Investigation Report on Characteristics Strength Partial Replacement of Fine Aggregate with Copper Slag and Granite Powder

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Abstract -
Concrete is one of the most widely used construction materials, consisting of cement, fine aggregates, coarse aggregates, and water. Traditionally, Ordinary Portland Cement (OPC), river sand, and Hard Broken Granite (HBG) stone are used in concrete production. However, the over-extraction of these natural resources has led to environmental concerns and increased costs. This has created a need for sustainable alternatives that maintain concrete's quality and performance.
This study investigates the partial replacement of fine aggregates with copper slag and granite powder in M25 grade concrete. Copper slag, a by-product of copper smelting, and granite powder, obtained during granite stone cutting, possess physical and chemical properties that make them suitable for concrete. Additionally, Pozzolana Portland Cement (PPC) is examined as a sustainable alternative to OPC. PPC, with its pozzolanic characteristics, enhances workability, chemical resistance, and long- term strength while reducing the carbon footprint.
The research evaluates the mechanical and chemical properties of concrete incorporating PPC, copper slag, and granite powder. The study also highlights the environmental and economic benefits, demonstrating how these materials can contribute to sustainable construction practices. By promoting the use of industrial by-products and alternative binders, this research aims to develop high-performance, eco-friendly concrete suitable for modern construction needs.

Keywords: Concrete, sustainable construction, fine aggregate replacement, copper slag, granite powder, Pozzolana Portland Cement (PPC), M25 grade concrete, industrial by-products, environmental sustainability.
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1.INTRODUCTION

Concrete, a durable and versatile building material, is widely used globally due to its high compressive strength and long service life. However, the increasing demand for raw materials such as cement, natural aggregates, and river sand has led to significant environmental challenges, including resource depletion and ecological imbalance. To address these concerns, researchers are exploring sustainable alternatives like industrial by-products, including copper slag and granite powder, as partial replacements for fine aggregates in concrete.

Copper slag, a by-product of copper smelting, offers excellent mechanical properties such as durability, abrasion resistance, and stability. Studies indicate that replacing up to 40% of fine aggregates with copper slag can enhance the compressive strength and durability of concrete while reducing environmental impact [1-4]. Similarly, granite powder, a waste material from the granite industry, holds potential as a replacement for river sand in concrete. Utilizing granite powder not only minimizes waste disposal issues but also conserves natural resources [5-7].

This research investigates the use of copper slag and granite powder in M25 grade concrete, focusing on mechanical properties and environmental benefits. The findings aim to promote sustainable construction practices and the effective utilization of industrial by-products [8-10].

This project explores the potential of using industrial by-products, specifically copper slag and granite powder, as partial replacements for fine aggregates in M25 grade concrete. The study focuses on assessing the compressive and flexural strengths of

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concrete by individually replacing fine aggregates with these materials, as well as combining them. Pozzolana Portland Cement (PPC), which includes 20% fly ash, is used as the binder instead of Ordinary Portland Cement (OPC), thereby eliminating the need for separate fly ash replacement. The primary objective of the project is to develop an optimal mix design for sustainable concrete, reducing reliance on natural river sand while ensuring that the concrete meets performance requirements.

1.2 OBJECTIVES OF THE STUDY

To determine the optimal percentage of granite powder and copper slag that can replace conventional sand without compromising the concrete's strength.

1. To evaluate the compressive strength, flexural strength, and split tensile strength of M25 grade concrete at 7, 28, 56, and 90 days, with granite powder and copper slag replacing fine aggregates by 15%, 30%, and 40%.
2. To assess the compressive strength, flexural strength, and split tensile strength of M25 grade concrete at 7, 28, 56, and 90 days, with combinations of granite powder and copper slag replacing fine aggregates by 30%, 60%, and 80%.
3. To explore the various properties of the concrete when using Portland Pozzolana Cement (PPC) as a binder, in place of Ordinary Portland Cement (OPC).

2. EXPERIMENTAL STUDY

2.1 Materials

Cement (PPC): Portland Pozzolana Cement (PPC) was used, with a specific gravity of 3.01, a fineness modulus of 5.66%, and a consistency of 31%. Its chemical composition includes 23.50% SiO_2, 12.90% Al_2O_3, 47.00% CaO, and 2.04% Fe_2O_3, which make it suitable for the intended mix.

Fine Aggregate: Locally sourced river sand, conforming to IS 383-1970 (Zone II), was used as the fine aggregate. It had a specific gravity of 2.60 and a fineness modulus of 2.46.

Coarse Aggregate: Crushed granite of 20 mm size was used as the coarse aggregate, with a specific gravity of 2.74 and a fineness modulus of 6.17.

Copper Slag: Industrial copper slag with a specific gravity of 3.64 and a fineness modulus of 2.60 was used. The chemical composition of the copper slag includes 33% SiO_2, 55% Fe_2O_3, and 0.6% Cu.

Granite Powder: Granite powder, with a specific gravity of 2.58 and a fineness modulus of 2.81, contains 69.88% SiO_2, 12.21% Al_2O_3, and 3.17% CaO.

Cement (Kg)	Fine aggregate (Kg)	Coarse aggregate (Kg)	w/c ratio
391	670.85	1153.48	191.58
1	1.72	2.95	0.49

Table.1 Mix proportions

3.EXPERIMENTALRESULTS

3.1.1 COMPRESSIVE STRENGTH STUDIES

For the compressive strength test, standard cubes of size 150mm x 150mm x 150mm were used. The average strength was calculated from three specimens for each mix after curing for 28, 56, and 90 days, as per IS 516-1969.

The compressive strength results for the various concrete mixes at 28, 56, and 90 days show distinct trends. The reference mix (M0) exhibited compressive strengths of 31.8, 33.8, and 35.4 N/mm², respectively. In the copper slag mixes (MC series), the mix with 40% copper slag replacement (MC40) achieved the highest 90-day strength of 36.77 N/mm², indicating the optimal replacement percentage. Similarly, the granite powder mixes (MG series) followed a comparable pattern, with the mix having 40% granite powder replacement (MG40) reaching a 90-day strength of 35.93 N/mm².

The combined copper slag and granite powder mixes (MCG series) demonstrated promising results as well. Although the mixes with 30% replacement showed relatively lower strengths, significant improvements were observed at higher replacement levels. The MCG80 mix achieved the highest 90-day compressive strength of 37.51 N/mm², surpassing all other mixes. This indicates the synergistic effect of combining both copper slag and granite powder as partial sand replacements.

Overall, both copper slag and granite powder prove to be effective in enhancing the long-term performance of concrete, demonstrating their potential as sustainable alternatives for fine aggregate replacement. These results are illustrated in Fig. 1.1.

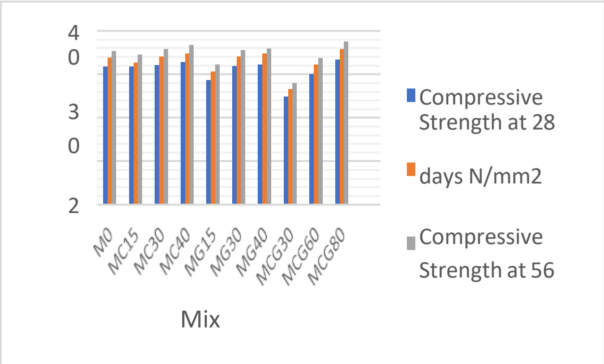

Fig.1.1 Compressive strength

3.1.2 Flexural Strength

The flexural strength results at 28, 56, and 90 days reveal clear trends across the different concrete mixes. The control mix (M0) exhibited flexural strengths of 31.8, 33.8, and 35.4 N/mm², respectively. Among the copper slag mixes (MC series), the MC40 mix achieved the highest 90-day flexural strength of 36.77 N/mm², indicating it as the optimal replacement level. Likewise, the granite powder mixes (MG series) showed a similar pattern, with the MG40 mix reaching a 90-day strength of 35.93 N/mm².

The combined copper slag and granite powder mixes (MCG series) demonstrated notable improvements in flexural strength at higher replacement levels. The MCG80 mix, in particular, reached the highest 90-day flexural strength of 37.51 N/mm², outperforming all other mixes. This indicates a synergistic effect when both materials are used together, contributing to enhanced long-term concrete performance.

These results highlight the potential of copper slag and granite powder as sustainable alternatives to conventional fine aggregates, improving both the flexural strength and overall durability of concrete. The trends are shown in Fig. 2.

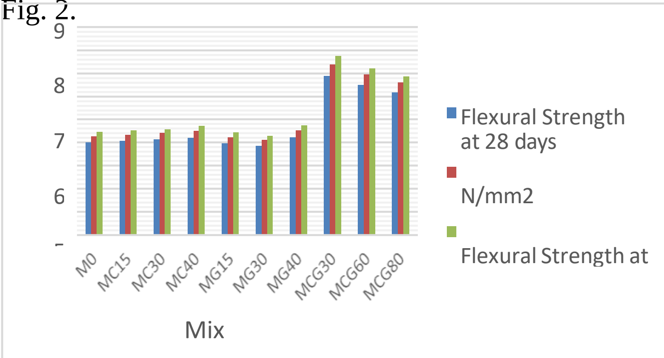

Fig.2 Flexural strength

3.1.3 Split Tensile Strength Studies

The split tensile strength results at 28, 56, and 90 days reveal distinct performance trends across the various concrete mixes. The control mix (M0) achieved split tensile strengths of 4.01, 4.27, and 4.46 N/mm², respectively. Copper slag mixes (MC series) showed a slight improvement in strength, with MC40 reaching a maximum of 4.73 N/mm² at 90 days. Granite powder mixes (MG series) displayed consistent performance, with MG40 achieving 4.74 N/mm² at 90 days.

The combined copper slag and granite powder mixes (MCG series) demonstrated superior results, particularly with the MCG30 mix, which recorded the highest split tensile strength of 7.75 N/mm² at 90 days. This significant increase in tensile strength underscores the synergistic effect of using both materials together.

These findings highlight the potential of combining copper slag and granite powder to enhance the tensile strength of concrete, suggesting a promising approach for improving the overall mechanical properties of concrete while utilizing industrial by-products. The trends are illustrated in Fig. 3.

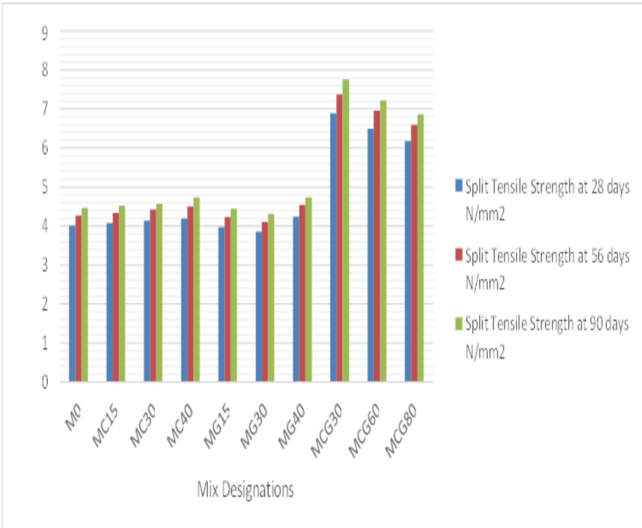

Fig.3 Split tensile strength

4.Conclusion

The study highlights the impact of copper slag (CS) and granite powder (GP) as fine aggregate replacements on the strength properties of concrete. The compressive strength increased by 3.08% at 40% replacement with copper slag, surpassing control mix strength, except at 15% replacement. Similarly, at 40% replacement with granite powder, compressive strength improved by 1.41%. Flexural strength at 28 days also improved for all CS replacements, with a maximum increase of 1.74% at 15%. For GP, flexural strength peaked at 5.73% higher than the control mix at 40% replacement.

Split tensile strength showed significant improvement, increasing by 13.08% and 14.04% for 40% replacement with copper slag and granite powder, respectively. A synergistic effect was observed at 80% replacement with a combination of CS and GP, where compressive strength increased by 5.15%, flexural strength by 5.40%, and split tensile strength by 12.08%.

At elevated temperatures (1000°C), the strength trends were consistent. The compressive strength increased by 3.08% and 1.57% for 40% replacement with CS and GP, respectively. Flexural strength improvements were recorded as 6.25% (GP) and maximum for CS. Split tensile strength rose by 12.50% (CS) and 4.16% (GP), emphasizing their effectiveness under thermal conditions.

4.2 FUTURE OF WORK

Future research should focus on the long-term durability of concrete with copper slag and granite powder under various environmental conditions. Additionally, exploring the effects of different particle sizes, other waste material combinations, and their impact on shrinkage, cracking, and cost-effectiveness will be valuable. This would further optimize concrete performance and support its sustainable use in large-scale applications.

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