Influence of copper slag and GGBS on mechanical properties of concrete

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Abstract. The construction industry consumes a huge amount of concrete due to fast urbanization and an increase in the construction field is depleting the resources of natural sand and M sand at a high rate of concern hence leading to various problems in the environment. Besides that, cementitious material in concrete releases a large amount of CO2 into atmosphere. Similarly cost of concrete is attributed to the cost of its ingredients. The concept of using eco-friendly materials in concrete enhances scope for green concrete which utilizes many kinds of industrial by-products thus resulting in the use of substitute materials which are economical in concrete production. This has attracted the attention of investigators to look out for new replacements for fine aggregate and cement. At this degree, copper slag, which is an industrial by-product produced while smelting and refining copper may be a partial alternative for fine aggregate and GGBS, a by-product of steel manufacturing industry can effectively replace cement with better durable concrete mix. Thereafter, an attempt has been made to control the cost of cement and sand with concrete blend of grade M25&M30 through methodical evaluation of physical, mechanical and chemical properties in the present work. Series of concrete mixtures are prepared with a constant 40% copper slag substituting fine aggregate and GBBS replaces cement at 0%, to 50% with 5% increment. The results suggest that copper slag and GGBS can replace fine aggregate and cement in reinforced cement concrete, without compromising on the quality, thereby contributing to the effort of environment friendly building materials with economic benefits, which is the need of the hour.

1. Introduction
Concrete has become a highly essential construction material that cannot be avoided. According to the present trend, concrete has evaded the stage of sheer four component system, that is, cement, water, coarse aggregate and fine aggregate. It can be a mix of various other components. In the recent past, besides the four components, fly ash, ground granulated blast furnace slag, silica fume, rice husk ash, metakaolin and super plasticizer are six more materials which are normally used when concrete is produced in practice accordingly, as and when the situation demands \cite{1,2}. The main aim of sustainable construction is reducing the negative impact on the environment caused by the construction industry which is the largest consumer of natural resources. Over the years, managing waste has become one of the most difficult and challenging issues in the world affecting the
environment to a great deal. Many kinds of byproducts have been generated due to the fast growth of industrialization kinds of waste which have proved hazardous to the environment and has also given rise to storage problems. The construction industry has constantly been at the forefront in the consumption of these waste products in huge quantities [3]. The use of slag in concrete not only helps in decreasing greenhouse gases but also helps in producing materials which are environmental friendly.

Copper slag is utilized as an alternative material in the manufacture of concrete. During the matte smelting process, while manufacturing copper products, copper slag is the waste material that is generally generated from the industrial sector. It is very expensive to dispose this waste safely and leads to polluting the environment. [4]. The only area where the waste material (copper slag) can be safely disposed is the construction industry. When it is used to replace natural sand in making concrete, it reduces pollution of the environment, space problem and also decreases the cost of concrete. Due to the higher density of copper liquid it settles down in the smelter and the smears of copper slag remaining on the surface (also in liquid form) are removed and cooled. A hard and crystalline product is created due to slow cooling of air amorphous, glassy granulates are produced due to fast cooling in water. In the production of concrete, copper slag can be used as a part of concrete production in the place of natural sand[5,6].

When iron slag is doused, Ground granulated blast furnace slag (GGBS) is obtained (a by- product of iron and steel production) from a blast furnace in water or steam, producing a smooth, granular product. By drying and grinding this to a fine powder, GGBS, is used to make concrete structures when mixed with common Portland cement along with other pozzolanic materials [7,8]. Presently, about 33 million tons of copper slag is being created yearly globally; India contributes 6-6.5 million tons among them. The cost of development is reduced along with GGBS when copper slag is used thereby decreasing the harmful effects on the environment [9] Hereafter, in the present scenario an attempt has been made to restrain the cost of cement and sand with concrete blend of grade M25 and M30. The cement has been replaced with GGBS at 0%,5%, 10%,15%, 20%,25%, 30%, 35%,40% and 50% by dry weight of cement and sand is replaced with copper slag at a constant proportion of 40% by dry weight of sand for M25 and M30 mix. Concrete mixes are prepared, tested and analyzed regarding compressive, flexural and split tensile strength. The obtained test results are compared with that of conventional concrete and the proportion of GGBS and copper slag replaced which will give higher strength is selected to be optimum proportion for construction works.

2. Materials and methods

2.1. Properties of materials

Properties of the cement used in the mixture greatly influences the performance of the concrete prepared. In the present set of experiments ordinary Portland cement (OPC) grade 53 was used, along with the required specifications as per IS:12269-1987 [12].

When preparing fine and coarse aggregates clean and dry river sand with specific gravity of 2.65, fineness modulus of 2.80 and passing through IS 4.75 mm sieve and crushed granite aggregate with specific gravity of 2.76, fineness modulus 5.85 and passing through 12.5 mm and 20 mm sieves were used, respectively, for moulding all the samples[13-15]. When copper is smelted and refined, Cu slag (an industrial by-product) is produced .Two types of slags which are (i) an air-cooled slag with light black colour and glassy texture and (ii) porous granulated copper slag with vesicular structure can be made as the by-product [16]. Based on the presence of iron content in the slag, its specific gravity can have values between 3.2 to 3.8 and its water absorption can vary depending on the porosity [17]. Cu slag obtained from Vedanta Ltd., Thootukkudy, India was utilized in the present study which had a specific gravity of 3.45 and bulking factor of 1 [15]. A comparative study of the physical properties of river sand and Cu-slag used for the present experiments are presented in Table 1.
Table 1. Properties of river sand and Cu-slag used for present research work.

| Particulars      | River sand | Cu-slag |
|------------------|------------|---------|
| Bulk density (kg/m³) | 1.55       | 2.056   |
| Void ratio       | 0.642      | 0.664   |
| Porosity         | 0.391      | 0.339   |
| Specific gravity | 2.67       | 3.42    |

2.2. Experimental methods

Sieve analysis was carried out as per IS:383-1970 [14]. Compositional analysis of the Cu slag was carried out using energy dispersive analysis of x-rays in a JEOL SEM system with OXFORD XMX N attachment. Direct shear measurements were carried out to evaluate the cohesion and angle of friction values for the river sand and copper slag. The tests were conducted here with three normal stresses of 100, 200 and 300 kPa in a direct shear test apparatus. Compressive strength, split-tensile strength and flexural strength were evaluated for mix designs, M25 and M30, prepared by constant substitution of 40% River sand by Cu slag and by partially replacing cement with GGBS in varying proportions (IS: 10262-2009, IS: 516-1959 (reaffirmed 1997) and IS: 5816-1999)[18-20]. For M25 the proportion for the mix of the cement, fine aggregate and coarse aggregate followed were 1:2.08:3.283 with the ratio of water and cement being 0.47. The mix proportion of 1:1.815:2.973 with a water cement ratio of 0.44 was used for M30, respectively. The quantities (by weight) of GGBS included in the cement in mixtures of the concrete were as follows: 0% (for the control mix), 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 50%. The target of the control mixture was decided to have a 28-day characteristic compressive strength of 38.25 N/mm² (M30) and 31.60 N/mm² for M25. The chemical admixture used was Auramix V 200. Compressive strength was evaluated by preparing cubes of 15 cm x 15 cm x 15 cm using various proportions of GGBS in place of cement with 40% of copper slag as a fine aggregate replacing river sand in both the mix designs [18, 19]. The cubes were then cured in water and tested using compression testing machine to assess the compressive strength after 7 days and 28 days of curing. Split tensile strength of cylindrical specimen of respective samples of 15 cm diameter and 30 cm length were assessed with a universal testing machine after 28 days of curing in water as per IS: 5816-1999 [20]. Flexural strength of various samples were assessed by casting concrete beams of size 150 mm x 150 mm x 700 mm, cured in water for 28 days followed by testing in Flexural testing machine (IS: 516-1959 (reaffirmed 1997)) [19]. Rapid chloride Permeability test was conducted to assess the strength of concrete for different kinds of substitution of GGBS in Cement with 40% replacement of sand with Cu slag. In this method water logged 50mm thick, 100mm diameter concrete sample is exposed to a 60-V applied DC voltage for 6 hours. One end of the sample is sustained in 3% NaCl and the other in 0.3M NaOH solution and the total charge passed is calculated which is then used to rate the concrete [5].Ultrasonic pulse velocity test is a conserving test done to calculate the durability of concrete by measuring the speed of an ultrasonic pulse passing through the concrete sample. This test is performed by passing an ultrasonic pulse wave through the concrete to be tested and assessing the time taken by pulse to pass through the structure in cross probing method.

3. Results and discussion

3.1. Physical and mechanical properties

Size distribution of the aggregate particles were determined using sieve analysis and the semi-log graph signifying the zoning and the results for river sand and Cu slag are shown in figures 1 (a) and (b), respectively. Table 2 shows the tabulation based on sieve analysis and mechanical property evaluation between river sand and Cu slag are compared and presented. The results of the sieve analysis clearly indicate that Cu slag comes under the category of Zone 2 which is suggested for mass concrete as per IS: 383-1970 [14].
Figure 1. Semi log graph showing the sieve analysis of River-sand (a) and Cu-Slag (b).

Table 2. Mechanical property evaluation of river sand versus Cu-slag.

| Sl. No. | Property               | River sand                  | Cu-slag                      | Remarks                  |
|---------|------------------------|-----------------------------|------------------------------|--------------------------|
| 1       | Shape                  | Spherical particle          | Granular particle, irregular, glassy and black | Good                     |
| 2       | Gradation              | Cannot be controlled        | Can be controlled            | Good                     |
| 3       | Specific gravity       | 2.3-2.7                     | 3.3-3.9                      | May vary                 |
| 4       | Water absorption       | 1.5 - 3%                    | 0.15-0.35 %                  | Limit 2 %                |
| 5       | Ability to hold surface moisture | Up to 7 %              | Up to 0.5 %                  | Endurance limit          |
| 6       | Grading zone           | Zone 2 and 3                | Zone 2                       | Recommends Zone 2 for mass concrete |

3.2. Compositional analysis

Figure 2. EDAX pattern and the corresponding elemental analysis of Cu-slag.

As the by-product of the smelting process is Cu slag, they can differ in their chemical compositions with a likely presence of high saturated content of heavy metals like arsenic, cadmium and lead.
making them hazardous. Hence it is important to assess the chemical composition of the slag with caution. Taking into account this fundamental composition of the copper slag used in the present experiments, investigations were done using EDAX and figure 2 summarizes the results. The table clearly indicates that the slag is basically a ferrous silicate material.

3.3. Direct sheartest analysis
Since bonding of materials is important in reinforced cement concrete, it is essential to understand the bonding of the fine aggregate which in turn depends on the cohesion and the angle of friction. Direct shear test is carried out to discover the friction of the materials so as to assess the quality of the copper slag utilized as the fine aggregate replacement of river sand in concrete. Variation of shear stress with respect to shear displacement obtained for river sand and copper slag when subjected to normal stress values of 100 kPa, 200 kPa and 300 kPa are shown in figures 3 (a) and (b), respectively. The corresponding direct shear parameters are summarized in table 3. The values of cohesion (C) and angle of friction (Φ) for river sand and Cu sand are comparable suggesting that it is possible to explore the usage of copper slag to replace river sand.

![Figure 3. Direct shear test analysis of River sand and Cu-slag.](image)

| Table 3. Direct shear parameters of River sand and Cu-slag. |
|---------------------------------|
| **Parameters** | **RIVER SAND** | **COPPER SLAG** |
| Normal stress | 1 | 2 | 3 | 1 | 2 | 3 |
| Shear stress | 0.76 | 1.61 | 2.35 | 0.61 | 1.19 | 1.96 |
| Cohesion (C) | 0 | 0 |
| Angle of friction (Φ) | 36.95 | 33.87 |

3.4. Mix Design-Substitution of River sand by Cu-slag and cement by GGBS
Compressive strength, split-tensile strength and flexural strength were evaluated for mix designs M25 and M30 by replacing river sand partially/fully with copper slag in various percentages (IS: 10262-2009, IS: 516-1959 (reaffirmed 1997) and IS: 5816-1999 [18-20]. 20mm was the biggest size of the aggregate used. Results of the compressive strength evaluated after 7 and 28 days of curing for both the mix designs M25 and M30 for various replacements is tabulated and the respective graphs are shown in figures 4 (a) and (b), respectively. The results clearly suggest that the compressive strength systematically increases initially for up to 30% replacement of GGBS in cement, beyond which the values starts to decrease with increasing replacement. Reduction in the strength due to more than 30%
replacement of GGBS in RCC is due to excess GGBS which could not enter in to reaction behave like fine aggregate. GGBS instead of cement will lower early-age temperature rise in concrete, which decreases the risk of cracking thermally. Also, it reduces the risk of causing harm to internal reactions such as Alkali Silica reaction and delay in the formation of Ettringite. Being finer than cement, GGBS demands more water. This increment in water demand can thus be controlled by adding copper slag in the concrete. As the size of the particle reduces, the strength increases for all substitutions of cement with GGBS. Since the copper slag is having irregular shape compared with that of cubical River sand particles, it increases the strength of concrete produced. Also, the addition of GGBS improves the packing of particles. GGBS can be used as a replacement for cement because it contains the same oxides and undergoes the same hydration process.

![Compressive Strength](image1)

**Figure 4.** Compressive strength with varying percentage replacements of cement with GGBS and Cu slag in River-sand for mix designs M25 and M30 after 7 days and 28 days of curing.

Split tensile strength as well as flexural strength for both the mix designs M25 and M30 were evaluated for various percentages of replacements after 28 days of curing and the results are summarized and the corresponding graphs are shown in figures 5 and 6, respectively. In all the cases, it is clearly evident that optimal replacement of 40% of River sand by Cu-Slag and 30% of OPC 53 grade cement by GGBS beyond which the values are decreasing.

![Split Tensile Strength](image2)

**Figure 5.** Split tensile strength with varying percentage replacements of cement with GGBS and River-sand with Cu slag for mix designs M25 and M30 after 7 days and 28 days of curing.
3.5. Rapid chloride permeability test

In order to further understand the use of copper slag and GGBS as a possible substitute for natural fine aggregate and cement, it is important to examine the durability properties of concrete prepared using different percentages of partial replacement of cement with GGBS and 40% river sand by Cu-slag. Rapid chloride permeability tests were conducted on both the composition of the mix, M25 and M30 with various percentage replacements and the obtained results are tabulated in table 10. Chloride ion permeability based on charge passed (ASTM C1202-94) is summarized in table 4 [11]. A comparison of the results suggest that the control mix with 0% Cu-slag and 0% GGBS (100% cement) falls in the category of moderate permeability whereas mixes with 10%, 20%, 30%, 40% and 50% of replacement of cement with GGBS and fixed 40% replacements of Cu-slag with sand fall in the category of low chloride ion permeability. The rate of access of chloride into concrete is influenced by the pore structure of concrete. Therefore a decrease in permeability with a rise in the quantity of Cu slag and GGBS content may suggest an enhancement in the microstructure and thereby an improvement in the durability of concrete.

| Sl. No. | % Replacement of River sand by Cu slag and cement by GGBS | M25 | M30 |
|---------|----------------------------------------------------------|-----|-----|
|         |                                                          | Total charge passed (C) | Chloride ion permeability | Total charge passed (C) | Chloride ion permeability |
| 1       | G0%;CS0%                                                 | 2200 | Moderate | 2325 | Moderate |
| 2       | G0%;CS40%                                                | 1750 | Low     | 1810 | Low     |
| 3       | G10%;CS40%                                               | 1620 | Low     | 1700 | Low     |
| 4       | G20%;CS40%                                               | 1480 | Low     | 1550 | Low     |
| 5       | G30%;CS40%                                               | 1355 | Low     | 1410 | Low     |
| 6       | G40%;CS40%                                               | 1410 | Low     | 1490 | Low     |
| 7       | G50%;CS40%                                               | 1495 | Low     | 1510 | Low     |

Table 4. Results of rapid chloride permeability test for mix designation M25 and M30.
3.6. Ultrasonic pulse velocity test

Ultrasonic pulse velocity of concrete cubes casted for the mix of both the components of M25 and M30 were assessed for different percentage substitution after 28 days of curing and summarizes the results and the parallel graphs are indicated in figure 7. The quality of concrete is measured through the ultrasonic pulse velocity and is mainly related to its modulus of elasticity and density of concrete. Consequently, this depends on the components and mix proportions used when preparing concrete and the process of placing, compaction and curing of concrete. Higher velocities indicate the good quality of concrete sand continuity of the material while lower velocity indicate that the concrete may be having many cracks or voids. From the graph it is observed that the maximum pulse velocity for M25 and M30 mix concrete cube is 4.84 km/s and 4.97 km/s for the 40% replacement of fine aggregate with Cu-slag and GBBS replaces 30% of cement. This may be because of the increase in the density and less number of pores in concrete in this composition. Moreover it has been observed that all stages of replacement the concrete had shown high quality as per table 2 of IS 13311(1)-1992.

![Ultrasonic Pulse Velocity](image)

**Figure 7.** Ultrasonic pulse velocity with differences in the percentage of GBBS and Cu slag replacing river sand in cement for mix designs M25 & M30 after 28 days of curing.

4. Conclusions

In conclusion the possibilities of utilizing copper slag, an industrial waste product, as an eco-friendly building material is explored in detail through systematic evaluation of physical, mechanical and chemical properties. The results indicate that the physical properties of Cu-slag help in raising the functioning levels of concrete. Moreover, the fineness modulus, specific gravity, angle of friction and water absorption coefficients of Cu-slag are in conformation with the limits that are permitted. Elemental composition analysis indicates that the copper slag is mainly composed of ferrous silicates. Assessment of the compressive strength, split tensile strength and flexural strength for different mix designs suggested that the ideal results were found for the best substitution of 40% of river-sand by Cu-slag and 30% cement by GGBS. It was also observed that the maximum ultrasonic pulse velocity for concrete cube is for the same optimal replacement. When the GGBS reacts with the surplus calcium hydroxide it forms calcium silicate and calcium aluminate hydrates which results in filling and blocking the pores within the crystalline structure. A hardened cement paste is then produced, which consists of significantly reduced calcium hydroxide that results in chemically stronger concrete and the ability of aggressive chemicals to diffuse through the concrete is controlled by the finer structure of the pores. The strength of concrete is increased because of the partial replacement of GGBS with OPC also because of the increase in hydration products caused by pozzolanic reactivity, and due to the finer pore structure.

The reduction in values beyond optimal replacement may be due to the increase in voids as well as the free water content with increasing slag content due to its modified properties. The abundance of
GGBS beyond this optimum value causes decrement in strength as not much calcium hydroxide is produced. Above results indicate that an efficient use of copper slag and GGBS strengthened cement concrete as a fine aggregate replacement of natural river sand is a possible alternative contributing to sustainable development with added economic benefits resulting from the utilization of industrial waste product, thereby moving towards a waste to wealth generated economy.

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