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Influence of Ceramic Waste on Properties of Fly Ash Blended Cement Concrete Pavement

Neeraj Singhal[1], Deepak Mathur[2]
[1]M. Tech Scholar, Department of Civil Engineering,
Kautilya Institute of Technology and Engineering, Jaipur, India
[2] Associate Professor, Department of Civil Engineering,
Kautilya Institute of Technology and Engineering, Jaipur, India

Abstract

The construction industry's increasing use of ceramic products, such as tiles and sanitary fixtures, has led to a surge in ceramic waste due to breakage at various stages, including manufacturing and installation. This rising concern has driven researchers to explore sustainable solutions, particularly focusing on reusing ceramic waste in construction materials to mitigate environmental impact and improve material properties. This study introduces a novel approach by examining the use of waste from floor and wall tiles as a substitute for natural aggregates in concrete mixes, a method especially relevant in India due to the wide availability of ceramic tiles.The research aims to evaluate the effects of incorporating ceramic waste into concrete, assessing mechanical properties like compressive, tensile, and flexural strength, alongside permeability and water absorption. By replacing fine aggregate with ceramic waste powder across a range of 0% to 50%, the study identifies an optimal replacement level for enhanced concrete performance. Among the tested mixes, the CW30 mixture stands out, significantly increasing compressive strength over time, with a notable peak in flexural strength and improved tensile strength up to a 20% replacement level. This mixture also demonstrated reduced water penetration, indicating better durability compared to the control mix.The findings reveal that ceramic waste can significantly enhance cement concrete's performance at certain replacement levels, highlighting the importance of determining the optimal threshold for waste incorporation. This approach not only offers a solution to ceramic waste disposal but also suggests a path toward more sustainable and high-quality concrete pavements. The study emphasizes the potential of waste ceramic integration in sustainable construction practices, potentially revolutionizing the industry by reducing environmental impacts and improving infrastructure durability and resilience.

Keywords: Concrete Pavement, Ceramic waste, mechanical strength, durability

1. Introduction

Ceramic products, encompassing tiles, electrical insulators, and sanitary fittings, have become integral to modern construction and building structures due to their versatility and aesthetic appeal. Predominantly crafted from natural clay, these items are pivotal in the architectural fabric of our built environment. However, the fragile nature of ceramics, prone to breakage during production, transportation, and installation phases, has precipitated a significant increase in ceramic waste globally. This burgeoning waste issue not only exacerbates environmental pollution but also presents a substantial challenge in waste management, urging nations like India to adopt specialized regulations and methodologies for mitigating the industrial waste surge. Despite notable advancements in waste management, achieving holistic sustainable development remains an ambitious goal. India, being the world's eighth-largest ceramic producer, accounts for approximately 2.5% of global ceramic output, bolstering employment for over half a million people. The ceramic sector, encompassing the manufacture of sanitary ware, electrical insulators, tiles, tableware, and glass, plays a crucial role in the nation's economy.

Concurrently, concrete's ubiquity as a construction material highlights the environmental footprint of its production, primarily due to the extraction and use of natural aggregates. This extraction not only depletes natural resources but also poses significant environmental challenges, propelling the cement industry towards innovative recycling and reuse strategies for aggregates. Amid growing environmental concerns, the reutilization of ceramic industrial waste in concrete production has emerged as a focal area of research, aiming to alleviate the ecological burden imposed by both the ceramic and construction sectors. For instance, Spain, responsible for nearly a quarter of the European Union's ceramic sanitary ware output, produces significant quantities of ceramic waste, highlighting the urgent need for sustainable disposal and recycling methods.

In Rajasthan, India, a nexus of over 500 enterprises engaged in ceramics, glass, sanitary ware, and mineral processing significantly contributes to the state's economic landscape, with Bikaner alone accounting for a substantial portion of the state's ceramic output. This production intensity results in considerable waste generation, necessitating efficient waste management solutions such as RIICO's provision of dumping yards for enterprise waste disposal.

Addressing these challenges necessitates a comprehensive investigation into the mechanical properties of concrete incorporating waste ceramic aggregates. Given the global diversity in ceramic production techniques, raw material behavior, and mix proportions, this study emphasizes the need to evaluate the impact of recycled ceramic aggregate on concrete properties, factoring in the unique characteristics of locally sourced tableware ceramic waste. Such an inquiry not only underscores the conservation of natural resources and reduction of transportation emissions but also aligns with global sustainability goals by comparing findings with international data.

The traditional manufacturing of glazed tiles, requiring dual firing processes, contrasts starkly with contemporary production methods that favor efficiency, reducing the firing to a singular, expedited operation. Modern tile production utilizes a blend of finely ground, uniform clays, fluxing agents, and recycled tile waste, aiming for minimal and consistent shrinkage. This formula, enriched with silica for glazes and various oxides for coloration, exemplifies the evolving practices in ceramic manufacturing, contributing to the waste stream.

This study sets forth several objectives: exploring the viability of substituting waste ceramic for natural aggregates in cement concrete mixes, examining the mechanical properties of such concrete compared to conventional mixes, assessing the long-term durability of waste ceramic-infused concrete, and evaluating the potential cost benefits and environmental advantages of incorporating waste ceramic materials in construction. Through these objectives, the research endeavors to contribute to the development of more sustainable construction materials and practices, reflecting a broader commitment to environmental stewardship and resource conservation.

In conclusion, the interplay between ceramic production and concrete manufacturing presents both challenges and opportunities in the pursuit of sustainable development. By focusing on the reuse of ceramic waste as an aggregate in concrete, this study not only addresses the pressing issue of waste management but also explores the potential for enhancing the mechanical and durability properties of concrete. In doing so, it advocates for a shift towards more sustainable construction practices, aiming to reduce the environmental impact of both the ceramic and construction industries, while fostering innovation and sustainability in the built environment.

2. Materials and Methodology

Ordinary Portland Cement (OPC) of grade 43 served as the binding agent, while natural river sand conforming to Zone II was utilized as the fine aggregate. Crushed stone, adhering to IS 383 standards, was employed as the coarse aggregate, and waste from ceramic tiles was used as a substitute for aggregate material.

A mix design for concrete was created after establishing the physical qualities of all the elements following the standards necessary for concrete pavement design. Total six concrete mixes were prepared with a water/binder ratio of 0.33 and Ceramic waste levels ranging from 0% to 50% at interval of 10% replaced with natural sand.

The quantities of materials required for each mix are given in Table1.

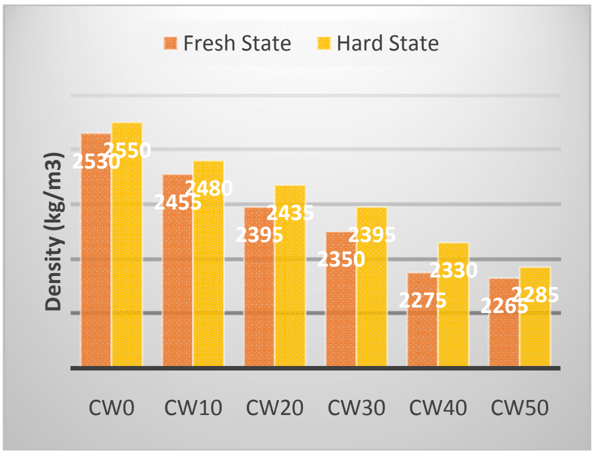
Concrete Mix Parameters

Mix No.	Ceramic Waste (%)	Cement (kg)	Fly Ash (kg)	Natural Sand (kg)	Ceramic Waste (kg)	Coarse Aggregate (kg)	Water
CW0	0%	332	142	719	0	1069	155
CW10	10%	332	142	647.1	71.9	1069	155
CW20	20%	332	142	575.2	143.8	1069	155
CW30	30%	332	142	503.3	215.7	1069	155
CW40	40%	332	142	431.4	287.6	1069	155
CW50	50%	332	142	359.5	359.5	1069	155

3. Results and Discussion

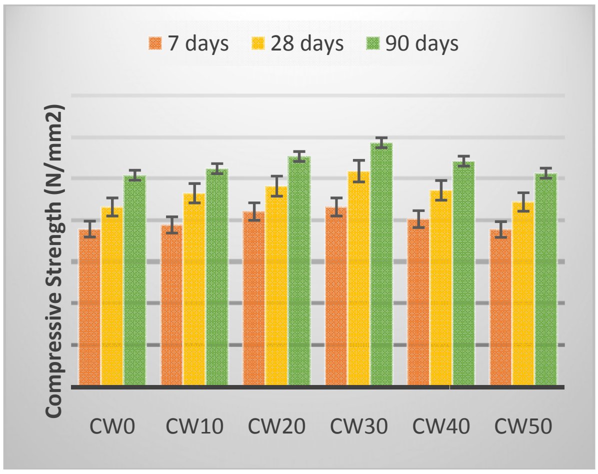
3.1 Fresh and Harden Density of concrete

The fresh density of concrete, determined by the mass-to-volume ratio of fully compacted concrete in a predetermined volume mold (e.g., cylinder, cube), varies between 2000 – 2300 Kg/m^3, influenced by material voids and specific gravity. Table 4.2 reveals that using waste ceramic as a fine aggregate substitute in concrete mixes leads to a decrease in concrete density, primarily due to the lower specific gravity and porous nature of ceramic waste. However, strength assessments indicate that this reduction in density does not compromise the load-bearing capacity of the concrete mixes.



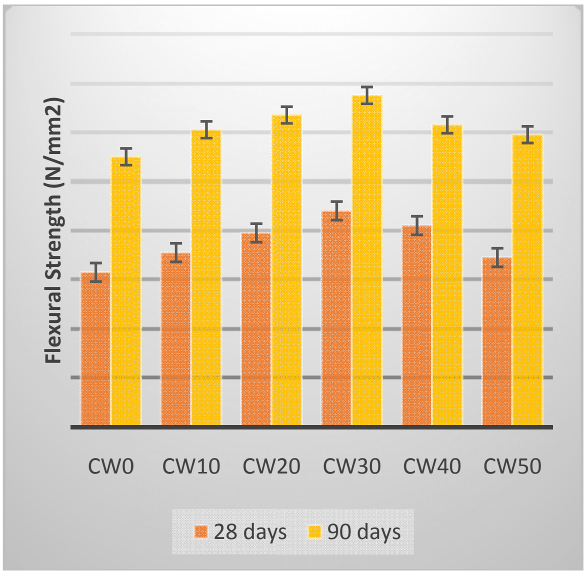
3.2 Compressive Strength

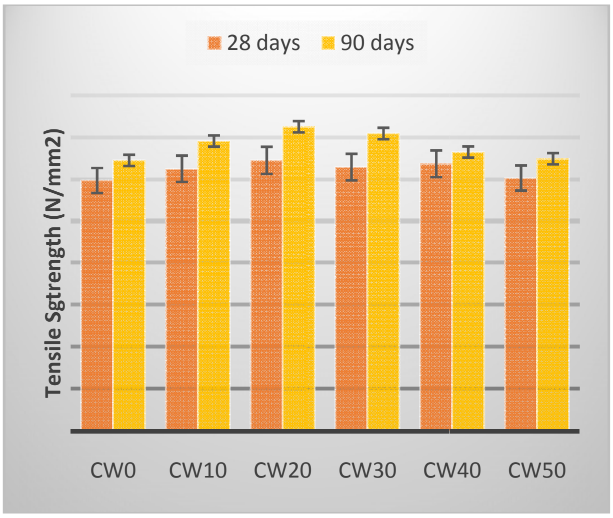
Compressive strength, crucial for determining concrete's usability and acceptance, shows improvement with the incorporation of ceramic waste as a replacement for conventional coarse aggregate. Compressive strength increases by 13%, 19%, and 15% at 7, 28, and 90 days, respectively, with the CW30 mix showing peak strengths of 43.2 MPa, 51.8 MPa, and 58.6 MPa after respective water curing periods. The increase in strength up to the CW30 mix is attributed to enhanced pozzolanic activity and hydration products. The ceramic aggregate and cement matrix's interaction zone outperforms that of natural aggregate, improving mechanical properties. However, beyond 30% replacement, strength declines due to the non-condensation of cement mixes and reduced binder content, indicating an optimal replacement threshold for maximizing concrete's mechanical performance.



3.3 Flexural Strength

After 28 days of water curing, an increase in the bending strength of concrete samples was observed, mirroring improvements in compressive strength. The inclusion of ceramic waste significantly enhances concrete's bending strength, with Mix CW30 showcasing a peak flexural strength of 4.15% at 28 days, compared to 6.28 MPa and 6.67 MPa for the control mix at 28 and 90 days, respectively. This increase is attributed to the ceramic's angularity and improved interfacial transition zone (ITZ). A high correlation between compressive and flexural strengths was confirmed through linear regression analysis, as depicted in Figure 10, with the correlation equation y = -0.0014x^2 + 0.1611x + 1.6733 (R^2 = 0.9025), indicating a significant impact of ceramic waste on concrete's mechanical properties.



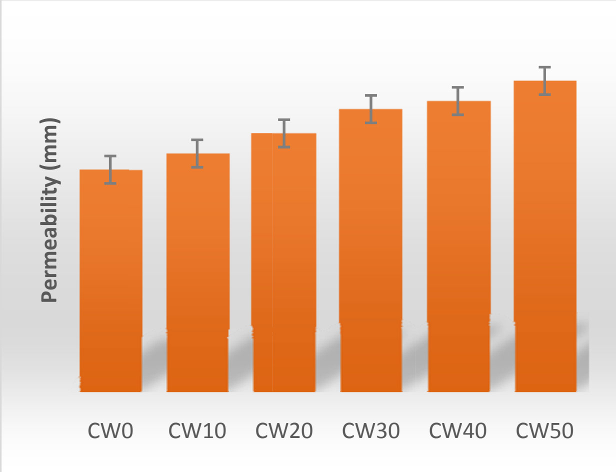


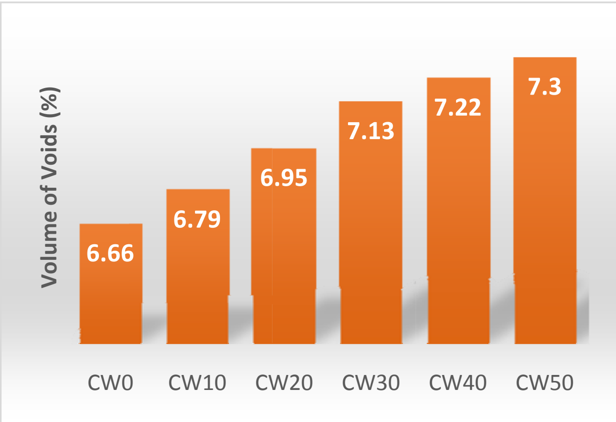
3.4 Tensile Strength

The splitting tensile strength of concrete samples, evaluated after 28 and 90 days of water curing, exhibits trends akin to those observed in compressive strength, as detailed in table 4.5. An increase in tensile strength was noted up to a 20% ceramic waste replacement level, with a subsequent decrease beyond that point. The peak tensile strengths recorded were 3.22 MPa and 3.62 MPa at 20% replacement after 28 and 90 days, respectively. This enhancement in tensile strength is credited to improved bonding between ceramic particles and concrete. A high correlation between compressive and tensile strengths was established through linear regression analysis, evidenced by figure 4.7 ($R^2 = 0.9211$) and its correlation equation $y = -0.0068x^2 + 0.6651x - 13.153$, indicating a strong relationship.

3.5 Permeability and Volume of Voids

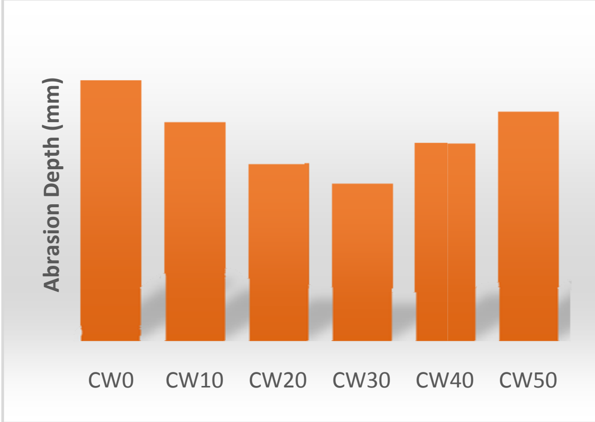
Water permeability, a critical factor affecting concrete's long-term structural integrity, is measured according to DIN-1048 (Part-5) standards. This test, performed on 150 mm cubic samples after 28 days of curing, involves subjecting oven-dried samples to a constant water pressure of 0.5 N/mm^2 for 72 hours. Upon completion, the samples are split to gauge the depth of water penetration, with the maximum depth recorded. Findings reveal that permeability increases with the addition of ceramic waste to concrete, with the control mix showing a minimal water penetration depth of 55 mm. This heightened permeability is attributed to an increased void ratio and porosity, evidenced by a strong correlation between void volume and water penetration depth, detailed in Figure 4.10, with a correlation coefficient (R) of 0.9914, indicating a significant relationship between permeability and porosity.





3.6 Abrasion Resistance

Ceramic waste, sourced from demolished construction sites and manufacturing processes, impacts the abrasion behavior and surface durability of cement concrete. Wear depth increases with higher levels of ceramic waste substitution in concrete mixes. Abrasion resistance is assessed on cube specimens after 28 days of curing, with wear depth increasing over time for all mixtures. Compared to conventional mixes, a certain level of ceramic waste replacement reduces wear depth, with the lowest wear observed in the CW30 mix, highlighting an optimal substitution level for improved surface strength.



4. Conclusion

This research focuses on the use of waste ceramic as a partial substitute for natural fine aggregate in fly ash blended concrete pavements, emphasizing strength as a crucial factor in pavement design. The study assesses the properties of fresh and hardened concrete, comparing them to conventional concrete, and investigates the impact of ceramic waste on various parameters including compaction, strength (compressive, tensile, and flexural), permeability, abrasion, and water absorption to evaluate durability.

Key findings include:

- Increased ceramic waste leads to a higher need for water-reducing agents due to the ceramic's rough, angular nature.
- Concrete with ceramic waste is less dense, attributed to ceramic waste's lower specific gravity and the mixture's voids.
- Optimal compressive strength observed in the CW30 mix, with a noted decrease in strength beyond this mix level.
- Tensile strength peaks with the CW20 mix, while still showing improvements over the control mix up to CW50.
- Flexural strength improves up to the CW30 mix, suggesting a strong correlation with compressive strength.
- The addition of ceramic waste enhances concrete strength due to the pozzolanic reaction of ceramic particles, leading to a

robust interfacial transition zone and improved microstructure.

- Higher permeability in concrete with ceramic waste is linked to its porous nature and void presence, impacting water penetration.
- The CW30 mix exhibits the lowest wear depth, correlating with its superior compressive strength.

In summary, a 30% replacement of natural aggregate with ceramic waste is identified as the optimal level for enhancing concrete characteristics, balancing workability, strength, and durability.

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