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# Analysis of Ceramic Waste as Supplementary Cementitious Material in Concrete

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**ABSTRACT:** Due to the rising demand for cement in building, it is necessary to cut cement output by partially substituting cement with alternative materials. When waste material is utilised to make cement, the cost is lowered and the environmental impact is favourable. The amount of cement produced emits the same amount of CO<sub>2</sub> as the amount of lime stone used, resulting in a very unfavorable environmental effect. The purpose of this study is to reduce the environmental impact and cement consumption in concrete by using ceramic material as a supplemental cementitious material. These studies initially explore the pozzolanic activity of ceramic electrical insulator waste material using three tests: strength activity test, frattini test, and saturated lime test. According to these discoveries in ceramic electrical insulator material, pozzolanic activity of material has been revealed, and it may be replaced up to 20% in mortar; nevertheless, more research, such as durability, is required. Following the successful completion of the pozzolanic activity test in mortar, research is conducted in concrete for the same ceramic electrical insulator material partial replacement with cement in the concrete, and its mechanical properties, workability, durability. Cement has been largely substituted in concrete with 5%, 10%, 15%, and 20% ceramic waste, respectively. Investigate the test performance in concrete for the exploitation of these ceramic waste, here workability test (by slump cone test), mechanical properties test (compressive strength test, flexural strength test. According to the results of the workability test, mechanical properties test, durability test, and micro-structure analysis, the ceramic waste material performs better up to 15% (Fifteen percent) replacement of ceramic waste, and higher than 15%, i.e. 20% or more, does not perform better. According to these findings, ceramic waste can replace up to 15% of cement in future applications; however, more study is needed. Because the ceramic has a low specific gravity (poor workability), the procedure is carried out with a low water cement ratio and fine dancing particle.

**KEYWORDS:** Ceramic waste, Cost analysis, Compressive strength, Workability

## I. INTRODUCTION

A substantial amount of ceramic insulator trash has been discovered in the electrical board as a result of high voltage insulator breakage. These ceramic insulator wastes have not been utilized after breaking; nevertheless, in the research field, these ceramic waste have been used to substitute fine or coarse aggregate.

History of construction has witness that construction industry rapidly increases with increase in development of construction and due to high volume of raw material used in the construction and the environment has been impacted. High amount of waste generated in the construction industries, with respect to development of construction waste material and pollution has been generated day by day continuously. It's requiring to reuse the waste material in any purpose to reduce the environmental impact.

Infrastructure development is always rising, but the environmental effect is also increasing. The usage of a large volume of cement and other raw materials has a negative impact on sustainability because of the large amount of carbon-dioxides emitted during the cement manufacturing process. CO<sub>2</sub> has increased greenhouse gas emissions, contributing to the global warming impact. Because global warming is the primary issue or concern for the planet, it is necessary to regulate global warming and other environmental issues. Waste has been used in concrete in the scientific sector to lessen environmental effect. Currently, fly ash, silica fume, and other waste materials are routinely utilized as building materials up to a certain degree; similarly, ceramic insulator waste has been employed in concrete with the substitution of fine and coarse aggregate in study. If ceramic waste is used in concrete, it is environmentally and eco-friendly micro-structure properties of the material etc. In concrete adopted mechanical properties and durability test of concrete that which amount of ceramic waste material has been used for the replacement with cement, both test has a physical properties of the material that indicate the strength and durability of concrete.

In the mechanical characteristics of concrete, perform compressive strength, flexural strength, and split cylinder tests, as well as an analysis of the workability of concrete. Years ago, mechanical qualities were linked to concrete strength,



which defined structural stability. The workability of concrete has also played an essential part in determining whether the concrete is workable or not in the field. For the workability of concrete, two tests are often employed: the slump cone test and the compaction factor test. The compaction factor test produces more accurate results with less error, but it is not utilized in the field due to the weight of the instrument. The slump cone test was used in the field to determine the workability of concrete because it produces results quickly and is simple to apply.

Concrete durability testing pertains to the durability of concrete structures in construction sectors. There are several tests accessible in disabilities, such as sulphate attack test, acid attack test, carbonation test, chloride penetration test, water absorption and water penetration test, and so on. The water penetration test determines the permeability of concrete and is performed in accordance with DIN 1048.

## II. METHODOLOGY

The methodology of these works is stated as follows: the cement replaced by the ceramic insulator material (size passing through 90 micron filter) with the percentages of 5%, 10%, 15%, and 20% implies comparing the control mix with these percentage replacements. The test was run for 7 days and the microstructure was examined after 28 days. Various tests, such as mechanical characteristics (compressive strength, flexural strength, split cylinder strength, etc.), durability qualities (water absorption and water penetration), and the microstructure of concrete (FE-SEM test and XRD test), were done in these works. In place of cement, a varied percentage of ceramic insulator waste was used in the concrete mix.

Water cement ratio 0.43 are constant for all the concrete mix and it is designed as per IS 456 and IS 10262-2009, other concrete properties are compared with respect to this water cement ratio.

Table 1: IS codes for different test performed in this concrete project work are followings:

Sl. No	TEST	IS CODE
1.	Specific gravity of fine aggregate	IS 2386 (PART-III) 1963
2.	Specific gravity of coarse aggregate	IS 2386 (PART-III) 1963
3.	Specific gravity of cement	IS 2720 (PART-III) 1980
4.	Sieve analysis or Gradation	IS 383-1970

Test results for the preparation of concrete mix design proportion are given in table:

Table 2: Required test result data for mix proportion are given.

Sl.No.	Test	Results
1.	Specific gravity of cement	3.12
2.	Specific gravity of fine aggregate	2.68
3.	Specific gravity of coarse aggregate (20mm)	2.73
4.	Specific gravity of coarse aggregate (10mm)	2.72
5.	Water absorption of coarse aggregate	0.85 %
6.	Water absorption of fine aggregate	1 %
7.	Sand zone (as per IS 383, table 4 and IS 456)	Zone –II
8.	Cement OPC	Ultratech 43 grade cement

### Methodology of Mix Proportion of Concrete

Ceramic waste material is completely replaced by cement, which is inconvenient for the concrete and structure, and there is no special code to build for these materials. The design of concrete mixes is based on experimental mixtures. These studies did not design the grade of concrete, but rather fixed the water cement ratio and other factors that changed the percentage replacement. The water cement ratio is 0.43, and the mix is designed according to the tables below: These mix design is based on IS 456 and IS 10262-2009.

Table 3: Mix design at water cement ratio of 0.43 with different percentage of ceramic waste.

Sl. No.	Replacement (in %)	Water Kg/m <sup>3</sup>	Cement Kg/m <sup>3</sup>	Ceramic waste (Kg/m <sup>3</sup> )	10mm (Kg/m <sup>3</sup> )	20mm (Kg/m <sup>3</sup> )	Sand (Kg/m <sup>3</sup> )	Super P. (kg/m <sup>3</sup> ) (0.5%)
1.	Control or 0	180	418.60	0	545.87	545.87	787.10	2.09
2.	5	180	397.67	20.93	545.87	545.87	787.10	2.09
3.	10	180	376.74	41.86	545.87	545.87	787.10	2.09
4.	15	180	355.81	62.79	545.87	545.87	787.10	2.09
5.	20	180	334.88	83.72	545.87	545.87	787.10	2.09

*Weighing process*

Cement, sand, coarse aggregate, fine aggregate, water, ceramic waste, and superplasticizer are all weighed by weight in mg or kg.

*Process of mixing of concrete*

Concrete is made in a concrete mixer by first mixing coarse and fine material for 2 minutes, then adding cement and mixing for 5 minutes. After properly mixing the dry mix, add the water and superplasticizer in the quantities specified and spin the mix for 15 to 30 minutes. Once completed, check the workability of the concrete and fill the mould with concrete.

*Process of preparation of specimens*

The specimen is being prepared by preparing the mould 100\*100\*100 mm<sup>3</sup>, the beam 100\*100\*500 mm<sup>3</sup>, and the cylinder 150 mm diameter with 300 mm height for the concrete filling. Do the necessary oiling in the interior sides of the mould before putting the concrete material in the mould to eliminate the concrete adhesion in the moulds. Vibrating table machine vibrates concrete materials packed with two or three layers.

*Process of curing of specimen*

After 24 hours of casting, the specimen is demoulded and placed in the curing tank for the desired time, i.e. 7 days, 28 days, 56 days, and 90 days, etc.



Figure 1: Concrete specimens of cubes, beams and cylinder.



### III. EXPERIMENTAL PROGRAMME

#### Frattini test

##### i. Principle

The Frattini test is based on the EN196-5 code. According to these codes, a sample of 100ml of water and 20 gramme of cement were obtained, and for comparison, pozzolanic material was substituted by cement by 20%. These samples were collected in sealed bottles in the incubator at 40 0C. These samples were filtered by a filtering machine after 8 days (with filter paper watman 542). Titrate the sample for OH<sup>-</sup> concentration using methyl orange indicator and HCL solution, and for Ca<sup>2+</sup> utilise pattern indicator with EDTA solution before titrating with EDTA solution. If the pH is less than 12.5, add the NaOH solution to boost the pH.up until this point After titration, display the results on the standard graph.

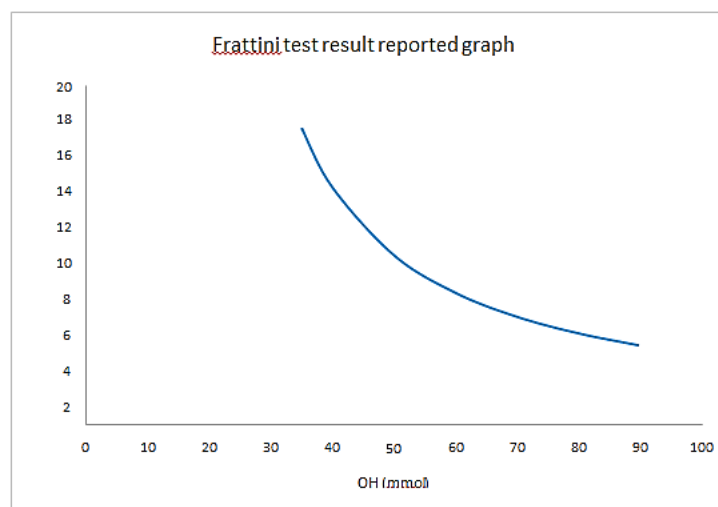


Figure 2: Frattini test result reported graph

According to these code and graph the control sample lies in the range of these graph and if the pozzoalnic materials comes under or below the graph line than the pozzolanic material shows the pozzolanic activity , so that the material has pozzolanic properties.

##### ii. Reagents

HCL solution (0.1 mol/L), methyl orange, EDTA, patton reader, CaCO<sub>3</sub>, sodium carbonate, ammonium purpurate (murexide), NaOH.

Before start the test standardization of the solution must be required there are two solutions HCL and EDTA solution.

##### iii. Standardization of EDTA solution

For the standardization of EDTA solution take 400 ml flask than 100 ml of water added after that carefully added 10 ml of concentrated HCL, stir this solution with glass rod. After that add the water up to make these solution 1000 ml exactly.

Pipette out the 50 ml of calcium solution into the beaker than dilute these solution with water for suitable operation. Maintained the pH range 12.5 of these solution by NaOH solution.

##### iv. End point determination

Add pattern reader indicator in the solution, colour changes purple to blue colour.

$$\text{Calculate the f1 factor} = f1 = m1/v1 * 16.652$$

Here m1 = mass of CaCO<sub>3</sub>, in gm

and V1 = titrated volume used for EDTA solution, in millilitres.

Figure 3: Determination of end point of Ca<sup>2+</sup> (colour changes from purple to blue).



End point of the EDTA solution titration that which point where colour changes form purple pink to blue colour in the visual observation.

v. *Standardization of HCL solution*

Take sodium carbonate  $0.2 \pm 0.0001$  gm in the sample of 50ml to 75ml in the 250 ml of the flask. Calculate factor

$$F2 = m2/v2 * 188.70$$

Here m2 = sodium carbonate (mass in gm)

And V2 = titrated volume used for hydrochloride acid solution, in millilitres

vi. *Procedure*

Sample kept in a sealed bottle in an incubator at a constant temperature of 400 degrees Celsius for 8 days and 15 days; if satisfied after 8 days, no need for 15 days. After 8 days, remove the sample and quickly filter it using a vacuum filter at room temperature. The solution and sample were then made in accordance with the process outlined in principle, and it was titrated.

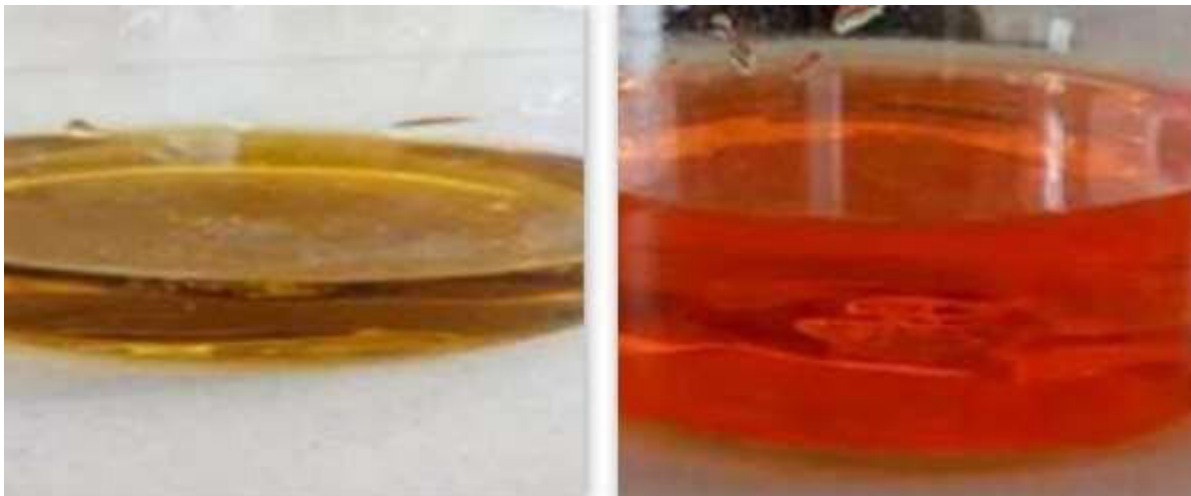


Figure 4: Determination of end point of OH<sup>-</sup> (colour changes from yellow to orange)

vii. *Determine the OH<sup>-</sup> concentration*

$$OH^- \text{ (in milimol/litre) } = 2 * V3 * f2$$

Here V3 = titrated volume used for hydrochloric acid solution of 0.1 mol/litre.

And  $f_2$  = factor of hydrochloric acid of 0.1 mol/litre solution

viii. **Determination of CaO concentration**

$\text{CaO (in milimol/litter)} = 0.6 \cdot V_4 \cdot f_1$

Where  $V_4$  = titrated volume used for EDTA solution. And  $f_1$  = factor from the EDTA solution.

ix. **Calculation and expression of result**

x. **Assessment of result**

**Saturated lime test**

i. **Principle**

The saturated lime test is a shortened or modified form of the frattini test. The reason that the solid particle held over the filter paper is that a known quantity of lime is supplied at the beginning and residual lime is measured at the end. Sand is predicted to have zero or no pozzolanic activity in these tests, and only lime solution is present. The sample was obtained at a steady temperature and without contact with carbon dioxide since it fluctuates with temperature because lime reacts with carbon dioxide to form calcium carbonate.

ii. **Procedure**

In the sample preparation, combine 75ml of saturated lime with 1g of material and mix in a sealed bottle. 2 grammes of lime is mixed with 1 litre of distilled water to make this saturated lime solution. The sample is placed in a sealed bottle and placed in an incubator at a constant temperature of 40 OC for 1, 3, 7, and 28 days. The titration technique is therefore the same as a ferttini test.



Figure 5: Bottles used for ferttini and saturated lime test

#### IV. EXPERIMENTAL PROGRAMME IN CONCRETE

**Workability test**

The workability of concrete is primarily determined by two tests: the slump cone test and the compaction factor test. The compaction factor test produces superior results but is not utilised in the field. Use the slump cone test in the field since it provides results in less than a minute and does not require a hefty instrument like the compaction factor test. The slump cone test was carried out in accordance with IS 7320-1974 (reaffirmed 2000). Workability of concrete can be measured by mainly two test first one is slump cone test and



Figure 6: Slump cone test for workability

Table 4: Slump cone test for workability

Sl.No.	Replacent level (in percentage)	ompressive strength at 14 days (in MPa)	mparison of replacement with control (in %)
1.	Control (0%)	27.00	100 %
2.	5% ceramic waste	26.19	97.00 %
3.	10% ceramic waste	24.10	89.25 %
4.	15% ceramic waste	22.90	84.81 %
5.	20% ceramic waste	20.83	77.14 %

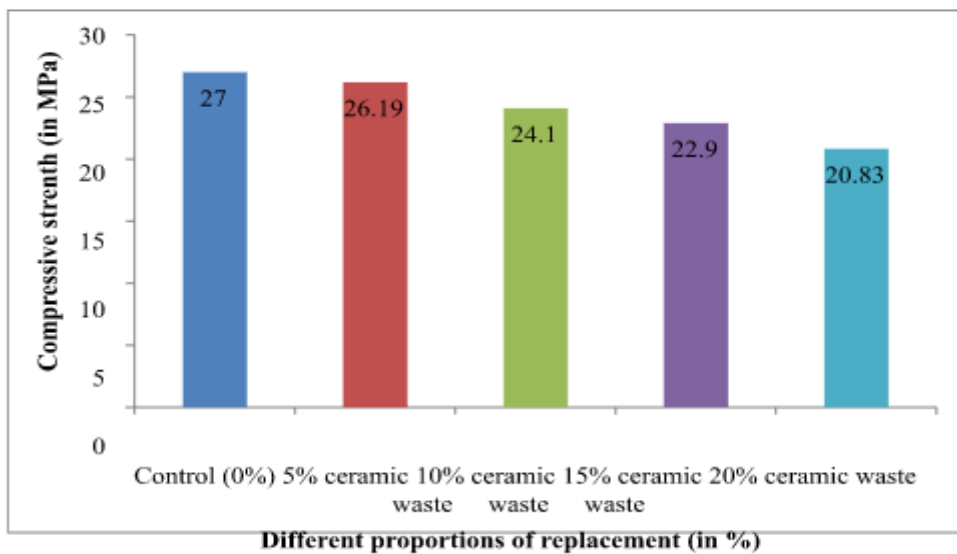


Figure 7: Compressive strength of percentage rate of ceramic replacement at 14 days.





According to the results, the compressive strength of concrete at 3 days, 7 days, 14 days and 28 days falls as the proportion of ceramic replacement increases. It has greater than 80% strength up to 15% replacement and less than 80% strength at 20% replacement when compared to control.

Table 5: Compressive strength result at 28 days of replacement level of ceramic waste.

Sl.No.	Replacement level(in percentage)	Compressive strength at 28 days (in MPa)	Percentage of replacement with control (in %)
1.	Control (0%)	29.5	100 %
2.	5% ceramic waste	27.5	93.22 %
3.	10% ceramic waste	26.16	88.67 %
4.	15% ceramic waste	24.33	82.47 %
5.	20% ceramic waste	21.5	72.88 %

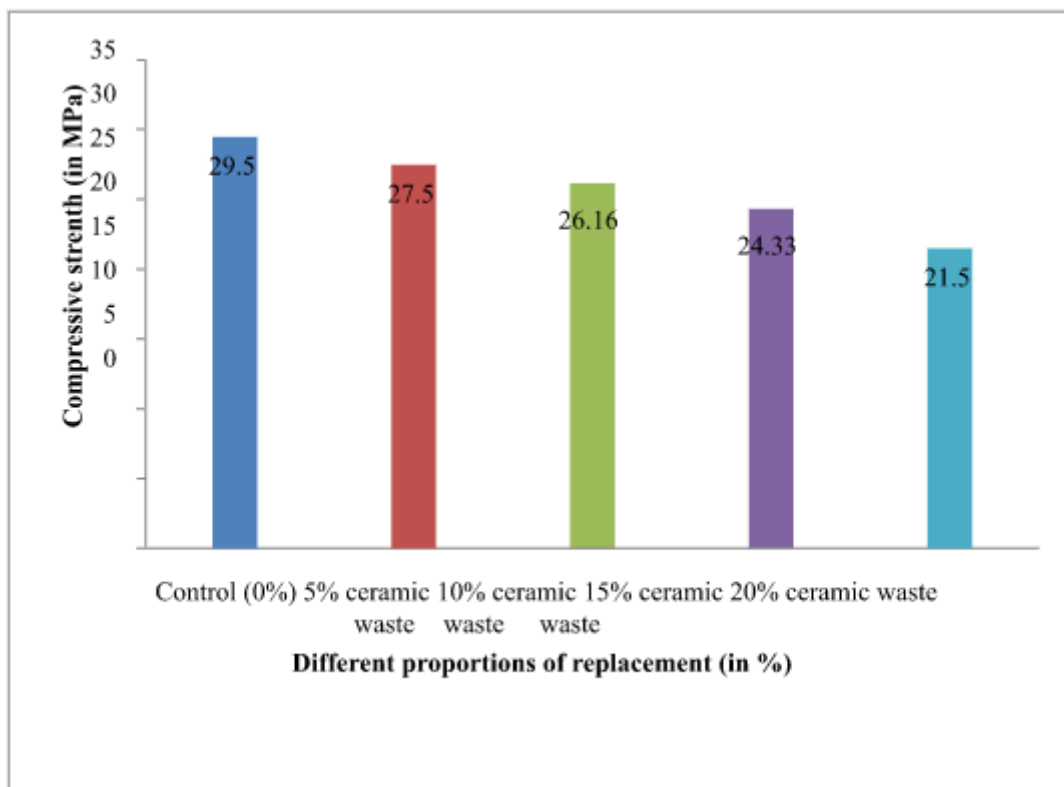


Figure 8: Compressive strength of percentage rate of ceramic replacement at 28 days.

According to the results, the compressive strength of concrete at 28 days falls as the amount of ceramic replacement increases. It has greater than 80% strength up to 15% replacement and less than 80% strength at 20% ceramic waste replacement when compared to the control. As a result, at 20% replacement, the concrete performance is poor.

**Cost effect of ceramic waste concrete and control concrete.**

During the experiment work, the production cost of 1m<sup>3</sup> concrete with ceramic waste replacement were comparatively evaluated for M30 grade concrete. In preparing the waste material to be reusable cost, incurred in transporting crushing and sieving to the required particle. This cost has considered for the cost benefit analysis. It was observed that the cost



saving increases from 0-100%. Also, the percentage cost saving on concrete was observed to have increased as the ceramic waste content increases.

Table 6: Cost analysis between control concrete and ceramic waste concrete

Sl.No.	Replacement level (in percentage)	Cost of ceramic waste (in Rs.)	Cost of 1m <sup>3</sup> Concrete (in Rs.)	Percentage Cost saving on concrete (%)	Cost saving on ceramic (in Rs.)
1	Control (0%)	0	4523	0	0
2	5% ceramic waste	109	4375	3.27	148
3	10% ceramic waste	218	4228	6.53	296
4	15% ceramic waste	327	4080	9.81	443
5	20% ceramic waste	437	3932	13.06	592

## V. CONCLUSION

The following conclusions can be made on the basis of the investigations:

- a) The use of ceramic waste in concrete mix can be reduced the workability of concrete as replacement level increases.
- b) The strength of ceramic waste in concrete decreases due to high flakiness value, weaker bonding of aggregate and high water absorption ratio.
- c) The density of concrete reduced while using the ceramic waste replacement increases.
- d) The uses of ceramic waste are cost effective to reduce the overall cost of concrete mix.
- e) According to the mechanical characteristics and durability test results of ceramic insulator waste material replacement in concrete has been effective up to a limit of 15% replacement with cement.
- f) According to the pozzolanic activity test findings, the ceramic insulator waste has a positive result in the mortar, demonstrating pozzolanic activity in the saturated lime test, strength activity test, and frattini test.
- g) The ceramic waste can be used for the both structural and non-structural works.
- h) Ceramic waste material could not be used in concrete structures where strength is main concerned.

### FUTURE SCOPE

According to the test results, cement can be substituted up to 20% in the mortar, although durability and other tests are also necessary for the use of these waste materials. In the future, the amount of ceramic material replacement may be increased, and further research effort may be necessary for that study.

According to the mechanical properties and durability test results, such as water absorption and penetration test, ceramic can replace up to 15% of the concrete, but for confirmation, other durability tests such as acid attack test, chloride attack test, carbonation test, and micro- structure study are required.

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