term strength. [5]

In the present paper an investigation was carried out on the practicality of developing a self-compacting concrete by replacing cement with SCM such as Alccofine, PFA and ultra-fine GGBS (Alccofine). It highlights the outcomes of the mechanical properties and different durability studies of SCC mixtures. The paper moreover looks into the effects of using silica fume and Alccofine on the initial stage and long-time properties of SCC. Hence, the paper addresses the improvement of SCC blended with SCM and examine its various properties like workability, strength and durability which will lead to a sustainable construction. For this paper in fresh concrete phase, the ratio between the mass of aggregates and the mass of the concrete excluding air (M_s/M_c) is 0.733 and the water/cementitious material ratio by mass (M_w/M_{cm}) is 0.5 and superplasticiser is fixed amount 0.843% of cementitious material (3.4 kg) to obtain the required flow properties (EFNARC guidelines). Robo sand is used as fine aggregates for its well graded format rather than the river sand.

MATERIALS AND EXPERIMENTAL PROCEDURE

Materials

Ordinary Portland cement of grade 53 conforming to Indian Standard IS 12269-1987 was used throughout the experimental program which was obtained from Ultratech Cement. Density of cement – 3150 kg/m^3. The superplasticizer used was MasterGlenium® SKY 8233 which is a high-performance super plasticiser based on PCE (polycarboxylic ether) for concrete (Specific gravity~1.08).
Manufactured sand (here Robo sand) conforming to IS 383: 1970 was used as fine aggregate, having a density of 2500 kg/m^3. Robo Sand is a fine aggregate that is produced by crushing stone, gravel, or slag. Used for aggregate material less than 4.75 mm that is processed from crushed rock or gravel and intended for construction use. Robo sand is a material of high quality, in contradiction to non-refined surplus from coarse aggregate production. The coarse aggregate used for the concrete mix contains 15% of aggregates passing from 20 mm sieve while other 85% of aggregates passing through 10mm sieve of the total coarse aggregate content.
Pulverised fuel ash conforming to IS 3812-1 (2003) is used, which replaces 10% of cement powder used for all the mixtures. The specific gravity of the PFA used is 2.16. Ground granulated blast furnace slag is also used as SCM, replacing 10% of cement powder for all concrete mixtures. The specific gravity of the GGBS is 2.85. ALCCOFINE 1203 is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. The raw materials are composed primary of low calcium silicates. The processing with other select ingredients results in controlled particle size distribution (PSD). The computed blain value based on PSD is around 12000cm^2/gm and is truly ultra-fine. Due to its unique chemistry and ultra-fine particle size, ALCCOFINE 1203 provides reduced water demand for a given workability, even up to 70% replacement level as per requirement of concrete performance. ALCCOFINE 1203 can also be used as a high range water reducer to improve compressive strength or as a super workability aid to improve flow.

Mix proportions

Role of water to cement ratio on compressive strength of concrete

According to Abram's law of water to cement ratio, the compressive strength of concrete depends on the water-cement ratio adopted and the strength is inversely proportional to water-cement ratio (in terms of mass). So, based on this law it is clear that the strength of SCC also depends mainly on the water to binder material. According to this law the expression for compressive strength in terms of w/cm ratio is given by

$$f_{cu} = \frac{132.77}{11^{\left(\frac{w}{cm}\right)}} \quad (1)$$

Where, f_{cu} is the 28-day cube compressive strength of concrete in MPa.

$\frac{w}{cm}$ represents the adopted water to cement ratio of the concrete mixture.

Table 1 Chemical and physical properties of Ordinary Portland Cement, fly ash and GGBS

CHEMICAL COMPOSITION (%)	OPC	FLY ASH	GGBS	ALCCOFINE
CaO	65.23	1.78	40.64	33
SiO_2	18.64	60.13	35.15	34
Al_2O_3	5.72	28.37	19.60	24
Fe_2O_3	4.54	5.10	0.53	0.8-3
SO_3	4.32	0.11	1.89	0.1-0.4
K_2O	0.59	2.16	0.40	-
TiO_2	0.50	1.42	0.92	-
Specific Gravity	3.15	2.16	2.85	2.9

Development of plastic viscosity-based mix design for SCC

Step by step mix design procedure, M.S. Abo Dhaheer et al [6];

1. The first step is to choose a corresponding grade of concrete and accordingly water to cement ratio is calculated from equation (1).
2. Plastic viscosity of the paste is to be adopted based on the water to cement ratio obtained from step (1). The values of plastic viscosity of the paste are obtained either by measuring using Brookfield Viscometer or from standard literature available. For the current study these values are obtained using Brookfield Viscometer.
3. Based on the required workability of the mix, a trial plastic viscosity of the mix has to be chosen. With the increase in plastic viscosity of the mix, T_{50} time increases accordingly.
4.

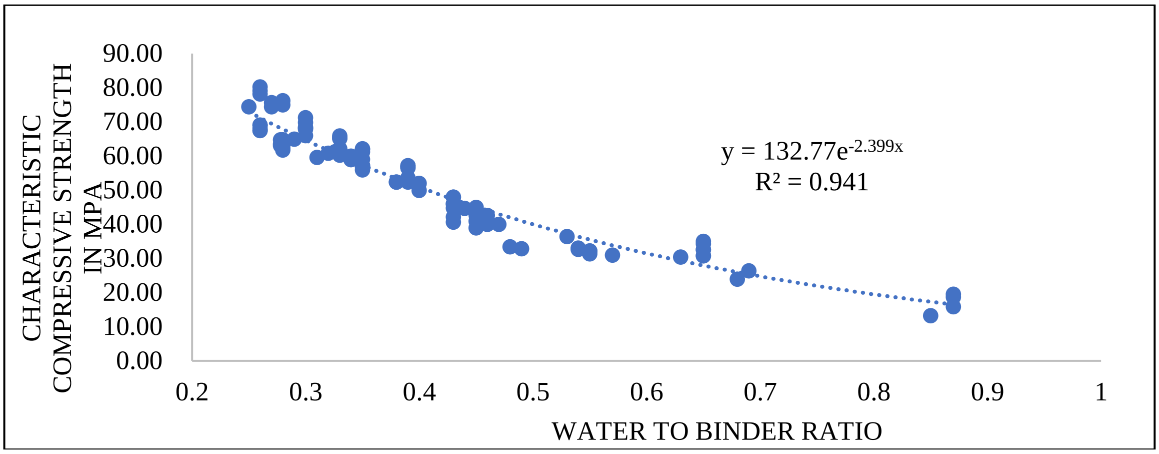

Figure 1 Regression curve for water to cement ratio

5. Adopt suitable water content as per the standard EFNARC guidelines ranging from 150 to 210 kg/m^3 based on the overall workability of the mix.
6. With the known water to cement ratio and water content, total cementitious content is to be calculated. Total cementitious content is a combination of OPC, fly ash, GGBS and Alccofine.
7. GGBS and Fly Ash content is kept constant equal to 10% of total cementitious content each and varying the percentage of Alccofine from 0% to 20% of total cementitious content with gradual change of 5% at a time.
8. A trial super-plasticizer dosage as % of cementitious material is adopted which satisfies the required workability of the SCC mix.
9. Individual amount of ingredients i.e. amounts of coarse and fine aggregate to be added can be found from the volume fractions of materials obtained from equation (2 and 3). t_1 and t_2 are arbitrarily chosen such that t_1 x t_2 = 1. Each of them corresponding to the factor representing the volume fraction of fine and coarse aggregate.

$$\boldsymbol{\emptyset_{FA}} = \frac{\frac{FA}{\rho_{FA}}}{\left(\frac{cem}{\rho_{cem}}+\frac{w}{\rho_{w}}+\frac{SP}{\rho_{SP}}+0.02\right)+\frac{FA}{\rho_{FA}}} \quad \textbf{(2)}$$

$$\boldsymbol{\emptyset_{FA}} = \frac{\frac{CA}{\rho_{CA}}}{\left(\frac{cem}{\rho_{cem}}+\frac{w}{\rho_{w}}+\frac{SP}{\rho_{SP}}+\frac{FA}{\rho_{FA}}+0.02\right)+\frac{CA}{\rho_{CA}}} \quad \textbf{(3)}$$

10. Total volume of the mix should be equal to 1 m^3. Suitable adjustments have to be made to ensure that the total volume equals 1 m^3.
11. Equation (4) is to be used to estimate the plastic viscosity of the mix with the obtained proportions of raw materials. The percentage difference between the assumed plastic viscosity from step (3) and the estimated plastic viscosity should be within $\pm$ 5%. If the difference is more, then different sets of volume fractions for solid phase ingredients i.e. fine and coarse aggregates are to be chosen and steps 9 and 10 are to be repeated. The proportions for different combinations of SCC mixes are given in Table 2.

$$\boldsymbol{\eta_{mix} = \eta_{paste} * \left(1-\frac{\emptyset_{FA}}{0.63}\right)^{-1.9} * \left(1-\frac{\emptyset_{CA}}{0.74}\right)^{-1.9}} \quad \textbf{(4)}$$

Table 2 Mix proportions (kg/m^3)

MIX ID	A00C80	A05C75	A10C70	A15C65	A20C20
Coarse Aggregate (20 mm)	113.22	113.43	113.36	113.29	113.21
Coarse Aggregate (10 mm)	641.57	642.79	642.38	641.98	641.57
Fine Aggregate	927	927	927	927	927
Water	202	202	202	202	202
Cement	323.2	303	282.8	262.6	242.4
GGBS	40.4	40.4	40.4	40.4	40.4
Fly Ash	40.4	40.4	40.4	40.4	40.4
Alccofine	0	20.2	40.4	60.6	80.8
Chemical Admixture	3.4	3.4	3.4	3.4	3.4

Observations

Fresh concrete properties

The results of fresh properties of all SCC mixtures are included in figure 2, 3 and 4 which shows the properties such as slump-flow L-box and V funnel time of SCC mixtures. The **Slump flow** indicates the mean diameter of the mass of concrete after release of a standard slump cone. Flowability is measured with the help of slump flow test. This test starts like a standard slump test, although many testing technicians will turn the cone upside down to make it easier to fill. When the cone is lifted, the SCC spreads out like pancake batter. The slump flow is measured as the diameter of the pancake. Typical SCC mixes have slump flows ranging from 460 to 760 mm. Alccofine is a chemical admixture which on addition to SCC increases the number of fines. The partial replacement of cement by Alccofine results in higher volume of paste due to its lower density and this increase in the paste volume decreases the friction at the fine aggregate-paste interface and improves the cohesiveness and plasticity, and thus leads to increased workability.

In addition to the slump flow, **V funnel** test was also performed to access the flowability and stability of the SCC mixture. The equipment consists of a v shaped funnel. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus is measured. V-funnel time is the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top.

L-box test is used to measure the filling and passing ability of self-compacting concrete. This test is also applicable for highly flowable concrete. The apparatus consists of an L-shaped box. This test targets the flowing ability of concrete considering the size of the aggregates used. L-box test represents the filling and passing ability of the SCC mix. L-box is more sensitive to blocking. Blocking ratio should lie between 0.8 to 1.0. Three batches were made consisting of 15 samples, all of them are listed below along with their fresh concrete properties.

In Figure 2, 3 and 4 test results on fresh concrete properties indicated that all SCC mixtures meet the EFNARC guideline for good SCC mixes.

In total 3 batches were made containing in total 15 samples. Here **A00C80** sample stands for – Batch containing Alccofine – 0% and Cement – 80%, whereas FA and GGBS kept constant 10% each. All of them are tested for slump flow test, V-funnel and L-Box Test. The slump value gradually decreases starting from 0% Alccofine content to 10% Alccofine content then gradually increases thereafter till 20% for the mix. The time taken for concrete to fully empty the V-funnel gradually decreases for 0% to 20% Alccofine content. The L box test shows increasing values for increasing Alccofine content in the mixture.

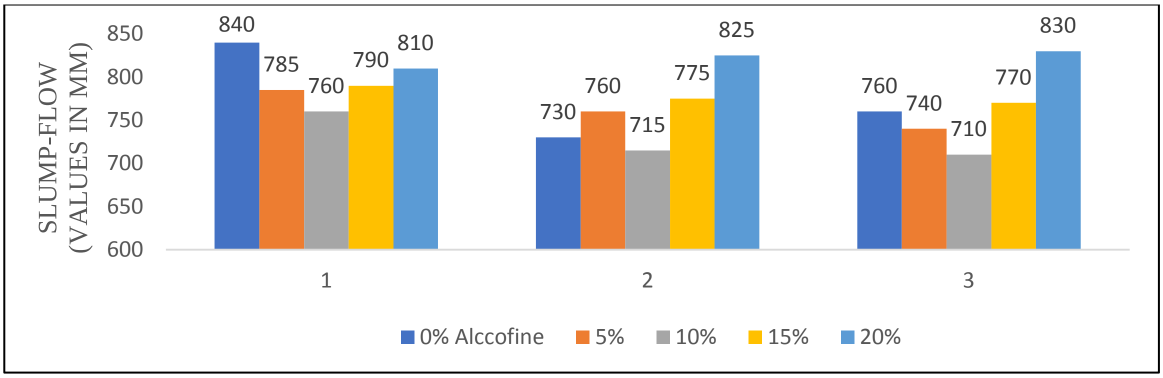

Figure 2 Slump-flow Test data

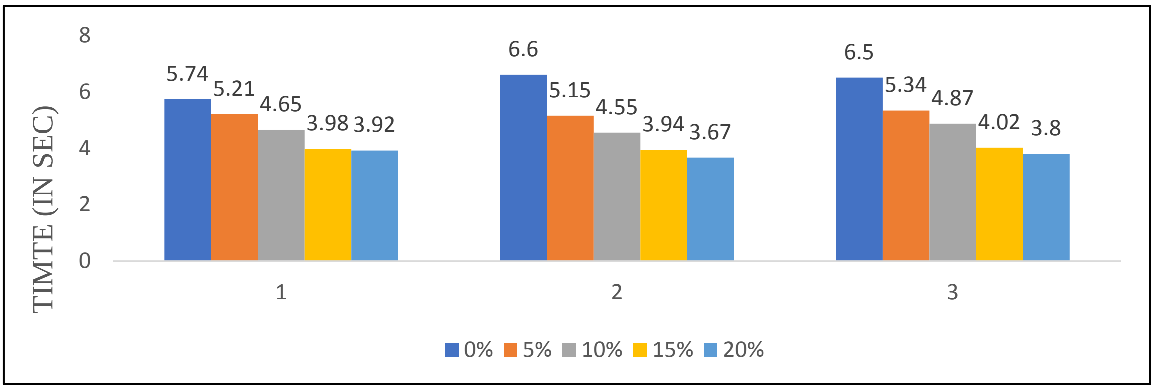

Figure 3 V-funnel Test data

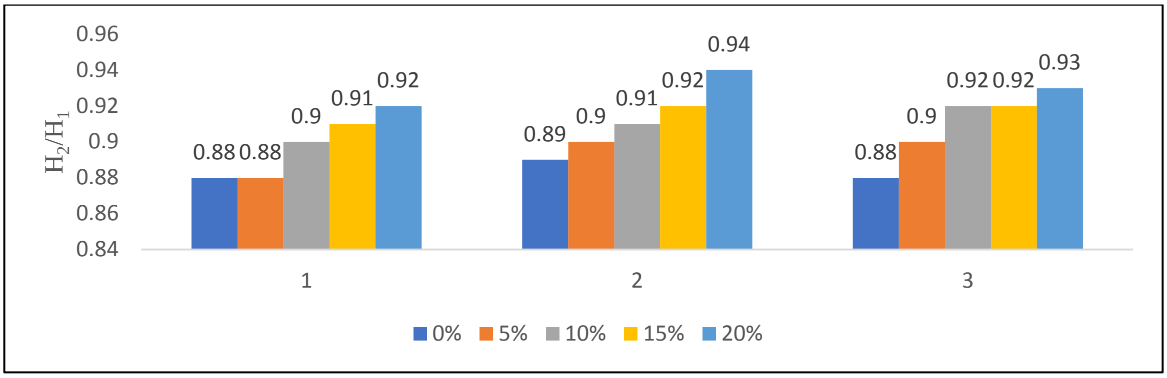

Figure 4 L-box Test Data

Hardened Properties

The compressive strength of the samples is shown in figure 5. The values for compressive strength follow a pattern where maximum strength occurs at 15% Alccofine content.

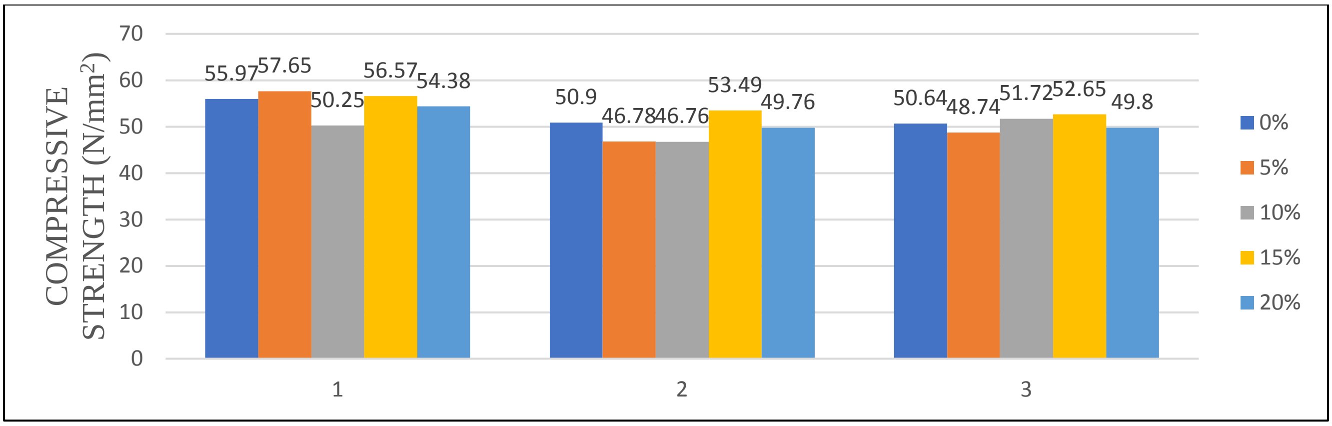

Figure 5 Compressive Strength test data

CONCLUDING REMARKS

The mixture design with adequate amounts of superplasticizer gave a highly viscous but workable mix. The slump-flow test values for all the mixes exceed 700 mm (minimum of all 710 mm and maximum being 840 mm) which is remarkably good and would be easy to work with on field. The V-funnel show a visible trend of decrease in time taken to empty the funnel (Figure 3), whereas L-box tests show increase in h_2/h_1 ratios (Figure 4), this shows that the fresh concrete mix has better flowability characteristics with increment in the Alccofine content. The result obtained from all the concrete mixtures satisfy the requirements suggested by EFNARC. All the mixtures have good flowability and good self-compaction characteristics.

The compressive strength initially decreases with % variability of Alccofine until a sudden spike at 15% Alccofine is observed and that being the maximum value, it decreases for 20% Alccofine content. {Average values (MPa) - 52.50, 51.06, 49.58, 54.24, 51.31}.

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