Use of copper slag in concrete production – a sustainable solution for solid waste management

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Abstract. In India, the construction activities are increasing day by day and as a result, the natural sand has become scarce and costly material. To meet this increase in demand one has to go for excessive mining of river bed and that leads to natural imbalance. Therefore reducing the consumption of natural sand in construction is a major issue considering both the environment and economic issues. To balance the demand one has to go for sustainable unconventional innovative materials and particularly the industrial by products where there mass disposal and solid waste management is the problem. Copper slag is one of the industrial by-product obtained during manufacture of copper. This paper presents the experimental results on concrete made of copper slag. Mechanical properties like compressive strength, abrasion resistance and durability properties like acid resistance were carried out. The test results shows the concrete containing copper slag as fine aggregate has good strength and properties and the copper slag replacement level can be limited to 40-60% (by weight).

Keywords Natural sand, industrial by-product, copper slag, mass disposal solid waste management

1. Introduction
In India, river sand is used for concrete and masonry works such as plastering, boundary walls and block work. Naturally there will be increase in demand for river sand and one has to search for suitable alternative. Industrial by-products and waste materials which are causing difficult to dispose and leads variation in solid waste management can be used partially or fully in the production of concrete as a substitution to river sand. Copper slag one such type of industrial by-products obtained in the process manufacture of copper.

2. Literature survey
Across globe copper industries producing about 24.6 million tons of copper slag and this slag has good resistance to abrasion [1]. The mechanical strength properties of concrete containing copper slag (CS) are on par with the concrete containing river sand up to 50% replacement and CS can be a substitute for river sand [2]. The concrete containing CS as fine aggregate has good strength and durability properties and the replacement level can be limited to 40% by weight [3]. The manufactured sand (M-sand) and industrial by products are a good alternative for river sand for concrete provided the workability in terms of flow ability is compensated by the plasticizer [4].
The abrasion resistance of concrete was directly proportional to the compressive strength [5]. The abrasion strength of concrete was influenced by factors like surface finish, aggregate properties, compressive strength, and curing techniques [6]. In order to produce the high abrasion resistance mortar, it is essential to use hard aggregates and high strength cement paste [7]. The pozzolonic activity of CS is similar to that of fly ash and greater than silica fume [8]. The optimum content of CS as partial replacement to river sand is 60% to get enhanced durability behavior of self-compacting concrete [9]. By considering the land disposal problems and sustainable application the river sand can be effectively replaced by CS in structural members [10]. The ultra-high performance concrete can be produced by considering complete replacement of natural river sand by CS [11]. From this study, it can be concluded that CS has tremendous potential for use in mortar and concrete. Based on this a detailed investigation is planned in order to understand the performance of typical concrete mix with fresh and hardened properties.

3. The objectives of the present study
   - To assess the surface characteristics of copper slag the by Scanning Electronic Microscopy(SEM) technique
   - To determine fresh and hardened properties of concrete
   - To determine the abrasion characteristics
   - To assess the durability by acid resistance test

4. Physical properties
   Some physical properties of M-sand and copper slag are shown in Table 1.

| Physical properties | M-sand | Copper slag |
|---------------------|--------|-------------|
| Shape               | Irregular | Irregular   |
| Specific gravity    | 2.63   | 3.75        |
| Zone                | II     | II          |
| Moisture content (%)| 0.30   | 0.11        |
| Water absorption (%)| 1.5    | 0.3         |
| Fineness modulus    | 2.24   | 3.12        |
| Bulk density (g/cc) | 1.78   | 2.15        |
| Voids (%)           | 31     | 37          |

Figure 1. Copper slag having average size less than 4.75 and more than 2.36mm

5. Materials and methodology
The cement OPC of 43 grade conforming to IS 8112:2013[12] is used. Copper slag took from Sterlite Industries India Limited (SIIL), Tamilnadu, India. Figure 1 shows the photograph of the copper slag having size in between 2.36 and 4.75mm. The results show that the grains are originally having smooth, shiny, nonporous and sharp edged surfaces. Potable fresh water used for concrete making and curing purposes. In the present study, it is targeted at concrete mix of M35 grade with fractional replacement of M-sand with copper slag at 20% intervals. M35 mix of proportion 1:2.08:3.4 are designed as per IS 10262:2019[13] and W/C of 0.50 by considering both target slump value and compressive strength. The abrasion and acid resistance tests were performed at 56 day concrete ages.

Figure 2. SEM photograph of the copper slag grain (at different enlargements)
6. Results

Workability Test is done on fresh concrete as per IS 1199:1959[14] using slump cone apparatuses and results are presented in Table 2. The average compressive strength tests on hardened concrete at periods at 7, 28, and 56 day and at different curing media is done as per IS 516 :1959[15] and Test data are tabulated in Table 3. Abrasion resistance of concrete pieces cut from cubes was measured as per IS 1237: 2012[16] provisions. The abrasive powder used was aluminium oxide and the test was conducted as specified in code. Figure 2 shows Scanning Electronic Microscopy photographs of the copper slag grain at different enlargements. The results show that the grains are originally having smooth, shiny, nonporous, and sharp edged surfaces. Figure 3 shows testing of specimen under abrasion resistance and Figure 4 shows the specimen after abrasion test. The variation of abrasion resistance in terms reduction in weight and depth of wear are tabulated in Table 4. The percentage loss in weight of concrete specimens due to acid curing is tabulated in Table 5. Figure 5 shows the deviation of compressive strength of concrete specimens with water and acid curing at 56 day.

![Figure 3. Specimen under abrasion testing](image1)

![Figure 4. Specimen after abrasion test](image2)

**Table 2.** Test results on workability of concrete

| Type of Mix          | Slump (mm) |
|----------------------|------------|
| Control Mix          | 50         |
| 80% MS + 20% CS     | 55         |
| 60% MS + 40% CS     | 60         |
| 40% MS + 60% CS     | 65         |
| 20% MS + 80% CS     | 70         |
| 100% CS             | 75         |

*MS: M-sand, CS: copper slag

**Table 3.** Compressive strength of concrete for different type of mixes at different curing ages

| Type of Mix   | Compressive strength (MPa) |
|---------------|----------------------------|
|               | 7day | 28day | 56day (WC) | 56day (AC) |
| 100% MS       | 38.06 | 42.55 | 47.90       | 35.24       |
| 80% MS+ 20% CS| 27.14 | 42.27 | 42.15       | 38.55       |

7. Discussions

The fresh property of concrete is measured in terms of slump as presented in Table 2. The result shows that with the increase in percentage copper slag content the slump value also increases this is due to heavier specific gravity of the copper slag compared to M-sand and free water content in copper slag mix.
60% MS+ 40% CS  32.25  47.34  52.03  44.49
40% MS+ 60% CS  31.02  39.76  45.03  44.32
20% MS+ 80% CS  27.33  37.42  45.03  42.74
100% CS         26.00  35.12  40.58  36.81

*AC: Acid curing; WC: Water curing

Figure 5. Variation of compressive strength of concrete with water and acid curing at 56 day

Table 4. Abrasion resistance of concrete

| Type of Mix         | Reduction in weight (Avg.), g | Depth of Wear (Avg.), mm |
|---------------------|-------------------------------|--------------------------|
| 100% MS             | 20.03                         | 1.49                     |
| 80% MS+ 20% CS      | 20.25                         | 1.53                     |
| 60% MS+ 40% CS      | 20.40                         | 1.56                     |
| 40% MS+ 60% CS      | 20.64                         | 1.67                     |
| 20% MS+ 80% CS      | 20.76                         | 1.78                     |
| 100% CS             | 20.90                         | 1.87                     |

Table 5. Effect of acid on weight of concrete cubes at 56day

| Type of Mix         | Weight (kg) | Loss in Weight (%) |
|---------------------|-------------|--------------------|
|                     | Initial     | Final              |                  |
| 100% MS             | 8.37        | 8.22               | 1.79             |
| 80% MS+ 20% CS      | 8.44        | 8.31               | 1.55             |
| 60% MS+ 40% CS      | 8.65        | 8.51               | 1.62             |
| 40% MS+ 60% CS      | 8.71        | 8.60               | 1.26             |
| 20% MS+ 80% CS      | 8.86        | 8.73               | 1.46             |
| 100% CS             | 8.76        | 8.61               | 1.71             |

The effect of copper slag in concrete is given in Table 3 which shows the compressive strength at 7, 28 and 56 day aged concrete cubes. A mix of 40% copper slag content gives strength of 47.34 MPa and 52.03 MPa at 28 and 56 days and then for mix more than 40% copper slag there is a decline in strength. This reduction in strength due increase in the free water content in the mix.

The abrasion resistance of copper slag concrete is slightly less (more loss in weight) compared to mortar with M-sand. This is due to the irregular surface features of the copper slag and also due to its brittle nature. In addition, the wear depth increases as the copper slag content increases which is due to lower strength of mortar. The increased wear may have some issues when copper slag is used in pavement application.
Acid resistance (hydrochloric acid) test is conducted to know the durability properties on cube specimens at 56 days. Copper slag content of 40% yielded maximum comprehensive strength of 44.49 MPa compared to control mix of M-sand 35.24 MPa. From Table 5 can be seen that only 1-2% of loss in weight occurs. The concrete made of copper slag having more resistance to acid attack.

8. Conclusion
The slump value of fresh concrete increases as the increase in copper slag content due to heavier specific gravity of copper slag. At replacement level copper slag with M-sand at 40% got maximum compressive strength around 10%. The concrete containing copper slag has more HCL attack resistance compared with conventional concrete as 40% copper slag content yields 26% more compressive strength than M-sand concrete. The concrete containing CS as fine aggregate has good strength and durability properties and the replacement level can be limited to 40-60% (by weight).

The use copper industry by product copper slag can be effectively use in the field of civil infrastructure construction activities by partial replacement to river or M-sand and interns this can be effective solution for solid waste disposal.

9. References
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