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*Original Article*

# Experimental Study of the Effect of Ceramic Waste Powder on the Mechanical and Structural Properties of Concrete: A Sustainable Approach

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***Abstract** - This research article aims to assess the impact of substituting fine aggregates in concrete with Ceramic Waste Powder at different proportions (conventional, 5%, 10%, 15%, and 20%) on the deflection behaviour of reinforced concrete beams. This study aims to identify the optimal replacement percentage that minimizes deflection compared to conventional concrete, consequently enhancing structural performance. This article presents the results of an experimental investigation into the impact of Ceramic Waste Powder (CWP) on concrete's mechanical properties and performance. The study assessed concrete specimens' compressive strength, split tensile strength, and deflection behaviour with varying CWP replacement percentages. The results demonstrated that adding CWP had a negligible impact on concrete's compressive and divided tensile forces. However, the deflection behaviour of the concrete beams with 10% CWP replacement was superior to that of the conventional beams. This indicates that the incorporation of CWP into concrete can enhance structural performance. Ultrasonic Pulse Velocity (UPV) tests demonstrate that incorporating 10% CWP into concrete preserves the structure's integrity, presenting CWP as an environmentally friendly production alternative. The findings show the viability of CWP as an option for sustainable waste management in the construction industry. To achieve a balance between improved deflection behaviour and acceptable strength characteristics in concrete structures, a 10% CWP replacement level is recommended. This research contributes to understanding the advantages and limitations of CWP in concrete, thereby providing valuable insights for future sustainable construction practices.*

***Keywords** - Concrete, Fine aggregates, Ceramic Waste Powder, Deflection behaviour, Reinforced concrete beams, Structural performance, Ultrasonic Pulse Velocity (UPV).*

## 1. Introduction

Concrete is the most widely used construction material globally, and its production is a significant source of greenhouse gas emissions. The International Energy Agency reports that cement production alone accounts for 7% of global $CO_2$ emissions. To mitigate the construction industry's environmental impact, finding ways to make concrete production more sustainable is essential. Finding alternative materials for fine aggregates, such as sand, is one way to make concrete production more sustainable.

Fine aggregates account for 30 to 35 percent of the concrete volume and provide the mixture with the necessary workability and strength [1]. However, the mining and extracting natural sand can have severe environmental significance, with habitat destruction, water pollution, and soil erosion. Therefore, finding substitutes for fine aggregates in concrete is essential for sustainable building practices.

Ceramic tile manufacturing yields ceramic tile waste powder as a byproduct. It results from cutting or shaping ceramic tiles to specific dimensions or designs. Typically, this waste powder is disposed of in landfills, which can lead to environmental issues. However, this waste material can potentially replace fine aggregates in concrete [2]. Figure 1 depicts ceramic waste powder's manufacturing process highlights the sequential steps required to create this sustainable material. Ceramic tile waste powder is a fine powder with similar physical properties to cement.

It comprises common cement oxides such as silica, alumina, and others. It has been discovered that incorporating this waste powder into concrete increases the mechanical and durability behaviour of the resulting concrete [3]. In addition, the global demand for sand is growing. By 2100, the world's population will require an additional 230 billion tons of sand to meet the demand for construction materials. This demand for sand is causing environmental degradation, including habitat loss, biodiversity reduction, and soil erosion. Finding alternative materials for concrete's fine aggregates can reduce the demand for natural sand and mitigate the environmental impact of sand mining. Finding alternative materials for fine aggregates in concrete can lead to cost savings and environmental benefits [4].

Substituting waste materials for conventional materials can reduce the cost of raw materials and disposal fees. Finding and evaluating alternative materials for fine aggregates in concrete, such as ceramic tile waste powder is crucial for sustainable building practices. This research can lead to the development of new, more sustainable construction performs that simultaneously reduce the environmental influence of the construction industry and are cost-effective [5].


**Fig. 1 Steps involved in creating ceramic waste powder**

Ceramic tile manufacturing generates ceramic tile waste powder as a byproduct. It is produced when ceramic tiles are cut or shaped to accommodate specific dimensions or designs. Typically, this waste is discarded in landfills, which can cause environmental issues. Ceramic tile waste powder possesses similar properties to cement due to its composition of silica, alumina, and other common oxides [6]. It has been demonstrated that its addition to concrete improves the mixture's mechanical and durability properties. Ceramic tile waste powder can provide the construction industry with a more sustainable alternative to natural sand, decreasing the mandate for natural resources and mitigating the environmental impacts of sand mining.

Evaluating the potential of ceramic tile waste powder in concrete can lead to more sustainable, cost-effective and environmentally friendly construction practices [7]. Concrete production uses fine aggregates, mainly natural sand, from rivers and beaches, which harms the environment [8]. The addition of UPV testing expands the scope of material analysis by providing a non-destructive way to evaluate the quality of the concrete. The construction industry is struggling with resource depletion as acceptable aggregate demand rises. Concrete production can be made cheaper and greener using alternatives to fine aggregates. Sustainable and high-performance concrete requires materials that maintain or improve concrete properties. Searching for alternative materials can also promote construction industry innovation and research, leading to new materials and technologies [9, 10]. Figure 2 depicts the ceramic waste powder used in this study.

1. Fine aggregates were extracted from rivers, beaches, and other natural sources, harming the environment. Alternatives to fine aggregates can reduce concrete production's environmental impact.
2. Due to the construction industry's prompt expansion, the demand for fine aggregates is increasing. As a result, natural resources like sand are becoming scarcer, which can result in a price increase. Alternative materials can aid in reducing reliance on natural resources.
3. Due to depletion, fine aggregates, mainly natural sand, cost more. Fine aggregates can be replaced with waste, recycled, or crushed glass. This reduces concrete production costs while maintaining quality.
4. Concrete workability, strength, and durability depend on fine aggregates. High-performance and sustainable concrete can be made from alternative materials that maintain or improve these properties.
5. Searching for alternative materials in construction leads to innovation, research, and enhanced concrete durability and performance.

**Fig. 2 Ceramic waste powder**

The novelty of this study resides in its exhaustive evaluation of the effect of Ceramic Waste Powder (CWP) on the mechanical behaviour of concrete, with a particular emphasis on deflection properties. This research investigates the impact of varying CWP proportions (ranging from conventional to 20%) on the deflection performance of reinforced concrete beams. Unlike previous studies, which frequently focused on the compressive and split tensile strengths, this study investigates the effect of varying CWP proportions (ranging from conventional to 20%) on the deflection behaviour of reinforced concrete beams. In addition, identifying an optimal replacement percentage (10% CWP) that improves structural performance while maintaining acceptable strength characteristics represents a significant advancement in sustainable concrete technology. Moreover, incorporating Ultrasonic Pulse Velocity (UPV) testing is essential to this inquiry. This study demonstrates the potential of CWP as a sustainable waste management option in construction diligence. Still, it provides valuable insights for guiding future practices towards more environmentally conscious and structurally efficient concrete structures.

### *1.1. The Objective of the Research*

The primary purpose of this article is to assess the impact of incorporating ceramic waste powder as a part standby for fine aggregates in concrete at different percentages (conventional, 5.00%, 10.00%, 15.00%, and 20.00%) on the strength of compression, split tensile and deflection behaviour of reinforced concrete beams. The learning aims to identify the optimal replacement percentage that minimizes deflection compared to conventional concrete, thus enhancing structural performance.

## 2. Literature Review

The reviewed studies collectively highlight the potential of incorporating ceramic waste into concrete applications. The findings demonstrate improved mechanical properties, enhanced durability, and reduced environmental impacts when ceramic waste is utilized as a limited standby for conventional materials in concrete manufacture. These sustainable practices offer promising solutions for waste management, resource conservation, and climate change mitigation in the construction industry. Ceramic waste as a sustainable alternative in concrete production has become essential in recent years.

This literature examination aims to summarize and analyze various studies exploring the incorporation of ceramic waste into concrete, focusing on its impact on the mechanical properties, durability, and sustainability of the resulting concrete composites. [11] Jie Liu et al. (2023) investigated polymers' compressive and fracture tensile strengths incorporating refuse ceramics as fine aggregate based on sulfur. The results demonstrated that the polymer with refuse ceramics as fine aggregate exhibited superior strength to polymers with conventional or river grains.

The study also identified distinct trends in pore distribution, which significantly influenced the strength variations of the composites. [12] Lilesh Gautam et al. (2023) evaluated the durability of self-compacting concrete containing bone-China ceramic particles and granite-cutting refuse. The findings revealed that the durability of self-compacting concrete improved when bone-China ceramic particles and granite-cutting refuse were replaced. However, concrete modified with ceramic granite demonstrated reduced weight and compressive strength compared to conventional concrete, up to the optimal replacement level. This study highlighted the potential of industrial residues in self-compacting concrete as a sustainable waste management solution with reduced $CO_2$ emissions. [13] Chang et al. (2023) used supervised machine learning algorithms to predict the compressive strength of ceramic waste powder concrete, revealing the RF algorithm's highest efficiency and lower RMSE and MAE values. The 10% ceramic waste powder in concrete reduced environmental impacts.

[14] Chokkalingam et al. (2022) considered geopolymer concrete durability and mechanical belongings using slag and CWP. Results showed deterioration with CWP as the sole binder, but linking 40% of CWP and 60% of slag improved performance. [15] Liqing Zhang et al. (2023) explored the usage of Ceramic Waste Tile Aggregate (CTWA) in Ultrahigh-Performance Concrete (UHPC) to minimize carbon emissions. The study revealed that incorporating CTWA reduced the flow ability of UHPC, but the concrete still exhibited a spread flow of 398 millimetres when 100% CTWA was used. At 28 days of curing, UHPC with CTWA displayed enhanced mechanical properties, including increased compressive and flexural strength. Microstructure analysis confirmed improvements in the Interfacial Transition Zone (ITZ) plus pore structure due to internal curing and improved particle gradation.

[16] Hamad Achak et al. (2023) investigated the use of Ceramic Waste (CW) as a partial replacement for natural coarse aggregates in Self-Compacting Concrete (SCC). They discovered that increasing the percentage of CW negatively affected efficacy, whereas adding M and PP fibres increased viscosity. CW50M10P0.15 possessed the greatest compressive strength, CW25M5P0.3 had the most excellent tensile and flexural strengths, and CW25M10P0.3 possessed the greatest electrical resistivity. [17] Ali Altheeb et al. (2023) inspected the possibility of consuming ceramic tile residue as a substitute for natural aggregates in alkali-activated mortars.

The study found that alkali-activated mortars with 100% ceramic tile residue achieved comparable strengths to the control specimens. Additionally, adding higher fly ash content enhanced the durability performance, increasing the porosity and reducing abrasion resistance. [18] Jianyu Yang et al. (2023) developed an Artificial Intelligence (AI) model for concrete incorporating Ceramic Waste Powder (CWP) to reduce environmental contamination and waste generation [19]. The XG Boost model exhibited superior performance, as evidenced by higher R2 and lower RMSE and MAE values. This AI-based model has the potential to be implemented in construction projects to mitigate land degradation and water pollution associated with CWP concrete. [20, 21] Rachied et al. (2023) found that combining CWP and blast furnace slag can restore reinforced concrete strength and structural performance. A ternary binder with 10%, 35% and 55% of CWP, BF Sand cement reversed the decline in flexural, shear, and bond strengths, increasing CWP's value in construction. [22, 23] Xuyong Chen et al. (2022) developed Recycled Aggregate Concrete (RAC) by partially substituting Portland cement with CWP. The study demonstrated that RAC with CWP achieved higher strength and reduced costs, thermal energy intake, and carbon emissions.

The consumption of CWP in RAC presents an environmentally sustainable approach to waste reuse, yielding favourable outcomes. [24] Joshi et al. (2023) conducted a review focusing on using CW in self-compacting concrete. The study investigated the effects of various design elements, such as the ratio of water-to-cement, ratio of water-to-binder, super-plasticizer dosage, and replacement percentage of ceramic waste. The findings emphasized the importance of these design parameters in achieving desired properties and performance in self-compacting concrete incorporating ceramic waste.

Compression and split tensile tests, as well as Ultrasonic Pulse Velocity (UPV) and deflection analysis with Linear Variable Differential Transformers (LVDTs) were used to assess concrete properties in this study. Compression tests determined load-bearing capacity, whereas split tensile tests determined tensile strength. Using high-frequency pulses, the UPV test revealed information about structural integrity. LVDTs enabled precise deflection measurements, allowing for CWP-based concrete strength evaluations. This multifaceted methodology ensured the accuracy and dependability of the data, laying the groundwork for solid conclusions. Incorporating cutting-edge technologies and rigid testing protocols increases the credibility and significance of the learning results in concrete behaviour and performance evaluation.

## 3. Experimental Investigation

The experimental investigation tested 150mm x 150mm concrete cubes for their compressive strength to determine their performance. For different percentages of CWP incorporation, the average compressive strength values were measured in Mega Pascals (MPa). The investigated ratios include 0%, 5%, 10%, and 20% of CWP with partial acceptable aggregate replacement in the concrete mix. The compressive strength tests were conducted after 7, 14, and 28 days of curing. The obtained results spotlight the effect of CWP on the compressive strength properties of the concrete cubes, highlighting any improvements or variations caused by the varying percentages of CWP replacement. Figure 3 depicts the concrete cubes cast with different amounts of CWP. Figure 4 represents the post-casting condition of concrete cubes containing varying quantities of CWP. The experimental investigation on split tensile strength involved testing concrete cylinders with changing percentages of CWP replacement. Results showed a decreasing trend in split tensile strength with increased CWP replacement. The conventional concrete exhibited the highest split tensile strength, while the 20% replacement showed the lowest.

However, the 10% replacement slightly improved split tensile strength related to conventional concrete. This suggests that the partial substitution of fine aggregates with CWP can positively impact the mechanical performance of the concrete mixture. Figure 5 illustrates the variations in the appearance of concrete cylinders with different percentages in CWP during the curing process. On the other hand, Figure 6 showcases the concrete cylinders with varying ratios of CWP after casting, providing visual evidence of the fusion of ceramic waste in the concrete mixture.

**Fig. 3 Concrete cubes with 0%, 5%, 10%, and 20% ceramic waste powder during casting**

**Fig. 4 Concrete cubes with 0%, 5%, 10%, and 20% ceramic waste powder after casting**

The experimental investigation involved casting and testing six supported concrete beams to evaluate their deflection behaviour. The beams were designed following IS 456-2000, and the concrete mix design followed IS

10262:2009 guidelines. The beams' dimensions were 1000mm in length and 300x300mm in cross-sectional dimension. The definite mix proportion used was 1.1:1.81:2.84 with a compressive strength of 30MPa. Each beam was reinforced with two φ12mm longitudinal bars at the bottom and top and φ8mm stirrups at 150mm centre-to-centre spacing. The adequate cover provided was 25mm. A single point load (P) was applied at the centre of the span within the effective length of the beams. The load application was performed using a Universal Testing Machine (UTM) with a capacity of 2000 kN.

**Fig. 5 Concrete cylinders with 0%, 5%, 10%, and 20% CWP during curing**

**Fig. 6 Concrete cylinders with 0%, 5%, 10%, and 20% CWP after casting**

Out of the six beams, three beams were cast as conventional concrete beams, while the remaining three had delicate aggregate parts with ceramic waste powder of 10%. During the testing, the deflection behaviour of the beams was measured using LVDT sensors to determine the influence of ceramic waste powder on the deflection characteristics of the beams. The experimental investigation aims to provide insights into the effect of the partial replacement of fine aggregate with ceramic waste powder on the deflection behaviour of reinforced concrete beams, contributing to the understanding of sustainable practices in concrete production. Table 1 displays the material belongings utilised for this experiment. Employing LVDT Figure 7 depicts the experimental setup used in this study. Figure 8 illustrates the presence of cracks in beams.

**Fig. 7 Experimental setup**

**Fig. 8 Cracking in beams**

The experimental procedure involved casting and testing concrete beams to investigate the deflection behaviour using LVDT with and without partially acceptable aggregate replacement using ceramic waste powder. Each of the six beams had a length of 1000mm and a cross-sectional area of 300x300mm. The concrete mixture proportions adhered to industry standards for concrete mix design.

Three beams were cast without any replacement, while 10% ceramic waste powder was utilised as a partial standby for fine aggregate in the remaining three beams. The testing procedure involved applying progressive loads to the beams and measuring the resulting deflections. Gradual load increments were used, beginning with a low load and gradually increasing to the maximum load. The beam deflection was measured and averaged at each load increment for the conventional (0% replacement) and 10% replacement beams. Figure 9 depicts an illustration of the beam used in the present investigation.

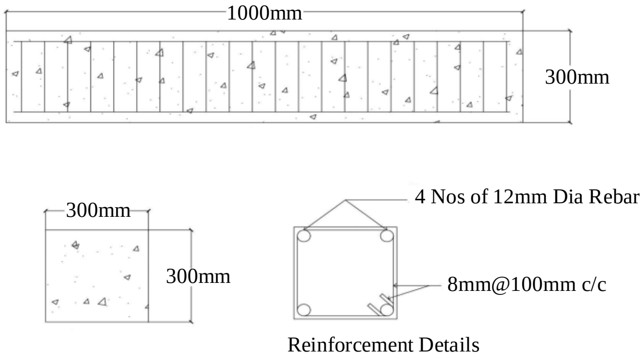


**Fig. 9 A detailing of the beam employed in this study**

Using LVDT, the deflection values were meticulously measured throughout the testing process. The average deflection values of conventional beams and those with 10% replacement were recorded and compared. The goal was to observe and evaluate any differences in deflection behaviour between the two beam types. Analyzing the recorded deflection data determined the effect of the partial replacement of fine aggregate with ceramic waste powder on concrete beams' deflection characteristics. The experimental procedure enabled a thorough evaluating the beams' structural performance and deflection behaviour yields valuable insights into the probable advantages of consuming powdered ceramic waste as a sustainable alternative in concrete production.

**Table 1. Properties of materials**

| Test | Cement | Fine Aggregate | Coarse Aggregate |
|---|---|---|---|
| Consistency % | 30. 0 | - | - |
| Initial setting time, mins | 190 | - | - |
| Final setting time, mins | 330 | - | - |
| Specific gravity | 3.08 | 2.59 | 2.68 |
| Fineness | 2.7 | 3.04 | |
| Water absorption % | - | 3.12 | 3.71 |
| Silt content % | - | 3.2 | - |
| Bulk density, kg/m$^3$ | Loose | 1605.4 | 1364.2 |
| | Compact | 1835.2 | 1556.3 |

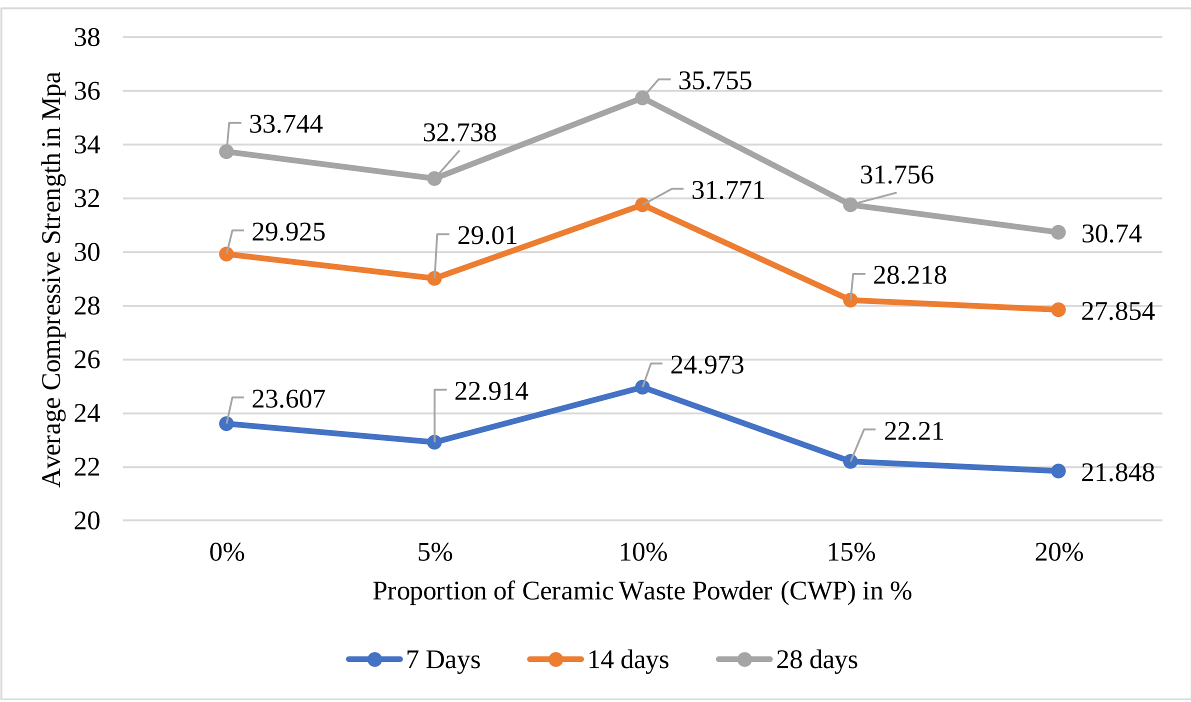


**Fig. 10 Average compressive strength comparison for concrete with 0%, 5%, 10%, and 20% CWP**

## 4. Results and Discussion

### 4.1. Compressive Strength

The investigational findings illustrate the mean compressive strength of concrete specimens with varied percentages of CWP at various curing durations. As indicated in Table 2, the compressive strength measurements were taken at seven days, 14 days, and 28 days of curing. The average compressive strength values exhibit an upward trend over time for the concrete samples without any CWP (0% replacement). Specifically, the average compressive strength is recorded as 23.607 MPa at seven days of curing, increasing to 29.925 MPa at 14 days and 33.744 MPa at 28 days.

When 5% of the fine aggregate is replaced with CWP, the average compressive strength values slightly decrease compared to the 0% replacement. The average compressive strength at seven days is 22.914 MPa, which slightly increases to 29.01 MPa at 14 days and 32.738 MPa at 28 days increasing the percentage of CWP to 10% results in a higher average compressive strength than the 0% and 5% replacement.

The compressive strength values for the 10% replacement are 24.973 MPa at seven days, 31.771 MPa at 14 days, and 35.755 MPa at 28 days. For the 15% and 20% replacement of fine aggregate with CWP, the average compressive strength values decrease compared to the 0% and 10% replacement.

**Table 2. Average compressive strength (MPa) of 150mmx150mm concrete cubes**

| % / Days | 7 Days | 14 Days | 28 Days |
|---|---|---|---|
| 0% | 23.607 | 29.925 | 33.744 |
| 5% | 22.914 | 29.01 | 32.738 |
| 10% | 24.973 | 31.771 | 35.755 |
| 15% | 22.21 | 28.218 | 31.756 |
| 20% | 21.848 | 27.854 | 30.74 |

At seven days, the compressive strength values are 22.21 MPa and 21.848 MPa for 15% and 20% replacement, respectively. These values increase to 28.218 MPa and 27.854 MPa at 14 days and 31.756 MPa and 30.74 MPa at 28 days for 15% and 20% replacement, correspondingly. Figure 10 demonstrates that replacing fine aggregate with CWP can impact the compressive strength of concrete. 10% replacement may increase the strength, whereas more significant percentages decrease the power. Additional analysis and testing is required to determine the optimal CWP replacement percentage for the desirable strength and mechanical properties.

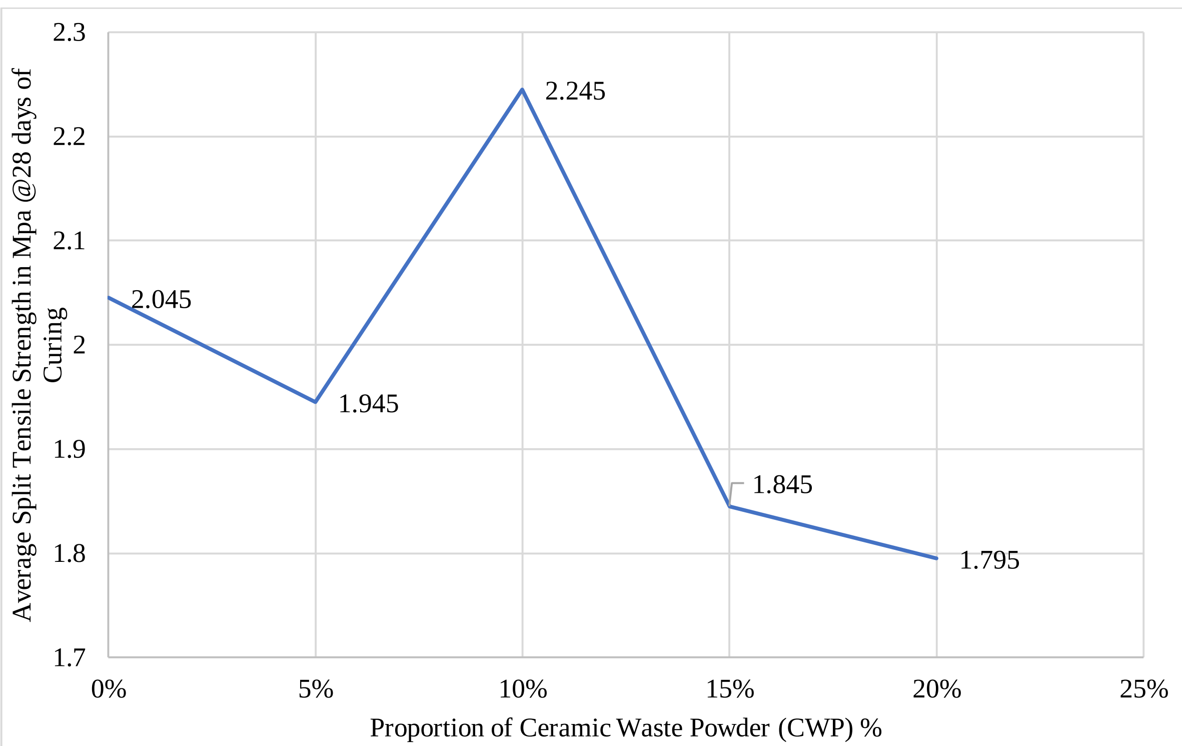


**Fig. 11 Average split tensile strength (MPa) of concrete cylinders with various CWP replacement proportions**

### 4.2. Split Tensile Strength

The split tensile strength of concrete cylinders with varying CWP percentages is offered in Table 3. The average strength of conventional concrete was 2.045 MPa, but it decreased to 1.94 MPa when 5% fine aggregates were replaced with CWP. As the CWP replacement percentage increased, its strength diminished progressively. At 10% workforce replacement, the average split tensile strength was 2.2445 MPa, representing a modest improvement over the 5% replacement scenario. The study discovered that CWP replacement considerably impacts the tensile strength of split concrete. With a 10% replacement, the concrete's strength was marginally superior to conventional concrete, but the strength decreased progressively beyond this percentage. Figure 11 depicts the average split tensile strength of concrete cylinders with changing amounts of CWP replacement.

### *4.3. Investigating Deflection Evaluation with LVDT Technology*

The experimental results reveal the deflection behaviour of concrete beams with and without the partial substitution of fine aggregate using ceramic waste powder. The recorded average deflection values for various load increments are tabulated for the 0% replacement (conventional) and 10% replacement beams. In the case of the traditional beams (0% replacement), the rays showed an increasing average deflection with increased applied load.

**Table 3. Average split tensile strength (MPa) of concrete cylinders with different percentages of CWP replacement**

| Cylinder No. | Conventional | 5% Replacement | 10% Replacement | 15% Replacement | 20% Replacement |
|---|---|---|---|---|---|
| 1 | 2.1 | 2 | 2.3 | 1.9 | 1.85 |
| 2 | 2.05 | 1.95 | 2.25 | 1.85 | 1.8 |
| 3 | 2 | 1.9 | 2.2 | 1.8 | 1.75 |
| 4 | 2.15 | 2.05 | 2.35 | 1.95 | 1.9 |
| 5 | 1.95 | 1.85 | 2.15 | 1.75 | 1.7 |
| 6 | 2.1 | 2 | 2.3 | 1.9 | 1.85 |
| 7 | 2 | 1.9 | 2.2 | 1.8 | 1.75 |
| 8 | 2.2 | 2.1 | 2.4 | 2 | 1.95 |
| 9 | 1.9 | 1.8 | 2.1 | 1.7 | 1.65 |
| 10 | 2 | 1.9 | 2.2 | 1.8 | 1.75 |
| Average | 2.045 | 1.945 | 2.245 | 1.845 | 1.795 |

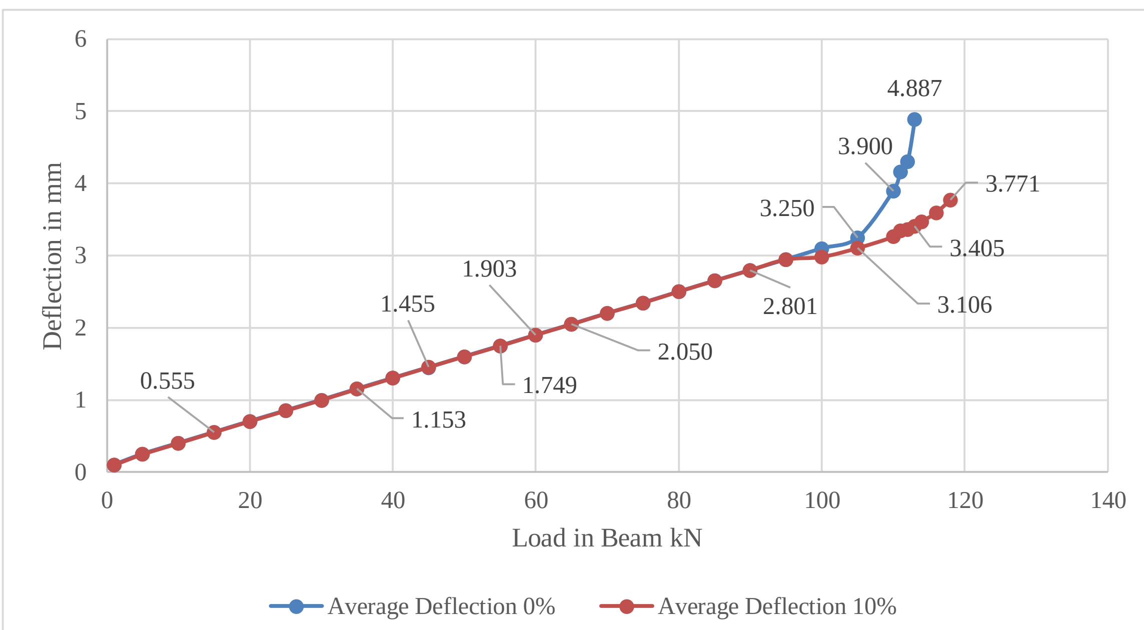


**Fig. 12 Average deflection of concrete beams with 0% and 10% CWP until failure**

The initial cracks were observed at loads of 92 kN, 94 kN, and 93 kN for Beam 1, Beam 2, and Beam 3, respectively. However, the beams failed at a load of 113 kN, and the data for loads of 114 kN, 116 kN, 118 kN, and 120 kN are missing from the provided results. This indicates that the conventional beams could not sustain the higher loads beyond 113 kN, failing. Similar trends were observed in deflection behaviour with increasing load for the beams with

10% replacement of fine aggregate using ceramic waste powder. The initial cracks were observed at 97 kN, 99 kN, and 101 kN for Beam 1, Beam 2, and Beam 3, respectively. However, the beams continued to withstand higher loads, and failure occurred at 118 kN. The data for loads of 114 kN, 116 kN, and 120 kN are also missing in this case.

**Table 4. Average comparative deflection of concrete beams with 0% and 10% CWP until failure**

| Load (kN) | Average Deflection 0% | Average Deflection 10% |
|---|---|---|
| 1 | 0.102 | 0.101 |
| 5 | 0.250 | 0.249 |
| 10 | 0.402 | 0.402 |
| 15 | 0.553 | 0.555 |
| 20 | 0.705 | 0.705 |
| 25 | 0.853 | 0.853 |
| 30 | 1.000 | 1.000 |
| 35 | 1.154 | 1.153 |
| 40 | 1.304 | 1.304 |
| 45 | 1.453 | 1.455 |
| 50 | 1.602 | 1.604 |
| 55 | 1.751 | 1.749 |
| 60 | 1.902 | 1.903 |
| 65 | 2.050 | 2.050 |
| 70 | 2.202 | 2.205 |
| 75 | 2.348 | 2.348 |
| 80 | 2.503 | 2.503 |
| 85 | 2.653 | 2.653 |
| 90 | 2.800 | 2.801 |
| 95 | 2.949 | 2.949 |
| 100 | 3.102 | 2.984 |
| 105 | 3.250 | 3.106 |
| 110 | 3.900 | 3.262 |
| 111 | 4.158 | 3.345 |
| 112 | 4.306 | 3.367 |
| 113 | 4.887 | 3.405 |
| 114 | - | 3.474 |
| 116 | - | 3.594 |
| 118 | - | 3.771 |
| 120 | - | - |

The deflection measurements were carried out using LVDT sensors placed at the centre of the effective span of the beams. This ensured accurate and consistent measurements of the deflection behaviour throughout the testing process. Comparing the deflection behaviour between the conventional beams and those with 10% replacement, it can be observed that the beams with the partial replacement of fine aggregate exhibited better load-carrying capacity. The 10% replacement beams sustained higher loads without failure than conventional beams, indicating improved structural performance. The experimental results highlight the potential benefits of incorporating ceramic waste powder as a part substitution for concrete with fine aggregate production. The 10% replacement beams demonstrated enhanced structural performance, with a higher load-carrying capacity and better resistance to failure. Overall, the experimental findings indicate that the partial replacement of fine aggregate with ceramic waste powder can effectively improve the structural performance of concrete beams, as evidenced by reduced deflection and enhanced load-carrying capacity.

Figure 12 presents the average deflection behaviour of concrete beams until failure with 0% and 10% CWP replacement. This figure illustrates the disparate deflection characteristics of conventional concrete beams and those incorporating 10% CWP, shedding light on the potential structural performance improvements that can be achieved by combining CWP in concrete beams. Comparative Average Deflection of Concrete Beams with 0% and 10% CWP until Failure is shown in Table 4.

**Fig. 13 UPV experiment conducted using concrete samples**

## 5. Non-Destructive Test

Non-Destructive Testing (NDT) is crucial for evaluating innovative materials such as CWP used in concrete production. NDT provides vital information without compromising the structural integrity of the specimens [25].

### *5.1. Ultrasonic Pulse Velocity*

Ultrasonic Pulse Velocity (UPV) testing, a non-destructive technique, is indispensable for determining concrete's structural integrity and material properties. In the context of this study, UPV is instrumental in assessing comprehensively the impact of substituting fine aggregates with 10% CWP, which is optimal. UPV measures the time the waves travel from the sending to the receiving transducer by transmitting high-frequency ultrasonic pulses through concrete specimens. This information is then utilized to calculate the pulse velocity in kilometres per second (km/s). Figure 13 illustrates the experimental setup for the UPV test carried out on concrete specimens.

**Table 5. UPV results for concrete specimens with 0% and 10% CWP replacement**

| Specimen No. (100mm X 200mm) | Average Value of Pulse Velocity (km/s) | | Quality of Concrete as per IS 516 (Part 5, Sec 1) - 2018 |
|---|---|---|---|
| | CWP 0% | CWP 10% | |
| 1 | 4.12 | 4.28 | Good |
| 2 | 4.14 | 4.25 | Good |
| 3 | 4.11 | 4.33 | Good |
| 4 | 4.21 | 4.35 | Good |
| 5 | 4.22 | 4.32 | Good |

As shown in Table 5, the results indicate that, on average, the pulse velocity values at 0% and 10% CWP replacement levels fall within the range associated with high-quality concrete. This suggests that the totalling of Ceramic Waste Powder did not meaningfully disturb the structural integrity and homogeneity of the concrete samples. These results are consistent with the principles outlined in IS 516 (Part 5, Sec 1) - 2018, further validating the suitability of CWP as a viable alternative material for sustainable concrete production. This UPV analysis provides valuable insights into the material possessions of the concrete samples. It contributes to a broader understanding of how CWP can be utilized effectively in concrete construction to improve sustainability.

## 6. Conclusion

Depending on the comprehensive investigational studies conducted on concrete samples, including strength of compression, split tensile, and deflection, the following key conclusions can be highlighted:

1. The concrete strength of compression exhibits a reducing trend as the percentage of CWP replacement increases, specifically for the 5%, 15%, and 20% replacement levels. However, a notable exception is observed at the 10% CWP replacement, where the compressive strength performs better than conventional concrete. At 28 days of curing, the compressive strength of the 10% CWP replacement reaches 35.75 MPa, surpassing the power of traditional concrete, which measures approximately 33.74 MPa. These findings indicate that incorporating 10% CWP replacement in concrete positively influences its compressive strength, suggesting the potential for utilizing CWP as a beneficial component in concrete production.
2. The concrete strength of split tensile displays a consistent pattern, whereby there is a rise in the percentage of CWP replacement, precisely at 5%, 15%, and 20% levels) effects in a decrease in split tensile strength. However, the 10% CWP replacement demonstrates enhanced split tensile strength, measuring at 2.245 MPa, surpassing the value of conventional concrete at 2.045 MPa. This indicates that incorporating a 10% CWP replacement positively influences the concrete split tensile strength, highlighting its potential to improve the material's tensile properties.
3. The analysis of the deflection behaviour indicates that higher percentages of CWP replacement led to increased deflections, highlighting potential concerns regarding structural behaviour. However, the concrete sample with a 10% CWP replacement demonstrates similar deflection behaviour, measuring around 3.771mm until failure at a load of approximately 118kN. In comparison, the conventional concrete exhibits deflection behaviour of 4.887mm until failure at a load of 113kN. These results suggest that a 10% CWP replacement can be considered suitable for structural applications, as conventional concrete, while offering the benefits of showing comparable deflection behaviour to incorporating CWP as a sustainable material in construction.
4. These findings suggest that a partial replacement of fine aggregates with 10% CWP can be a viable option, as it offers improved split tensile strength and similar deflection behaviour compared to conventional concrete while still meeting the necessary strength requirements.
5. Concrete specimens with both a 10% and a 0% CWP replacement show UPV values within the range of high-quality concrete, according to UPV tests. This implies that the inclusion of CWP does not compromise structural integrity. The potential of CWP as a sustainable substitute in the production of concrete is highlighted by this finding.
6. The study highlights the potential of ceramic waste powder as a sustainable alternative in concrete production, offering both environmental benefits and satisfactory mechanical performance.
7. Further research should focus on optimizing the CWP replacement percentage and exploring strategies to mitigate any adverse effects on mechanical properties and structural behaviour.

Overall, the results of this research demonstrate the promising potential of incorporating ceramic waste powder in concrete at a 10% replacement level, indicating its feasibility for practical applications in the construction industry.

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