A STUDY ON THE PROPERTIES OF CONCRETE ON PARTIAL REPLACEMENT OF CEMENT AND SAND WITH COPPER SLAG

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Abstract—This study is aimed to evaluate the effectiveness of copper by replacing cement in the range of 0% (without Copper slag), 5%, 10%, 15%, and 20% is one phase and sand has been replaced by Copper slag accordingly in the range of 0% (without Copper slag), 10%, 20%, 30%, 40% and 50% is second phase by weight of cement for M25 and M30 mix. Comparative study is carried out by compressive test, split tensile test. From the experimental investigation it is observed that replacement of 40% of fine aggregate by copper slag strength increased by 21% and replacement of 15% of fine aggregate by copper slag strength increased by 18%.

Keywords—Concrete, copper slag, cement, split tensile test, sand.

I. INTRODUCTION

In the present scenario, as a result of continuous growth in population, rapid industrialization and the accompanying technologies involving waste disposal, the rate of discharge of pollutants into the atmosphere, copper slag is one of the industrial waste which comes out from blast furnace during metal extraction process. Copper slag is produced as a by-product of metallurgical operations in reverberatory furnaces. Originally imported from Japan, copper slag was used as an abrasive material for removing rust and marine deposits from ships through sandblasting. After repetitive recycling and reuse, the copper slag lost its original abrasive property and with no good use thereafter and was disposed in landfills. However, there were environmental concerns about the leaching of heavy metals into soil and ground-water, and hence were dumped in landfill sites in the distant island of Pulau Semakau for decades which again had very little room for further landfills. Holcim Singapore found a novel way of encapsulating this waste into concrete thereby not only removing the environmental concern but also finding a value-added and meaningful substitute for natural sand.

Copper slag is totally inert material and its physical properties are similar to natural sand. A laboratory study was carried out in the Institute to investigate the potential of using copper slag as a partial replacement of sand in cement concrete.

The use of copper slag when grounded fine can be used as a replacement for cement and concrete provides potential environmental as well as economic benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced.

In many countries, there is a scarcity of natural aggregate that is suitable for construction, whereas in other countries the consumption of aggregate has increased in recent years, due to increases in the construction Industry. In order to reduce depletion of natural aggregate due to
construction, artificially manufactured aggregate and some industrial waste materials can be used as alternatives.

The main objective of this thesis is to determine the concrete strength of M25 & M30 Grade by partial replacement of cement from 0% to 20% and sand from 0% to 50% with copper slag separately in two phases.

The mix design of M25 & M30 grade concrete was designed as per the method specified in IS 10262-2009.

Cubes of size 150mm × 150mm × 150mm, Cylinders of size 300mm×150mm and prisms of size 100mm × 100mm × 500mm were casted and tested for compressive strength, split tensile strength and flexural strength after the completion of respective curing periods.

II. LITERATURE REVIEW
The review of literature involves two aspects. The first one cover the properties of various ingredients of concrete like copper slag, cement etc. The second aspect deals with the strength properties of concrete by replacing cement with copper slag in the first phase and by replacing sand with copper slag in the second phase

2.1 Antonio M. Arino et. al. (1999):
A study of different nonferrous slag’s such as copper, nickel, and lead has indicated that copper slag has the potential for application as a cementitious material. Although it has successfully been used in ground form as a concrete mineral admixture in Canada, Europe, and Australia, the construction industry in the U.S. has been slow in adopting this slag. There is a considerable interest in the southwestern U.S. to use ground copper slag(GCS) as a partial substitute of portland cement since custom smelters are capable of producing as much as half a million tons of copper slag per year. By evaluating its potential use in concrete, there is an opportunity for both the copper and construction industries to benefit from using this material. The compression-test results indicated that GCS concrete was stronger but more brittle than ordinary portland cement concrete. As long as rapid strength gain is not a major design constraint, it was shown that use of GCS increased the strength significantly. Fracture test results confirmed the increased brittleness of concrete due to the use of GCS. An R-curve model was developed to characterize the effect of stable crack growth on the increased toughness demand of GCS concrete specimens. Long-term results showed equal or higher strengths for the GCS specimen without concern for degradation of other properties.

2.2 Meenakshi Sudarvizhi. S et. al. (2013):
Investigated that the effect of using CS and FS as partial replacement of sand. The strength characteristics of conventional concrete and slag concrete such as compressive strength, tensile strength were found. Six series of concrete mixtures were prepared with different proportions of CS and FS ranging from 0% to 100%. The test results of concrete were obtained by adding CS and FS to sand in various percentages ranging from 0%, 20%, 40%, 60%, 80% and 100%. All specimens were cured for 7, 28, 60 & 90 days before compression strength test and splitting tensile test. The results indicate that workability increases with increase in CS and FS percentage. The highest compressive strength obtained was 46MPa (for 100% replacement) and the corresponding strength for control mix was 30MPa. The integrated approach of working on safe disposal and utilization can lead to advantageous effects on the ecology and environmental also. It has been observed that upto 80% replacement, CS and FS can be effectively used as replacement for fine aggregate. The CS & FS, as it is, has higher fineness modulus indicating coarser average particle size. Therefore, it may be preferable to avoid the use of CS & FS as the only fine aggregate in concrete mixes; it may be
necessary to add conventional sand (and finer materials such as fly ash and stone dust) also in order to improve the particle size distribution of the concrete mix to get the cohesiveness and satisfactory workability.

In cases of higher percentage of CS & FS (of the order 60-80%), finer industrial wastes like quarry dust and fine ash may be gainfully utilized to achieve the necessary particle grading and exclude the possibility of bleeding. Compared to the control mix, the CS & FS based concrete showed an increase in the density up to 20%, whereas the workability was found to be often better for the mixes investigated in the present study.

III. METHODOLOGY

Structural concrete is one of the most commonly used construction materials in the world. The use of concrete in various conditions is a well known fact. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be moulded to virtually any form or shape. Concrete provides a wide latitude in surface textures and colours and can be used to construct a wide variety of structures, such as highways and streets, bridges, dams, large buildings, airport runways, irrigation structures, break waters, piers and docks, sidewalks, silos and farm buildings, homes and even ships.

In the present experimental work, copper slag are used as partial replacement for cement and sand in the concrete mix.

3.1 Cement:

Cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields sub microscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is Portland cement.

3.2 Aggregates:

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample fractions of aggregates in required proportion such that the sample contains minimum voids. Samples of the well graded aggregate containing minimum voids require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less water, which will further mean increased economy, higher strength, lower shrinkage and greater durability.

3.3 Concrete:

Mortar, a mixture of cement and sand, is used for binding bricks, stones and for plastering the walls. When mortal is mixed with gravel and allowed to set, it forms concrete. Concrete is sturdy construction material. Concrete is poured into moulds that hold it in place until it hardens. After two or three days of setting, the concrete becomes fir. This hardening is due to the formation of crystals. The crystals lock together and make a very hard artificial stone. Concrete can be moulded into desired shapes to make pre-fabricated parts of buildings and electric poles. Reinforced concrete cement (RCC) is even stronger and long lasting than concrete itself, because in reinforced concrete, steel rods or steel mesh are embedded in wet concrete. Concrete sticks to the steel as it sets. Ceilings
of modern multi-storeyed buildings are constructed with reinforced concrete cement. Big bridges and dams are also made up of reinforced concrete cement.

### 3.4 Admixtures:

Admixtures are those ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing. About 80% of concrete produced in North America have one or more admixtures. About 40% of ready-mix producers use fly ash. About 70% of concrete produced contains a water-reducer admixture. One or more admixtures can be added to a mix to achieve the desired results.

### 3.5 Copper Slag:

Copper Slag (CS) used in this work was brought from Sterile Industries Ltd (SIL), Kolkata, India. SIL is producing CS during the manufacture of copper metal. Currently, about 2600 tons of CS is produced per day and a total accumulation of around 1.5 million tons. This slag is currently being used for many purposes ranging from land-filling to grit blasting. These applications utilize only about 15% to 20% and the remaining dumped as a waste material and this causes environmental pollution. In order to reduce the accumulation of CS and also to provide an alternate material for sand as well as cement we have decided to study its use in the field of construction industry. But before we opt this material as replacer we have check its physical and chemical properties.

#### 3.5.1. For opting as cement the main properties desired for copper slag is
- Size – Grained to a size of less than 60µ
- Fineness – Copper Slag fineness is found to be 210 m²/kg (for size < 60µ)
- Normal consistency which is found to be 22

Finally these properties are almost similar to that of cement and hence these are satisfied for substituting as cement.

#### 3.5.2. For opting as FA (sand)

#### 3.5.2.1 Physical properties of copper slag

The slag is a black glassy and granular in nature and has a similar particle size range like sand. The specific gravity of slag lies between 3.4 and 3.98. The bulk density of granulated copper slag is varying between 1.9 to 2.15 kg/ m³, which is almost similar to the bulk density of conventional fine aggregate. It is also found that the copper slag has less moisture content so it has less heat of hydration.

Advantages of copper slag
- Reduces the construction cost due to saving in material cost.
- Reduces the heat of hydration.
- Refinement of pore pressure.
- Reduces permeability.
- Reduces the demand for primary natural resources.
- Reduces the environmental impact due to quarrying and aggregate mining.

### IV. EXPERIMENTAL PROGRAMME

Experimental investigation was planned to provide sufficient information about the strength characteristics of partially replaced cement and sand with Copper slag and tests were conducted on materials to know their physical properties. Results were analysed to derive useful conclusions regarding the strength characteristics of partially replaced cement and sand with Copper slag M25 and M30 grades has been used as a reference mix.

Material Properties
The materials used in the experimental work namely cement, fly ash, rice husk, fine aggregate and coarse aggregate (20mm passing and 10mm retained) have been tested in laboratory for use in the mix design. The details are presented below.

4.1 Cement:

**Table 1 Physical Properties of Cement (OPC 53 GRADE) (IS 8112-1989)**

| No. | Property                        | Value       |
|-----|--------------------------------|-------------|
| 1   | Specific Gravity                | 3.13        |
| 2   | Fineness of Cement by sieving   | 2 %         |
| 3   | Normal Consistency              | 32 %        |
| 4   | Setting Time                    |             |
| a)  | Initial Setting time            | 118 min     |
| b)  | Final setting time              | 242 min     |
| 5   | Compressive Strength            |             |
| a)  | 3 days                          | 25.3 N/mm²  |
| b)  | 7 days                          | 36.6 N/mm²  |
| c)  | 28 days                         | 52.26 N/mm² |

4.2 Fine aggregates:

**Table 2 Physical properties of Fine Aggregate**

| S.No | Property                        | Value       |
|------|--------------------------------|-------------|
| 1    | Specific Gravity                | 2.64        |
| 2    | Fineness Modulus                | 2.74        |
| 3    | Bulk Density (Loose)            | 1352 Kg/m³  |

4.3 Coarse aggregate:

**Table 3 Physical Properties of Coarse Aggregate**

| S.No | Property                        | Value       |
|------|--------------------------------|-------------|
| 1    | Specific Gravity                | 2.74        |
| 2    | Fineness Modulus                | 8.772       |
| 3    | Bulk Density (Loose)            | 1379 Kg/m³  |

4.4 Copper slag:

**Table 4 Physical Properties of Copper slag**

| PHYSICAL PROPERTIES                        | COPPER SLAG  |
|---------------------------------------------|--------------|
| PARTICLE SHAPE                               | IRREGULAR    |
| APPEARANCE                                  | BLACK AND GLASSY |
| TYPE                                        | AIR COOLED   |
| SPECIFIC GRAVITY                            | 3.91         |
| PERCENTAGE OF VOIDS %                       | 43           |
| BULK DENSITY G/CC                           | 2.08         |
| FINENESS MODULUS OF COPPER SLAG             | 3.47         |
| WATER ABSORPTION %                          | 0.15 TO 0.20 |
| MOISTURE CONTENT                            | 0.1          |
V. ANALYSIS OF RESULTS

5.1 SAND REPLACEMENT RESULTS OF M25 & M30

5.1.1 Split Tensile Strength Results And Graphs

Table 5 Split tensile strength of M25 grade concrete with different replacement percentages of Copper slag

| % of sand replacement | 28 days | 56 days |
|-----------------------|---------|---------|
| 0                     | 3.468   | 3.845   |
| 10                    | 3.727   | 4.034   |
| 20                    | 3.9524  | 4.317   |
| 30                    | 4.341   | 4.784   |
| 40                    | 4.577   | 5.237   |
| 50                    | 3.798   | 4.176   |

Figure 1 Split tensile strength of concrete by replacing sand with copper slag in M25Mix

Table 6 Split tensile strength of M30 grade concrete with different replacement percentages of Copper slag (IS 516-1959)

| % of Sand replacement | 28 days | 56 days |
|-----------------------|---------|---------|
| 0                     | 3.727   | 4.199   |
| 10                    | 3.927   | 4.482   |
| 20                    | 4.254   | 4.695   |
| 30                    | 4.521   | 5.001   |
| 40                    | 4.785   | 5.402   |
| 50                    | 4.025   | 4.45    |
Figure 2 Split tensile strength of concrete by replacing sand with copper slag in M25Mix

5.1.2 Compressive Strength Results and Graphs:

Table 7 Compressive strength of M25 grade concrete with different replacement percentages of Copper slag

| % of sand replacement | 28 days | 56 days |
|-----------------------|---------|---------|
| 0                     | 34.37   | 44.296  |
| 10                    | 36.667  | 46.519  |
| 20                    | 38.667  | 48.296  |
| 30                    | 40.44   | 50.593  |
| 40                    | 41.667  | 52.519  |
| 50                    | 37.778  | 46.693  |

Figure 3 Compressive strength of concrete by replacing sand with copper slag in M25 Mix

Table 8 Compressive strength of M30 grade concrete with different replacement percentages of Copper slag

| % of Sand replacement | 28 days | 56 days |
|-----------------------|---------|---------|
| 0                     | 39.704  | 48.889  |
| 10                    | 41.778  | 50.889  |
| 20                    | 43.704  | 52      |
| 30                    | 46.741  | 53.481  |
| 40                    | 48.07   | 55.63   |
| 50                    | 42.963  | 51.185  |
5.2 CEMENT REPLACEMENT RESULTS OF M25 & M30

5.2.1 Split Tensile Strength Results And Graphs

Table 9 Split tensile strength of M25 grade concrete with different replacement percentages of Copper slag

| % of cement replacement | 28 days | 56 days |
|-------------------------|---------|---------|
| 0                       | 3.468   | 3.845   |
| 5                       | 3.774   | 4.128   |
| 10                      | 3.987   | 4.506   |
| 15                      | 4.246   | 4.789   |
| 20                      | 3.185   | 3.633   |

Figure 4 Compressive strength of concrete by replacing sand with copper slag in M30 Mix

Figure 5 Split tensile strength of concrete by replacing sand with copper slag in M25 Mix
Table 10 Split tensile strength of M30 grade concrete with different replacement percentages of Copper slag

| % of cement replacement | 28 days | 56 days |
|-------------------------|---------|---------|
| 0                       | 3.727   | 4.199   |
| 5                       | 4.034   | 4.577   |
| 10                      | 4.388   | 4.883   |
| 15                      | 4.742   | 5.237   |
| 20                      | 3.515   | 4.081   |

Figure 6 Split tensile strength of concrete by replacing sand with copper slag in M30 Mix

b) Compressive Strength Results and Graphs:

Table 11 Compressive strength of M25 grade concrete with different replacement percentages of Copper slag

| % of cement replacement | 28 days | 56 days |
|-------------------------|---------|---------|
| 0                       | 34.37   | 44.44   |
| 5                       | 36.519  | 47.852  |
| 10                      | 38.815  | 50.222  |
| 15                      | 40.667  | 52.444  |
| 20                      | 33.037  | 42.667  |
Table 12 Compressive strength of M30 grade concrete with different replacement percentages of Copper slag (IS 516-1959)

| % of cement replacement | 28 days | 56 days |
|-------------------------|---------|---------|
| 0                       | 39.704  | 48.889  |
| 5                       | 41.481  | 50.667  |
| 10                      | 43.259  | 51.481  |
| 15                      | 44.37   | 54.074  |
| 20                      | 37.852  | 46.815  |

Figure 7 Compressive strength of concrete by replacing sand with copper slag in M25 Mix

V. CONCLUSIONS

1. Sand replacement:
   
a) The compressive strength of concrete cubes is increases by 21% with fine aggregate replacement of 40% with copper slag for both M25 & M30 when compared with controlled concrete.

b) The Split tensile strength of concrete cylinders is increases by 13% with fine aggregate replacement of 40% with copper slag for both M25 & M30 when compared with controlled concrete.
2. Cement replacement:
   a) The compressive strength of concrete cubes is increased by 18% with cement replacement of
      15% by copper slag for both M25 & M30 when compared with controlled concrete.
   b) The Split tensile strength of concrete cylinders is increased by 8% with cement replacement of
      15% by copper slag for both M25 & M30 when compared with controlled concrete.

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