“Eco-Efficient” Concrete incorporating Ceramic Waste powder and Red brick dust as an effective replacement for Ordinary Portland Cement and Fine aggregate

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Abstract: Concrete is one of the most frequently used building material. Its usage worldwide is twice that of steel, wood, plastics and aluminum. Concrete is the mixture of cement, fine aggregate, coarse aggregate and water. The cement releases carbon-di-oxide which contributes 8% of annually released carbon content around the globe. The cement and fine aggregate in concrete can be partially or fully replaced by other cementitious materials. Ceramic waste powder is dumped away which brings about lot of ecological contamination and threatening both farming and general wellbeing. The cement is replaced with ceramic waste powder and red brick dust in replacement for fine aggregate in 5%, 10% and 15% by its weight. The mechanical and durability test were studied for the design mix of M20 grade concrete. The mechanical tests include compressive strength, split tensile strength and flexural strength for which the optimum percentage of replacement of ceramic waste powder and red brick dust is found. In a similar way, durability test includes acid test and corrosion test were taken for 5%, 10% and 15% replacements. The mechanical and durability test results were compared with conventional (without replacement) concrete. These tests were completed to access the mechanical properties for 7 days, 14 days and 28 days. Results showed that, mechanical properties of concrete increases for 10% effective replacement of ceramic waste powder and red brick dust. Corrosion study shows that less probability of corrosion for 10% effective replacement. Negligible loss of weight is experimented form the acid study. Thus in clear, the test results shows that, effective replacement of ceramic waste powder and red brick dust by 10% replacement to cement and 10% to fine aggregate shows contemporary results with various extends in concrete.

1. Introduction
In India, large quantities of waste materials are delivered by manufacturing organization, thermal power plant, municipal solid waste and other waste. By using this solid or liquid waste as replacement material will cause less damage to environment. Nowadays cement is consider as the expensive material. During the manufacturing of cement it releases the enormous amount of CO\(_2\) which causes many defects in human and environment. Ceramic waste, an industrial by-product utilized for improving the mechanical properties and micro-structural properties of OPC. From economical point of view, 10% replacement of ceramic waste in cement gives excellent compressive strengths [1]. A bone china ceramic fine aggregate (BCCFA) is utilized an alternative raw material for replacement of fine aggregate in concrete. This material plays a key role in enhancing the mechanism of hydration as well as water durability properties. The replacement was carried out at 0%, 20%, 40%, 60%, 80% and 100% partial replacement of fine aggregate in concrete. The study shows that up to 40% replacement gives better results and it can be used for structural related applications [2]. The cube compressive strength is tested at 120 days of curing period using ‘porcellanato’ and ‘monoporosa’ polishing
residues (MixPR) as an additional supplementary material to cement. The supplementary material is extracted from the sludge taken from ceramic tile polishing process. The strength exhibited was 41.5 MPa when using 25% MixPR. It also improves the efficiency index and reduces the cement utilization in concrete by 30% [3, 5].

It is evident that finely ground waste ceramic powder acts as a filler material for the manufacturing of self-consolidating concrete (SCC). At 15% replacement, it showed better results in strength and flow property parameters [4]. Ceramic waste in concrete as a supplementary material improves the mechanical properties (Flexural strength, compressive strength, cylinder tensile strength), micro structural particle analysis includes, SEM test and durability test such as water penetration and water absorption test effectively [5]. The apparent properties of cement based mortar were improved by adding various particle size of ground insulator powder. These insulators are used in high voltage transmission towers which are extensively made out of porcelain, glass and ceramic materials. In cement mortar the insulator powder is used as an admixture which are greatly effective in reducing the alkali aggregate reaction particularly alkali-silica reaction [6]. Waste red brick powder is an effective material which contributes the sufficient pozzolanic property. This is used as an additional supplementary material in replacing cement and fine aggregate. The study showed that these materials substantially increase the rheological properties of concrete even up to 100% replacement [7]. In order to achieve the strength, pozzolanic activity is important in the hydration process [8].

Utilization of brick powder in geo-polymer gives the most compact micro structure with high reaction rate mechanism. The specific pore volume is increased by the effectiveness of powdered brick. The experimental result reveals that, increasing the silicate modulus decreases the rate of early age reaction [9]. Use of recycled brick in concrete as a partial cement substitute up to 20% improves the strength and durability properties due to the pozzolanic activity of the powdered brick dust. This also gives a sustainable solution to environmental consideration necessitates in its usage [10].

2. Materials

The concrete used for test is M20 grade. The materials used includes cement, fine aggregate, coarse aggregate, water, ceramic powder, red brick dust.

2.1. Cement

For the experimental work, Ordinary Portland Cement of 43 grades is used as shown in figure 1. The tests were carried out confirming to IS 8112:1989 [16]. OPC acts as a binder material constituent in concrete through which the heat of hydration process is carried out effectively. Table 1 shows the physical and chemical characteristics of OPC 43 Grade cement.

| Physical Characteristics | Results obtained | Chemical Characteristics | Results obtained (%) |
|--------------------------|------------------|--------------------------|----------------------|
| Fineness of cement       | 225 m²/kg        | CaO                      | 64.25                |
| Specific gravity         | 3.15             | SiO₂                     | 21.08                |

![Cement](image1)

![Sand](image2)

![Coarse aggregate](image3)

Table 1. Physical and Chemical Characteristics of Cement
Fine aggregate (sand) is an important constituent in concrete which acts as a pore filler material as shown in figure 2. The property of sand mainly depends on its physical characteristics and volume as shown in table 2. Almost all the fine particles are shaped normally as cubical or rounded and have a smooth surface texture. Being cubical, rounded and smooth texture it give good workability. Sand which is used in this research work was collected from Vaigai River. The important field test to analyze the grade of fine aggregate is fineness modulus. Its value comes out around 2.73. The test was done as per the procedure given in IS 383-1970 [12].

### Table 2. Physical and Chemical Characteristics of Fine aggregate

| Physical Characteristics | Results obtained | Chemical Characteristics | Results obtained (%) |
|--------------------------|------------------|--------------------------|----------------------|
| Specific gravity         | 2.52             | CaO                      | 35.51                |
| Fineness modulus         | 2.73             | SiO₂                     | 41.91                |
| Loose Bulk density       | 13.85kN/m³       | Al₂O₃                    | 6.46                 |
| Water absorption         | 2%               | Fe₂O₃                    | 6.82                 |
| Grading zone             | II               | Others                   | 2.09                 |

2.3. Coarse Aggregate

The coarse aggregate occupies nearly 70% of its bulk volume in concrete is shown in figure 3. This binds all the cementitious particles together in concrete. 10-12mm size coarse aggregate is taken 50% of the aggregate and remaining 50% are used of 20mm in size. IS: 2386-1963 specifies the standard test for coarse aggregate, which includes the following test like sieve analysis, fineness, bulk density, elongation index and flakiness index test [18]. Strength and durability of aggregate depends on the quality and size of aggregate utilized in the study. Table 3 shows the physical and chemical characteristics of Coarse aggregate.

### Table 3. Physical and Chemical Characteristics of Coarse aggregate

| Physical Characteristics | Results obtained | Chemical Characteristics | Results obtained (%) |
|--------------------------|------------------|--------------------------|----------------------|
| Specific gravity         | 2.71             | CaO                      | 19.15                |
| Fineness modulus         | 6.62             | SiO₂                     | 52.12                |
| Loose Bulk density       | 1.43 Kg/L        | Al₂O₃                    | 2.56                 |
| Water absorption         | 0.4 %            | Fe₂O₃                    | 4.41                 |
| Flakiness index          | 14.1 %           | Others                   | 22.58                |
| Elongation index         | 22.4%            |                          |                      |
2.4. Water
Water is utilized for making a good concrete which should be perfect and free from harmful polluting agents. Potable water is used and is one of the key ingredients in concrete which helps to bind all the concrete constitutions together. Concrete attains sufficient strength through hydration process. Table 4 shows the chemical characteristics of water.

| Chemical Characteristics | Results obtained |
|--------------------------|------------------|
| pH                      | 7.2              |
| Organic matter          | 200 mg/l         |
| Inorganic matter        | 3000 mg/l        |
| Chloride                | 1000 mg/l & 2000 mg/l for RCC & PCC work |
| Sulphates               | 500 mg/l         |
| Total Acidity           | Not less than 6  |
| Suspended matter        | 2000 mg/l        |

2.5. Ceramic Powder
Usage of solid waste material in concrete makes the sustainable solution in the construction field. One such waste utilized is acquired from ceramic waste products. Using Ceramic waste collected from roof and floor tiles, brick and electrical insulator parts which increase the strength of conventional concrete. The ceramic waste is collected and it is crushed to fine powder which is used as a replacement material to cement is shown in figure 4.

| Figure 4. Ceramic powder | Figure 5. Red brick dust |
|--------------------------|-------------------------|

There ceramic powders are effective in improving the strength and other durability properties in concrete. Ceramic waste can be utilized as a partial replacement to cement or as a partial replacement of fine aggregate. In this experimental work, the ceramic waste powder can be used as an effective replacement to ordinary Portland cement.

| Physical Characteristics | Results obtained | Chemical Characteristics | % of constituents |
|--------------------------|------------------|--------------------------|------------------|
| Specific gravity         | 2.36             | Calcium Oxide (CaO)      | 1.52             |
| Fineness modulus         | 3.76             | Silicon Dioxide (SiO₂)   | 78.20            |
| Loose Bulk density       | 14.21 kN/m³      | Aluminium Oxide (Al₂O₃)  | 0.820            |
2.6. Red Brick Dust

Normally the broken brick are not used in the construction works and these bricks are collected and grinded to the particle size of less than 1mm. The brick dust is collected and sieved for further use is shown in figure 5. Red brick dust is partially replaced to fine aggregate in concrete and their physical, chemical properties are shown in table 6

| Water absorption | 12% | Iron oxide (Fe₂O₃) | 4.32 |
|------------------|-----|-------------------|------|
| Gradation        | Zone II | Magnesium Oxide (MgO) | 3.61 |
|                  |       | Chloride (Cl)     | 0.304|
|                  |       | Sulphur trioxide (SO₃) | 0.062|
|                  |       | Loss of ignition  | 3.62 |

Table 6. Physical and Chemical characteristics of Red brick dust

| Physical Characteristics | Results obtained | Chemical Characteristics | % of constituents |
|--------------------------|------------------|--------------------------|-------------------|
| Specific gravity         | 2.7              | Calcium Oxide (CaO)     | 12.86             |
| Fineness modulus         | 2.58             | Silicon Dioxide (SiO₂)  | 39.54             |
| Loose Bulk density       | 10.75 kN/m³      | Aluminium Oxide (Al₂O₃) | 15.72             |
| Water absorption         | 2%               | Iron oxide (Fe₂O₃)      | 14.05             |
| Gradation                | Zone II          | Magnesium Oxide (MgO)   | 3.29              |
|                          |                  | Potassium oxide (K₂O)   | 1.96              |
|                          |                  | Sulphur as Sulphur trioxide (SO₃) | 0.47 |
|                          |                  | Sodium oxide (Na₂O)     | 0.00              |
|                          |                  | Loss of ignition         | 11.28             |

3. Design Mix

The design mix ratio arrived for M20 grade concrete is 1: 1.52:3.12 is as per the IS: 10262: 2009 [11]. The water-to-cement ratio adopted is 0.40

Grade designation : M20
Type of cement used : OPC 43 grade
Workability       : 25-50mm
Exposure condition : Moderate
Degree of supervision : Good
Type of aggregate  : Crushed annular Agg.

3.1. Mix Design

The mix design is shown in table 7. Ceramic powder and red brick dust is replaced by 5%, 10% and 15% for cement and fine aggregate
4. Experimental Tests

4.1. Compressive Strength:
The compressive strength of concrete is evaluated by casting 150 x 150 x 150mm cubes. Minimum three samples of cubes have to be casted for better results. The characteristic compressive strength of cubes was tested at 7, 14 and 28 days ($f_{ck}$). Compression testing machine is used to standard testing of cubes. The maximum load at which the cube specimen fails completed with maximum number of cracks is noted. The ratio of maximum load to the cross-sectional area gives the compressive strength of each specimen. Water to cement ratio, type of cement, quality of aggregate used are the factors which affects the compressive strength of concrete. IS: 516-(1959) gives the method of testing procedure for cube compressive strength [14]. The compressive strength of conventional concrete cube (0% replacement) is compared with the 5%, 10% and 15% replacement of cement with ceramic waste powder and fine aggregate. The tests are carried out for 7, 14 and 28 days of curing period for both conventional and replacement concrete cubes. Figure 6 shows the concrete cube specimen under compression testing.

![Testing of cube specimen in compression testing machine before and after failure](image)

4.2. Split tensile Strength:
The split tensile strength of concrete is evaluated by casting the cylinder specimen of diameter 150mm and height of 300mm. IS: 5816-(1999) gives the method of testing procedure for splitting tensile strength of concrete [15]. The results were arrived for 5%, 10% and 15% replacements of ceramic powder and red brick dust for cement and fine and aggregate and compared with conventional...
concrete (0% replacement). The failure crack patterns are noted and shown in figure 7.

Figure 7: Split tensile strength  
Figure 8: Flexural strength test

4.3. Flexural Strength:
The brittleness of the concrete is determined using flexural strength by casting a prism of size 100mm x 100mm x 500mm. IS: 516-(1959) gives the method of testing procedure for flexural strength of concrete [14]. The specimen was tested for 7, 14 and 28 days curing period for all the replacement percentages and crack pattern were analyzed for maximum load. Flexural testing of Prism is shown in figure 8.

4.4. Durability Test
Concrete durability should be accessed in every structure which gives the resistance to external weathering agents. It also plays a key role in life span of the structure. The amount of deterioration of concrete is measured as an important factor in durability criteria. The durability test is performed after 56 days and in this experimental work corrosion test and acid test were performed. The durability tests were carried out for the replacement proportions of 0%, 5%, 10% and 15% of ceramic powder and red brick dust.

4.4.1. Corrosion Test
Tests were carried out to investigate the amount of corrosion induced in steel reinforcement which is embedded in concrete. Cover concrete plays a major role in corrosion deterioration process. For performing the corrosion test, two 150mm cubes were casted with exposing 8mm or 16mm reinforcing bars. The potential of the steel bar is measured using half cell potentiometer. The corrosion test is carried out after a period of 56 days of curing implies with the code ASTM C876 – 15 [17]. Figure 9 and 10 shows the specimen before and after corrosion test.

Figure 9: Specimen before corrosion test  
Figure 10: Specimen after corrosion test
4.4.2. Acid Test
For performing the acid test, the two concrete cubes of size 150 x 150 x 150 mm were casted. The specimens were allowed to cure for a period of 28 days. After 28 days, the cube samples were weighed and it is taken as $W_1$ is shown in figure 11. A solution of sulphuric acid was prepared by adding 2.5% of $\text{H}_2\text{SO}_4$ having a normality of 1N to about 20 liters of distilled water. The specimens were immersed in the solution for about 56 days. After 56 days, the specimens were taken out from the solution, wiped off and dried for about 24 hours. The final weight of the specimen is noted and it is taken as $W_2$. The deterioration in weight is considered as the acid attack on the specimen is shown in figure 12.

![Figure 11: Specimens immersed in acid solution](image1)

![Figure 12: Specimen after Acid test](image2)

5. Results and Discussion

5.1. Compressive strength test results
From the test results, it is evident that, compressive strength increases as the curing period increases. This is due to increased rate of hydration process. The compressive strength at the curing periods of 7, 14 and 28 days of control concrete (0% replacement) shows 24.95 MPa, 28.27 MPa and 35.22 MPa respectively. At the replacement of 5% ceramic powder and brick dust, the results were 25.12 MPa, 29.15 MPa, and 36.68 MPa respectively at the age of 7, 14 and 28 days. Similarly for replacement of 10% and 15%, the compressive strengths were 26.19 MPa, 31.21 MPa, 38.68 MPa and 23.24 MPa, 26.42 MPa and 33.58 MPa respectively at 7, 14 and 28 days is shown in figure 13.

![Figure 13: Compressive Strength of Cubes at 7, 14 and 28 days](chart)
The strength increases at 10% replacement of ceramic powder and red brick dust in place of cement and fine aggregate. At 15% replacement, strength drops gradually. This is due to the increase of fineness in cement and fine aggregate. Increase in fineness causes the concrete to be more water permeable which reduces the compressive strength.

5.2. Split tensile strength test results

The tests are conducted for the cylinder specimens after 7, 14 and 28 days of curing are shown in figure 14. The maximum Split tensile strength was obtained at 10% replacement of cement and fine aggregate with ceramic powder and brick dust. The Table 8 shows the Split tensile strength results for 0%, 5%, 10% and 15% at the respective curing periods.

| Sl. No | % Replacement | Split tensile Strength (N/mm²) |
|--------|----------------|-------------------------------|
|        |                | 7days | 14days | 28days |
| 1      | 0%             | 2.1   | 2.84   | 3.49   |
| 2      | 5%             | 2.24  | 2.92   | 3.61   |
| 3      | 10%            | 2.53  | 3.14   | 3.70   |
| 4      | 15%            | 2.28  | 2.96   | 3.63   |

Figure 14 Split tensile strength at 7, 14 and 28 days
5.3. Flexural strength test results

![Graph showing flexural strength test results](image)

Figure 15: Flexural strength at 7, 14 and 28 days

The variation in flexural strength was similar to split tensile results. The flexural strength of concrete mixtures increases marginally with increase in ceramic powder and red brick dust. The flexural strength results for various replacement levels at 7, 14 and 28 days are shown in Figure 15. It is evident that, the maximum flexural strength 5.08 N/mm² was achieved for 10% replacement of ceramic powder and red brick dust with cement and fine aggregate. When the fineness of the concrete materials increases, it causes brittleness which in turn gradually reduces the flexural strength of concrete.

5.4. Corrosion test

The effect of corrosion on the reinforcement bar placed inside the concrete for M20 grade was determined. The half cell potential was measured in volts (V). No significant weight loss was observed in the specimen replaced with ceramic powder and red brick dust. This is because of the effect of replacement materials which is resistant to corrosion. They also act as a barrier for the corrosive agents. Study shows that, for 10% optimum replacement, no severe corrosion probability is observed as it has lesser potential. The half cell potential values for different replacement specimens are shown in Figure 16. Table 9 shows the inference for the corresponding replacements.

| Replacement (%) | Half Cell Potential (V) | Inference |
|-----------------|-------------------------|-----------|
| 0               | 0.25                    | Note 1: Corrosion activity uncertain if Hall-cell Potential is 0.20 to -0.35 V |
| 5               | 0.21                    | Note 2: 90% probability of no corrosion if half cell potential value is less than or equal to 0.20 V |
| 10              | 0.19                    | Note 3: More than 90% probability of corrosion occurs if hall cell potential value is more than 0.35 V |
| 15              | 0.23                    |           |
5.5. Acid test
Acid attack was carried out on conventional mix (0% replacement) and for 5%, 10% and 15% replacement of ceramic powder and red brick dust. Figure 17 shows the loss of weight due to acid attack after immersion of M20 conventional and replacement concrete. Table 10 shows the weight loss of the specimen after acid test. From these observations, for 10% effective replacement the weight loss observed was 0.03kg and it shows more resistance towards the acid compared to the other mixes.

| Replacement (%) | Dry Weight (Kg) | Weight After Immersed In Acid(Kg) | Loss In Wt. (Kg) |
|-----------------|-----------------|----------------------------------|-----------------|
| 0               | 3.52            | 3.46                             | 0.06            |
| 5               | 3.51            | 3.47                             | 0.04            |
| 10              | 3.53            | 3.50                             | 0.03            |
| 15              | 3.55            | 3.48                             | 0.07            |

6. Conclusions
- The replacement materials incorporated in concrete showed the effectiveness in both mechanical strength and durability aspects.
- It was found that compressive strength, split tensile and flexural strength increased with increase in the percentage replacement up to a 10% and beyond that it was found to be decreased. Hence the optimum replacement percentage of cement and fine aggregate with ceramic waste powder and red brick dust was 10%. It was observed that the strength obtained was more than the conventional (0% replacement) concrete. The maximum mechanical strength was achieved at 28 days of curing period.
- At 10% replacement of ceramic waste powder and red brick dust, the maximum compressive strength, split tensile strength and flexural strength observed at 28 days was 38.68 N/mm², 3.70 N/mm² and 5.08 N/mm² respectively.
The minimum loss of weight was observed in acid test and only 0.03kg weight loss was noticed for 10% optimum replacement in comparison with other mixes. The study also showed that, ceramic waste powder and red brick dust are effective under durability test. Some adverse effects were shown when the percentage of replacement increases. Hence, the suitable replacement was considered as 10% which gives better resistance under acid tests.

The determination of corrosion risk over a structure is not straight forward. The rate of corrosion when replaced up to 10% showed the better improvement and the probability of corrosion was greatly reduced when the potential is less than 0.20V. Beyond 10% replacement, the rate of corrosion was gradually increased and this deteriorates the steel and concrete.

From the investigations carried out, it is positive to use the ceramic waste powder and red brick dust as a partial replacement with cement and fine aggregate. It also provides eco-efficient concrete which helps against polluting the land from waste dumping.

Utilization of such natural resources saves the cost of cement and fine aggregate which gives the sustainable solutions in future.

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