Performance of Binary Steel Fibre Concrete Consisting of Copper Slag as Partial Replacement to Fine aggregate

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Abstract. Concrete is the combination of H₂O, cement, fine aggregate and coarse aggregate. Concrete consumption is extremely high and its demand is increasing rapidly. OPC production leads to emission of harm full gas. 1 Ton of OPC production leads about 1 Ton of CO₂ emission. In the present situation there is deficiency in natural river sand due to ban of dredging of river sand in most of the states. To overcome these problems it is essential to search for substitute materials. GGBS, Metakaolin, Copper slag,Silica fume, Steel slag etc are few Industrial by-products are identified as alternative materials. Here M40 concrete grade mix is used, in which 30% and 50% of GGBS is partially replaced with OPC and copper slag of 40% and 60% is utilized as fine aggregate. Concrete is brittle material, to make concrete as ductile material, steel fibres are used. The hardened concrete properties and fresh concrete properties such as compressive split tensile and flexure strength determined respectively as well as it is compared through regular concrete. As per the experimental investigation results 50% of GGBS is used as partial substitute to OPC, copper slag about 60% is used to partial substitute to fine aggregate along with steel fibre of 1% is recommended.

Key words: Mechanical Properties Ordinary Portland Cement (OPC), Fresh concrete properties, Ground Granulated Blast Furnace Slag (GGBS) and Copper Slag.

1. Introduction

Due to its high strength and stability, concrete is most popular construction material. Protecting the environment has become a serious problem in our society under the present conditions. During the manufacturing of 1 ton of OPC leads to emission of 1 ton of CO₂ in to the atmosphere. To reduce the CO₂ emission in the atmosphere, industrial by-products were used in construction industry as an alternative to conventional materials[1].

Due to its inherent cementitious properties, GGBS as a partial substitute for OPC is utilized. GGBS is Industrial by-product derived from the production of pig iron.

At present, there is a restriction in dredging of river sand which leads to deficiency to get the river sand. By dredging the river sand the environmental imbalance such as infiltration, soil erosion problem will occur. To conquer the above problem alternative materials are utilized. Slag, an industrial by-product, is obtained from the manufacturing process when copper is produced. In this study, the author considered GGBS as partial substitute to OPC and copper slag as partial substitute to aggregate (fine) along with 1% of steel fibre. Environmental pollution can be reduced by using Copper Slag as partial substitute to aggregate (fine) without compromising the properties of aggregate (fine)[2]. 40% slag is more economical[3], 40% GGBS gives durability, life span of structure and optimum strength[4], 10% GGBS and 30% Copper Slag gives the optimum value while testing mechanical properties[5], Compressive strength is increased by 20% substitute of OPC when compared with conventional mortar[6]. To revise the standard grade properties like fresh and hardened with steel fibre concrete in which GGBS is partially substituted for OPC. The objectives of present study is to cram fresh properties and hardened properties of standard concrete grade of steel fibre in which fine aggregate is
partially substituted by Copper Slag. To decide the optimum percentage of Industrial by-products can be utilized. To decide the optimum utilization percentage of industrial by-products as partial substitute for OPC and aggregate (fine). To save the natural resources and reduction in Co₂ emission.

2. Methodology and Materials

2.1 Materials

Manufactured sand, cement and coarse aggregate, water, GGBS, Copper Slag and chemical admixture are utilized in the present study. All these materials are locally available. The properties of the material are determined as per BIS.

2.1.1 Cement

According to IS: 269-2015, in the present research 53 grade of cement is used. The physical properties, OPC 53 grade is depicted in Table 1. The representative sample of cement is publicized in Figure 1.

| Test Performed       | Result | IS Codes       |
|----------------------|--------|----------------|
| Consistency (%)      | 32     | IS: 5513-1976  |
| Setting time initial (min) | 45 | IS: 4031 Part 5-1988 |
| Setting time final (min) | 250  | IS: 4031 Part 5-1988 |
| Fineness (%)         | 1      | IS: 4031 Part 1-1996 |
| Specific Gravity     | 3.13   | IS: 2720 Part 3 |

2.1.2 GGBS

In this investigation GGBS is brought from the JSW Cement Pvt Ltd confirming to IS: 16714-2018. The physical property of GGBS is provided by JSW Cement Pvt Ltd is furnished in Table 2. The representative sample of steel GGBS is shown in Figure 1.

| Properties          | Physical Component |
|---------------------|--------------------|
| Water Absorption    | 0.75               |
| Colour              | White              |
| Specific Gravity    | 2.77               |
| Fineness            | 3%                 |

2.1.3 Fine aggregate

a) Manufactured sand

The manufactured/robo sand confirming to IS 383-2016 is utilized in the present study. Robo sand physical properties are depicted in Table 3. The representative sample of steel fibre is shown in Figure 1.

| Test                | Result   | IS Codes       |
|---------------------|----------|----------------|
| Sieve Analysis      | Zone II  | IS383-2016     |
| Water Absorption    | 6.38%    | IS 2386 Part 3-1963 |
| Specific Gravity    | 2.35     | IS 2386 Part 3-1963 |

b) Copper Slag

Throughout the process of extraction of copper, an industrial by-product named copper slag is obtained. In this study fine aggregate is replaced with slag as substitute material. Copper slag physical
properties are provided by manufacturer (Blastine India Pvt Ltd) and its properties are furnished in Table 4. The representative sample of slag is publicized in Figure 1.

**Table 4. Copper slag physical properties**

| Properties          | Physical Component         |
|---------------------|----------------------------|
| Grain shape         | Angular, Multifaceted      |
| Colour              | Black & glassy             |
| Hardness            | 7 MOH                      |
| Bulk Density at 25°C | 3.25 x 10^3               |
| Specific Gravity at 25°C | 3.5                     |
| Conductivity at 25°C | 4%                        |
| Moisture Content    | <0.001%                    |

2.1.4 Coarse aggregate

20mm size aggregate is locally available confirming to IS 383-2016 is used. Coarse aggregate physical properties are depicted in Table 5. The representative sample of coarse aggregate is revealed in Figure 1.

**Table 5 Coarse aggregate physical properties**

| Test                  | Result | IS Codes          |
|-----------------------|--------|-------------------|
| Specific Gravity      | 2.78   | IS 2386 Part 3-1963 |
| Water Absorption (%)  | 1.6    | -                 |

2.1.5 Steel Fibre

Hooked end steel fibres confirming to ASTM A-820M 06 are used in this investigation. Manufacturer named Vaishnav Composites provided steel fibre properties which are depicted in Table 6 and the representative sample of fibre is exposed in Figure 1.

**Table 6. Properties of Steel Fibre**

| Properties             | Result                          |
|------------------------|---------------------------------|
| strength of wire (tensile) mpa | >1100                           |
| Diameter (D) mm        | 0.55                            |
| Strain at failure (%)  | <4                              |
| Camber of Fibre        | Max. 5% of L                    |
| Length (L) mm          | 30                              |
| Number of Fibres Per kg| 16924                           |
| Aspect Ratio           | 54.55                           |

2.1.6 Super Plasticizer

PCE based super plasticizer (KVRPCE-100) has been utilized in the study. Super plasticizer physical properties are depicted in Table 7. The properties of super plasticizer are obtained from Gujarat Polysol Chemicals Pvt. Ltd. The representative samples of all the materials are made known in Figure 1.

**Table 7 Physical Properties of Super Plasticizer**

| Properties             | Physical component              |
|------------------------|---------------------------------|
| Appearance             | Pale yellowish to brown         |
| pH value               | 5.5-6.5                         |
| Solubility             | Readily soluble in water        |
| Solid (%)              | 50                              |
| Specific Gravity       | 1.108                           |
| Chloride Content       | < 0.02%                         |
2.1.7 Design Mix

Design mix for M40 concrete grade is agreed for every IS10262-2019. Material required 1m³ conventional concrete (CC) are furnished in Table 8 and also the materials required for binary concrete with different replacement are depicted in Table 9.

### Table 8. Materials quantity required for CC (kg/m³)

| Material     | Quantity |
|--------------|----------|
| Cement       | 415      |
| Fine aggregate | 613    |
| Coarse aggregate | 1172  |
| Water        | 174.3    |
| Super plasticizer | 83     |

### Table 9. Materials quantity required for Binary concrete (kg/m³)

| Mix ID | Mix Designation | OPC%+GGBS%+CS%+SF % | Cement | GGBS | FA | CS | CA |
|--------|-----------------|----------------------|--------|------|----|----|----|
| M1     | 30+40+1         | 290.5                | 124.5  | 367.8| 245.2| 1172|
| M2     | 30%+40+1.5      | 290.5                | 124.5  | 367.8| 245.2| 1172|
| M3     | 30+60+1         | 290.5                | 124.5  | 367.8| 245.2| 1172|
| M4     | 30+60+1.5       | 290.5                | 124.5  | 367.8| 245.2| 1172|
| M5     | 50+40+1         | 207.5                | 207.5  | 376.8| 245.2| 1172|
| M6     | 50+40+1.5       | 207.5                | 207.5  | 376.8| 245.2| 1172|
| M7     | 50+60+1         | 207.5                | 207.5  | 376.8| 245.2| 1172|
| M8     | 50+60+1.5       | 207.5                | 207.5  | 376.8| 245.2| 1172|

3. Results and Discussion

#### 3.1 Workability

According to IS 1199-1959 slump cone test is carried out. The targeted slump is of 100mm. The workability grades are furnished in Table 10. Workability is decreased when the slag percentage is increased. By adjusting the dosage of chemical admixture targeted slump is achieved.

### Table 10. Workability test results

| Mix Designation | Super Plasticizer Dosage (ml) |
|-----------------|------------------------------|
|                 | Actual | Adjusted |
| M1              | 238.7  | 328.7    |
| M2              | 238.7  | 335.5    |
| M3              | 217.6  | 307.6    |
| M4              | 217.6  | 315.0    |
| M5              | 155.4  | 245.4    |
3.2 Test on hardened concrete
The concrete hardened properties, for example compressive, flexure and split tensile strength were performed.

3.2.1 Compressive strength
As per IS 14858-2000, cube specimens are tested at 3 days, 7 days and 28 days of curing for compressive strength. The compressive strength of binary concrete is depicted in Table 11. The optimum packing effect of concrete is observed in Mix 7 when compared with erstwhile mixes. The graphical image of the optimum mix is exposed in Figure 2.

| Mix Designation | GGBS (%) | Copper Slag (%) | Steel Fibres (%) | Compressive (Mpa.) |
|-----------------|----------|-----------------|-----------------|-------------------|
| CC              | 0        | 0               | 0               | 16.4              |
| M 1             | 30       | 40              | 1.0             | 29.8              |
| M 2             | 30       | 40              | 1.5             | 25.9              |
| M 3             | 30       | 60              | 1.0             | 31.0              |
| M 4             | 30       | 60              | 1.5             | 18.3              |
| M 5             | 50       | 40              | 1.0             | 27.2              |
| M 6             | 50       | 40              | 1.5             | 26.9              |
| M 7             | 50       | 60              | 1.0             | 45.1              |
| M 8             | 50       | 60              | 1.5             | 40.3              |

Figure 2. Concrete compressive strength for 3 days, 7 days and 28 days
From the given Figure 2, 3 days compressive strength result is increased by 36.3%, 7 days compressive strength result is increased by 56.66% and 28 days compressive strength result is increased by 65.42% when compared with conventional concrete respectively.
3.2.2 Split tensile

According to IS 516-2016 cylinder specimens are tested for 3 days, 7 days and 28 days. Binary concrete split tensile strength is depicted in Table 12. Optimum pore refinement of concrete is observed in Mix 7 when compared with former mixes. The graphical representation of the optimum mix up is shown in Figure 3.

Table 12. CC and Blended concrete Split tensile results

| Mix Designation | GGBS % | Copper Slag % | Steel Fibres | 3     | 7     | 28    |
|-----------------|--------|---------------|--------------|-------|-------|-------|
| CC              | 0      | 0             | 0            | 1.34  | 3.30  | 4.40  |
| M 1             | 30     | 40            | 1            | 2.73  | 4.55  | 6.57  |
| M 2             | 30     | 40            | 1.5          | 2.21  | 3.27  | 5.35  |
| M 3             | 30     | 60            | 1            | 2.61  | 3.52  | 4.56  |
| M 4             | 30     | 60            | 1.5          | 1.86  | 2.88  | 3.82  |
| M 5             | 50     | 40            | 1            | 3.00  | 3.25  | 4.63  |
| M 6             | 50     | 40            | 1.5          | 2.72  | 3.0   | 4.09  |
| M 7             | 50     | 60            | 1            | 3.85  | 5.24  | 6.98  |
| M 8             | 50     | 60            | 1.5          | 3.52  | 3.96  | 4.96  |

Figure 3. Concrete split tensile for 3, 7 and 28

3.2.3 Flexure strength

As per IS 516-2016, prism moulds are tested for 3 days, 7 days and 28 days. The flexure strength of binary concrete is furnished in Table 13. Optimum packing effect of concrete is observed in Mix 7 when compared by other mixes. The graphical representation of optimum mix is shown in Figure 4.
Table 13. Flexure strength results of CC and Binary concrete

| Mix Designation | GGBS (%) | Copper Slag (%) | Steel Fibres (%) | Flexure (Mpa.) |
|-----------------|----------|----------------|------------------|---------------|
| CC              | 0        | 0              | 0.0              | 4.1           |
| M 1             | 30       | 40             | 1.0              | 4.0           |
| M 2             | 30       | 40             | 1.5              | 3.6           |
| M 3             | 30       | 60             | 1.0              | 3.9           |
| M 4             | 30       | 60             | 1.5              | 3.0           |
| M 5             | 50       | 40             | 1.0              | 3.8           |
| M 6             | 50       | 40             | 1.5              | 3.6           |
| M 7             | 50       | 60             | 1.0              | 4.9           |
| M 8             | 50       | 60             | 1.5              | 4.5           |

Figure 4. Concrete flexure strength for 3, 7 and 28 days

4. Conclusion

1. Based on above tests results, the strength compressive of Mix 7 is 72.15 Mpa. This is highest of all mixes.
2. From the above test results, the split tensile of Mix 7 is 6.98 Mpa. This is highest of entire mixes.
3. From the above test results, the flexure of Mix 7 is 6.01 Mpa. This is highest of the entire mixes.
4. As the slag percentage increases the workability decreases. The targeted 100mm slump is gained by adjusting quantity of super plasticizer.
5. From the above experimental results, it is recommended that OPC is partially replaced with 50% of GGBS, fine aggregate is partially substitute with 60% of slag along with 1% steel fibre in concrete.

6. By using the GGBS and copper slag, reduction in CO₂ emission and conserving natural resources is established.

7. This study is applicable in general construction, runways, bridges etc.

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