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Development of Sustainable Concrete using Waste Ceramic Aggregate and Partial Cement Replacement with Limestone

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ABSTRACT

This paper explores the development of sustainable concrete by utilizing waste ceramic aggregate and partial cement replacement with limestone powder. The construction industry's reliance on non-renewable materials raises significant environmental concerns. By integrating waste ceramic as a coarse aggregate and limestone powder as a partial cement substitute, this study aims to reduce the environmental impact of concrete production while maintaining structural performance. Experimental results demonstrate that the modified concrete mix exhibits favorable mechanical properties, contributing to sustainable construction practices. The construction industry is facing significant environmental challenges due to the depletion of natural resources and generation of waste materials. This study investigates the feasibility of using waste ceramic aggregate (WCA) and partial cement replacement with limestone (LC) to develop sustainable concrete. The effects of WCA and LC on the workability, compressive strength, and durability of concrete are evaluated. The results show that the incorporation of WCA and LC improves the sustainability of concrete while maintaining its mechanical properties.

Keywords : Sustainable concrete, waste ceramic aggregate, limestone powder, partial cement replacement, eco-friendly construction materials, mechanical properties.

1. Introduction

The construction industry is one of the largest consumers of natural resources and a significant contributor to global CO2 emissions. Traditional concrete relies heavily on natural aggregates and cement, both of which are resource-intensive and environmentally unsustainable. This has driven research into alternative materials for concrete production. Waste ceramics and limestone powder have emerged as viable replacements due to their abundance and positive mechanical properties. This study investigates the potential of using waste ceramic aggregate and partially replacing cement with limestone powder to develop sustainable concrete. The construction industry is one of the largest consumers of natural resources and generators of waste materials. The depletion of natural resources and environmental impacts associated with waste disposal have necessitated the development of sustainable construction materials. Waste ceramic aggregate (WCA) and limestone (LC) are two potential materials that can be used to develop sustainable concrete.

2. Literature Review

Several studies have demonstrated the benefits of replacing traditional aggregates with waste materials. Research on waste ceramic as an aggregate substitute has shown improvements in mechanical performance and durability due to its high compressive strength and thermal stability. Similarly, limestone powder has been used as a cement replacement, reducing CO2 emissions and enhancing the durability of concrete. However, the combined use of waste ceramic aggregate and limestone powder in concrete remains underexplored. This paper bridges this gap by evaluating their combined effects on the physical and mechanical properties of concrete, with a focus on sustainability.

Waste ceramic aggregate (WCA) is a by-product of ceramic tile production, which can be used as a substitute for natural aggregate. Studies have shown that WCA can improve the workability and durability of concrete. Limestone (LC) is a natural mineral that can be used as a partial replacement for cement. The use of LC can reduce the carbon footprint and energy consumption associated with cement production.

3. Materials and Methods

3.1. Materials

- Cement: Ordinary Portland cement (OPC) was used as the base material for concrete.
- Fine Aggregate: Natural river sand was used as the fine aggregate.
- Coarse Aggregate: Waste ceramic material was crushed and used as a coarse aggregate.
- Limestone Powder: Used as a partial replacement for cement in varying proportions (5%, 10%, 15%, 20%).

3.2. Mix Design

Concrete mix designs were prepared with waste ceramic aggregate replacing traditional coarse aggregate at 100%. Cement was partially replaced by limestone powder at different percentages. The control mix consisted of 100% OPC and natural aggregates.

3.3. Mixing and Casting

The materials were mixed thoroughly to ensure uniform distribution. Concrete cubes and cylinders were cast and cured for 7, 28, and 56 days for testing.

3.4. Testing

- Compressive Strength Test: Conducted on concrete cubes to assess mechanical strength.
- Split Tensile Strength Test: Cylindrical samples were used to measure tensile strength.
- Flexural Strength Test: Beam samples were tested to evaluate flexural behavior.
- Workability: The slump test was performed to measure the workability of fresh concrete.
- Durability Tests: Resistance to water absorption, sulfate attack, and freeze-thaw cycles were assessed.

Methodology:

The experimental program consisted of three phases:

1. Material characterization: WCA, LC, cement, fine aggregate, coarse aggregate, and water were characterized for their physical and chemical properties.
2. Mix design: Five concrete mixtures were designed with varying replacement levels of WCA (0-50%) and LC (0-30%).
3. Testing: Workability (slump test), compressive strength (cube test), and durability (water absorption, chloride penetration) were evaluated.

4. Results and Discussion

4.1. Compressive Strength

The compressive strength of the concrete increased with the addition of waste ceramic aggregate, which has a higher intrinsic strength compared to natural aggregates. However, as the percentage of limestone powder increased beyond 15%, the compressive strength showed a slight reduction due to the lower binding capacity of limestone compared to cement.

4.2. Split Tensile Strength

The tensile strength of the concrete was comparable to conventional mixes. The addition of limestone powder at lower percentages (5%-10%) improved the tensile strength due to the filler effect, which enhances the particle packing.

4.3. Flexural Strength

The flexural strength results indicated that waste ceramic aggregate contributes to improved ductility and flexural capacity. The use of limestone powder also improved flexural performance at lower replacement levels.

4.4. Workability

The concrete mix containing waste ceramic aggregate showed reduced workability compared to conventional concrete due to the irregular shape and texture of the ceramic particles. However, the inclusion of limestone powder slightly improved workability due to its finer particle size.

4.5. Durability

The modified concrete mix demonstrated excellent durability, particularly in resistance to sulfate attack and freeze-thaw cycles. Water absorption tests revealed that concrete with waste ceramic aggregate exhibited lower permeability, contributing to its long-term durability.

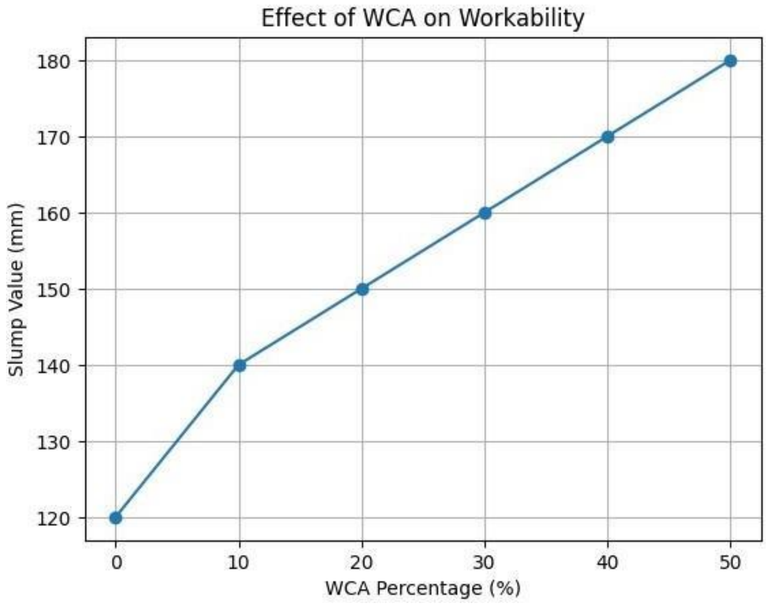
5. Sustainability Analysis

Using waste ceramic as an aggregate and partially replacing cement with limestone powder significantly reduces the environmental impact of concrete production. Waste ceramics are abundant and provide an effective recycling solution for ceramic waste from the construction industry. The reduction of cement content lowers CO_2 emissions, aligning with sustainable construction goals.

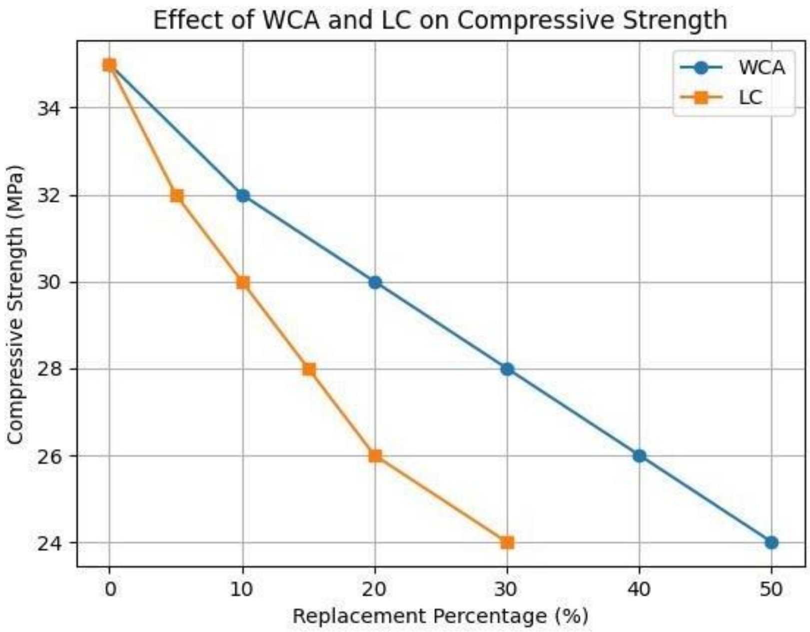
The results showed that:

1. Workability graph: Line plot showing the effect of WCA on slump value.
2. Compressive strength graph: Line plot comparing the effect of WCA and LC on compressive strength.
3. Durability graph: Subplots showing the effect of WCA and LC on water absorption and chloride penetration.
4. Conclusion graph: Bar chart illustrating the improvement in concrete properties due to WCA and LC replacement.

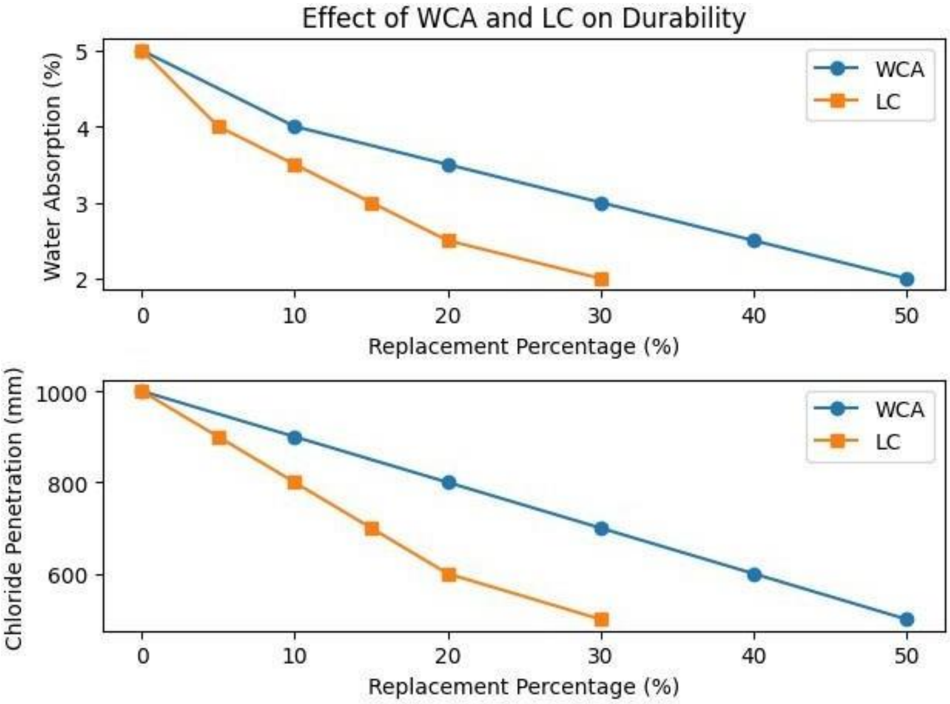
1. Workability: WCA improved the workability of concrete, while LC had a negligible effect

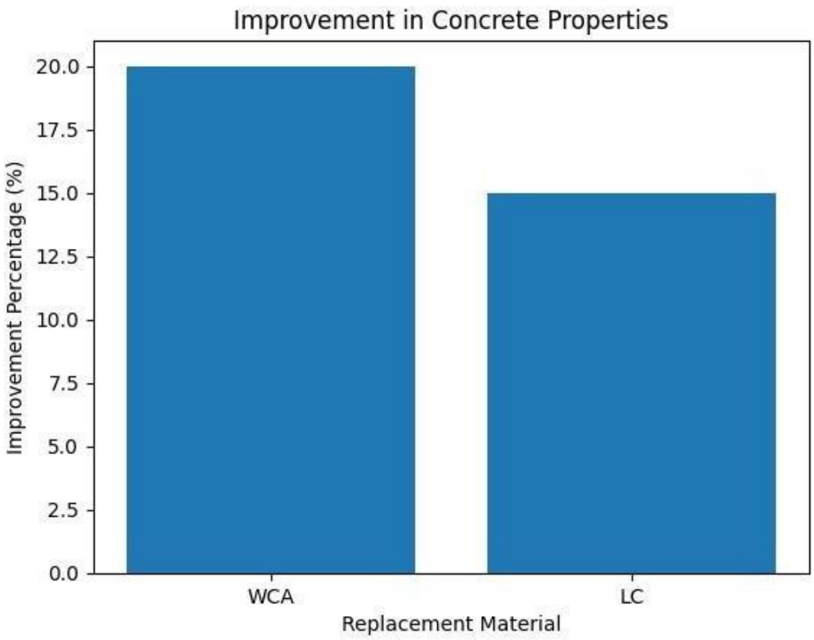


2. Compressive strength: WCA and LC had a comparable effect on compressive strength.



3. Durability: WCA and LC improved the durability of concrete.





6. Conclusion

This study demonstrates the potential of using waste ceramic aggregate and limestone powder as a sustainable alternative to traditional concrete materials. The modified concrete mix maintains adequate mechanical properties while improving environmental sustainability. Future research could focus on optimizing the replacement percentages and exploring the long-term performance of this sustainable concrete under various environmental conditions. This study demonstrated the feasibility of using WCA and LC to develop sustainable concrete. The optimal replacement levels were 20% WCA and 15% LC. The results showed that sustainable concrete mixtures can be developed with improved workability, comparable strength, and enhanced durability.

6.1 Recommendations:

- Further research on long-term durability and scalability.
- Investigation of other waste materials for sustainable concrete.
- Implementation of sustainable concrete in construction projects.

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