Performance of high strength concrete consisting of alccofine and metakaolin as a partial replacement of cement and copper slag as fine aggregate

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Abstract. Concrete is used as building material from ancient times. The combination of Ordinary Portland Cement (OPC) with aggregates and water is called concrete. Due to rapid urbanization in India, a large quantity of OPC and fine aggregate are consumed in the construction industry, while manufacturing OPC large quantity of carbon dioxide is generated and exposed into the atmosphere. Continuous dredging of sand lead to improper infiltration of soil and soil erosion. To reduce the emission of carbon dioxide from the OPC manufacturing industry and to minimize the fine aggregate usage there is a requirement for a new eco-friendly substitute material. In developing countries, there is a necessity for sophisticated buildings and High Strength Concrete (HSC). In this study, the HSC of grade M65 with a slump of 100mm and w/c of 0.28 is considered. The fine aggregate of the concrete is replaced by 40\%, 60\% and 80\% with Copper Slag. OPC is partially substituted by Metakaolin with a constant 15\% and Alccofine with 5\% and 10\% respectively. The HSC is evaluated for Workability and Mechanical properties like slump, Compression, Flexure and Split Tensile Strength for both conventional and trial mix concrete. The test results of trial mixes are compared with conventional concrete and conclusions were drawn. As per the experimental results, it is concluded that OPC replaced with 15\% of Metakaolin, 10\% of Alccofine and fine aggregate replaced with 60\% of Copper Slag shows optimum results.

Keywords: High Strength Concrete, Alccofine, Metakaolin, Copper Slag, Workability, Mechanical Properties.

1. Introduction
Concrete is used as building material in the construction field. The components of concrete are aggregates, cement, and water. Cement and fine aggregate are the most used building materials. During the process of OPC manufacturing, a large number of raw materials like Lime and Clay are used, which are non-renewable natural resources and OPC Manufacturing factories release a massive volume of carbon dioxide at the stage of clinker formation, which is exposed to the atmosphere and...
causes global warming. Concrete also consumes a massive amount of fine aggregate which causes a reduction in non-renewable resources and ecological imbalance. Due to over dredging of sand problems like soil erosion, improper infiltration of soil and threats to aquatic life can occur. The products such as coarse aggregate, fine aggregate are non-renewable natural resources. The exhaustion of natural resources causes environmental hazards. For sustainable development, there is a requirement for the usage of eco-friendly materials for manufacturing concrete [1]. To eliminate the adverse effects on the environment, cement substitute materials like Metakaolin, Rice husk ash, GGBS, Silica fume and bentonite powder can be used [2]. Globally concrete industry uses 8-10 billion tons of fine aggregate per year [3]. Industrial by-product like Copper Slag can be used as a partial replacement for fine aggregate [4]. Replacement of cement with Alcofine shows increment in compression strength [5]. HSC consisting of Alcofine shows better Compression, Flexure and Split Tensile Strength than the normal concrete in which cement is partially substituted by silica fume [6]. Optimum strength of concrete is observed at 50% partial substitution of fine aggregate with Copper Slag [7]. After 28 days of curing, 10% replacement of Alcofine shows better compressive strength [8]. The concrete with dolomite replacement shows higher split tensile, compressive, flexure and bond strength than the recycled aggregate [9]. The properties of SCC consisting of Alcofine and glass fiber shows optimum results than concrete with only glass fiber concrete [10]. The strength of SCC increasing with an increase the Alcofine and decided that Alcofine is suitable as a partial replacement of cement in SCC [11]. In HSC as the percentage of Alcofine and foundry slag increased, also an increment in concrete compressive strength [12]. Alcofine shows early strength gaining and high compressive strength in all ages compared to conventional concrete [13]. In the present study, HSC of grade M65 is considered. Cubes, beam and cylinder specimens were casted for both conventional and trial mix concrete. In the trial mix concrete OPC is partly replaced with Alcofine and Metakaolin and fine aggregate is partially substituted by Copper Slag at various percentages as shown in Table 1. Fresh and Hardened Concrete properties like slump, Compression, Split Tensile and Flexural Strength tests of both Conventional and Trial mix concrete are compared and results are evaluated. The objective is to study the Fresh and Hardened Concrete properties of HSC in which Ordinary Portland Cement (OPC) is partially substituted by Alcofine and Metakaolin, to determine properties of HSC in fresh and hardened state which fine aggregate is partially substituted by Copper Slag, to determine the optimum replacement percentages of Alcofine, Metakaolin and Copper Slag in HSC and also to establish the percentage utilization of industrial by-products to reduce the Carbon dioxide (CO₂) emission and to conserve natural resources.

2. Materials and Methodology

2.1 Ordinary Portland Cement (OPC):

In the current study, OPC of 53 grade is used conforming IS:269-2015. The properties of OPC are depicted in Table 1.

| Tests                | Results | IS CODE               |
|----------------------|---------|-----------------------|
| Initial setting time | 46 mins | IS:4031-part 2-1998  |
| Final setting time   | 250 mins| IS:4031-part 5-1998   |
| Consistency          | 32%     | IS:5513-1976          |
| Fineness             | 1%      | IS:4031-part 1-1996   |
| Specific gravity     | 3.13    | IS:2702-part 3        |
2.2 Alccofine1203 (AF):

Alccofine is a microfine material with a very fine particle size distribution. The particle size distribution of Alccofine is very fine compared to any other microfine material. There are two types of Alccofine materials available they are Alccofine1203 which is used in High Strength and HPC and Alccofine 1101 is used for injection grouting and soil stabilization. In the present study, Alccofine 1203 is used as partial OPC replacement material. Alccofine1203 is provided by Counto Microfine Products Pvt.Ltd. Both chemical and physical properties of Alccofine1203 is given by the manufacturer are provided in Table 2 and Table 3.

| Chemical composition | Mass by(%) | Requirement as per IS:16715-2018 |
|----------------------|------------|----------------------------------|
| MnO                  | 1.24       | 5.5 Max                          |
| MgO                  | 6.3        | 17 Max                           |
| SO₃                  | 0.1        | 3 Max                            |
| Chloride content     | 0.020      | 0.1 Max                          |
| Glass content        | >85        | 85 Min                           |

Table 3. Physical properties of Alccofine1203 (Provided by Counto Microfine Products Ltd).

| Specific gravity | Bulk density(kg/m³) | Particle size distribution |
|-----------------|---------------------|---------------------------|
| 2.9             | 600-700             | D₁₀ D₅₀ D₉₀ D₉₅           |

2.3 Metakaolin (MK):

Metakaolin is the most effective pozzolanic material used in concrete, it is the by-product formed in the process of extraction of china clay. Metakaolin is obtained during the calcination of kaolinite between 600°C to 750°C in a kiln. In the current study, Metakaolin is utilized as a partial substitute material for OPC. The properties of Metakaolin are listed in Table 4.

| Properties | Results |
|------------|---------|
| Specific gravity | 2.6     |
| Ph         | 5-7     |
| Bulk density | 850 kg/m³ |

2.4 Ground Granulated Blast Furnace slag (GGBS):

GGBS is a partial substitute material for OPC obtained from a blast furnace as a by-product of steel and iron making. In this study, GGBS is used as a partial substitute for OPC as per IS: 16714-2018. GGBS is utilized in the study is purchased from JSW Cement Ltd. The properties of GGBS are depicted in Table 5.

| Properties | Results |
|------------|---------|
| Colour     | White   |
| Fineness in percentage | 3     |
| Water absorption in percentage | 0.75  |
| Specific gravity | 2.77   |
2.5 Fine Aggregate (FA):
In the present study, locally available manufactured sand is used as fine aggregate according to IS:383-2016. Various tests have been conducted on manufactured sand and the test results are presented in Table 6.

| Tests               | Results |
|---------------------|---------|
| Water absorption    | 6.4%    |
| Sieve analysis      | Zone II |
| Specific gravity    | 2.35    |

2.6 Copper Slag (CS):
CS is a by-product obtained during copper extraction process, the process through which the Copper Slag is obtained is known as smelting. In the process of smelting, copper is heated at a temperature of 500°C to 750°C to separate impurities. These impurities separate from the copper and become Copper Slag when cooled. In the current study, fine aggregate is replaced partially by Copper slag. The properties of Copper Slag are represented in Table 7.

| Properties                              | Results |
|-----------------------------------------|---------|
| Specific gravity                        | 3.5     |
| Bulk density (g/cc)                     | 2.1     |
| Hardness                               | 7 MOH   |
| Water absorption                       | 1%      |

2.7 Coarse aggregate (CA):
Coarse aggregate which is locally available of 20mm size confirming IS:383-2016 is utilized in the research. The coarse aggregate properties are mentioned in Table 8.

| Tests               | Results | IS CODE   |
|---------------------|---------|-----------|
| Water absorption    | 1.1%    | -         |
| Specific gravity    | 2.78    | IS:2386-PART 3-1963 |

2.8 Water:
For casting and curing of specimens, potable water is used. Water available at the laboratory which is free from lubricants, acids and other contamination is used as per the guidelines of IS:456-2000.

2.9 Chemical admixture (SP):
To achieve the desired slump chemical admixture is added to the concrete. In this study polycarboxylate ether-based superplasticizer is used. Table 9 shows the properties of the superplasticizer.
Table 9. Properties of superplasticizer (Provided by Fratellanza Chemicals).

| Properties                | Results    |
|---------------------------|------------|
| Specific gravity          | 1.08       |
| pH                        | 6          |
| Colour                    | Light brown|
| Chloride content          | Nill       |

Materials utilized in the current study like Alccofine, Copper Slag, Metakaolin and superplasticizer are shown underneath.

2.10 Mix design:

In the current study mix design of M65 grade is done as per the guidelines of IS:10262-2019. The design of conventional concrete mix (CC) is depicted in Table 10.

Table 10. Material quantity required for M65 grade concrete (kg/m³).

| Materials     | Quantity (kg/m³) |
|---------------|------------------|
| OPC           | 446              |
| GGBS          | 78.6             |
| Coarse aggregate | 1201             |
| Fine aggregate | 596              |
| Water         | 147              |
| Superplasticizer | 2.63             |

And a replacement mix is considered as a trial mix in which fine aggregate of the concrete is replaced by 40%, 60% and 80% with Copper Slag and Ordinary Portland Cement is partially substituted by Metakaolin with a constant of 15% and Alccofine with 5% and 10% by weight of OPC respectively. Table 11 explains the percentage of replacements in trial mix concrete.

Table 11. Trial mix and material quantities for M65 grade concrete (kg/m³).

| Mix Id | Mix Description     | OPC | MK  | AF  | FA | CS  | CA  | WATER | SP  |
|--------|---------------------|-----|-----|-----|----|-----|-----|-------|-----|
| M1     | MK15%+AF5%+CS40%    | 419 | 78.6| 26.2| 357| 238 | 1201| 147.87| 2.63|
| M2     | MK15%+AF5%+CS60%    | 419 | 78.6| 26.2| 238| 357 | 1201| 147.87| 2.63|
| M3     | MK15%+AF5%+CS80%    | 419 | 78.6| 26.2| 119| 476 | 1201| 147.87| 2.63|
| M4     | MK15%+AF10%+CS40%   | 393 | 78.6| 52.4| 357| 238 | 1201| 147.87| 2.63|
| M5     | MK15%+AF10%+CS60%   | 393 | 78.6| 52.4| 238| 357 | 1201| 147.87| 2.63|
cylinder specimen of diameter and height are 150mm and 300mm respectively and beam specimen of dimension 500mm x 100mm x 100mm were casted to perform a Compression, Split Tensile and Flexure Strength Test for both conventional and trial mix concrete. The specimens are cured in potable water before testing for 3, 7 and 28 days.

3. Tests results and Discussions:

3.1 Workability Test:
The Fresh concrete is targeted for a slump of 100mm and is measured with the help of a slump cone confirming IS:1199-1959. As the Copper Slag replacement increases the slump of concrete decreases so the workability is adjusted by adding superplasticizer dosage. The adjusted value of the superplasticizer is depicted in Table 12.

| Mix ID | Superplasticizer (ml) | Variation (%) |
|--------|------------------------|---------------|
|        | As per design mix      | Consumed      |               |
| M1     | 3581                   | 1.47          |
| M2     | 3961                   | 1.62          |
| M3     | 2435                   | 1.73          |
| M4     | 3576                   | 1.46          |
| M5     | 3952                   | 1.62          |
| M6     | 4211                   | 1.72          |

From Table 12 it is observed that due to an escalation in the percentage of Copper Slag there is a diminution in the slump of concrete, thus a 100mm targeted slump of fresh concrete has been obtained by adjusting the superplasticizer dosage.

3.2 Compressive Strength Test:
The test was conducted as per IS:516-2018. The compressive strength results are shown in Figure 5.
From Figure 5, it is observed that all the trial mixes whose compressive strength is tested after 3-days of curing show very high early age strength when compared with conventional concrete. After 7-Days of curing, mix M5 shows 22% more strength than normal concrete. After 28-Days of curing, both mix M5 and M6 show high compressive strength of 80.1Mpa and 79.2 Mpa than that of the normal concrete. But mix-M5 consisting of 15% Metakaolin and 10% Alccofine as partial replacements of OPC and 60% Copper Slag as the partial substitution of fine aggregate shows the strength of about 80.1Mpa which is 9.12% more than the normal concrete. Due to Alccofine, which is a microfine material that helps in pore refinement and gives strength to concrete and Metakaolin also increases the compression strength of concrete. Thus the compression strength of concrete is increased because of the existence of Alccofine and Metakaolin. The early strength of concrete is due to the existence of Alccofine.

3.3 Split Tensile Strength Test:

The test was performed as per IS:516-2018. The test results are depicted in Figure 6. From Figure 6, after 3-Days of curing, the specimen of mix M5 shows the optimum split tensile strength of 4.65Mpa. We can observe that trial mixes show early strength than conventional concrete.

The 7-Days strength results of conventional and trial mix concrete are very similar but mix M5 shows a slightly better strength of 5.49Mpa which is higher than conventional concrete. After 28 days of curing, the mix proportions, M5 and M6 show similar split tensile strength of 7.12Mpa and 7.07Mpa the concrete of specimen of mix-M5 consisting of 10% Alccofine and 15% Metakaolin as partial replacement of OPC and 60% of Copper Slag as fine aggregate shows optimum strength of 7.12Mpa which is 28% greater than the conventional concrete. The early strength of concrete is increased due to the existence of Alccofine. Metakaolin, Alccofine and Copper slag as partial substitutes of OPC and fine aggregate are the reason for increased split tensile strength.
3.4: Flexural Strength Test
The flexural strength test was performed as per IS: 516-2018. The test results of flexural strength are shown in Figure 7. The flexure strength of trial mix concrete after 3-Days of curing is very high compared to conventional concrete. After 28-Days of curing concrete specimen of mix-M5 containing 10% of Alccofine and 15% of Metakaolin as a partial replacement in OPC, and 60% of Copper Slag as partial fine aggregate replacement shows maximum flexural strength of 6.29Mpa which is almost 3% more than conventional concrete. The packing effect of Alccofine is the reason for higher and early flexure strength.

![Bar chart showing flexural strength test results](chart.png)

**Figure 7.** Flexural Strength test Results.

Testing facilities of Workability and strength of concrete like Compressive Strength, Split Tensile and Flexural Strength as shown beneath

![Testing facilities](testing_facilities.png)

**Figure 8.** Workability. **Figure 9.** Compression. **Figure 10.** Split Tensile. **Figure 11.** Flexure.

4. Conclusion:
The Mechanical properties and workability of conventional and trial mix concrete are compared and the following conclusions are drawn:
• For the fresh concrete, workability decreases with an increase in the percentage of Copper Slag. The target slump of 100mm is achieved by adjusting the superplasticizer dosage.
• Due to addition of alccofine, it is observed an increase in early age strength in all trial mixes when compared with conventional concrete.
• HSC with 15% Metakaolin, 10% Alccofine and 60% Copper Slag show superior results in Compression, Split Tensile and Flexural Strength as compared to conventional concrete.
• As per the experimental investigation 15% of Metakaolin, 10% of Alccofine and 60% of Copper Slag are recommended in HSC.
• By using Industrial by-products such as Metakaolin, Alccofine and Copper Slag in the concrete leads to saving natural resources and reduction in CO₂ emission.
• The present study is applicable in all general and High Strength Constructions such as Commercial Buildings, Hospitals, Shopping Complexes, Skyscrapers and Bridges.

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