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Utilization of Ceramic Waste Powder and Bagasse Ash as Partial Replacement of Cement in Concrete

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Abstract- The construction sector consumes large quantities of cement, contributing significantly to global CO_2 emissions and environmental degradation. To address these issues, this study investigates the combined use of Ceramic Waste Powder (CWP) and Sugarcane Bagasse Ash (SCBA) as partial replacements for cement in M30 grade concrete. Experimental mixes were prepared with replacement levels of 0%, 10%, 20%, 30%, and 40%, and specimens were tested at 7, 14, and 28 days. Results indicate that 10–20% replacement levels enhance or maintain compressive strength comparable to conventional concrete, while higher replacement levels lead to reduced performance. The optimum replacement level was found to be 20%, providing improved sustainability without compromising strength. This study demonstrates that incorporating CWP and SCBA can significantly reduce cement consumption, lower carbon emissions, and promote environmentally conscious construction practices.

Index Terms- ceramic waste powder, bagasse ash, pozzolanic materials, sustainable concrete, cement replacement.

1.Introduction

Concrete is the most widely used construction material worldwide, with cement serving as its primary binder. However, cement manufacturing accounts for nearly 8% of global CO_2 emissions, creating an urgent need for sustainable alternatives. Industrial and agricultural wastes—including ceramic waste and bagasse ash—offer promising solutions due to their pozzolanic characteristics. Ceramic waste is generated from tile, porcelain, and sanitaryware industries, whereas bagasse ash originates from sugar mills after burning sugarcane residue. Both materials are rich in silica and alumina, making them suitable supplementary cementitious materials (SCMs).

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2. METHODOLOGY

The present study investigates the performance of M30 grade concrete incorporating ceramic waste powder and bagasse ash as partial replacement materials. The methodology adopted in this work includes material selection, preliminary characterization, mix proportioning, casting, curing, and mechanical testing of concrete specimens. The overall experimental procedure is described in the following subsections.

A. Material Collection

The basic ingredients used for concrete include Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate, potable water, ceramic waste powder, and bagasse ash. All materials were collected from reliable sources and stored in dry conditions to maintain uniform quality during experimentation.

B. Preliminary Testing of Material

Prior to mix design, the physical properties of the materials were determined in accordance with relevant IS standards.

1. Cement Tests
- Fineness
- Standard consistency
- Initial and final setting time
- Specific gravity

2. Aggregates Tests
- Fineness modulus
- Specific gravity
- Water absorption
- Bulk density
- Aggregate impact value and crushing value

3. Supplementary Materials (CWP & BA)
- Fineness
- Specific gravity
- Visual & literature-based chemical assessment

C. Mix Design for M30 Grade Concrete

The mix design was carried out as per IS 10262:2019 and IS 456:2000. The target mean strength, water–cement ratio, cementitious content, and aggregate proportions were determined. Ceramic waste powder and bagasse ash were introduced as partial replacements in predefined percentages. A control mix (0% replacement) and modified mixes were prepared for comparison.

D. Casting of Specimens

Concrete was mixed using a mechanical mixer to ensure uniform distribution of materials. The following specimens were cast for each mix:
- Cubes (150 mm × 150 mm × 150 mm) – Compressive strength

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• Cylinders (150 mm × 300 mm) – Split tensile strength
• Beams (100 mm × 100 mm × 500 mm) – Flexural strength
Fresh concrete properties were evaluated through slump and compaction factor tests. Specimens were demoulded after 24 hours.

E. Curing Procedure
All specimens were cured in a water tank at room temperature for 7, 14, and 28 days as per IS 516:1959. Standard curing conditions ensured uniform hydration and strength development.

F. Mechanical Testing
After completion of curing, the following tests were conducted:
1. Compressive Strength Test
Cube specimens were tested at different curing ages using a calibrated compression testing machine.
2. Split Tensile Strength Test
Cylinder specimens were evaluated to assess tensile behaviour.
3. Flexural Strength Test
Beam specimens were tested to determine the modulus of rupture.

G. Analysis of Results
The strength values obtained for modified mixes were compared with the control mix. The influence of ceramic waste powder and bagasse ash on:
• Workability
• Compressive strength
• Split tensile strength
• Flexural strength
was analysed using graphs and tabulated values.

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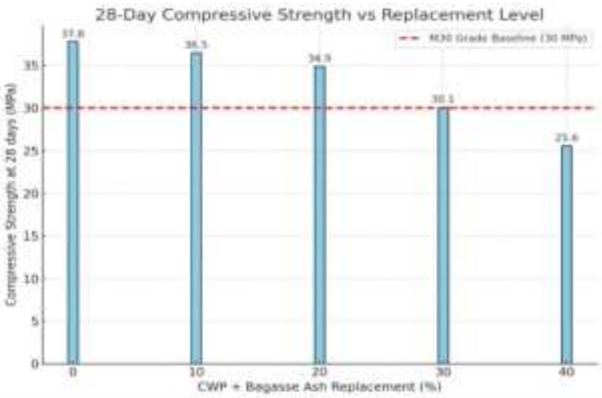


IV. RESULTS AND DISCUSSION

A. Compressive Strength Performance
Compressive strength tests were conducted for five concrete mixes containing 0%, 10%, 20%, 30%, and 40% replacement of cement with an equal blend of Ceramic Waste Powder (CWP) and Bagasse Ash (BA). Tests were performed at 7, 14, and 28 days of curing.
0% replacement
Exhibited a 28-day average strength of 40.19 MPa, which meets the requirements of M30 grade concrete. The trend of compressive strength for modified mixes shows a progressive reduction with increasing levels of cement replacement.
10% Replacement:
The 28-day strength recorded was 35.65 MPa, indicating approximately a 10–12% reduction compared to the control mix. Although lower, it still satisfies structural-grade concrete requirements. Early-age strength (7 & 14 days) remained close to the reference mix due to the filler effect of CWP.
20% Replacement:
The 28-day strength was 33.41 MPa, representing a moderate drop. At this level, the pozzolanic activity of BA partly compensates for the cement reduction, maintaining acceptable performance
30% Replacement:
The strength further decreased to 30.09 MPa at 28 days. This value marginally meets M30 requirements. Reduced cementitious material causes delayed hydration and insufficient C–S–H formation.
40% Replacement:
A significant reduction was observed with only 25.57 MPa at 28 days. At this high replacement level, the binder deficiency and incomplete pozzolanic reaction greatly weaken the concrete.

Key Observation:
Maximum compressive strength among modified mixes occurs at 10–20% replacement. Beyond 20%, the dilution effect dominates over pozzolanic benefits.

B. Strength Development with Curing Age
The strength gains between 7, 14, and 28 days follows typical cement hydration trends for all mixes.
However:
The rate of strength gain decreased with higher replacement levels.
Mixes containing BA exhibited improved later-age strength compared to early-age results due to delayed pozzolanic reaction.
CWP enhanced particle packing at lower percentages, improving early strength marginally.
Overall, Strength Growth Trend:
0% > 10% > 20% > 30% > 40%

C. Influence of Ceramic Waste Powder (CWP)
CWP primarily acts as:
1. Micro-filler: Reduces voids and improves packing density.
2. Partial pozzolan: Contributes marginally to later-age C–S–H gel formation.
At ≤ 15% CWP, the filler effect considerably enhances the internal matrix, improving compactness.
At > 20%, excessive inert content reduces effective cementitious compounds, thereby lowering strength.

D. Influence of Bagasse Ash (BA)
BA consists of amorphous silica, which reacts with $Ca(OH)_2$ to produce C–S–H gel.
Effects observed in this study:
Enhanced 28-day strength due to slow pozzolanic reaction.
Improved microstructure and reduced permeability.
At higher percentages (>20%), BA's low calcium content limits the total amount of hydration product formation.
Therefore, BA is beneficial up to moderate levels, beyond which it negatively affects strength
E. Combined Effect of CWP and BA
When used together in equal proportions:
CWP improves early-age compactness.
BA contributes to long-term strength via pozzolanic activity.
This complementary behavior explains why 10–20% replacement shows acceptable strength, while ≥30% replacement exhibits significant performance decline.

F. Optimum Replacement Level
Based on experimental data:
Optimum Range: 10–20% cement replacement
Provides:
Acceptable 28-day strength (≥33 MPa)
Reduced cement content and cost
Environmental benefits by utilizing industrial/agricultural waste
Improved sustainability without compromising structural safety

G. Comparison with Literature
The results align closely with previous studies:
Many researchers reported optimum ceramic waste replacement at 10–20%.
Bagasse ash showed beneficial effects between 10–15% replacement.

The current study confirms similar behaviour when used in combination, supporting their use as supplementary cementitious materials (SCMs).

H. Summary of Findings

Replacement (%)	28-Day Strength (MPa)	Suitability
0%	40.19	Excellent (Reference)
10%	35.65	Good – Meets M30
20%	33.41	Acceptable – Optimal Range
30%	30.09	Borderline for M30
40%	25.57	Not Suitable for Structural Use

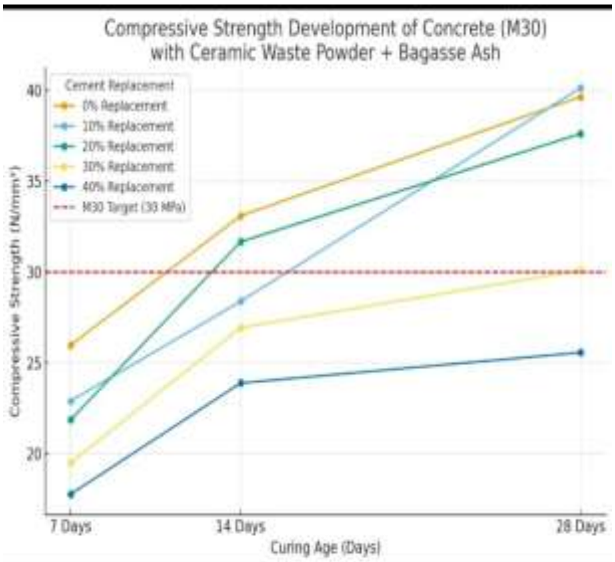
B. Split Tensile Strength Test

The Split Tensile Strength Test is an indirect method used to determine the tensile strength of concrete. Since concrete is weak in tension and direct tensile tests are difficult to perform, this test provides a practical way to estimate its tensile capacity. The test is conducted on a cylindrical concrete specimen, usually of size 150 mm diameter and 300 mm height.

In this test, the cylinder is placed horizontally between the loading surfaces of a compression testing machine. A compressive load is applied gradually along the length of the cylinder. As the load increases, it creates a tensile stress perpendicular to the direction of loading. When the tensile stress exceeds the tensile strength of concrete, the specimen splits vertically into two halves.

The maximum load at failure is recorded, and the split tensile strength is calculated using the standard formula as per IS 5816:1999.

This test helps in evaluating the concrete's resistance to cracking, which

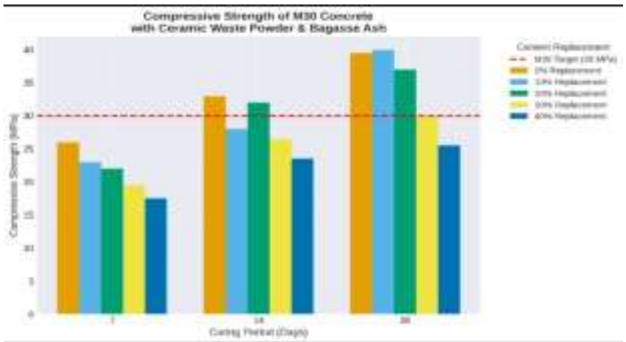


is crucial for structural elements like pavements, slabs, roads, water tanks, and precast members. It is widely used in laboratory investigations and quality control of construction materials.

Replacement %	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
0%	2.40	2.90	3.10
10%	2.45	2.80	3.25
20%	2.50	2.75	3.30
30%	2.30	2.70	2.95
40%	2.10	2.70	2.75

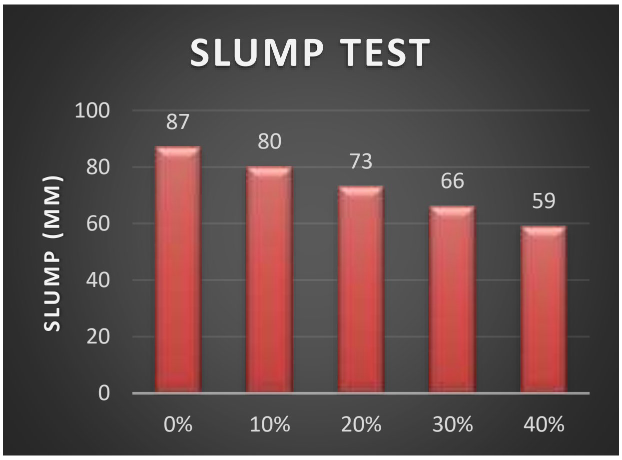
- Strength improves at 10–20% replacement due to pozzolanic reaction.
- Beyond 20%, tensile strength decreases because cementitious content is reduced.

C. SLUMP CONE TEST



The slump cone test is one of the most widely used methods to determine the workability of freshly mixed concrete. Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished without segregation or loss of consistency.

The test is conducted using a standard slump cone apparatus, also known as the Abrams cone, which is a hollow frustum-shaped mould.



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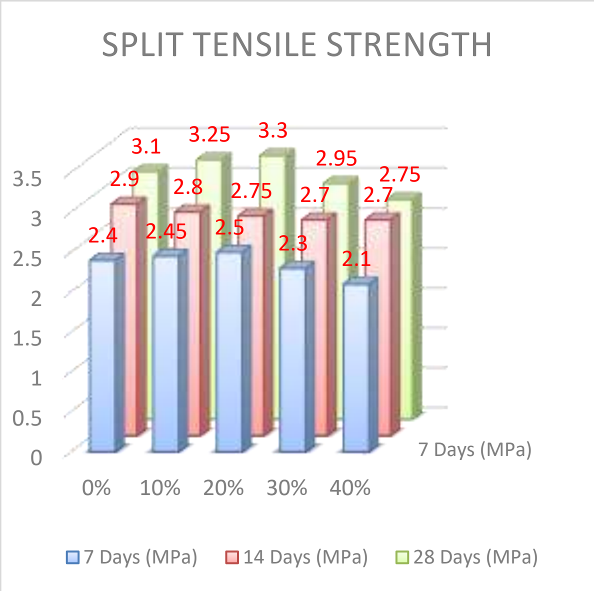
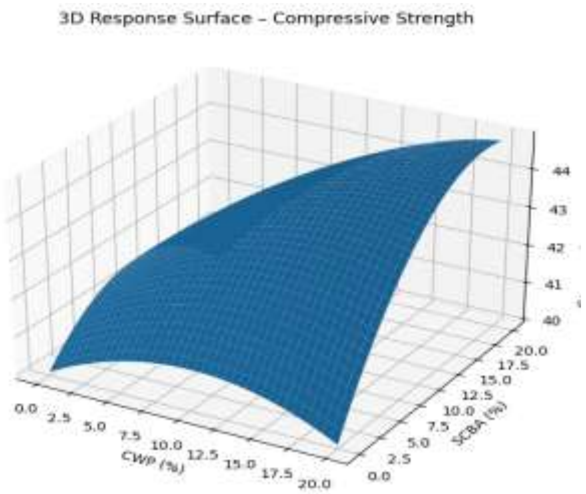


- Workability decreases with higher replacement.
- Finer particles in CWP & SCBA increase water demand.
- Can be improved using superplasticizers.

D. RSM (Response Surface Methodology) Analysis

This 3D surface plot illustrates how Ceramic Waste Powder (CWP) and Sugarcane Bagasse Ash (SCBA) together influence the 28-day compressive strength of concrete. The plot is based on a quadratic Response Surface Methodology (RSM) model.



The 3D response surface for 28-day compressive strength reveals a curved ascending trend with respect to both CWP and SCBA contents. Strength increases steadily with increasing levels of both SCMs and reaches a maximum when CWP and SCBA are used in the approximate range of 18–20%. The pronounced curvature confirms the significance of quadratic and interaction effects in the fitted RSM model. The synergy between CWP (filler effect) and SCBA (pozzolanic reaction) results in an optimum compressive strength of around 44–45 MPa in the upper right region of the design space.

4. CONCLUSIONS

- The research demonstrates that the utilization of ceramic waste powder and bagasse ash as partial replacement of cement in M30 grade concrete is technically feasible, environmentally sustainable, and economically viable.
- The experimental results confirm that:

Replacement %	Slump (mm)
0%	87
10%	80
20%	73
30%	66
40%	59

- Replacement levels up to 20% can be adopted without compromising the compressive strength of M30 concrete.
- 10–20% replacement is the most effective range, where strength properties are either equal to or slightly superior to conventional concrete.
- Replacement levels beyond 30% lead to a decline in strength and are not recommended for structural applications.
- Thus, the optimum replacement percentage for practical use can be considered as 20%, balancing strength performance and sustainability benefits.

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