Innovative High-Strength Concrete: Utilizing Waste Ceramic Tiles As Partial Replacement Of Fine Aggregate And Cement For Enhanced Performance And Eco-Efficient Construction

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ABSTRACT

The rapid evolution of high-rise construction has necessitated advancements in high-strength concrete (HSC), making it an indispensable structural material for modern skyscrapers. Simultaneously, the excessive consumption of natural aggregates and the growing accumulation of solid waste from construction and demolition activities have raised significant environmental concerns. This study explores an innovative approach by partially replacing fine aggregates and cement with waste ceramic tiles in M80 grade high-strength concrete. Experimental investigations were conducted with replacement levels of 10%, 20% for fine aggregates and 5%, 10%, 15% for cement to assess the impact on compressive and split tensile strength. The results indicate that the modified concrete mix not only maintains structural integrity but also exhibits potential strength enhancements. This sustainable approach contributes to environmental conservation by minimizing landfill waste while offering a cost-effective alternative in high-performance concrete applications. The research highlights the feasibility of integrating waste materials into HSC, paving the way for greener and more resilient construction practices in the future.

Keywords: Waste ceramic tiles, Compressive strength, split tensile strength, fine aggregate, cost, cement

1. INTRODUCTION

The rapid expansion of urbanization and infrastructure development has led to an increased demand for construction materials, placing immense pressure on natural resources. The excessive extraction of raw materials for cement and aggregate production has resulted in environmental degradation, including deforestation, depletion of water tables, and loss of biodiversity. Additionally, cement manufacturing is a major contributor to CO_2 emissions and airborne pollutants, intensifying global climate concerns. Simultaneously, the construction industry generates millions of tonnes of solid waste annually, posing serious disposal challenges. Among these, ceramic tile waste from demolitions and manufacturing processes remains largely underutilized. Recycling such waste in concrete production presents a sustainable alternative that reduces environmental impact while ensuring structural integrity. The study explores the feasibility of utilizing waste ceramic tiles as a partial replacement for fine aggregates and cement in M80 grade high-strength concrete. By evaluating compressive and split tensile strength characteristics, the research aims to establish an eco-efficient and cost-effective solution for high-performance concrete applications. The integration of recycled materials not only promotes waste management but also enhances the durability and long-term sustainability of modern construction.

LITERATURE REVIEW

Fengli et al. concluded that it is feasible to reuse recycled ceramic aggregate under 9.5 mm as partial replacement of natural aggregate in concrete. Since the apparent density of ordinary concrete is higher than that of recycled ceramic concrete (RCC), this can be helpful to reduce the self- weight of constructions. Under similar workability condition, when the replacement rate is lower than 20%, the splitting tensile strength of RCC is poor because the ultra-fine sand has high mud content. Moreover, when the replacement rate is greater than 40%, the compressive strength and splitting tensile strength are higher than those of the reference concrete. The use of 100% recycled ceramic as fine aggregate increases both splitting tensile strength and compressive strength significantly. Torgal et al. studied the chemical and physical characteristics of crushed ceramic waste from landfills. Besides, ceramic powder was used in concrete mixes as partial substitution of cement, while fine and coarse ceramic aggregates were used as 100% substitution of fine and coarse natural aggregates. They found that compressive strength increases by incorporating ceramic waste in concrete. Al Bakri et al. used different types of recycled ceramic wastes as partial replacement of coarse aggregate in concrete mixes with different w /c ratio; 0.4, 0.5, and 0.7. It was found that all concrete mixes incorporating ceramic aggregates have compressive strength higher than that of conventional concrete. Halickaet al. used ceramic sanitary ware waste as coarse aggregate in concrete mixes. The scanning electron microscopy of the ceramic particles revealed the porosity of their structure. Also, by investigating its properties, it was noticed that ceramic aggregates has low crushing ratio and high water absorption. They reported that high performance concrete as well as high abrasion resistance concrete can be obtained by using ceramic sanitary ware waste aggregate.

In another study, Medina et al. used ceramic sanitary ware waste as a partial substitute of gravel with replacement levels 20% and 25%.They found that the incorporation of ceramic aggregate with natural gravel slightly raised the porosity. Both compressive strength and tensile splitting strength increased as replacement percentage increases. In addition, concrete mixes with recycled ceramic aggregate has lower slump, lower density, higher water absorption, higher sorpitivity, and higher porosity compared to that of reference concrete. On the other hand, de Brito et al. used ceramic wastes from construction and demolition wastes, in concrete mixes as partial replacement of coarse aggregate with replacement ratios of 0, 1/3, 2/3, and 3/3. It was found that as replacement percentages increases, compressive strength, flexural strength, and loss of thickness by abrasion decreased compared to conventional concrete. They reported that since ceramic aggregates have high water absorption, this can be overcome by restoring to pre-saturation procedure. Gonzalez and Etxeberria prepared high performance concrete mixes using mixed recycled aggregate from construction and demolition treatment plant as partial substitution of gravel with replacement levels 20%, 50%, and 100%, in addition to preparing mixes incorporating fine ceramic aggregate as partial replacement of sand with levels 15%, and 30%. They reported that concrete mixes with fine ceramic aggregate have higher compressive and flexural strengths than conventional concrete. While concrete mixes incorporating ceramic mixed aggregates with replacement levels higher than 20% have lower compressive and flexural strengths than conventional concrete.

Marcio performed experiments on water absorption, modulus of elasticity and compressed stress on the concrete which is made up of ceramic tile aggregates. In concrete casting crushed ceramic blocks were used as coarse aggregates. For 0 to 100 percent replacement specific density of aggregates changes from 2630 to 2310 kg/m3. When replacement up-to 20 percent compression resistance and young's modulus of elasticity was same as the conventional concrete. Senthamarai concluded that based on strength of ceramic waste aggregates, it can be used effectively as a coarse aggregates in concrete. The crushing value, impact value, abrasion value for natural coarse aggregates 24, 17 and 20 percent correspondingly for ceramic scrap 27, 21 and 28 percent respectively. Ceramic waste tiles do not have much variation with respect to the natural aggregates. Paulo cachim experimented on use of waste ceramic tile aggregates, collected from ceramic industrial waste from different sources water absorption was 15.81 and 18.91 percent respectively. The more value of water absorption influenced the workability of concrete. In first 2 minutes 75 percent of total absorption takes place and after 5 minutes at least 91 percent of the total absorption occurred. Medina et al concluded that use of ceramic tile wastes with 4 mm and lower size as fine aggregates in concrete and density of concrete was 2.41 g/cm3 and compressive strength and split tensile strength were increased due to lower fraction of ceramic waste usage in to the concrete composition.

Pinchatorkittikul and arnonchaipanich experimented that use of ceramic waste as fine aggregates in concrete composition and concluded that the density of concrete casted with 100 percent ceramic waste aggregates was 2.31 g/cm3 which is 0.07 g/cm3 lower than with respect to conventional controlled 28 days concrete due to low specific gravity and density of ceramic waste aggregates. Veerareddy reported on ceramic waste's crushing value and impact value is 24.7 percent and 18.2 respectively. These values were within the permissible limit as per IS 383-1970 code, hence it was safe to use of ceramic tile waste as an alternative material to coarse aggregates. Correia et al. reported that the recycled aggregates have more water absorption due to higher porosity of recycled aggregated. Due to which there is a need of additional water quantity to make concrete with proper workability. Correiain his previous study of 2006 reported that the abrasion resistance of ceramic aggregates concrete showed even better than the reference concrete in their experimentation work. Sekar concluded that specific gravity of ceramic coarse aggregates varied between 2.2 and 2.56. These values were effected the density of ceramic aggregate concrete. Pancheco-Torgail and said jalali experimented the strength and durability of ceramic tile waste concrete as compared to natural aggregate ceramic aggregates have higher value of water absorption. Medina concluded on utilization of ceramic tile waste as an alternative material of coarse aggregates. It was produced by crushing of sanitary ware and shape curve is same as that of natural aggregates. Irregular shape provided that superior surface area and better bonding was observed in experimentation. Atul Uniyal et al. They replaced the aggregates with tile powder by 5%,10%,15% and 20. From there tests they concluded the following: They found the most optimal percentage for the replacement of ceramic tile powder with cement was 15 %. Above this percentage the compressive strength of their concrete decreases.

C&D wastes are generally the remains of construction and demolition wastes. Applications of these wastes as aggregates in concrete were investigated by many 8 researchers. Even though there was a reduction in strength on higher replacement levels, a successful replacement of 25% to 30% of coarse aggregates were generally observed in concrete without much changes in strength characteristics. Reduction in density and higher water absorption of concrete were also reported by many researchers. Excess water held in the pores of recycled aggregates gets evaporated during the hardening stage of concrete and results in porosity. According to Kou et al., porosity gradually decreases in long term due to self-cementing effects of the old cement mortar with new cement paste. Also, it was noted that washing and grading of the aggregates improved the compressive strength performance when compared to ungraded demolition wastes. Strength characteristics were also found depending up on the type of C & D wastes. A successful replacement of 30% recycled concrete aggregate was reported by many researchers with improved strength characteristics. While, 20% replacement of ceramic tile waste in concrete showed comparable strength as that of conventional aggregates. 10% of coarse aggregate replacement with glass cullets showed better strength characteristics against conventional concrete. But lower strength and durability of concrete was reported by researchers on increasing the replacement level using glass wastes due to alkali-silica reactions. C&D wastes as fine aggregate generally shows lower particle density and loose bulk density compared to natural fine aggregate. Also, these aggregates have higher water absorption due to the presence of adhered mortar from concrete or other construction wastes. This significantly affects the concrete properties, especially workability. The losses in compressive strength can be reduced on pre-soaking the recycled concrete aggregates. Permeability of these recycled fine aggregates is also generally high due to porosity. Even though the permeability of aggregate weakens the concrete, it helps in dissipating hydraulic pressures and thus improves the freeze thaw resistance.

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3. PROPOSED SYSTEM

The proposed system focuses on the utilization of waste ceramic tiles as a partial replacement for fine aggregates and cement in high-strength concrete (HSC). This approach aims to mitigate environmental issues caused by excessive quarrying and cement production while addressing the growing challenge of construction waste disposal. The system integrates an optimized mix design to ensure improved strength, durability, and sustainability.

Key Features of the Proposed System:

1. **Material Selection and Processing:**
    - Waste ceramic tiles are collected from demolition sites and tile manufacturing industries.
    - The collected tiles are crushed and sieved to obtain fine ceramic aggregates suitable for concrete mixing.
2. **Concrete Mix Design:**
    - Partial replacement of fine aggregates with waste ceramic tile aggregates at 10% and 20%.
    - Partial replacement of cement with powdered ceramic tile at 5%, 10%, and 15%.
    - Use of M80 grade high-strength concrete as the base material.
3. **Experimental Analysis:**
    - Preparation of concrete cubes and cylinders for strength evaluation.
    - Testing for compressive and split tensile strength at different curing intervals.
    - Comparison with conventional concrete to assess performance improvements.
4. **Environmental and Economic Benefits:**
    - Reduction in quarrying and natural resource depletion.
    - Minimization of landfill waste and recycling of ceramic materials.
    - Cost-effective alternative to conventional aggregates and cement.
5. **Structural Application Feasibility:**
    - Suitability analysis for high-rise buildings, bridges, and pavement applications.
    - Evaluation of durability, workability, and sustainability.

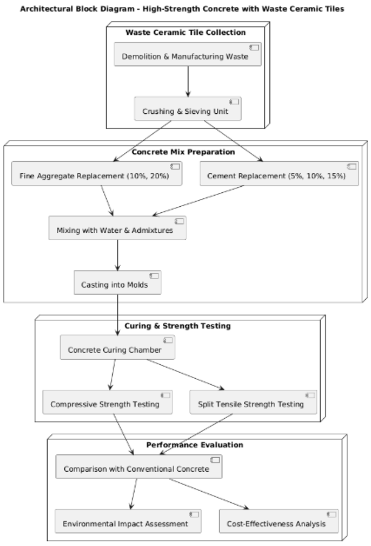

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are shown in table format and graph format, which is to be presented in this chapter.

4.1 Fresh properties of concrete (Workability Test)

4.1.1 Slump Test

The Slump test was performed on the tile powder – tile aggregate concrete to check the workability of it at different replacements viz. 0%-0%, 5%-10%, 10%-10%, 15%-10%, 5%-20%, 10%-20%, 15%-20% and the following results were obtained, according to which it can be concluded that with the increase in % of tile powder – tile aggregate from M1 to M7, workability increases. The results obtained for Slump test are shown below in Table 4.1.

Table 4.1: Results of Slump test

Mix No	Tile powder – tile aggregate	Slump (mm)
M1	0-0	100
M2	5-10	103
M3	10-10	104
M4	15-10	106
M5	5-20	109
M6	10-20	110
M7	15-20	115

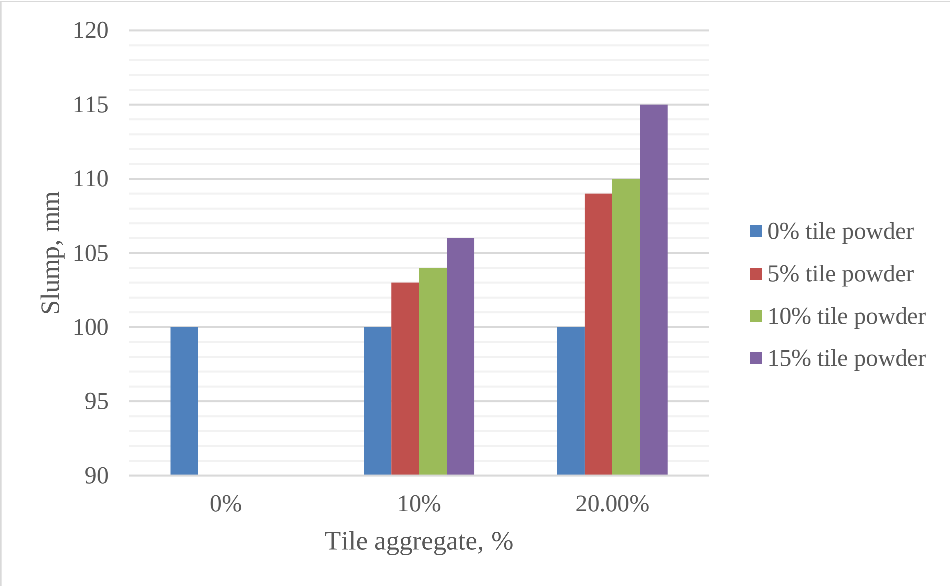

Fig 4.1: Slump test results

The above figure 4.1 shows the slump results. It was observed that, the slumps increased from M1 to M7 mix with increased tile powder – tile aggregate in the mix. It was varied from Medium Workability to High workability.

4.2 Harden properties of concrete

4.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of tile powder – tile aggregate based concrete and the results obtained are given in Table 4.2.

Table 4.2: Results of compressive strength test

Mix No	Tile powder – tile aggregate	Compressive strength of cubes (N/mm^2)		
		7 days	14 days	28 days
M1	0-0	54.25	78	87.5
M2	5-10	55.7	82.98	90.2
M3	10-10	58.4	85.8	94.3
M4	15-10	60	87.5	96
M5	5-20	56	85.7	93.2
M6	10-20	54.56	81.84	90
M7	15-20	53	79.1	88

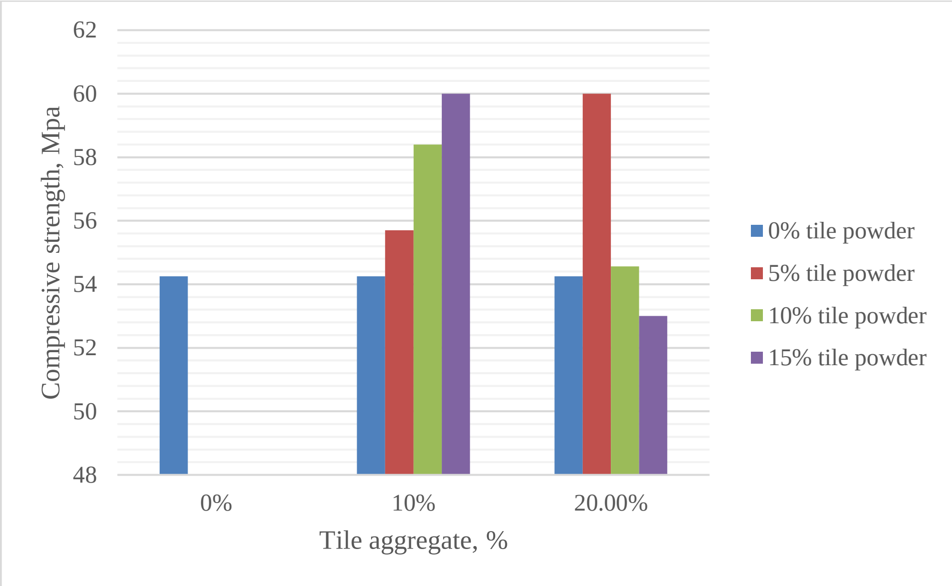

Fig 4.2: 7days Compressive strength test result graph

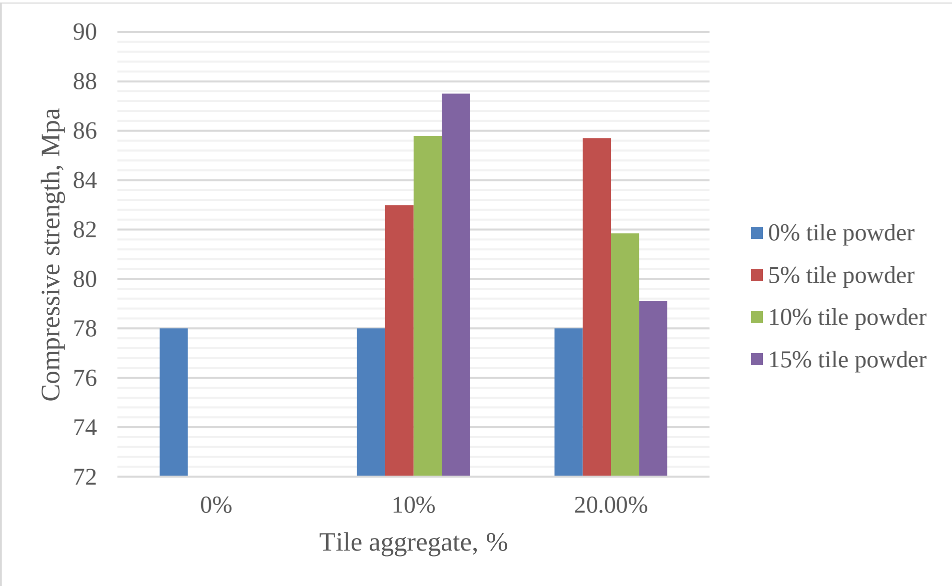

Fig 4.3: 14days Compressive strength test result graph

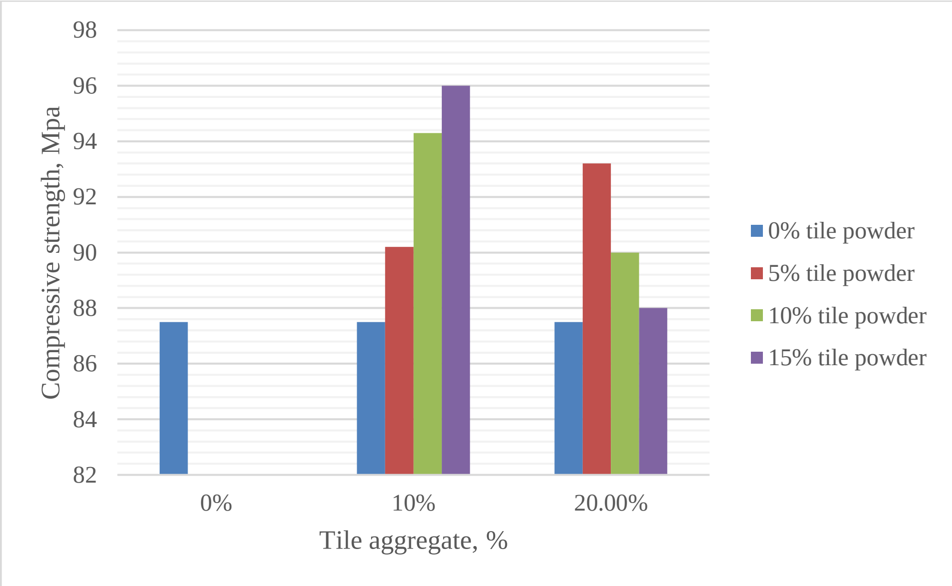

Fig 4.4: 28days Compressive strength test result graph

From the above results it was observed that with the increase in percentage of tile powder – tile aggregate from M2 to M7 in concrete the compressive strength more than control mix M1. The highest compressive strength gained for 15% tile powder – 10% tile aggregate replacing with cement and fine aggregate in the preparation of concrete. The optimum dosage suggested from this study was 15% tile powder – 10% tile aggregate.

4.2.2 Tensile Strength Test

The Tensile test was performed on the beams of size 300mm height x 150 diameter mm to check the Tensile strength of the concrete and the results obtained while performing the Tensile test on CTM are given in Table 4.3.

Table 4.3: Result of Tensile strength

Mix No	Tile powder – tile aggregate	Tensile Strength for 28 days (N/mm^2)
M1	0-0	10
M2	5-10	10.91
M3	10-10	11.41
M4	15-10	11.61
M5	5-20	11.27
M6	10-20	10.89
M7	15-20	10.64

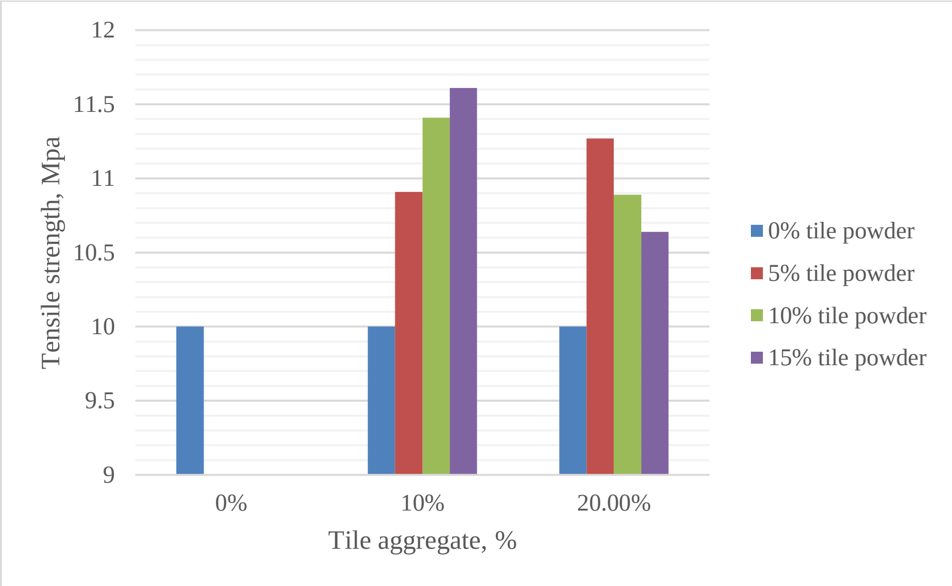

Fig 4.5: Tensile strength graph

From the above results it was observed that with the increase in percentage of tile powder -tile aggregate from M2 to M7 in concrete the tensile strength more than the control mix M1. The highest tensile strength gained for 15% tile powder – 10% tile aggregate replacing with cement and fine aggregate in the preparation of concrete. The optimum dosage suggested from this study was 15% tile powder – 10% tile aggregate.

4.3 Discussions

The workability was increasing with increasing tile powder – tile aggregate replacement in the cement and sand. The compressive and tensile strengths for tile powder – tile aggregate replacement in the cement and sand, was more than control mix. The strength increment percentages were mentioned below Table 4.4. The maximum or highest strength was gained for 15% tile powder – 10% tile aggregate replacing with cement and sand.

Table 4.4: Comparison of strengths

Mix	Tile powder – tile aggregate	28days compressive strength (Mpa)	Increment (%)	28days Tensile strength (Mpa)	Increment (%)
M1	0-0	87.5	-	10	-
M2	5-10	90.2	3.08	10.91	9.1
M3	10-10	94.3	7.77	11.41	14.1
M4	15-10	96	9.71	11.61	16.1
M5	5-20	93.2	6.5	11.27	12.7
M6	10-20	90	2.85	10.89	8.9
M7	15-20	88	0.57	10.64	6.4

5. CONCLUSIONS

The experimental investigation demonstrates that incorporating waste ceramic tiles as a partial replacement for fine aggregates and cement in high-strength concrete enhances both workability and mechanical performance. The optimal mix, consisting of 15% tile powder and 10% tile aggregate, exhibited significant improvements in compressive and tensile strength, with gains of 9.71% and 16.1%, respectively, compared to conventional concrete. This study highlights the potential of waste ceramic tiles as a viable alternative to traditional raw materials, offering both structural and environmental benefits. The integration of Supplementary Cementitious Materials (SCMs), such as tile powder and fly ash, further contributes to cost reduction and sustainable waste management by minimizing construction-related landfill waste. The findings reinforce the feasibility of utilizing recycled materials in high-performance concrete applications, paving the way for eco-efficient and resource-conscious construction practices.

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