Investigating the effect of using granite waste and combining porcelain ceramic waste on the mechanical behavior of reactive powder concrete (RPC)

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Abstract

This study investigates the feasibility of reducing silica sand consumption in Reactive Powder Concrete (RPC) by replacing it with granite waste powder (GWP) and combined granite–porcelain ceramic waste (PCW). Nine RPC mixtures were designed using two microsilica contents (12.5% and 25% by cement weight) and two replacement levels (50% and 75%) of silica sand. All mixtures had a constant water-to-cementitious materials ratio of 0.20 and a superplasticizer content of 2% by cement weight. Mechanical performance was evaluated through compressive and flexural strength tests at curing ages of 3, 7, 14, and 28 days under steam curing at 95°C. Results demonstrated that waste incorporation significantly improved mechanical properties while reducing material cost, confirming the technical and economic viability of sustainable RPC production.

Keywords

Reactive powder concrete, Compressive strength, Granite waste, Ceramic waste, Flexural strength.

1. Introduction

Reactive Powder Concrete (RPC) is classified as an ultra-high-performance cementitious composite due to its dense microstructure, very low porosity, and superior mechanical performance [1,2]. These properties are mainly achieved by eliminating coarse aggregates, using very fine silica sand, applying a low water-to-cementitious materials ratio, and incorporating highly reactive pozzolanic materials such as microsilica. Despite its advantages, the high consumption of silica sand and cement increases the cost and environmental footprint of RPC. Therefore, the use of industrial and construction wastes as alternative fine materials has attracted increasing attention. Granite cutting waste and porcelain ceramic waste are produced in large quantities and often disposed of in landfills, causing environmental concerns. Their mineralogical composition, mechanical strength, and particle angularity suggest that they can be suitable substitutes for silica sand in RPC [3-5].

The primary focus of this study was on the compressive strength of reactive powder concrete (RPC) incorporating waste materials, with the aim of identifying a mixture design that maximizes the utilization of such by-products. In the experimental program, 50% and 75% of the silica sand were replaced, in one case solely with granite waste and in another case with a combined mixture of granite and porcelain ceramic wastes. In addition, silica fume, as one of the most critical constituents in RPC production, was incorporated at two different dosage levels with a 50% variation between the investigated mix designs.

2. Materials and Methods

Portland cement Type I, microsilica, silica sand, granite waste powder, and porcelain ceramic waste were used in this study. Granite waste was collected from stone-cutting sludge, dried, crushed, and sieved to achieve the desired particle size distribution. Porcelain ceramic waste was obtained from discarded tiles and mechanically crushed into fine particles. A polycarboxylate-based high-range water-reducing admixture was employed to ensure adequate workability. Mixing was performed using a high-speed mixer following a staged procedure to achieve homogeneous dispersion. All specimens were steam-cured at 95°C after demolding. Compressive strength tests were conducted according to ASTM C109, while flexural strength tests were performed using the three-point bending method in accordance with ASTM C78.

In total, eight concrete mixture designs were prepared. One mixture served as the control specimen, while the remaining mixtures were developed by partially replacing silica sand with waste-derived aggregates.

In all mix designs, the water-to-cementitious materials ratio (W/CM) was kept constant at 20%, and the dosage of the superplasticizer (SP) was fixed at 2% by weight of cement. Silica fume was incorporated at two dosage levels of 12.5% and 25% by weight of cement. Moreover, silica sand was partially replaced with granite waste powder at replacement levels of 50% and 75%. In the hybrid mixtures, porcelain ceramic waste was used to replace 50% of the granite waste powder.

3. Results and Discussion

Figure 1 presents a comparison of the 28-day compressive strength of selected RPC mixtures. Most mixtures containing granite waste powder or combined granite–porcelain waste exhibited higher compressive strength than the control mixture.

The highest compressive strength was observed in mixtures containing combined wastes, which can be attributed to the angular shape of ceramic particles, their low water absorption, and improved particle interlocking. Flexural strength results showed similar trends, indicating enhanced crack resistance and improved load transfer mechanisms in waste-containing mixtures. Reducing microsilica content did not significantly compromise strength in mixtures incorporating combined wastes, highlighting the efficiency of ceramic particles in enhancing mechanical performance.

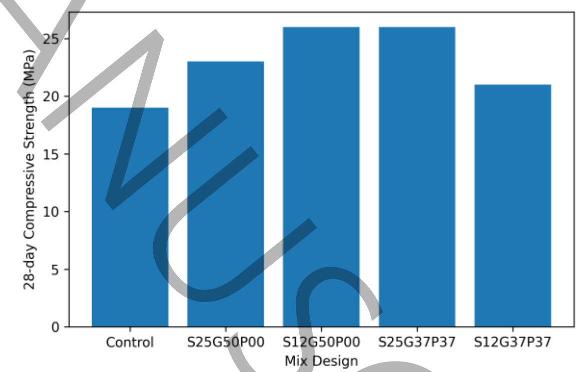

Figure 1. Comparison of 28-day compressive strengths

Also the results showed that when 50% of the silica sand was replaced solely with granite waste, the specimens containing the lower silica fume content (12.5%) consistently exhibited higher compressive strength than those with the higher silica fume content (25%) at all curing ages up to 28 days. This trend, however, was not observed when the replacement level increased to 75% of the silica sand. Nevertheless, in the case of 75% replacement of silica sand with granite waste alone, the compressive strength remained higher than that of the control mixture throughout the entire curing period up to 28 days.

Moreover, for mixtures with 50% replacement of silica sand by granite waste and 12.5% silica fume, the compressive strength exceeded that of the control mixture at all ages up to 28 days, whereas for mixtures containing 25% silica fume, the compressive strength surpassed that of the control only after 14 days of curing.

In the case of combined waste utilization (Figures 9c and 9d), different trends were observed. At a 50% replacement level, the mixture containing 25% silica fume exhibited higher compressive strength throughout the curing period up to 28 days, while at a 75% replacement level, the mixture incorporating 12.5% silica fume demonstrated superior compressive strength. This behavior can be attributed to the increased proportion of angular porcelain ceramic particles, which enhanced particle interlocking and load transfer within the concrete matrix.

In the case of using combined waste materials at a replacement level of 75% of the silica sand, reducing the silica fume content by 50% did not lead to any reduction in the achieved compressive strength enhancement. This outcome can be regarded as one of the most significant findings of the present study.

Compared with the mixtures incorporating only granite waste, this behavior can be reasonably explained by the distinctive characteristics of the porcelain ceramic particles. Specifically, their pronounced angularity and considerably lower water absorption appear to play a dominant role in maintaining the compressive strength, even at reduced silica fume contents.

4. Economic Evaluation

An economic assessment was conducted based on local market prices of raw materials. Silica sand was found to be significantly more expensive than granite waste and porcelain ceramic waste. Replacing 50% and 75% of silica sand with granite waste resulted in cost reductions of approximately 46% and 70%, respectively. Combined waste mixtures achieved cost savings ranging from 37% to 56%, while maintaining acceptable mechanical properties. Additionally, reducing microsilica content further decreased the overall production cost of RPC.

5. Conclusion

The results of this study confirm that granite waste powder and porcelain ceramic waste can be effectively utilized as partial replacements for silica sand in Reactive Powder Concrete. Combined waste mixtures demonstrated superior compressive and flexural performance, even at high replacement levels and reduced microsilica content. The proposed approach not only enhances mechanical performance but also significantly reduces material cost and environmental impact. Therefore, the sustainable production of RPC using industrial wastes is both technically feasible and economically attractive.

6. ,References

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