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Utilization of Ceramic Waste as Partial Replacement of Cement and Aggregates for Sustainable Concrete Production

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Abstract:
The rapid growth of the construction industry has resulted in increased consumption of natural resources and generation of industrial waste, leading to serious environmental concerns. Ceramic waste obtained from tile manufacturing units and construction activities is one such non-biodegradable material that creates disposal problems. This study focuses on the utilization of ceramic waste as a partial replacement of cement and aggregates in concrete production to promote sustainable construction practices. The ceramic waste is processed and incorporated in concrete at different replacement levels, and its influence on workability and mechanical properties is evaluated. The results indicate that concrete containing ceramic waste exhibits comparable or improved strength characteristics when compared to conventional concrete. The use of ceramic waste not only reduces environmental pollution but also lowers material cost, making it a viable and eco-friendly alternative for sustainable concrete production.

Keywords: *Ceramic waste, Sustainable concrete, Waste utilization, Eco-friendly construction, Green materials.*

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I. INTRODUCTION

Concrete is the most widely used construction material due to its strength, durability, and versatility. However, the extensive use of cement and natural aggregates has led to depletion of natural resources and increased carbon dioxide emissions. At the same time, ceramic industries produce a large quantity of waste materials such as broken tiles, sanitary ware, and rejected products, which are generally disposed of in landfills. Improper disposal of ceramic waste causes environmental pollution and land degradation. Ceramic waste has high mechanical strength, low water absorption, and good chemical stability, which makes it suitable for use in concrete. When processed properly, ceramic waste can be used as a partial replacement for cement or aggregates without adversely affecting concrete performance. Several studies have reported that ceramic waste exhibits pozzolanic behavior and contributes to strength development and durability of concrete.

The utilization of ceramic waste in concrete helps in reducing construction cost, minimizing landfill waste, and conserving natural resources. Therefore, this study aims to investigate the feasibility and effectiveness of using ceramic waste in concrete production, thereby promoting sustainable and environmentally responsible construction practices.

II. OBJECTIVES OF THE STUDY

1. To study the feasibility of using ceramic waste as a partial replacement of cement and/or aggregates in concrete.
2. To evaluate the effect of ceramic waste on the mechanical properties of concrete.
3. To determine the optimum percentage of ceramic waste replacement for sustainable concrete production.

4. To assess the environmental and cost benefits of incorporating ceramic waste in concrete.

III. SCOPE OF THE STUDY

The scope of this study is limited to the utilization of ceramic waste as a partial replacement of cement and/or aggregates in conventional concrete. The study focuses on evaluating the fresh and hardened properties of ceramic waste concrete under laboratory conditions. The investigation includes workability and selected mechanical properties such as compressive strength, split tensile strength, and flexural strength. Durability aspects are considered in a limited manner. The study aims to identify an optimum replacement level that provides acceptable performance while enhancing sustainability. Field performance and long-term behavior are beyond the scope of the present study.

IV. MATERIALS AND METHODOLOGY

[1] Materials

Ordinary Portland Cement (OPC) conforming to IS 12269 is used as the primary binding material in this study. Natural river sand confirming to IS 383 is used as fine aggregate, and crushed stone aggregate with a nominal maximum size of 20 mm is used as coarse aggregate. Clean potable water is used for mixing and curing of concrete.

Ceramic waste is collected from local ceramic tile and sanitary ware industries. The waste material is crushed, cleaned to remove impurities, and sieved to obtain the required particle size. The processed ceramic waste is used as a partial replacement of cement and/or aggregates in concrete.

Figure 1: Types of ceramics available for recycling

Figure 2. Processing steps of CWP and CWF.

Ceramic Waste

Ceramic waste is collected from local ceramic tile and sanitary ware industries. The waste is crushed using a jaw crusher, washed to remove dust, and sieved to the required size. The processed ceramic waste is used as a partial replacement of cement and/or aggregates.

Table 1: Properties of Ceramic Waste

Property	Value
Specific gravity	2.45
Water absorption	2.2%
Shape	Angular
Surface texture	Rough

Table: 3 Properties of Sanitary Ware Ceramic

Table 2: Properties of Sanitary Ware

S. No.	Property	Typical Value Range	Engineering Significance in Concrete
1	Chemical composition	SiO_2: 65–75% Al_2O_3: 15–25%	Similar to ceramic and pozzolanic materials; contributes to strength and durability
2	Specific gravity	2.2 – 2.6	Comparable to natural aggregates; influences density of concrete
3	Bulk density	2100 – 2400 kg/m³	Affects unit weight and mix proportioning
4	Water absorption	0.5 – 3.0%	Influences workability and effective water–cement ratio
5	Porosity	5 – 15%	Governs permeability and durability characteristics
6	Compressive strength (ceramic material)	80 – 300 MPa	Indicates high crushing resistance when used as aggregate
7	Hardness (Mohs scale)	6 – 7	Provides good abrasion resistance in concrete
8	Abrasion resistance	Los Angeles abrasion loss < 30%	Suitable for pavement and flooring applications
9	Thermal stability	Stable up to 1000–1200°C	Enhances fire and heat resistance of concrete
10	Chemical resistance	High resistance to acids and alkalis	Improves durability in aggressive environments
11	Particle shape and surface texture	Angular, rough	Improves bond strength at interfacial transition zone (ITZ)
12	Effect on concrete water absorption	Increase by 2–8%	Requires mix design adjustment

S. No.	Property	Typical Value Range	Engineering Significance
1	Specific gravity	2.3 – 2.6	Influences density and mix design of concrete
2	Water absorption	0.5 – 1.0%	Affects workability and durability
	Compressive strength	200 – 500 MPa	Indicates high crushing strength as aggregate
4	Hardness (Mohs scale)	6 – 7	Provides abrasion resistance in concrete
5	Abrasion resistance	LA abrasion loss < 25%	Suitable for pavements and flooring
6	Chemical resistance	High (acid & alkali resistant)	Enhances durability in aggressive environments

[2] Methodology

Mix Design: Concrete mix design is carried out as per **IS 10262:2019** for a target grade of concrete e.g., M30). A control mix is prepared using conventional materials. Ceramic waste is introduced as a partial replacement of cement and/or aggregates at different replacement levels such as 5%, 10%, 15%, and 20% by weight.

Table 4: Mix Proportions (kg/m³)

Mix ID	Cement	Fine Aggregate	Coarse Aggregate	Ceramic Waste (%)	Water
CM	380	680	1200	0	190
CW5	361	680	1200	5	190
CW10	342	680	1200	10	190
CW15	323	680	1200	15	190
CW20	304	680	1200	20	190

Preparation of Concrete Specimens

A. All materials are weighed accurately and mixed in a concrete mixer to achieve uniform consistency. Dry mixing is carried out first, followed by the addition of water. Fresh concrete is tested for workability using the slump cone test.

B. Concrete specimens are cast in standard steel molds:
- Cubes (150 × 150 × 150 mm) for compressive strength
- Cylinders (150 × 300 mm) for split tensile strength
- Prisms (100 × 100 × 500 mm) for flexural strength

C. After casting, specimens are compacted using a vibrating table to remove air voids.

Curing of Specimens

D. All specimens are demolded after 24 hours and cured in a water tank at room temperature for curing periods of 7, 14, and 28 days.

Table :5 Testing of Specimens

Test	Specimen	IS Code
Slump test	Fresh concrete	IS 1199
Compressive strength	Cube	IS 516
Split tensile strength	Cylinder	IS 5816
Flexural strength	Prism	IS 516

(V) Results and Discussion:

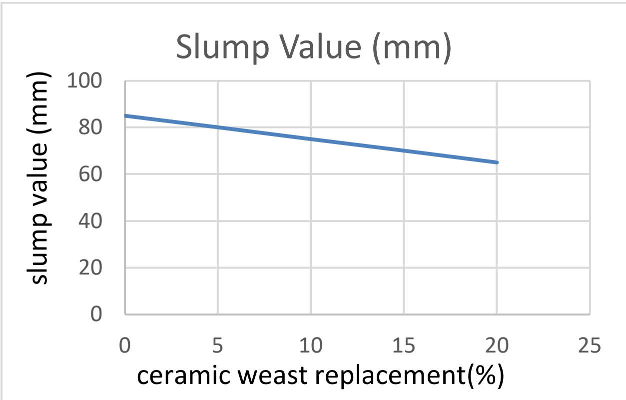
The experimental investigation was conducted to study the effect of ceramic waste on the workability and mechanical properties of concrete. The performance of ceramic waste concrete was compared with a conventional control mix (CM) to determine the optimum replacement level.

(i) Workability:

The slump test results show in Table 1 that workability decreases gradually with an increase in ceramic waste content. The control mix exhibited a slump of 85 mm, whereas 20% replacement reduced it to 65 mm. This reduction in workability is attributed to the angular shape and rough surface texture of ceramic particles, which increases internal friction and water demand. However, all mixes remained within the workable range for practical applications.

Table 1: Slump Test Results

Mix ID	Ceramic Waste Replacement (%)	Slump Value (mm)
CM	0	85
CW5	5	80
CW10	10	75
CW15	15	70
CW20	20	65



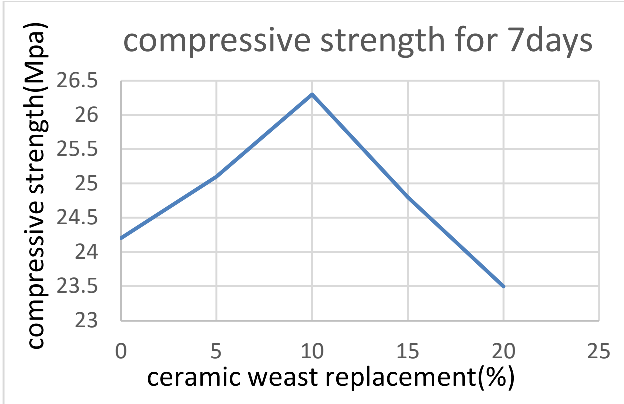
Observation: Workability decreases with increase in ceramic waste content due to angular particles.

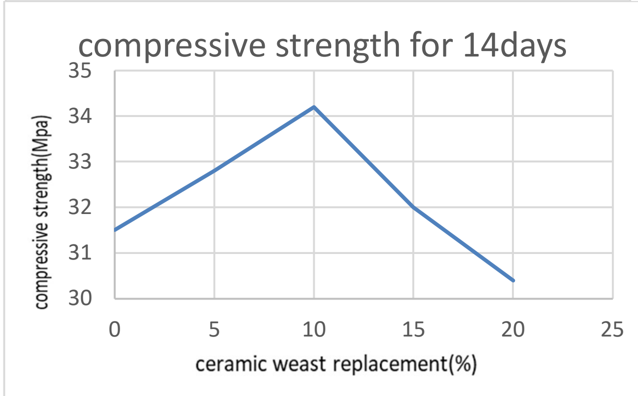
(ii) Compressive Strength

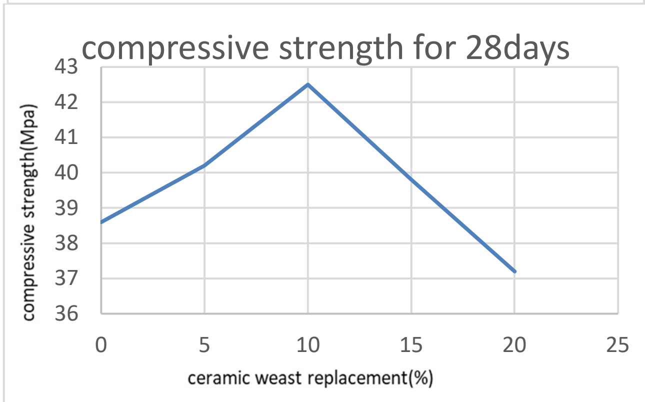
The compressive strength results are summarized in Table 2. Concrete containing 10% ceramic waste achieved the highest 28-day compressive strength of 42.5 MPa, representing a 10.1% increase over the control mix. Strength improved at lower replacement levels due to the pozzolanic effect and better particle packing of ceramic waste, which enhances the interfacial bonding between paste and aggregates. Replacement beyond 10% showed a slight reduction in strength, likely due to reduced cement content and weaker bonding at higher ceramic waste proportions.

Table 2: Compressive Strength Results

Mix ID	Ceramic Waste (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
CM	0	24.2	31.5	38.6
CW5	5	25.1	32.8	40.2
CW10	10	26.3	34.2	42.5
CW15	15	24.8	32.0	39.8
CW20	20	23.5	30.4	37.2







Observation: Optimum compressive strength is achieved at **10% ceramic waste replacement**.

(iii) Split Tensile Strength

Split tensile strength results shown in table 3 indicate a similar trend to compressive strength. The tensile strength increased with ceramic waste replacement up to 10%, achieving 3.62 MPa, and then decreased at higher replacement levels. The improvement at lower percentages can be attributed to improved microstructure and load distribution, while excessive replacement leads to reduced bonding strength.

Table 3: Split Tensile Strength Results (28 Days)

Mix ID	Ceramic Waste (%)	Split Tensile Strength (MPa)
CM	0	3.25
CW5	5	3.40
CW10	10	3.62
CW15	15	3.30
CW20	20	3.05

Observation: Split tensile strength increases up to 10% replacement and decreases thereafter.

(iv) Flexural Strength

The flexural strength of ceramic waste concrete (Table 4) also increased with replacement up to 10%, achieving 5.5 MPa at 28 days. Beyond this optimum level, flexural strength decreased slightly, indicating that excessive ceramic waste may compromise the ductility of concrete.

Table 4: Flexural Strength Results (28 Days)

Mix ID	Ceramic Waste (%)	Flexural Strength (MPa)
CM	0	4.8
CW5	5	5.1
CW10	10	5.5
CW15	15	5.0
CW20	20	4.6

Observation: Improved flexural performance is observed up to optimum replacement level.

Overall, the experimental results demonstrate that ceramic waste can effectively enhance the mechanical properties of concrete when used at optimum replacement levels. The optimum replacement level was found to be 10%, which showed improved compressive, tensile, and flexural strengths compared to conventional concrete. Higher replacement levels lead to a reduction in strength, emphasizing the need to limit the proportion of ceramic waste. The incorporation of ceramic waste also provides environmental benefits by reducing industrial waste disposal and conserving natural resources, making it a sustainable alternative for concrete production.

Table 5: Percentage Strength Variation Compared to Control Mix (28 Days)

Mix ID	Ceramic Waste (%)	Compressive Strength Change (%)
CW5	5	+4.1
CW10	10	+10.1
CW15	15	+3.1
CW20	20	−3.6

(VI) Environmental and Economic Benefits

The incorporation of ceramic waste in concrete production offers significant environmental and economic advantages. Ceramic waste is a non-biodegradable material, and its disposal in landfills leads to environmental degradation and land scarcity. By utilizing ceramic waste as a partial replacement of cement and aggregates, the quantity of industrial waste sent to landfills is considerably reduced.

From an environmental perspective, partial replacement of cement helps in lowering carbon dioxide emissions associated with cement manufacturing, which is one of the major contributors to global greenhouse gas emissions. The reuse of ceramic waste also conserves natural resources such as limestone, sand, and crushed stone aggregates.

Economically, the use of ceramic waste reduces the overall material cost of concrete, as ceramic waste is readily available at low or negligible cost. At the optimum replacement level of 10%, a noticeable reduction in cement consumption is achieved without compromising the strength and performance of concrete. Hence, ceramic waste concrete proves to be both cost-effective and environmentally sustainable.

(VII) Conclusions

Based on the experimental investigation carried out on concrete incorporating ceramic waste as a partial replacement of cement and/or aggregates, the following conclusions are drawn:

1. Workability of concrete decreases with an increase in ceramic waste content due to the angular shape and rough surface texture of ceramic particles; however, all mixes remained within acceptable limits.
2. Compressive strength of concrete increased up to 10% ceramic waste replacement, beyond which a gradual reduction in strength was observed.

3. Split tensile strength and flexural strength followed a similar trend, showing maximum values at 10% replacement.
4. The optimum ceramic waste replacement level was identified as **10%**, which provided improved mechanical properties compared to conventional concrete.
5. Higher replacement levels (above 10%) resulted in reduced strength due to lower cement content and weaker bonding.
6. Utilization of ceramic waste contributes to waste management, conservation of natural resources, and reduction in environmental pollution.
7. Ceramic waste concrete can be safely used for structural and non-structural applications where sustainable construction practices are desired.

(VIII) Scope for Future Work

The present study was limited to laboratory-scale experimentation and short-term performance evaluation. Further research can be carried out in the following areas:

1. Long-term durability studies such as sulfate attack, acid resistance, chloride penetration, and freeze–thaw behavior.
2. Microstructural analysis using SEM, XRD, and FTIR to understand the bonding mechanism and pozzolanic activity of ceramic waste.
3. Field-level performance evaluation of ceramic waste concrete in real construction projects.
4. Study of higher replacement levels using chemical admixtures to improve workability.
5. Life cycle assessment (LCA) and carbon footprint analysis to quantify environmental benefits more accurately.

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