Use of industrial waste as partial fine aggregate replacement in SCC

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Abstract. In the current scenario, SCC is used in the variety of massconcreting applications. But SCC involves usage of more quantities of binder and fine aggregate content compared to conventionally vibrated concrete (CVC). The availability of basic constituent materials required for preparing the concrete in the entire world is facing a major crisis. For example, the construction industry has faced the non-availability of river sand since it is the principal ingredient that contributes the homogeneity in concrete. The experimental investigation was planned with the total of ten SCC mixes using industrial wastes namely copper slag (CS) and steel slag (SS) from 0% to 50% (with an increment of 10%) as fine aggregate replacement along with one control SCC (SCC0). The water-powder (w/p) ratio of 0.38, the dosage of Super plasticizer (SP) as 1.5% by the weight of cement and viscosity modifying agent VMA as 0.15% by the weight of cement were arrived based on the laboratory test trials. The fresh property tests were conducted in greener SCC according to EFNARC guidelines. The mechanical properties (compressive strength and split-tensile) were determined after 28 days of curing. Keywords: Compressive strength; copper slag; self-compacting concrete; splitting tensile strength; steel slag.

Keywords: CVC, SCC, copper slag, VMA, compressive strength

1. Introduction
Self-Compacting Concrete (SCC) was emerged out to solve the issues faced by the construction industry. The places where manual compaction is difficult, usage of vibrator affects the reinforcement or the form-work, SCC could be used to yield good results. Nowadays natural sand that is available in river beds becoming scarce due to depletion or overexploitation of renewable resources. Sand is being extracted at a far greater rate than at which it is naturally replenished. Due to the current demand in the sand, there is a need to search for some alternatives, and use of waste materials and industrial byproducts appears to be an attractive option. Since these wastes are not going to be used for any other purposes, they need to be disposed. Instead, they can be used in construction, and the current shortage of sand can be compensated to some extent. India produces more than 6.5 MT of copper slag (CS) and 12 MT of steel slag (SS) per year.

A simple mix design method of SCC was proposed using the volume of sand to mortar in the range of 54–60%[1]. The potential usage of industrial wastes namely CS and SS as substitute for fine aggregate was found to be feasible[2]. Incorporation of steel slag in concrete has reduced the workability beyond 50% whereas the strength was achieved with lesser replacements [3,4]. The strength was improved by 20% copper slag and the resistance against durability was better pronounced by 60% CS as the replacer of sand in SCC [5]. The use of iron slag in SCC has shown increase in the strength and durability characteristics in comparison with control mix[6]. In HSC, using CS as replaceto sand has improved workability (along with SP dosage), strength and durability properties [7,8]. Implementing SS by 40% as the substitute for fine aggregate and by 30% for the coarse aggregate in concrete has shown increase in strength and durability properties [9]. The optimum percentage of CS in the range of 40% to 50% as fine aggregate replacement has shown improved strength and durability characteristics[10]. Incorporation of 40% steel slag has shown improved compressive strength when compared to control mix and beyond that strength got decreased[11]. The
fine aggregate replacement by 60% quarry dust and by 30% brick dust in SCC has shown improved mechanical properties[12]. In SCC, the fine aggregate replacement up to 25% has shown improved strength at early ages[13]. SCC using 25% quarry dust as fine aggregate replacement has improved mechanical properties. Further, the fresh properties were satisfied up to 50% fine aggregate replacement by quarry dust[14]. The partial cement replacement by 50% GGBS and 25% of fine aggregate using ROBO sand has shown improved mechanical properties in SCC[15].

The sand replaced by 85% of crushed rock dust and 15% of marble sludge powder could be the feasible option to produce SCC[16]. Incorporation of 50% of fly ash in SCC as the partial substitute for sand has improved the mechanical properties, when tested at early and later ages[17]. When SCC was prepared by 75% bottom ash as replacer to sand and 20% fly ash as replacer to cement has improved the flexural and split tensile strength than control mix[18]. The concrete was prepared using coal bottom ash as replacer to sand; improved strength than control concrete was inferred at later ages was due to pozzolanic action [19]. The mechanical properties of concrete containing bottom ash were correlated with international codes, and the analytical models were proposed[20]. There placer to sand using 20% bagasse ash has shown improved workability and strength behaviour in concrete[21]. The bleeding of concrete took place with the influence of bottom ash[22].

In concrete, the influence of industrial by-products was investigated. Use of 10% CKD has improved the mechanical properties in concrete[23]. SCC fresh properties were carried out according to European standards (EFNARC 2002 & 2005).

Based on the review of literature, the limited works were performed in SCC using copper and steel slag as replacer to sand. In this paper, the partial fine aggregate replacement using copper slag (CS) and steel slag (SS) from 0% to 50% (with an increment of 10%) was done to understand the fresh and strength behaviour in SCC. The objective is to prepare SCC using industrial waste as a replacer to sand that could reduce disposal problem faced by the industries and develop the greener sustainable environment. On the other hand, employing SCC at construction sites prevents the noise pollution due to external vibrators for compaction.

2. Materials used
OPC 53 grade was adopted conforming to ASTM C 150M-17. River sand used was well sieved whose grain size was less than 4.75mm was used as fine aggregate. The SG and FM were found to be 2.67 and 2.71 respectively, refer Figure 1. The coarse aggregate of saturated surface dried natural stone crushed to a nominal size < 12.5mm was adopted according to ASTM C 127-12. High- performance super plasticizer cum retarder-CERAPLAST 300M was used. Viscosity modifying admixture (VMA) of product type AURAMIXV100 from FOSROC Company was used.

2.1 Copper slag
The SG and FM of CS were 3.73 and 2.46 respectively.
2.2 Steel slag

The SG and FM of SS were 2.87 and 2.32 respectively. The particle size distributions were confirmed according to American standards (ASTM C33).

3. Mix design

SCC of M60 grade was adopted in the mix design. The quantity of binder (cement) is kept as constant as 600 kg/m$^3$ as per American standards ACI 211.1 for the required target strength. Table 1 shows the mix proportions developed for all SCC mixes. Table 2 illustrates the properties of fine aggregates.

| Mix ID | Cement | Fine aggregate | Coarse aggregate | Copper Slag(CS) | Steel Slag(SS) | Water | SP | VMA |
|--------|--------|----------------|------------------|----------------|----------------|-------|----|-----|
| SCC0   | 600    | 810            | -                | -              | -              | 228   | 9  | 0.90 |
| CS-10  | 729    | 660            | 113.20           | -              | -              |       |    |     |
| CS-20  | 648    | 660            | 226.30           | -              | -              |       |    |     |
| CS-30  | 567    | 660            | 339.47           | -              | -              |       |    |     |
| CS-40  | 486    | 660            | 452.63           | -              | -              |       |    |     |
| CS-50  | 405    | 660            | 565.80           | -              | -              |       |    |     |
| SS-10  | 729    | 660            | -                | 87.06          | -              |       |    |     |
| SS-20  | 648    | 660            | -                | 174.12         | -              |       |    |     |
| SS-30  | 567    | 660            | 261.18           | -              | -              |       |    |     |
| SS-40  | 486    | 660            | 348.24           | -              | -              |       |    |     |
| SS-50  | 405    | 660            | 435.30           | -              | -              |       |    |     |

Table 2. Properties of Fine Aggregates.

| Materials | Specific Gravity(SG) | Fineness Modulus(FM) | % of Water Absorption | Major Chemical Composition |
|-----------|----------------------|----------------------|-----------------------|---------------------------|
| Sand      | 2.67                 | 2.71                 | Nil                   | 80.78% SiO$_2$, 10.52% Al$_2$O$_3$ |
| CS        | 3.73                 | 2.46                 | 0.37                  | 28.54% SiO$_2$, 57.35% Fe$_2$O$_3$ |
| SS        | 2.87                 | 2.32                 | 1.21                  | 85.31% Fe$_2$O$_3$, 12.68% CaO |

Figure 2 to 5 illustrates the fresh property tests conducted in the laboratory. Figure 6 & 7 illustrates the tests conducted at hardened state.
4. Results & Discussion

4.1 Fresh property tests

From the Figure 8, the slump flow spread diameter (SFD) of control SCC mix was observed as 734mm which comes under class SF2 (660-750mm) under EFNARC guidelines. The SFD of CS 10% was 737mm and a maximum SFD of 762mm was found in CS 50%. The above results were due to low water absorption percentage of CS (0.3 - 0.4) as reported [7]. The SFD for SS 10% was 733mm and a minimum SFD of 670mm was found in SS 50%. The more water absorption percentage of SS (0.8 - 1.4) could be the reason as reported [3].

![Slump flow values for all SCC mixes.](image)
Table 3 illustrates the results of V-funnel, L-box and U-box test conducted in the laboratory. The values were well within the limits.

| Mix Description | V-Funnel Test (s) | L-Box Test (H₂/H₁) | U-Box Test (H₂-H₁)(mm) |
|-----------------|------------------|---------------------|------------------------|
| SCC0            | 9.54             | 0.93                | 19                     |
| CuS 50%         | 7.03             | 0.96                | 4                      |
| StS 40%         | 11.92            | 0.79                | 28                     |
| Range           | 6 to 12          | 0.8 to 1            | 0 to 30                |

4.2 Compressive strength
From the Figure 9, the reduction in compressive strength was found in all SCC mixes of CS and SS when compared to SCC0. This low early strength was mainly due to the delay in the hydration process for formation of pozzolans. The other reason was due to the presence of heavy metal oxides such as Fe₂O₃, in both CS (53.45 - 68.29% of weight) as reported [7] and SS (97.05% of weight) as reported [3].

Using CS in SCC has shown a gradual increase in the compression strength, but less compared to control mix SCC at all ages. It was observed that SCC with CS showed maximum compressive strength for 50% replacement of sand with values of 36.97, 47.73 and 56.61 MPa when tested at early ages. The presence of 20-30% of SiO₂ in CS was the main component that induces the pozzolanic activity. As reported in previous studies [5], the optimum percentage of CS for sand in SCC was found to be between 40-50%.

![Figure 9. Test on Compressive Strength at 7, 14 and 28 days.](image)

The compressive strength was increased using SS as a partial substitute for sand. The strength was increased by 7.5% at 14 d and 11.12% for 40% SS at 28 d in respect to control SCC but decreased by 2% for 7 days of curing due to the low early strength of SS in SCC. The alkali CaO present in SS (up to 52% of weight) forms calcium hydroxide upon hydration could reduce the pores. Then Ca(OH)₂ reacts with SiO₂ (up to 35% of weight) and forms calcium silicate (CS). Finally, CS reacts with pozzolans that could fill voids and enhance strength.

4.3 Split tensile strength
From the Figure 10, the split tensile strength of control SCC cylinder was observed to be 4.34 MPa for 28 days of curing. There was a systematic increase in tension values of CS substitution in SCC with a minimum of 3.7 MPa for 10% replacement and a maximum of 4.83 MPa for CS 50%. There was an increment of about 11.3% and detainment of about 14.74% for CS 50% and CS 10% by sand replacement in respect to SCC0 mix. The systematic increment of tensile strength was found using SS up to 40% with a minimum value of 4.37 MPa for SS 10% and a maximum of 5.46 MPa for SS 40%.
The tensile strength was increased by 25.8% for SS 40% when compared to control SCC. But SS 50% has obtained the tension value of 5.46MPa which was less compared to SS 40%.

Figure 10. Splitting Tensile Strength values at 28 days.

5. Conclusion
1. The substitution of CS as a replacer to sand in SCC escalated the SFD values in which CS 40% and CS 50% mixes shown results in class SF-3 with the range of 750 - 850mm.
2. The substitution of SS as a replacer to sand in SCC has shown lesser SFD values compared to SCC0, in which all the SS Mixes shown results within class SF-2 with the range of 650-750mm.
3. Early age compressive strength obtained by both copper slag and steel slag replacements as shown decreased values compared to control mix, which can be attributed due to the presence of heavy metal oxides such as Fe₂O₃, which slow down the hydration process and the formation of pozzolans.
4. In mechanical properties, SCC mix having 40% SS as a replacer to sand has shown highest strength. Incorporation of 50% of CS in SCC has shown compressive strength values equivalent to control mix and had higher splitting tensile strength values.

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