The Effect of GGBFS and Copper Slag on Strength of Self Compacting Concrete: An Experimental Study

Akhil S. Nair, P. R. Sreemahadevan Pillai

Abstract: The depletion of the natural resources and increased demand of constructional materials have always paved way for new advancements in the construction field. Engineers started research to find an alternative for the natural resources. Even though natural resources cannot be substituted completely, a partial replacement technique was introduced. Self-compacting concrete (SCC) can be defined as a fresh concrete which possesses superior flow ability under maintained stability, thus allowing self-compaction that is, material consolidation without addition of energy. Self-compacting concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration and it helps in achieving higher quality of surface finishes. However partial substitution of cement and fine aggregate by locally available waste materials like Ground Granulated Blast Furnace Slag (GGBFS) and copper slag have showed increase in the strength of SCC.

Keywords: Self-Compacting Concrete, Copper Slag, GGBFS, Partial Substitution

I. INTRODUCTION

Self-compacting concrete (SCC) was first developed in Japan in 1988 in order to achieve durable concrete structures by improving quality in the construction process. It was also found to offer economic, social and environmental benefits over traditional vibrated concrete construction. SCC is considered as a concrete which can be compacted under its self-weight with no vibration effort, and which is at the same time, cohesive enough to be handled without segregation or bleeding. It has several advantages over normal conventional concrete. It can flow easily in congested reinforced areas such as in beam column joints. SCC was developed at the time to improve the durability of concrete structures. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. The use of SCC eliminates the need for compaction thereby saves time, reduces labour costs and conserves energy. Furthermore use of SCC enhances surface finish characteristics. Preventing the depletion of natural resources and enhancing the usage of waste materials has become a challenge to the scientist and engineers. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. The use of steel slag to replace natural aggregate in concrete is initially based on consideration of slag

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Availability of natural resources and the good characteristics of steel. In nature, the resources of natural mineral aggregates of high engineering quality which can be used ultimately will become exhausted.

Concrete technology has made massive development in the past decade. Now a day's concrete is not a material that consist only cement, fine aggregate, coarse aggregate and water but it is an engineered material that consists of many new materials which performs satisfactorily under all conditions. The modern concrete consists of various filler materials such as fly ash, micro silica, GGBFS etc. There is no standard method for SCC mix design and many academic institutions, ready-mixed, precast and contracting companies have developed their own mix proportioning methods.

The self-compacting concrete proved to be the most revolutionary achievement of the engineering in the last 25 years. The idea of developing Self Compacting Concrete (SCC) incorporating GGBFS and Copper slag as partial replacement for cement and fine aggregates respectively is a novel approach to combine the advantages of both SCC and the waste materials readily available in the market. The use of the above said materials increases the hardened properties of concrete such as compressive strength, split tensile strength etc. However no tests have been conducted by incorporating both the materials in SCC simultaneously. So a study on fresh state behavior and mechanical performance of self-compacting concrete is attempted using the above said materials.

II. MATERIALS FOR SELF COMPACTING CONCRETE

Cement: Ordinary Portland Cement-53 grade cement conforming to IS: 12269 is used. The different laboratory tests were conducted on cement to determine standard consistency, initial and final setting time, and compressive strength as per IS 4031.

Fine aggregate: Fine aggregate used for SCC is properly graded to give the minimum voids ratio and is free from deleterious materials like clay, silt content and chloride contamination. Locally available river sand passed through 4.75mm IS sieve is used. The specific gravity 2.6 was used as fine aggregate.

Coarse aggregate: Crushed aggregate available from local sources passing 12mm sieve and Retained on 10 mm sieve are used. The maximum size of aggregate is restricted to 20 mm.

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GGBFS (Ground granulated blast-furnace slag): Ground granulated blast furnace slag (GGBFS) is a by-product from the blast-furnaces used to make iron. GGBFS as per BS: 6699 standard is used.

Fly Ash: Fly ash of class F is used.

Copper slag: The specific gravity of slag lies between 3.4 and 3.98. Gradation test was conducted on copper slag and sand, showed that both copper slag and sand had comparable particle size distribution. However, it seems that sand has higher fines content than copper slag.

Chemical Admixtures: Sika viscocrete 20 HE is used as super plasticizer. It is a high range water reducer based on polycarboxylate ether (PCE).

III. METHODOLOGY

3.1. Mix Proportions:

Mix design was done by trial and error method. The targeted strength was 30Mpa at 28 day and was achieved after conducting several repetitions on various mix proportions. The water powder ratio (w/p) was varied to obtain the strengths. The mixes were checked for self compatibility following EFNARC acceptance criteria. The self compatibility of the mixes was checked by J Ring test and L-Box test. Final mix proportion obtained is 1:0.6:3.3:2.6. Then different mixes were prepared by varying the proportions of GGBFS and Copper slag. The details of mix design are shown on Table 1.

3.2. Tests on Fresh Concrete:

J-Ring Test

J-ring test denotes the passing ability of the concrete. The equipment consists of rectangular section of 30 mm x 25 mm open steel ring drilled vertically with holes to accept threaded sections of reinforcing bars 10 mm diameter 100 mm in length. The bars and sections can be placed at different distance apart to simulate the congestion of reinforcement at the site. Generally these sections are placed 3 x maximum size of aggregate. The diameter of the ring formed by vertical sections is 300mm and height 100 mm. Around 6 litres of concrete is required to conduct the test. Moisten the inside of the slump cone and base plate. Place the J-Ring centrally on the base plate and the slump cone centrally inside the J-ring. Fill to the top of the cone without tamping. Raise the cone vertically and allow the concrete to flow out through the J-ring.

The concrete will attain a circular shape after the removal of slump cone. Measure the diameter of the concrete in 3 directions and the average value is taken. Measure the difference in height between the concrete just inside J-Ring bars and just outside the J Ring bars. The acceptable difference in height between inside and outside should be between 0 and 10 mm.

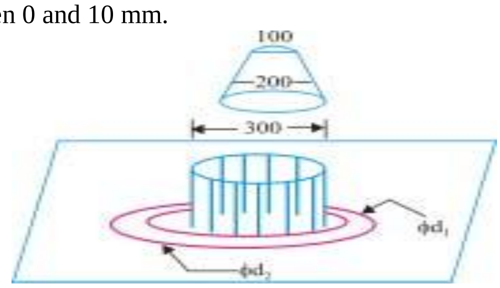

Fig 1: J-Ring Test Apparatus

L Box Test

About 14 litres of concrete is required for this test. Ensure that sliding gate can open freely and then close it. Moisten the inside surface, remove all surplus water. Fill the vertical section of the apparatus with concrete. Leave it standing for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously start the stopwatch and record the time taken for the concrete to reach 200 and 400 mm marks. When the concrete stops flowing, the height H1 and H2 are measured. Calculate, H2 /H1 the blocking ratio. The whole test has to be performed within 5 minutes.

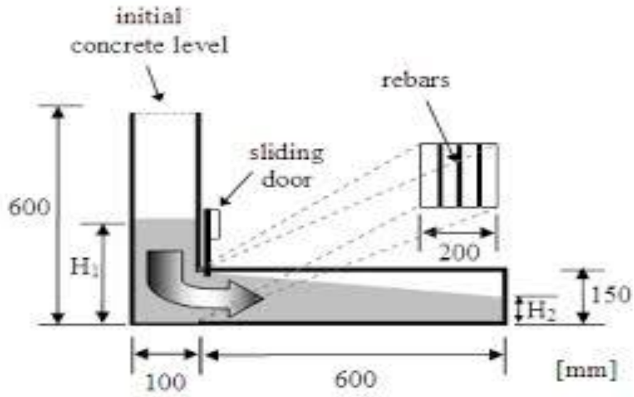

Fig 2: L - Box Test Apparatus

3.3. Preparation and Casting:

Initially fine aggregate was mixed well with varying proportions of copper slag. Then coarse aggregate was added to the mix. The cement, fly ash and varying quantity of GGBFS were added to the above said dry mix. Then water along with super plasticizer was mixed. Mixing was done continuously for a couple of minute. This was repeated for every proportion and was tested for fresh concrete properties.

Concrete moulds are cleaned properly and the screws are tightened to make sure that no slurry will escape through the joint. After tightening, the moulds are oiled properly for easy striping of the specimen. For making SCC with partial substitutions, GGBFS was varied from 0% to 27%, with 9% increase. Similarly Copper slag was varied from 0% to 30% with 5% addition on each mix. Here SCC denotes the normal self compacting concrete; SGxCy denotes the partial substitution of GGBFS by x% and Copper Slag by y%. The further detail was given on Table 1.

3.4. Test on Hardened Concrete:

Compressive Test: Cubes sizes were 150mm x 150mm x 150mm were cast with and without copper slag. The maximum load at failure reading was taken and the average compressive strength is calculated using the equation.

$$\text{Compressive strength (N/mm2)} = \frac{\text{Ultimate load in N}}{\text{Area of cross section (mm2)}}$$

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IV. TEST RESULTS AND DISCUSSIONS

The detailed mix proportions for SCC and Partially substituted SCC are given below.

Table 1. Mix Proportion

MIX DESIGNATION	CEMENT (Kg)	GGBS (Kg)	FLY ASH (Kg)	FINE AGG (Kg)	COPPER SLAG (Kg)	COARSE AGG(Kg)	W/P RATIO
SCC	267	0	161	887	0	710	0.65
SC5	267	0	161	842.65	44.35	710	0.65
SC10	267	0	161	798.3	88.7	710	0.65
SC15	267	0	161	753.95	133.05	710	0.65
SC20	267	0	161	709.6	177.4	710	0.65
SC25	267	0	161	665.25	221.75	710	0.65
SC30	267	0	161	620.9	266.1	710	0.65
SG9C0	242.97	24.03	161	887	0	710	0.65
SG9C5	242.97	24.03	161	842.65	44.35	710	0.65
SG9C10	242.97	24.03	161	798.3	88.7	710	0.65
SG9C15	242.97	24.03	161	753.95	133.05	710	0.65
SG9C20	242.97	24.03	161	709.6	177.4	710	0.65
SG9C25	242.97	24.03	161	665.25	221.75	710	0.65
SG9C30	242.97	24.03	161	620.9	266.1	710	0.65
SG18C0	218.94	48.06	161	887	0	710	0.65
SG18C5	218.94	48.06	161	842.65	44.35	710	0.65
SG18C10	218.94	48.06	161	798.3	88.7	710	0.65
SG18C15	218.94	48.06	161	753.95	133.05	710	0.65
SG18C20	218.94	48.06	161	709.6	177.4	710	0.65
SG18C25	218.94	48.06	161	665.25	221.75	710	0.65
SG18C30	218.94	48.06	161	620.9	266.1	710	0.65
SG27C0	194.91	72.09	161	887	0	710	0.65
SG27C5	194.91	72.09	161	842.65	44.35	710	0.65
SG27C10	194.91	72.09	161	798.3	88.7	710	0.65
SG27C15	194.91	72.09	161	753.95	133.05	710	0.65
SG27C20	194.91	72.09	161	709.6	177.4	710	0.65
SG27C25	194.91	72.09	161	665.25	221.75	710	0.65
SG27C30	194.91	72.09	161	620.9	266.1	710	0.65

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Table 2: Properties of Fresh Concrete

Mix Designation	J-Ring test		L-box test (h2/h1 ratio)
	Flow diameter (cm)	Difference in height(mm)	
SCC	56.5	10	0.81
SC5	60	10	0.82
SC10	64	10	0.82
SC15	63.5	10	0.83
SC20	61.5	10	0.84
SC25	60	8	0.81
SC30	60	8	0.8
SG9	61	10	0.84
SG9C5	61	7	0.86
SG9C10	62	6	0.88
SG9C15	62.5	7	0.87
SG9C20	64	8	0.86
SG9C25	61.5	8	0.86
SG9C30	61	10	0.84
SG18	60	10	0.8
SG18C5	61	10	0.81
SG18C10	63	9	0.84
SG18C15	63.5	8	0.84
SG18C20	64	6	0.86
SG18C25	63	7	0.85
SG18C30	61.5	10	0.84
SG27	61	10	0.8
SG27C5	61	10	0.82
SG27C10	61.5	9	0.82
SG27C15	62.5	9	0.82
SG27C20	63	8	0.84
SG27C25	62	9	0.83
SG27C30	60	10	0.81

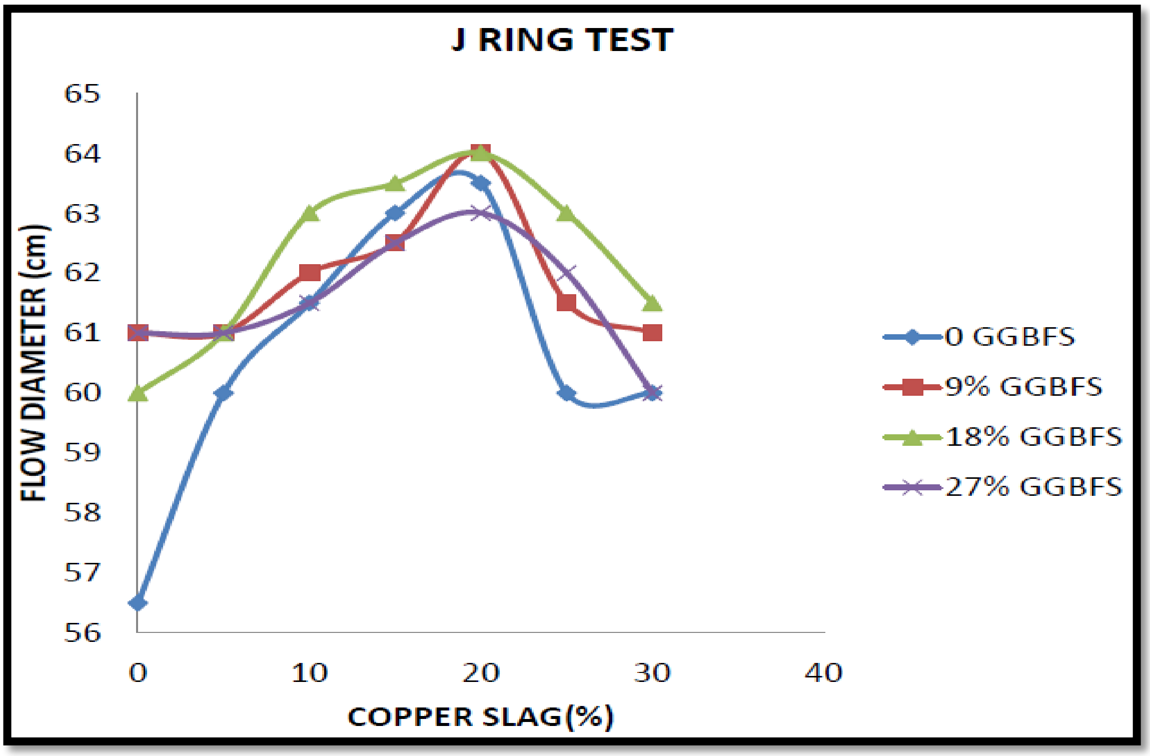

Fig 3: J Ring Diameter vs % Copper Slag

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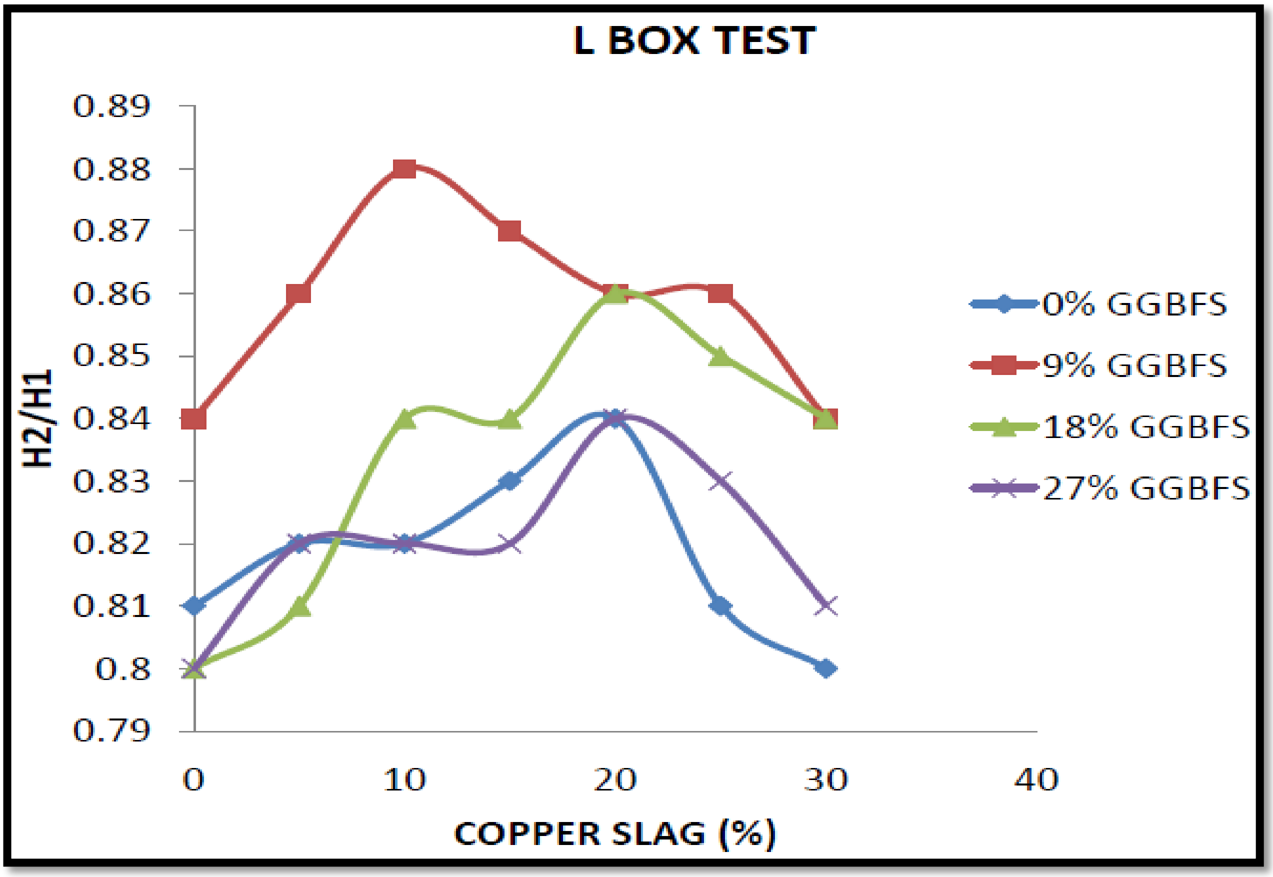

Fig 4: L Box H2/H1 vs % Copper Slag

Table 3: Properties of Hardened Concrete

Mix Designation	28 Day Compressive strength (N/mm2)
SCC	31
SC5	27.4
SC10	31.1
SC15	33.2
SC20	37.3
SC25	35.5
SC30	32.4
SG9	23.11
SG9C5	26.4
SG9C10	28.8
SG9C15	31
SG9C20	35.5
SG9C25	30
SG9C30	26.3
SG18	23.25
SG18C5	24.4
SG18C10	25.62
SG18C15	30
SG18C20	33.02
SG18C25	31.5
SG18C30	30
SG27	25.92
SG27C5	27.52
SG27C10	29.1
SG27C15	32
SG27C20	33.5
SG27C25	30
SG27C30	28.3

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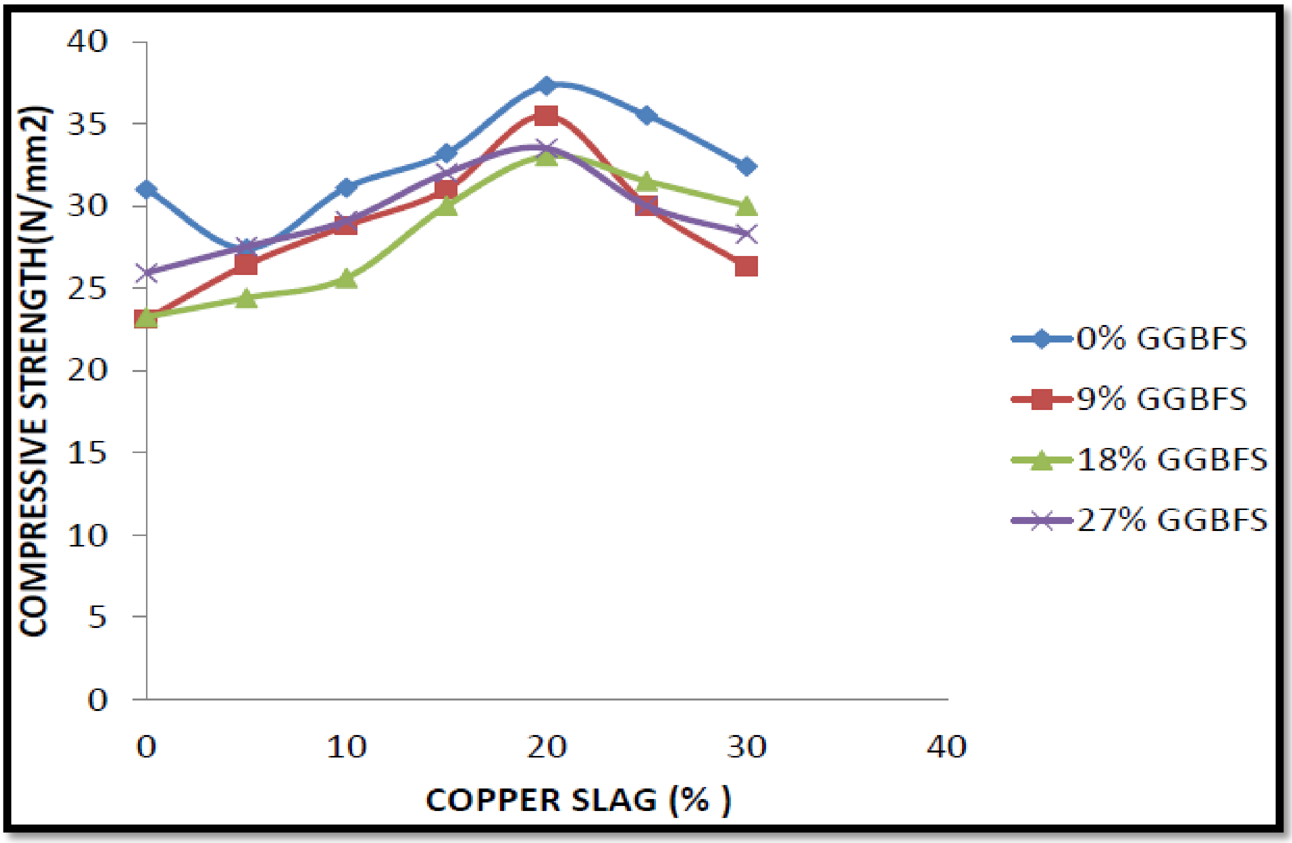

Fig 5: 28 Day Compressive Strength

V. CONCLUSION

After conducting various tests on prepared SCC mixes, the following conclusions were be obtained.

- The addition of GGBFS and CS increased the fresh and hardened concrete properties of SCC. Thus a new SCC is obtained containing both GGBFS and CS as partial substitutions having advantages over normal SCC.
- The mixes containing GGBFS alone showed great increase in workability while its effect on Compressive strength is marginal. It clearly shows that the GGBFS is much finer than cement and it helps SCC to flow easily between the reinforcements.
- The Mixes containing only Copper Slag showed only a marginal increase in workability and its effect on Compressive strength is impressive. It showed that Copper slag addition gives an advantage to the hardened concrete.
- Various mixes were tried and the optimum result were obtained when 9% of cement is substituted using GGBFS and 20% of fine aggregate by CS. The mix was designated as SG9C20.

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