Strength properties of ceramic waste concrete

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Abstract. Today significant research study is ongoing into the use of waste materials like, fly ash, GGBS, waste glass powder etc. as Portland cement replacements. A ceramic waste powder is used as a binder with partial replacement of cement which takes some part of reaction at the time of hydration, and also it acts as a filler material. This study is focused on the waste ceramic powder used as a replacement to the concrete ingredient i.e. cement and the strength properties like compressive, split tensile and flexural strengths were measured and the size effect of ceramic waste powder on strength of concrete. To check the strength effect of replacement of cement by ceramic waste powder, the cement ingredient in concrete is replaced at 10%, 20%, 30%, 40% and 50%. This paper focuses on the size effect of ceramic waste powder, having a size less than 90 micron and another size ranges from 90 microns to 150 microns. For this study, concrete mixtures were prepared, for low-grade M20 and medium grade M40. Strength studies like compressive, split tensile and flexural strengths were conducted and comparisons have to be made with the conventional concrete.

1. Introduction
Ceramic Industries are generating 15% -30% waste materials from the total production. Ceramic wastes are produced as a result of ceramic processing. These wastes cause soil, air, and groundwater pollution. This waste is not recycled in any form at present [1]. Ceramic waste powder coming from industries is dumping in nearby vacant spaces or pits. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal. [2-4]. The possibility of pozzolanic reactivity in ceramic products is responsible for long term strength and good durability due to Ceramic production conducts on temperature 200°C to 2000°C.[5-9].To get various properties of concrete, Ceramic waste powder can be used as a partial replacement of cement.

1.1 Objectives of the Study
• Carry out the mix design for low-grade M20 and medium grade M40 for both Conventional concrete and ceramic waste concrete.
• Study the strength characteristics of concrete-like compressive, split tensile and flexural strengths.
• Arrive the optimum percentage replacement of cement with ceramic waste.

1.2 Need for Present Study
The use of ceramic waste generated from the ceramic industry showing that, prospective application in construction as an alternative to the cement. The following problems of increasing magnitude are pressurizing the construction industries to use ceramic waste in the new concrete.

1.2.1 Sustainability in the concrete industry. Design of concrete mixtures with optimum content of cement and enhancement of concrete durability are the main issues towards sustainability in the concrete industry.
1.2.2 Shortage of Dumping Ground and Disposal Problems. In the present days, there has been an enormous increase in the quantity of ceramic waste. Therefore, disposal of such waste is posing a threat to the environment besides the shortage of dumping area.

2. Literature Review
The optimum percentage of waste ceramic tile to be used within the concrete mix with a water/cement ratio of 0.5 was about 30%. Their findings reveal that using waste ceramic tile leads to enhancing the properties of concrete [10]. The optimum percentage of replacement of OPC cement with ceramic waste achieved was 30% by weight for M20 grade concrete and decreases the compressive strength of the concrete by the further replacement [11]. The optimum percentage of replacement of OPC cement with ceramic waste achieved was 20% by weight for M30 grade concrete and decreases the compressive strength of the concrete by the further replacement [12].

3. Experimental Methods
Series of test specimens comprising, cubes, cylinders and prisms of standard dimensions were cast for concrete mixes produced with different percentage replacement (0%, 10%, 20%, 30%, 40% and 50%) of cement with ceramic waste to study the strength characteristics. The strength characteristics of concrete like compressive strength, split tensile strength and flexural strength are established experimentally.

3.1 Experimentation
In this study, cement was replaced by the ceramic waste powder of particle size less than 90 microns and 90 microns to 150 microns with replacement from 10% to 50%. For this study, low-grade M20 and medium grade M40 of concrete was adopted. Cubes, cylinders and prisms were cast to arrive at the strength parameters. The strength parameters were studied at the ages 7, 28, 56 and 90 days. Concrete mix with 0% ceramic waste powder forms the basic reference mix to compare the results of mixes with replacement from 10% to 50%.

3.2 Materials
The materials used in the present study namely cement, fine aggregate and coarse aggregate have been tested in the laboratory. The specifications and properties of these materials were presented in the following sections.

3.2.1. Cement. Ordinary Portland Cement of 53 Grade conforming to Bureau of Indian standards was used and tested for various properties as per IS 12269 1987 [13].

| Property               | Value       | IS Standards |
|------------------------|-------------|--------------|
| Normal consistency     | 34%         | 33-35%       |
| Fineness of cement     | 6.50%       | <10%         |
| I.S time               | 105 Min.    | ≥ 30 Min.    |
| F.S time               | 300 Min.    | ≤ 600 Min.   |
| Specific Gravity       | 3.1         | 3.1-3.2      |

3.3 Coarse Aggregates
20 mm size coarse aggregate were used for all mixes and tested as per IS 383 1970 [14]. The aggregate used here is brought from nearby quarries which were breached from the stone available near Godavari regions.

| Property               | Value       | IS Standards |
|------------------------|-------------|--------------|
| Bulk density gm/cc     | 1.451 (loose state) | 1.45-1.80 |
|                        | 1.576 (dry rodded)  |              |
| Specific gravity       | 2.85        | 2.6-2.9      |
| Water absorption (%)   | 0.6         | 0.5-1.0      |
| Fineness Modulus       | 7.21        | 6.5-8        |
3.4 Fine Aggregate
The river sand conforming to Zone II as per IS 383 1970 [14] was used as fine aggregate in this study.

| Property               | Results                        | IS Standards |
|------------------------|--------------------------------|--------------|
| Specific Gravity       | 2.69                           | 2.5-2.8      |
| Bulk Density gm/cc     | 1.58 (loose state)             | 1.45-1.65    |
|                        | 1.64 (dry state)               |              |
| Fineness Modulus       | 2.5                            | 2.2-2.6      |
| Zone                   | II                             | I – IV       |

3.5 Ceramic waste:
Ceramic waste is gathered from nearby SILICA CERAMICS PRIVATE LIMITED situated near Narayanapuram, West Godavari District, Andhra Pradesh, India.

| Materials      | Ceramic powder % |
|----------------|------------------|
| SiO₂           | 68.11            |
| Al₂O₃          | 16.48            |
| Fe₂O₃          | 0.59             |
| K₂O            | 3.14             |
| Na₂O           | 3.78             |
| CaO            | 0.85             |
| MgO            | 1.61             |
| TiO₂           | 0.02             |
| L.O.I          | 4.75             |

3.6 Casting and Curing
For preparing the specimens materials were weighed and mixed as per IS 516-1959 (1989) [15]. The demolded specimens after 24 hours are immersed in the potable water for curing period of 28 days at room temperature of 27°C ± 2°C.

| Type of Concrete | Concrete Mix Design Proportion |
|------------------|--------------------------------|
|                  | Water/ | Cement | Fine Aggregate | Coarse Aggregate | Ceramic Waste Powder | Water |
|                  | Cement ratio |       |               |                  |                        |       |
| L0               | 0.55    | 1      | 1.89          | 3.21             | 0                       | 0.55  |

| Type of Concrete | Concrete Mix Design Proportion |
|------------------|--------------------------------|
|                  | Water/ | Cement | Fine Aggregate | Coarse Aggregate | Ceramic Waste Powder | Water |
|                  | Cement ratio |       |               |                  |                        |       |
| M0               | 0.4     | 1      | 1.79          | 3.04             | 0                       | 0.4   |
Table 7. Design Mix Proportion for Different Concrete Mixes

| Grade of the Concrete | Type of the Concrete | Cement Replacement with Ceramic waste powder |
|-----------------------|----------------------|---------------------------------------------|
| M20                   | LA10                 | 10% -replacement                            |
|                       | LA20                 | 20% -replacement                            |
|                       | LA30                 | 30% -replacement                            |
|                       | LA40                 | 40% -replacement                            |
|                       | LA50                 | 50% -replacement                            |
| M20 (<90-micron size of ceramic waste powder) | LB10 | 10% -replacement |
|                       | LB20                 | 20% -replacement                            |
|                       | LB30                 | 30% -replacement                            |
|                       | LB40                 | 40% -replacement                            |
|                       | LB50                 | 50% -replacement                            |
| M40                   | MA10                 | 10% -replacement                            |
|                       | MA20                 | 20% -replacement                            |
|                       | MA30                 | 30% -replacement                            |
|                       | MA40                 | 40% -replacement                            |
|                       | MA50                 | 50% -replacement                            |
| M40 (<90-micron size of ceramic waste powder) | MB10 | 10% -replacement |
|                       | MB20                 | 20% -replacement                            |
|                       | MB30                 | 30% -replacement                            |
|                       | MB40                 | 40% -replacement                            |
|                       | MB50                 | 50% -replacement                            |

4. Results and Analysis

4.1 General

To examine the effect of replacement of cement with ceramic waste, five different concrete mixtures using different percentages of ceramic waste (10%, 20%, 30%, 40% and 50%) with the same compressive strength were produced. All the concrete mixtures with different percentage of replacement were compared with the reference concrete mix produced with conventional concrete i.e. 0% replacement. Compressive, split tensile and Flexural strengths tests were performed on the concrete specimens to obtain the strength characteristics of concrete made with ceramic waste and conventional concrete.

4.2 Strength Characteristics

4.2.1 Compressive Strength. The compressive strength test was conducted on test specimens at the ages of 7, 28, 56, 90 days after proper curing till the day of the test. The compressive strength values obtained from the test for Conventional Concrete, Concrete with different percentage (10, 20, 30, 40 and 50) of ceramic waste were presented in table 8. The results were plotted below in figure 1.

![Figure 1. Compressive Strength (MPa): M20 grade for < 90µ and 90-150µ for 7 to 90 days](image-url)
### Table 8. Compressive Strength (M Pa) Results of Cubes of M20 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0%                  | 15.24       | 26.33       | 29.1        | 31.33       | 15.24       | 26.33       | 29.1        | 31.33       |
| 10%                 | 14.02       | 25.52       | 26.67       | 28.89       | 13.2        | 24.55       | 26.02       | 28.06       |
| 20%                 | 13.23       | 23.24       | 25.21       | 26.55       | 12.65       | 21.33       | 24.22       | 25.55       |
| 30%                 | 12.05       | 21.55       | 22.44       | 24.45       | 11.52       | 20.05       | 21.15       | 23.33       |
| 40%                 | 10.16       | 17.72       | 19.54       | 20.56       | 10.01       | 16.41       | 18.44       | 19.04       |
| 50%                 | 8.65        | 13.15       | 14.23       | 15.55       | 7.55        | 12.55       | 13.55       | 15.11       |

### Table 9. Compressive Strength (M Pa) Results of Cubes of M40 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 0%                  | 30.36       | 50.55       | 53.25       | 55.24       | 30.36       | 50.55       | 53.25       | 55.24       |
| 10%                 | 31.24       | 48.52       | 50.52       | 52.11       | 29.54       | 47.55       | 49.54       | 51.24       |
| 20%                 | 26.67       | 43.24       | 46.87       | 49.15       | 24.02       | 43.04       | 45.87       | 48.24       |
| 30%                 | 23.33       | 39.55       | 43.22       | 45.14       | 23.12       | 38.64       | 41.14       | 42.88       |
| 40%                 | 21.11       | 35.06       | 38.65       | 39.54       | 19.55       | 33.54       | 35.24       | 36.22       |
| 50%                 | 16.45       | 29.44       | 31.98       | 30.88       | 13.23       | 27.65       | 29.14       | 30.14       |

**Figure 2.** Compressive Strength (MPa): M40 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

4.2.2 **Split Tensile Strength.** This test was conducted on test specimens at the ages of 7, 28, 56, 90 days after proper curing till the day of the test. The tensile strength values obtained from the test for Conventional Concrete, Concrete with different percentage (10, 20, 30, 40 and 50) of ceramic waste were presented in table 10. The results were plotted below.
Table 10. Splitting Tensile Strength (MPa): M20 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|--------------|---------------|---------------|---------------|----------------|----------------|----------------|----------------|
| 0%                  | 3.66         | 4.45          | 4.51          | 4.66          | 3.66           | 4.45           | 4.51           | 4.66           |
| 10%                 | 2.54         | 3.46          | 3.57          | 3.82          | 2.75           | 3.6            | 3.67           | 3.84           |
| 20%                 | 2.6          | 3.67          | 3.74          | 3.86          | 2.19           | 3.72           | 3.84           | 3.91           |
| 30%                 | 2.73         | 3.81          | 3.88          | 3.96          | 2.19           | 3.25           | 3.44           | 3.64           |
| 40%                 | 2.05         | 3.53          | 3.6           | 3.67          | 2.05           | 3.1            | 3.26           | 3.34           |
| 50%                 | 1.41         | 2.82          | 3.04          | 3.32          | 1.82           | 3.04           | 3.1            | 3.25           |

Figure 3. Split Tensile Strength (MPa): M20 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

Table 11. Split tensile Strength (MPa): M40 grade for < 90µ and 90-150µ for 7, 28, 56 and 90 days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|--------------|---------------|---------------|---------------|----------------|----------------|----------------|----------------|
| 0%                  | 3.53         | 4.24          | 4.3           | 4.81          | 3.53           | 4.24           | 4.3            | 4.81           |
| 10%                 | 3.18         | 4.03          | 4.38          | 4.81          | 3.46           | 4.03           | 4.03           | 4.52           |
| 20%                 | 3.32         | 4.17          | 4.52          | 4.69          | 3.32           | 4.38           | 4.38           | 4.43           |
| 30%                 | 2.61         | 3.81          | 4.38          | 4.38          | 3.11           | 3.88           | 3.99           | 4.39           |
| 40%                 | 2.61         | 3.53          | 4.38          | 4.24          | 3.11           | 3.03           | 3.31           | 4.17           |
| 50%                 | 1.76         | 2.75          | 3.53          | 3.67          | 3.47           | 2.88           | 3.17           | 4.02           |
4.2.3 Flexural Strength. This test was conducted on test specimens at the ages of 7, 28, 56, 90 days after proper curing till the day of the test. The Flexural strength values obtained from the test for Conventional Concrete, Concrete with different percentage (10, 20, 30, 40 and 50) of ceramic waste were presented in table 12. The results were plotted below.

Table 12. Flexural strength (MPa): M20 grade for < 90µ and 90-150µ for 7, 28, 56 and 90days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|--------------|---------------|---------------|---------------|----------------|----------------|----------------|----------------|
| 0%                  | 3.67         | 4.46          | 4.89          | 5.09          | 3.67           | 4.46           | 4.89           | 5.09           |
| 10%                 | 3.18         | 4.2           | 4.54          | 5.08          | 3.04           | 4.93           | 4.97           | 4.29           |
| 20%                 | 3.23         | 4.23          | 4.59          | 4.72          | 3.06           | 4.85           | 5.25           | 5.19           |
| 30%                 | 3.49         | 4.36          | 4.66          | 4.77          | 2.52           | 3.11           | 3.48           | 3.65           |
| 40%                 | 2.7          | 4.04          | 4.22          | 4.55          | 2.42           | 3.02           | 3.06           | 3.12           |
| 50%                 | 1.94         | 3.69          | 3.81          | 3.85          | 2.41           | 2.93           | 2.96           | 2.98           |

Figure 5. Flexural strength (MPa): M20 grade for < 90µ and 90-150µ for 7, 28, 56 and 90days
Table 13. Flexural Strength (MPa): M40 grade for < 90µ and 90-150µ for 7, 28, 56 and 90days

| % of Ceramic Powder | 7 days < 90µ | 28 days < 90µ | 56 days < 90µ | 90 days < 90µ | 7 days 90-150µ | 28 days 90-150µ | 56 days 90-150µ | 90 days 90-150µ |
|---------------------|-------------|---------------|---------------|---------------|---------------|----------------|----------------|----------------|
| 0%                  | 4.5         | 5.36          | 5.86          | 5.92          | 4.5           | 5.36           | 5.86           | 5.92           |
| 10%                 | 3.13        | 4.63          | 5.07          | 5.97          | 4.07          | 4.13           | 4.24           | 4.92           |
| 20%                 | 3.16        | 4.15          | 4.58          | 5.52          | 4.01          | 4.09           | 4.13           | 4.39           |
| 30%                 | 3.65        | 4.18          | 4.38          | 5.02          | 3.25          | 3.76           | 3.77           | 3.82           |
| 40%                 | 2.75        | 4.18          | 4.33          | 5.01          | 2.69          | 3.42           | 3.58           | 4.09           |
| 50%                 | 2.2         | 3.39          | 3.65          | 4.64          | 3.14          | 3.38           | 3.46           | 3.52           |

Figure 6. Flexural Strength (MPa): M40 grade for < 90µ and 90-150µ for 7, 28, 56 and 90days

5. Conclusions

By the experimental study, the following observations are made:

1. In M20 grade concrete, Compressive strength decreases when the replacements of cement with ceramic waste powder (of size < 90 microns and 90-150 microns) up to 30% by weight of cement and decrease the strength by the further replacement. Compressive strength loss obtained is 18.15% from L0 to LA 30 and 23.85% from L0 to LB 30.

2. In M20 grade concrete, split tensile strength decreases when the replacement of cement with ceramic powder of size < 90 microns up to 30% and ceramic powder of size for 90-150 microns up to 20% by weight of cement and decreases the strength by the further replacement.

3. In M20 grade concrete, Flexural strength decreases when the replacement of cement with ceramic powder of size < 90 microns up to 30% and ceramic powder of size for 90-150 microns up to 20% by weight of cement and decreases the strength by the further replacement.

4. In M40 grade concrete, Compressive strength decreases when the replacements of cement with ceramic powder (of size < 90 microns and 90-150 microns) up to 20% by weight of cement and decrease the strength by the further replacement. Compressive strength loss obtained is 14.46% from M0 to MA 20 and 14.85% from M0 to MB 20.

5. In M40 grade concrete, split tensile strength decreases when the replacement of cement with ceramic powder (of size < 90 microns and 90-150 microns) up to 20% by weight of cement and decreases the strength by the further replacement.

6. In M40 grade concrete, flexural strength decreases when the replacement of cement with ceramic powder (of size < 90 microns and 90-150 microns) up to 10% by weight of cement and decreases the strength by the further replacement.

With the increase of grades, the percentage of replacement of ceramic waste is decreased. The observations made during the present investigation are in agreement with the results reported by earlier
investigators. The experimental study has helped to investigate the various properties of Ceramic waste concrete as a partial replacement of cement with ceramic waste in the production of structural concrete. Because of the other advantages such as conservation of natural resources, free the ceramic waste material from landfills and elimination of disposal problems, the ceramic waste Concrete can be considered as a potential and suitable alternative material with a bright future.

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