Replacement of Cement and Fine Aggregate by Ceramic Powder and Copper Slag in Concrete

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Abstract

Concrete, a homogeneous mixture of cement, fine aggregate, coarse aggregate and water is widely been used in construction activities. But cement and fine aggregate are becoming consequently costlier and their demand also increases every day. Meanwhile, industrial waste from manufacturing units also increases. On behalf of utilization of industrial waste as well to minimize the construction material cost, some materials can replace the by-product of concrete. In this study we have chosen ceramic powder and copper slag as a replacement of cement and fine aggregate. More studies were carried out replacing cement but ceramic powder and replacing fine aggregate by copper slag separately. From the literature review we can to know maximum percentage of replacement of ingredients. In this study, different mix proportions were carried out by replacing different percentage of ceramic powder and copper slag. From the experimental results, it was observed that compressive strength was increased about 36%, when compared to conventional concrete.

Keywords: Ceramic Powder, Compressive Strength, Concrete, Copper Slag, Flexural Strength

1. Introduction

1.1 Concrete

Concrete is a homogenous mixture of Binder (Cement), Fine aggregate and Coarse aggregate with adequate water – cement ratio. It is one of the prime materials used for the construction. Concrete has good compressive strength and they are weak in tension, reinforcements are designed and added to improve the tensile properties of concrete.

Portland cement is most commonly used and they are the basic ingredient of concrete. Cement is manufactured through a closely controlled chemical combination of calcium, silicon, aluminium, iron and other ingredients. Portland cement gets its strength from chemical reactions between the cement and water. The process is known as hydration.

1.1.1 Fine Aggregates

Particles which pass by IS 4.75 mm sieve are considered to be fine aggregate. There are many type of fine aggregate particles used in construction. Sand is most commonly used in making concrete.

1.1.2 Sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt.

The most common constituent of sand, in inland continental settings and non-tropical coastal settings, is silica (Silicon dioxide or SiO₂), usually in the form of quartz, which, because of its chemical inertness and considerable hardness, is the most common mineral resistant to weathering.
1.1.3 Coarse Aggregate
Particles which are retained on IS 4.75 mm are classified as coarse aggregate. Aggregate are granular material, derived from the most part from the natural rocks, crushed stones or natural gravels and sands. Aggregates occupy more volume in making concrete.

1.1.4 Water
Water used in making concrete should be free from impurities and pH of the water should be 6.5–8. It is important that water is added based on the water-cement ratio as adopted in mix design or standards.

1.2 Need for Alternatives

1.2.1 Cement
Carbon concentration in cement spans from approximately 5% in cement structures to approximately 8% in the case of roads in cement. Cement manufacturing releases CO$_2$ in the atmosphere both directly when calcium carbonate is heated, producing lime and carbon dioxide and also indirectly through the use of energy if its production involves the emission of CO$_2$.

The amount of CO$_2$ emitted by the cement industry is nearly 900 kg of CO$_2$ for every 1000 kg of cement produced. The liberation of CO$_2$ causes environmental hazards and replacement of cement by an alternative can reduce the impact considerably.

1.2.2 Sand
Sand which was once available abundance in nature has become scarce now. It has become important to find a suitable alternative for sand at the same time, it should be cost effective. Manufactured sand is being used off late for the replacement of sand and also Copper slag is being used in sand as well as partial replacements.

Ceramic powder and Copper slag, both are added as alternatives with varying proportions and tests are carried out to determine their properties, which are then compared with conventional concrete.

1.3 Choice of Alternative
There are several alternatives being used and found to be effective for partial replacement of the scarce available construction materials and for cost effective construction.

We had chosen Ceramic powder for partial replacement of cement Since the availability is abundance (since they have been used in many forms), they also possess adequate properties and also they are cost effective material, which can be partially replaced with cement.

We have also opted for Copper slag as partial replacement for Fine aggregate, Copper slag can be considered as the left over particles after smelting process and which hardly have any further usage (waste material). They are cost effective and they possess good properties.

Tests results have proved that these alternatives have been good up to certain partial replacement and they have also been cost effective.

2. Ceramic Powder and its Properties
A ceramic is an inorganic, non-metallic solid comprising metal, non-metal or metalloid atoms primarily held in ionic and covalent bonds. Ceramics are generally made by taking mixtures of earthen elements, powders and water and shaping them into desired forms. Once the ceramic has been shaped, it is fired in a high temperature oven known as a kiln. Often, ceramics are covered in decorative, waterproof, paint-like substances known as glazes.

Powdered form of Ceramic raw materials is called as Ceramic Powder and there are several types of Ceramic powder that are available. Ceramic powder used in this

| Constituents | Content (%) |
|--------------|-------------|
| Al$_2$O$_3$  | 45          |
| SiO$_2$      | 52          |
| Fe$_2$O$_3$  | 0.5         |
| TiO$_2$      | <1.5        |
| CaO          | <0.5        |
| MgO          | <0.3        |
| K$_2$O       | <0.1        |
| Na$_2$O      | <0.2        |
| MnO$_2$      | <0.004      |
project, as partial replacement of cement is KAOLIN (Ceramic Powder).

- Kaolin is one of the types of ceramic powder. It is also called as Aluminium Silicate Powder.
- Kaolin is obtained from Mineral called Kaolinite, group of common clay minerals that are hydrous aluminium silicates.

2.1 Properties of Kaolin

- The chemical formula for kaolinite as used in mineral-ogy is \( \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \).
- Appearance – White in colour.
- When added to concrete, it makes the paved surface less porous, which minimizes problems with moisture and freezing.
- It also makes concrete more fire resistant and helps to slow the spread of heat and flames.

3. Copper Slag and its Properties

- Copper slag is a by-product created during the copper smelting and refining process.
- The slag serves as a fine or binding agent, which helps hold the larger gravel particles within the concrete.

![Ceramic powder](image1)

**Figure 1.** Ceramic powder.

![Copper slag](image2)

**Figure 2.** Copper slag.

| Content | Percentage (%) |
|---------|---------------|
| \( \text{Al}_2\text{O}_3 \) | 3.47 |
| TiO\(_2\) | 0.60 |
| Fe\(_2\text{O}_3\) | 58 |
| SiO\(_2\) | 34.50 |
| CaO | 0.20 |
| MgO | 0.90 |
| K\(_2\text{O}\) | 1.02 |
| Na\(_2\text{O}\) | 0.95 |
| Cu | 0.42 |

**Table 2.** Chemical composition

| Specification | Content |
|---------------|---------|
| Specific gravity | 3.848% |
| Hardness | 7 Mohr scale |
| Conductivity Ms/m | 4.8 |
| Chloride content | <0.0002 |
| Bulk density | 2.051 g/cc |

**Table 3.** Physical properties
Replacement of Cement and Fine Aggregate by Ceramic Powder and Copper Slag in Concrete

3.1 Properties

3.2 Variation of Compressive Strength for Various Proportion Mix of Ceramic Powder and Copper Slag for 7, 14, 28 Days

Table 4. Test results compressive strength of cubes (conventional concrete)

| Grade of Concrete | No. of Days | Load in (KN) | Compressive Strength (N/mm²) |
|-------------------|-------------|--------------|------------------------------|
| M25               | 7           | 375.45       | 16.68                        |
|                   | 14          | 540.28       | 24.01                        |
|                   | 28          | 630          | 28                           |

Table 5. Compressive strength of cubes (basic ceramic powder test)

| Specimen Identification | Days | Load in KN | Compressive Strength N/MM² | Average Compressive Strength N/MM² |
|-------------------------|------|------------|----------------------------|-----------------------------------|
| A                       | 7    | 633.05     | 28.13                      | 28.5                              |
|                         |      | 649.35     | 28.86                      |                                   |
| B                       | 7    | 645.95     | 28.7                       | 21.85                             |
|                         |      | 314.90     | 14.99                      |                                   |
| C                       | 7    | 420.35     | 18.68                      | 21.65                             |
|                         |      | 553.90     | 24.62                      |                                   |
| D                       | 7    | 477.70     | 21.23                      | 20.96                             |
|                         |      | 465.85     | 20.70                      |                                   |

The above experimental data shows that addition of the ceramic powder and Copper slag improves the physical and mechanical properties. These results are of greater importance because this kind of innovative concrete requires large amount of fine particles. As cement cost is going on increasing trend and fine aggregate demand is increasing day by day, the replacement of ceramic powder and copper slag for cement and fine aggregate proves to be economical and an also provides an efficient utilization of industrial waste. From the above study, it is concluded that the ceramic powder and copper slag for cement and fine aggregate may be used as a replacement material.

The replacement of cement and fine aggregate with ceramic powder and copper slag gives an excellent result in strength aspect and quality aspect. In this study, the percentage of cement and percentage of fine aggregate is replaced with ceramic powder and Copper slag with different proportions. From the result it was found to be very effective in compression strength and flexural strength when compared with nominal concrete.

The results shows for the above replacement, there is an increase in compressive strength achieved by 36% of nominal mix (M25).

From the experimental studies, it is suggested that replacement of cement and fine aggregate by ceramic powder for 20% and Copper slag for 40% is effective and can be used in the construction activities.
### Table 6. 7 day compressive strength of cube

| Specimen Identification | Average Compressive Strength (N/Mm$^2$) |
|-------------------------|----------------------------------------|
| N                       | 23.98                                  |
| A1                      | 26.44                                  |
| B1                      | 24.06                                  |
| C1                      | 24.39                                  |
| D1                      | 26.24                                  |
| E1                      | 20.74                                  |
| F1                      | 24.07                                  |
| G1                      | 31.42                                  |
| H1                      | 27.92                                  |
| I1                      | 29.6                                   |
| J1                      | 24.05                                  |
| K1                      | 24.65                                  |
| L1                      | 32.30                                  |

### Table 7. 14 day compressive strength of cube

| Specimen Identification | Average Compressive Strength (N/Mm$^2$) |
|-------------------------|----------------------------------------|
| N                       | 16.64                                  |
| A1                      | 19.77                                  |
| B1                      | 17.83                                  |
| C1                      | 17.64                                  |
| D1                      | 20.79                                  |
| E1                      | 16.13                                  |
| F1                      | 16.9                                   |
| G1                      | 26.94                                  |
| H1                      | 24.51                                  |
| I1                      | 20.335                                 |
| J1                      | 22.78                                  |
| K1                      | 19.30                                  |
| L1                      | 22.71                                  |

### Table 8. 28 day compressive strength of cube

| Specimen Identification | Average Compressive Strength (N/Mm$^2$) |
|-------------------------|----------------------------------------|
| N                       | 27.99                                  |
| A1                      | 30.6                                   |
| B1                      | 26.72                                  |
| C1                      | 28.74                                  |
| D1                      | 28.89                                  |
| E1                      | 26.28                                  |
| F1                      | 26.73                                  |
| G1                      | 33.42                                  |
| H1                      | 36.04                                  |
| I1                      | 31.19                                  |
| J1                      | 26.26                                  |
| K1                      | 24.57                                  |
| L1                      | 38.02                                  |

### Table 9. 7 day flexural strength of PRISM

| Specimen Identification | Load in KN | Flexural Strength N/Mm$^2$ |
|-------------------------|------------|----------------------------|
| N                       | 11.5       | 5.75                       |
| A                       | 10         | 5                          |
| B                       | 9.5        | 4.75                       |
| C                       | 13         | 6.5                        |
| D                       | 12         | 6                          |
| E                       | 9          | 4.5                        |
| F                       | 6.5        | 3.25                       |
| G                       | 12         | 6                          |
| H                       | 11         | 5.5                        |
| I                       | 9          | 4.5                        |
| J                       | 12         | 6                          |
| K                       | 12.5       | 6.25                       |
| L                       | 12         | 6                          |
Table 10. 28 day flexural strength of beam

| Specimen Identification | Load in KN | Flexural Strength N/Mm² |
|-------------------------|------------|-------------------------|
| N                       | 14.5       | 7.25                    |
| A                       | 16.5       | 8.25                    |
| B                       | 15         | 7.5                     |
| C                       | 15.5       | 7.75                    |
| D                       | 14         | 7                       |
| E                       | 12         | 6                       |
| F                       | 18.5       | 9.25                    |
| G                       | 16.5       | 8.25                    |
| H                       | 12.5       | 6.25                    |
| I                       | 18.5       | 9.25                    |
| J                       | 18.5       | 9.25                    |
| K                       | 16.5       | 8.25                    |
| L                       | 18.5       | 9.25                    |

Figure 4. 7th day compressive strength of different proportions.

Figure 5. 14th day compressive strength of different proportions.

Figure 6. 28th day compressive strength of different proportions.

Figure 7. Comparison of 7, 14 and 28 day compressive strength of different proportions.

Figure 8. 7th day compressive strength of different proportions.
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Figure 9. 28th day compressive strength of different proportions.

Figure 10. Variation of flexural strength for various proportion mix of ceramic powder and copper slag for 7 and 28 days.