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Research paper

Study on Strength Characteristics of Binary Blend Self Compacting Concrete Using Mineral Admixtures

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Abstract

Self-compacting concrete (SCC) is the flowable concrete which tends to fill the formwork under its weight without external compaction. In the present research, 9 different SCC mixes in binary blend along with control SCC and conventional vibrated concrete (CVC) mixes were developed. In binary combination, cement was partially replaced by SF from 7 to 21%, MK from 10 to 30% and GGBS from 20 to 60%. For the above 9 combinations of SCC mixes, the basic rheological properties test namely slump flow and T500 were carried out in the fresh state of SCC. The flowability was achieved using Superplasticizer and viscosity modifying admixture (VMA), added by the percentage of the weight of cement. In hardened state, the compressive strength of the cube specimens and the split tensile strength of the cylinder specimens were carried out.

***Keywords:** Self-compacting concrete, silica fume, metakaolin, ground granulated blast furnace slag, compressive strength, split tensile strength.*

1. Introduction

Self-Compacting Concrete (SCC) was initially developed by Prof.H.Okamura of Japan in the early 1980s when there was unskilled labour problem faced during the construction of Akashi Kaikyo Bridge. The evolution of SCC has solved the above issue faced by the construction industry of Japan. SCC also used in the structural locations namely beam-column joints, piers, basements, and foundations where congested reinforcement exhibit. SCC had extensive precast applications all around the world. The basic property that differs from conventional vibrated concrete (CVC) and SCC was the mix constituents and the rheological properties. In CVC, the proportion of coarse aggregate was higher than fine aggregate whereas in SCC the percentage of fine aggregate and powder content was higher could be the major comparison. The reason was to develop the rheological properties in SCC. SCC could be prepared using mineral admixtures, chemical admixtures and the combination of both. When mineral admixtures were used in the SCC, then it is regarded as powder type SCC. If the SCC was prepared using chemical admixtures namely superplasticizer (SP) and viscosity modifying admixture (VMA) was referred as VMA based SCC. Finally, combining the advantages of both mineral admixtures and chemical admixtures, the combined type SCC was developed. Michal et al. [1] have studied the rheological properties of SCC and their influence on the formwork pressure. The relationship between the rheological parameters and pressure reduction over time factors were observed. Omar et al. [2] have studied the differences in the cement characteristics influencing the workability properties of SCC. The variations in the cement characteristics were sufficient to affect the flow properties of SCC. Huajian et al. [3] made an investigation on the water-powder ratio affecting the shear thickening of SCC. VMA type SCC's shear thickening was more sensitive to change of water-powder ratio.

Gonzalo et al. [4] have made a study on the microstructure properties and hardened characteristics of SCC. The compressive strength of the specimens increased with the increase of porosity in the pastes with minimum filler materials. Sina and Jiping [5] have researched SCC using GGBS, metakaolin (MK) and fly ash (FA). The authors have identified that 25% slag, 20% MK and 15%FA were found as the optimum mixes. Thus increase in the cement replacement content lead to the decrease in the strength characteristics. Mouhcine et al.[6] investigated on SCC using silica fume (SF) and viscosity modifying agent. The proper dosage of VMA identified as 0.1-0.2% by the weight of the cement and 10% SF content was found to be optimum. Kunlin et al. [7] have studied the influence of slump flow on the mix design. The slump flow values were found optimum and in the range of 650 to 800 mm. Hence, the values not satisfying this range leads to the poor workability. Vivek and Dhinakaran [8] investigated on SF based SCC as a partial substitute to the cement. The mechanical properties and the flow behaviour of SF based SCC mixes were studied. Anjali et al. [9] researched SCC containing MK and evaluated the fresh properties and compressive strength. Nan et al. [10] have developed the proper mix design for the SCC mix. Dinakar and Manu [11] have studied the properties of SCC using MK as the cement replacement. Mucteba and Mansur [12] have studied the effect of the admixtures used in SCC namely SF, GGBS & FA by partial cement replacement. The incorporation of mineral admixtures in SCC minimized the expenditure and also increased the compressive and tensile strength by 72% and 46% respectively. Celine et al. [13] have researched SCC containing the slurry form of MK along with the limestone. The utilization of MK resulted in the increased mechanical properties and durability and also preferred for the precast products. Mostafa et al. [14] have researched SCC using low-lime and high-lime fly ash. The addition of FA especially in higher dosages in SCC has increased the transport and workability properties.

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Heba [15] has studied the influence of SF and FA as a partial substitute for cement in SCC. The substitution of SF and FA increased the compressive strength by 58% respectively. Miao [16] has investigated the SCC blended with Ground Glass. The Glass in SCC reduced the compressive and tensile strength by 39% and 27% respectively. The SCC mix design and the fresh properties test were conducted according to the guidelines given by EFNARC [17 & 18]. In the present research, the combined type of binary blended SCC was prepared using silica fume (SF), metakaolin (MK) and ground granulated blast furnace slag (GGBS). The cement was partially replaced by SF by 7%, 14% & 21%, MK by 10%, 20% & 30% and GGBS by 20%, 40% & 60% (total nine binary blended SCC mixes). Binary blended SCC mixes were undergone the preliminary fresh properties tests namely slump flow, and T_{500} tests to understand the flow and filling ability was conducted in the laboratory. The superplasticizer and VMA were added by the percentage of the weight of cement to initiate the flow and to maintain the homogeneity of SCC mixes with the control of segregation. In hardened state, the test on compressive strength of cube specimens and the split tensile strength of cylinder specimens were conducted after the respective age of curing period.

2. Material Used

Cement: OPC 43 grade was used as per ASTM C150 [19].

Fine aggregate (FA): Natural river sand (< 4.75 mm) grading Zone III of ASTM was used. The physical properties were determined as per ASTM C127 [20], and their particle size distributions confirmed to the requirements of ASTM C33 [21].
Coarse aggregate (CA): The maximum size of coarse aggregate was restricted less than 12.5 mm.
Mineral admixtures: silica fume (SF), metakaolin (MK) and ground granulated blast furnace slag (GGBS) was used as per ASTM C1240-99 [22].
Chemical admixtures: High-range superplasticizer (9 litres/ m^3) and stabilizer (0.90 litres/m^3) was used.

3. Experimental Programme

Mix Design

As per EFNARC guidelines, the mix design was carried out for SCC mixes by slump flow test trials. Since it is an ad-hoc method, the mix proportions of fine aggregate and coarse aggregate were adjusted initially. The dosage of SP was adjusted based on water demand and to necessitate the flow in the slump flow test trials. The percentage of mineral admixtures, SP and VMA dosages in the SCC mix have improved the rheological properties and prevented the segregation and bleeding. Table 1 shown below has illustrated the mix constituents of CVC and SCC mixes.

Table 1: Materials used for CVC and SCC mixes in kg/m^3 of concrete

Mix	Cement	SF	MK	GGBS	FA	CA	Water	w/p ratio	SP	VMA
CVC	600	-	-	-	397	1074	196	0.33	-	-
C+7% SF	558	42	-	-	810	660	228	0.38	7.1	0.57
C+14% SF	516	84	-	-						
C+21%SF	474	126	-	-						
C+10%MK	540	-	60	-						
C+20%MK	480	-	120	-						
C+30%MK	420	-	180	-						
C+20%GGBS	480	-	-	120						
C+40%GGBS	360	-	-	240						
C+60%GGBS	240	-	-	360						

4. Fresh Properties Test- Slump Flow and T_{500} Test

The fresh properties tests namely slump flow and T_{500} time were conducted to understand the behaviour of SCC at the fresh state and carried out as per EFNARC guidelines. In slump flow test, the flowability of SCC was obtained as shown in the Figure 1a. This test was similar to conventional slump test using Abram's cone, but the concrete was subjected to collapse and could spread over the base plate. Thus slump flow spread diameter was measured. Here the rate of flow was measured using T500 test, which gave the time taken in seconds (s) to reach 500 mm diameter in the base plate as shown in Figure 1b.

Fig. 1a: Slump flow test

Fig. 1b: T500 test

5. Preparation of Mould

The cube specimens were prepared in the timber mould of size 100 mm x 100 mm x 100 mm as shown in Figure 2. The cylinder specimens were developed using PVC pipe mould of inner dimensions 100 mm (diameter) x 200 mm (height). The mould should be leak-proof has been ensured and properly lubricated. After conducting the slump flow test, the concrete of SCC type was poured directly into the desired mould without compaction. The CVC mixes were cast and prepared in the vibrator table. The specimens were removed from the mould after 24 hours of casting.

Fig. 2: Casting of cube and cylinder specimens

6. Curing

The cube specimens were subjected to the curing period of 7 days, 14 days and 28 days respectively. The cylinder specimens were undergone curing for 28 days. Thus specimens were subjected to early age compressive and split-tensile strength (28 days).

7. Compressive and Indirect Tensile Strength

After subjected to necessary curing period, the specimens were taken out from the curing tank and wiped off using dry clothes. Then the specimens were placed in an open atmosphere for three hours before subjected to testing, dried off completely. The compressive strength of cube specimens and the split-tensile strength on cylinder specimens were conducted in the automatic compression testing machine (ACTM) at the rate of loading of 2.9 kN/s as shown in Figure 3a and 3b.

Fig. 3a: Test on Compressive strength of cube specimens

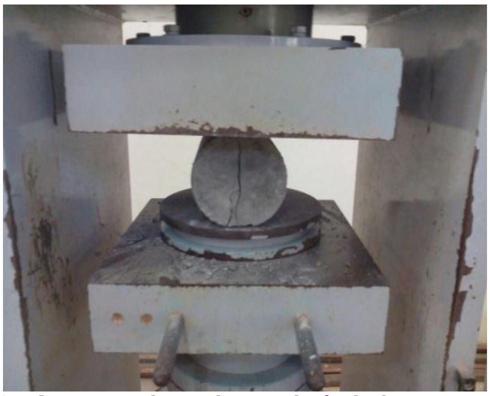

Fig. 3b: Test on split-tensile strength of cylinder specimens

8. Results

The results obtained from the experimental programme namely SCC rheological properties were illustrated in the form of a table as shown below. Further, mechanical properties of CVC, SCC 0 and binary blended SCC mixes were illustrated below in the form of figures.

9. Basic Rheological Properties Tests

The rheological tests namely slump flow and T_{500} tests was conducted for SCC control mix (SCC 0), and the binary blended SCC mixes using SF, MK and GGBS as the partial cement replacement as shown in Table 2. In slump flow test, the mix containing SF 14%, MK 20% and GGBS 20% have obtained better flow characteristics among other binary blended mixes. From the overall slump flow test results, SCC 0 and MK 20% has obtained the slump flow spread diameter 730 mm was found superior and belonged to the consistency class of SF2 category as per EFNARC (2005) guidelines. In GGBS based SCC mixes, GGBS 20% has obtained the spread diameter of 727 mm, similar to the obtained values of SCC 0 and MK 20% respectively. The flow rate or filling ability of SCC mixes were studied by T_{500} time in seconds (s). In binary blended SCC mixes, MK 20% have obtained the flow rate as 3.1s, and the presence of MK in SCC mixes shown significant influence on the viscosity characteristics as mentioned in Table 2. Thus the better flowability characteristics of binary blended SCC mixes were due to low viscosity and by the moderate shear stress developed. Hence, the basic rheological properties were developed in SCC mixes by maintaining w/p ratio of 0.38 at par with SP and VMA dosages of 1.5% and 0.15% by weight of cement respectively.

Table 2: SCC Slump flow & T_{500} tests

Mix Description	Slump flow: Spread diameter (mm)	T_{500} test (s)
SCC 0	730	3.7
SF 7%	694	4.3
SF 14%	714	2.9
SF 21%	675	3.2
MK 10%	695	3.5
MK 20%	730	3.1
MK 30%	715	3.3
GGBS 20%	727	4.9
GGBS 40%	699	3.5
GGBS 60%	686	4.2

10. Compressive Strength

From the Figure 4, the compressive strength values of CVC, SCC 0, SF (from 7% to 21%), MK (from 10% to 30%) and GGBS (from 20% to 60%) was observed. It was inferred that control SCC (SCC 0) and binary blended SCC using admixtures had obtained better strength characteristics than CVC mixes. The strength gain has exhibited due to higher pozzolanic activity took place in SCC mixes because of the partial substitution of cement by mineral admixtures. Among all binary SCC mixes, SF 14%, MK 20% and GGBS 20% have obtained the highest compressive strength. By overall strength comparison, GGBS 20% have obtained the highest strength value of 65.79 MPa with the increase in the percentage of 14.95% and 9.85% in respect of control CVC and SCC mixes. The reason for highest strength in GGBS based SCC mixes was due to pore size refinement took place by 20% as the partial cement replacement. Further, the reaction of slag with the calcium hydroxide phases has developed the C-S-H gel formation along with C-H could be the reason for improving the compressive strength.

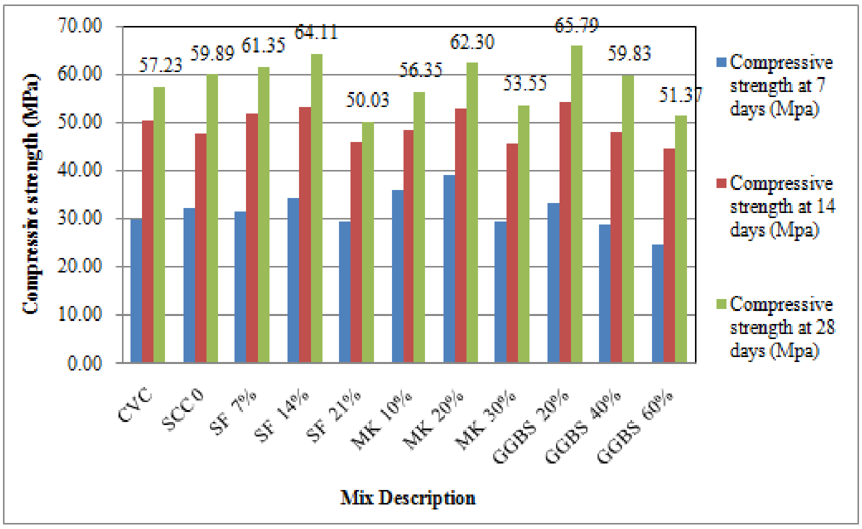

Fig. 4: Compressive strength (MPa) of binary blend SCC mix

11. Tensile Test

In tensile test (indirect), the cylinder specimens were subjected to the state of tri-axial compression test. It was observed from the Figure 5, SF 7%, MK 10% and GGBS 40% as the partial cement replacement have obtained the highest tensile strength characteristics than CVC and SCC 0 mixes. There exhibited the less significant effect of the mineral admixtures on the tensile strength properties.

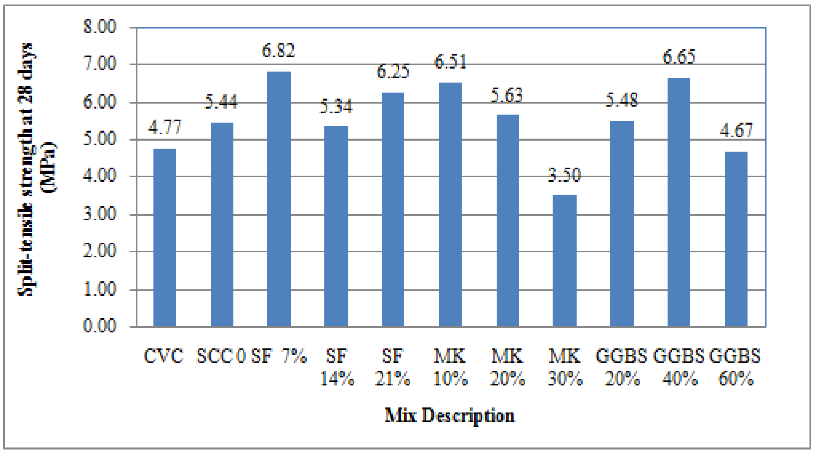

Figure 5- Split-tensile strength (MPa) of binary blend SCCmix

12. Conclusions

From the obtained results of experimental programme conducted on binary blended SCC mixes, the following conclusions were made:

- The rheological behaviour of SCC was developed by slump flow & T500 tests in which MK 20% has yielded better results.
- From the cube compressive strength results, GGBS 20% have obtained better performance than CVC, control SCC and other binary blended SCC mixes.
- From the indirect tensile strength results on cylinder specimens, SF 7% has obtained the increase in strength of 43% and 25% concerning CVC and SCC mixes.
- Hence from the optimum values of binary blended SCC mixes, the quaternary mixes could also be developed for the future scope of the present research.

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