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Investigations on Fresh properties of Self Compacting Concrete with various mineral admixtures

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Abstract
Self compacting concrete (SCC) is having enormous advantages compared with the vibrated concrete. Production of SCC requires a large amount of powder content, thus demanding the high quantity of cement with one or more admixtures. Using large quantity of cement leads to production demand and environmental pollution due to high energy consumption. In view of this aspect, mineral admixtures are used to replace the cement in high volume. Industrial by products such as fly ash, Silica fume and granulated blast furnace slag are used as mineral admixtures in SCC. These mineral admixtures can improve particle packing and decrease the permeability of concrete. This study investigates the influence of various mineral admixtures on the fresh properties of SCC. Cement is replaced with GGBS and FA in the range of 20, 40 and 60% and SF in the range of 5, 10, and 15% for all mixtures. Fresh properties of the SCC with these mineral admixtures are tested for slump flow, T 500, V-funnel flow, and L-box tests. The results indicate that all the mixtures shows improved fresh properties without segregation even at higher replacement levels.

Keywords: Self compacting concrete, Mineral admixtures, Fresh property

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I. INTRODUCTION

Self Compacting Concrete (SCC) is special type of concrete and is gaining popularity all over the world due to its self flow ability, which can be placed and compacted under its self weight without any external vibration [1]. The main features of fresh SCC are filling ability, passing ability and very high segregation resistance. The above properties can be achieved by using, large amount of powder content, high-range water reducing (HRWR) admixtures, thus demanding large quantity of cement with one or more admixtures [2]. However, costs of such concretes are high, due to high volume of Portland cement and chemical admixtures [3 & 4]. In order to reduce energy consumption, CO_2 emission and production demand, cement is replaced with mineral admixtures in concrete [5]. Additionally, the mineral admixtures can improve particle packing and decrease the permeability of concrete leading to concrete with enhanced durability [6]. Mineral admixtures are the by- products of different industries and dumped as waste. Various mineral admixtures such as fly ash (FA), Silica fume (SF), granulated blast furnace slag (GGBS) and metakaolin etc are used as cement replacement in SCC [7–14].

An extensive review of literature has been carried out to examine the effect of mineral admixtures on the properties of SCC. Proper replacement of cement by suitable mineral admixtures can result not only in economical and ecological benefits, but technical benefits as well. In that way, the fresh properties of SCC is improved and the amount of by-products or waste materials used can be increased [14].The incorporation of mineral admixtures also eliminates the need for viscosity-enhancing chemical admixtures and it can reduce the amount of super-plasticizer necessary to achieve a given fluidity [15]. The water demand and workability are controlled by particle shape, particle size distribution, particle packing effects and the smoothness of the surface texture of the mineral admixtures [16].

Khatib [5] studied the effect of different fly ash content on the performance of SCC. The results show that, generally, there is strength reduction for concretes containing fly ash compared with that of the control concrete. Dinakar [17] et al investigated the influence of FA on the fresh properties of SCC. The author found that 30% to 50% replacement of FA is ideal for developing SCC. Turk [18] examined the incorporation of SF in SCC up to 20% and FA in the range 25% to 40%. These result show that increase in the amount of SF and FA gives better fresh properties. Bingol (10) studied the fresh property of SCC with 5%, 10% and 15% of SF and 25%, 40%, 55% of FA. The result also proves that increase in replacement of SF improves the fresh and mechanical properties. Boukendak dji [8] examined the fresh property of SCC with up to 25% of GGBS, with different types of super- plasticiser (SP), and concluded that the optimum usage of GGBS is 15% with the poly carboxylic ether type of SP. Bensalem [19] also studied the effective use of GGBS in SCC compared with Marble powder and Limestone filler. The result shows that GGBS mixes have improved fresh property and lowest viscosity of the mixture. Yazici [16] investigated the fresh properties of SCC with SF. The author found that 10% SF with various percentages of FA content shows the better flowability of SCC. Previous studies stated that the effect of a comparatively low content of mineral admixtures on the properties of fresh SCC is well-documented, and it has been shown that while fly ash and slag increase the workability of SCC, silica fume does not. Therefore, this experimental work, investigates the effects of SF, GGBS and FA at higher level replacement on the fresh properties of SCC.

II. OBJECTIVES

The main objective of this study is to investigate the effects of using higher volume replacement of mineral admixtures on SCC the fresh properties of SCCs. In the study, FA, GGBFS, and SF were used as the mineral admixtures. Fresh concrete tests such as slump-flow, J- ring, required time of SCC to reach 500 mm length slump-flow radius (T500), L-box, V funnel are conducted to achieve this objective.

III. EXPERIMENTAL PROGRAM

In this investigation, 10 mixtures are tested to evaluate the fresh properties of SCC with different percentages of fly ash, GGBS, SF.

3.1 Materials properties

The constituent materials for the production of SCC are discussed as follows:

3.1.1. Cementations materials

Ordinary Portland cement (43 grade) was used for this experimental investigation. Class F Fly ash with specific gravity of 2.05, GGBS with specific gravity of 2.85 and silica fume with specific gravity of 2.3 are used as a replacement of the cement content by different percentage. The physical properties of OPC are shown in Table 1 and the chemical compositions of cement and mineral admixtures are shown in the Table 2.

3.1.2. Aggregates

Crushed granite obtained from the local quarry was used. The aggregate passing in 16 mm sieve and retained on 4.75 mm sieve is used as coarse aggregate. The nominal size of the natural coarse aggregates was 16 mm. The physical and mechanical properties of CA and FA were determined in accordance with IS 2386-1963 [20] and presented in Table 3. Locally available river sand with 4.75mm maximum size was used as fine aggregate.

3.1.3. Chemical additives

In this study, Poly carboxylic ether based super plasticizer BASF Glennium 8233 is used to increase the flow capability of the concrete and improve the viscosity. The used dosage of Glennium 8233 was 1 % of the total weight of powder content, to achieve good workability.

3.2 Mix Proportion

In this study SCC mixes were produced adopting particle packing mix design approach [21], whose detailed proportions are presented in Table 4. For all SCC mixes, the amount of cementitious materials used was generally maintained as 560 kg/m^3 approximately, with a free water-to-binder ratio of 0.35-0.37.Three series of concrete mix are chosen, the first one (Series I) was combination of ordinary Portland cement (OPC) and fly ash (FA), the second (Series II) was combination of PC and silica fume (SF), and the third one (Series III) was combination of PC, GGBS. The various replacement levels considered for SF, FA and GGBS in range of 5% to 15%, 20% to 60% and 20% to 60% respectively. Totally 10 mixtures were prepared including one reference mix produced with OPC, which is designated as SCC and other SCC mixtures designations are given in the Table 5.

3.3 Testing methods

Fresh properties of SCC were quantified through slump flow, T500 slump flow time, J ring test, V - funnel test and L box test. The above tests were performed according EFNARC guidelines to evaluate the characteristics of SCC such as passing ability, flowability and segregation resistance. Slump flow and T500 time test to assess the flowability and the flow rate of SCC in the absence of obstructions. In slump test, the cone is filled with concrete and then lifted vertically. The spread diameter, the time measurement T500 (i.e., the time of flow to reach a diameter of 500 mm) and the general visual appearance of the concrete are recorded as shown in Fig. 2. The result is an indication of the filling ability of SCC, and the T500 time is a measure of the speed of flow. J- Ring test is to investigate both the filling ability and the passing ability of SCC. It consists of a rectangular section open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. The J-ring bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the spread diameter is measured at two directions and the average is reported the result. This is an indication of passing ability, or the measure of degree to which the passage of concrete through the bars is restricted.

In the V funnel test, the funnel is filled with the concrete and the time taken by it to flow through the funnel is measured. This test gives account of the filling capacity of SCC. In the L box test, the test was conducted by removing the gate to allow the flow of concrete through the horizontal part and of the remaining concrete is in the vertical part and then the ratio of h_2/h_1 were determined.

Table 1: Properties of Ordinary Portland cement

Sl.No	Property	Values
1.	Standard Consistency (%)	29.5
2.	Initial setting time(min)	120
3.	Final setting time(min)	270
4.	Soundness (mm)	1
5.	Specific gravity	3.15

Table 2: Chemical and Physical composition of FA, GGBS and SF.

Component	SF	GGBS	FA
Silica (SIO_2) %	99.89	34.15	57.9
Alumina (Al_2O_3) %	0.043	--	33.54
Ferric Oxide (Fe_2O_3) %	0.040	--	2.69
Titanium Oxide (TiO_2) %	0.001	--	
Calcium Oxide (CaO) %	0.001	36.66	0.65
Magnesium Oxide (MgO) %	0.000	7.73	0.49
Pottasium Oxide (K_2O) %	0.001	--	0.87
Sodium Oxide (Na_2O) %	0.003	--	0.46
Insoluble Residue (%)	--	0.49	--
Sulphide Sulphur (%	--	0.50	--
Sulphite Content (%)	--	0.38	--
Manganese Content (%)	--	0.12	--
Chloride Content (%)	--	0.009	--
Moisture Content (%)	0.10	0.26	1.05
Specific gravity	2.3	2.85	2.05
Fineness (M/Kg)		390	98.1

Table 3: Physical properties of aggregate.

S.No	Physical properties	Fine aggregate	Coarse aggregate
1.	Specific gravity	2.59	2.27
2..	Bulk density (kg/m^3)	1375	1209
3.	Water absorption (%)	1	7.79
4.	Fineness modulus	3.06	7.24

Table 4: Mix Proportions of SCC

Materials	Quantity
Cement (kg/m3)	560
Water content (l/m^3)	196
Coarse aggregate – 16 to 12.5mm (kg/m3)	497
Coarse aggregate - 12.5 to 4.75mm (kg/m3)	325
Fine aggregate (kg/m3)	788
Super Plasticisers (%)	1
W/C	0.35

Table 5: Mix designations for various SCC mixtures.

Mix designations	Series I (FA)	Series II (GGBS)	Series III (SF)
SCC FA20	20	--	--
SCC FA40	40	--	--
SCC FA60	60	--	--
SCC GGBS20	--	20	--
SCC GGBS40	--	40	--
SCC GGBS60	--	60	--
SCC SF5	--	--	5
SCC SF10	--	--	10
SCC SF15	--	--	15

Table 6: Acceptance criteria for SCC according to EFNARC guidelines.

Test method	Unit	Typical range of values	
		Min	Max
Slump-flow	Mm	650	800
The spread diameter (T50)	S	2	10
J ring – Slump flow	Mm	0	10
V-funnel	S	6	12
L-box (H2/H1)		0.8	1

The results obtained from these tests indicated that, SCC mixes had good filling and passing ability as well as segregation resistance.

Fig 1: Apparatus set up and flow diagram for slump flow test

Fig 2: Apparatus set up and flow diagram for J ring flow test

Fig 3: Apparatus set up and flow diagram for V funnel flow test

Fig 4: Apparatus set up and flow diagram for L box test

IV. TEST RESULT AND DISCUSSION:

4.1 Slump flow:

The slump flow value of various mixes incorporating SF, GGBS and FA are shown in the Fig 5. It is evident from these figures that the slump flow increases from reference mix with increasing the quantity of SF, GGBS and FA. All mixtures exhibited good workability with flow values of at least 620 mm. The values of all the mixtures obtained are within the range specified in EFNARC guidelines [2]. Generally, the mixtures which contain mineral admixtures have shown better performance than the control mixture with regards to workability.

Fig 5 also shows that incorporating the SF significantly decreases concrete workability than control mix. At the same time, increasing the content of SF further increases the slump value; at higher volume replacement level it reaches the control mix flow, the slump flow increases with increasing the quantity of SF. On the other hand, comparing the Visual Stability index of mixtures containing SF with that of the control mixture and SCC containing other mineral admixtures shows that SF enhances concrete stability [22]. This is due to the fact that the high surface area of SF increases water demand and reduces the amount of water, consequently enhancing concrete ability to resist segregation.

SCC mixtures containing GBFS and FA series have shown higher slump-flow values at all replacement levels compared with reference mix. All the replacement level of cement by GGBS and FA contents showed improved the filling ability of concrete due to its spherical shape reduce inter particle friction and lower water retention. This results leads to lower water demand for a specific workability or increased workability for a constant W/C ratio, while maintaining constant paste volume.

It is evident from Fig. 5 that the GGBS and FA help in increasing flowability of mix without segregation even at the 60% replacement ratio. This is attributed to lower viscosity of mix, without losing its cohesiveness resulting out of better dispersion of the cementitious content. At the time of testing, increasing the replacement of FA no mortar halo in the slump flow patty was observed [22].

4.2 T 500 slump flow

Results regarding time T50, however, show that a high content of FA enhances the flow of SCC, whereas a high content of GGBS produces similar results to that of the control SCC.

The slump flow time to reach diameter of 500 mm (T500) for all the SCC mixtures are shown in Fig 6. T-500 represents the test of mixture viscosity. Shorter time of T- 500 indicates the better flow capacity, but lower viscosity. As seen in Fig 6, T-500 values varied from 1.2 to 3.11sec for mixtures. According to EFNARC specifications and guidelines [2], the T-500 slump flow time of SCC generally ranges from 2 to 5 sec. Hence, the T-500 slump flow times were less than the acceptable range. However at the time testing, all the mixtures were observed with good flow capacity without any bleeding and segregation. This is mostly due to the increased content of powder.

4.3 J ring Slump flow:

The slump flow values of J-ring are shown in the Fig 7. A flow range between 510 to 690mm is considered to be acceptable mix with stability and good passing ability [2]. Slump value is observed through the J ring for all mixtures with all replacement of SF, GGBS and FA. This is also considered to be acceptable and indicates satisfactory mix stability and segregation resistance for flow through reinforcement.

4.4 V funnel flow time:

The V-funnel flow times of different mixes are presented in Fig 8. From this figure, it can be seen that the V-funnel times for SF, GGBS and FA concrete groups were in the range of 11.4–12.4sec, 10–12 sec and 10.1–12.5 sec, respectively. The highest V-funnel flow time of 13sec was measured for the control concrete. The V- funnel flow times of all mixtures satisfy this requirement of EFNARC [2]. Incorporating mineral admixtures, in SCC makes it highly flowable with decreased viscosity. The quantity of mineral admixtures influences the V funnel flow time of all the SCC mixes.

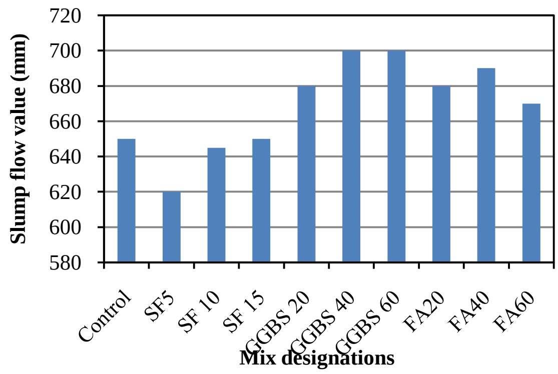


Fig 5: Slump flow values for various mixtures

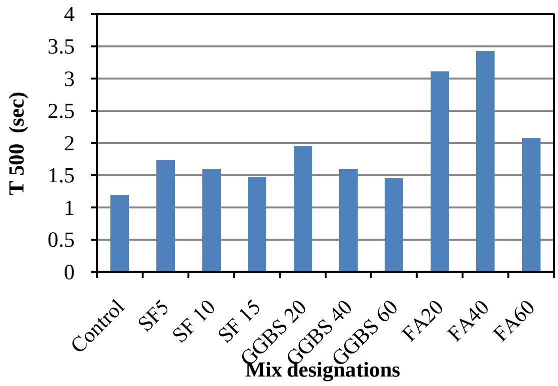
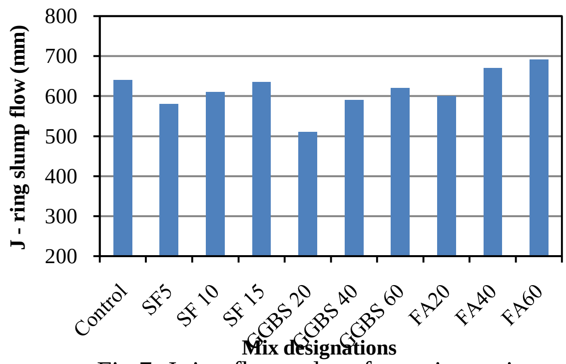


Fig 6: T 500 values for various mixtures



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4.5 L box

The results from the L-box test are shown in the Fig.9. The L-box ratio characterizes the filling and passing ability of SCC. The blocking ratio value of all SCC containing GGBS varied from 0.8 to 0.98, FA changed from 0.86 to 0.94 and SF changed from 0.86 to 0.9. With the increase in the quantity of mineral admixtures, there is a significant decrease compared with control mix in the blocking index. The highest blocking risk was observed in control mix and 5% SF, 20% GGBS and 20%, 40% of FA. SCC with high blocking ratio is resulted with low pump-ability in site. All the

SCC mixtures shows satisfactory blocking ratio as per EFNARC recommendation [2]. Also at the time of testing, the authors did not observe any tendency of blockage between reinforcement. Hence, it is inferred that all the mixes have good segregation resistance with good filling ability. It is evident from these Fig. 9 that, increasing replacement of mineral admixtures content replaced by cement shows the increased filling and passing ability of SCC mixtures.

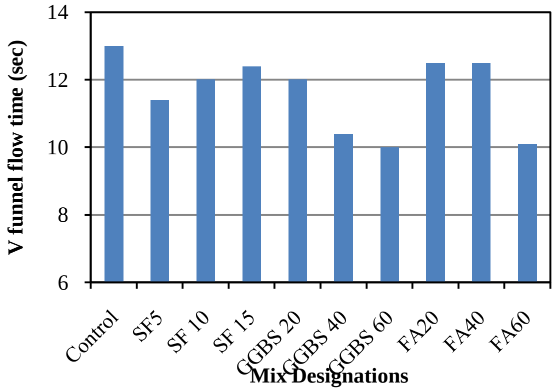

Fig 8: V funnel flow time for various mixtures

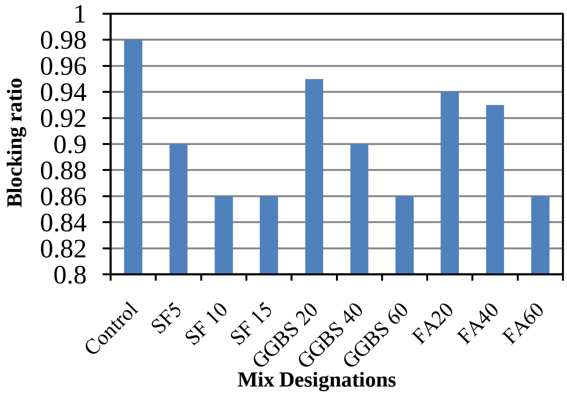

Fig 9: Blocking ratio for various mixtures

V. CONCLUSION

Based on the results obtained, the main conclusions are arrived as follows:

1. Although all the concrete mixtures investigated in the experimental study showed satisfactory self-compacting properties in accordance with EFNARC, only particular mixtures showed better fresh state performance.
2. SCC with 15% SF showed very good flow ability, passing ability and segregation resistance.
3. The replacement of cement by 60% of GGBS also exhibited improved the flowability, passing ability and segregation resistance than that of reference mixture.
4. A SCC mixture with 40% FA is found to be best in flow ability, passing ability and segregation resistance. However the mix with 60% FA, slight bleeding as sheen on the concrete mass was observed. Hence it is recommended to replace cement up to 40% FA.
5. It is observed from the experiment study that the mixes satisfying good slump flow and J ring will definitely prove to satisfy the other properties such as V funnel and L box tests, provided the nominal size of aggregates are maintained.
6. The factors that greatly influenced the fresh properties of SCC are powder content and coarse aggregate size only.

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