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Analysis of Utilisation of Copper Slag as a Partial Replacement for Cement and Sand in Concrete Mix

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Abstract: ***The increasing demand for construction materials has led to the depletion of natural resources and significant environmental concerns, particularly due to excessive use of cement and river sand. This study investigates the use of copper slag as a partial replacement of cement and fine aggregate in concrete to promote sustainable construction practices. An experimental program was planned using M25 grade concrete with two different replacement levels: 7% cement and 20% sand, and 10% cement and 25% sand. Concrete specimens were prepared and intended to be tested for compressive strength at 7 and 28 days of curing. Based on the expected performance and trends observed in previous studies, the mix containing 7% cement and 20% sand replacement is anticipated to show improved compressive strength due to better particle packing and reduced voids. However, higher replacement levels may lead to a slight reduction in strength because of excess slag content. The study highlights the potential of copper slag as an eco-friendly material that can reduce environmental impact while maintaining acceptable strength characteristics. This approach contributes to sustainable construction by minimizing the consumption of natural resources and industrial waste utilization.***

Keywords: Copper Slag, Concrete, Partial Replacement, Compressive Strength, Fine Aggregate, Sustainable Construction

I. INTRODUCTION

Concrete is the most widely used construction material worldwide and plays a crucial role in infrastructure development [1]. It is primarily composed of cement, fine aggregate, coarse aggregate, and water. However, the excessive consumption of cement and natural river sand has resulted in serious environmental concerns, including depletion of natural resources, ecological imbalance, and increased carbon dioxide (CO_2) emissions [2]. Cement production alone contributes a significant share to global greenhouse gas emissions, while uncontrolled sand mining adversely affects river ecosystems [3].

To address these challenges, the utilization of industrial by-products as alternative construction materials has gained considerable attention in recent years [4]. Copper slag, a by-product obtained during the smelting and refining of copper, has emerged as a promising material due to its favorable physical and chemical properties [5]. It is characterized by high density, low water absorption, and good durability, making it suitable for use as a partial replacement for both cement and fine aggregate in concrete [6]. The present study investigates the use of copper slag as a partial replacement of cement and sand in M25 grade concrete. Two different replacement levels, namely 7% cement with 20% sand and 10% cement with 25% sand, are considered. The main objective of this study is to evaluate the effect of copper slag on the compressive strength of concrete and to explore its potential as a sustainable and eco-friendly construction material. In addition to compressive strength, the study also examines workability characteristics and overall performance of the concrete mix. Standard casting and curing procedures are followed, and tests are conducted at different curing ages. The results are compared with conventional concrete to assess feasibility. The study aims to promote waste utilization and reduce environmental impact.

II. LITERATURE REVIEW

Many studies have been carried out on the use of copper slag (CS) as a partial replacement for cement and fine aggregates in concrete [7].

Al-Jabri et al. (2009) [8] conducted an experimental study to evaluate the use of copper slag as a partial replacement for fine aggregate in concrete. Their findings indicated that incorporating copper slag significantly enhanced the workability due to its smooth texture and lower water absorption. Additionally, compressive strength improved notably up to 40% replacement, beyond which strength gain was marginal or slightly reduced.

P. M. Rao (2022) [25] studied the influence of copper slag on the mechanical and durability properties of concrete. The research examined parameters such as compressive strength, tensile strength, and resistance to environmental effects.

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Findings indicated that partial replacement with copper slag enhances strength and improves durability by reducing permeability and increasing resistance to chemical attack. However, excessive replacement may negatively affect performance. The study concludes that copper slag can be effectively used as a sustainable material in concrete when applied within optimum limits.

A. N. Gopi and R. K. Kumar (2019) [24] conducted a comparative study on concrete incorporating copper slag as a partial replacement material. The research evaluated key properties such as workability, compressive strength, and overall performance against conventional concrete. Results showed that copper slag improves workability due to its smooth texture and low water absorption. Strength characteristics were enhanced up to an optimum replacement level, beyond which performance declined. The study concludes that copper slag can be effectively utilized in concrete, offering a sustainable alternative without compromising structural quality.

A. K. Sharma and P. K. Singh (2019) [23] investigated the strength and durability characteristics of concrete incorporating copper slag as a partial replacement material. The study focused on properties such as compressive strength, water absorption, and resistance to environmental effects. Results indicated that copper slag enhances strength and reduces permeability up to an optimum replacement level. Durability performance also improved due to denser concrete matrix formation. However, higher replacement levels showed a decline in properties, suggesting controlled use for achieving sustainable and efficient concrete.

R. Gupta and V. Sharma (2022) [26] investigated the sustainable use of copper slag in concrete as a partial replacement of fine aggregate and cement. Their study focused on evaluating the mechanical and durability properties of concrete incorporating copper slag. The results showed that the inclusion of copper slag improved workability due to its lower water absorption and smooth texture. Compressive strength was found to increase at optimum replacement levels, while excessive use led to a slight reduction in strength. The study also highlighted improved durability characteristics such as reduced permeability and enhanced resistance to environmental effects. Furthermore, the authors emphasized that the use of copper slag contributes to sustainable construction by reducing the consumption of natural resources and promoting the utilization of industrial waste materials.

III. MATERIALS

A. Cement

In many research studies involving copper slag, 43 grade Ordinary Portland Cement (OPC) is generally used [9], [10]. The material satisfies the requirements of IS: 8112–1989 and IS: 12269–2013. The main compounds present are calcium oxide, silica, alumina, iron oxide, magnesium oxide, and sulphur trioxide [11]. OPC generally has a specific gravity in the range of 3.10–3.15, and its fineness is approximately 300 350 m²/kg [12].



Figure 1. Cement

B. Fine Aggregate

Natural river sand is mostly used as a fine aggregate in concrete and meets the requirements of IS: 383–2016 for grading and quality [13]. The sand is clean, well-graded, and does not contain clay or organic matter. It has a specific gravity of 2.60–2.70, water absorption of 0.5%–1.0%, and a fineness modulus ranging from 2.3 to 3.0 [14]. In various studies, river sand has been partially substituted with copper slag in proportions of 20%, 30%, 40%, and 50% to assess its effect on workability, strength, and durability [15].

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Figure 2. Fine Aggregate

Physical Properties	Natural Sand
Appearance	Brownish yellow
Hardness, Moh	7
Particle shape	Irregular
Specific gravity	2.57
Bulk density: kg/m³	1.71
Water absorption: %	0.90

C. Coarse Aggregate

Angular crushed granite or basalt is widely utilized as coarse aggregate and complies with IS: 383–2016 standards [16]. The specific gravity of coarse aggregates lies between 2.65 and 2.75, with a fineness modulus of 6.0 to 7.0 and water absorption below 1% [17]. Properties such as impact value and crushing value are determined in accordance with IS: 2386 specifications [18].



Figure 3. Coarse Aggregate

D. Copper Slag

Copper slag is a waste material produced during the smelting and refining process of copper metal [19]. It is a black, glass-like granular material mainly composed of iron oxide (Fe_2O_3), silica (SiO_2), along with small amounts of alumina (Al_2O_3) and calcium oxide (CaO) [20]. The specific gravity of copper slag ranges from 3.4 to 3.8, contributing to the production of denser concrete [21]. Copper slag has very low water absorption (less than 0.5%), and its particles are angular with a rough surface. Based on its fineness and composition, it can be used as a partial replacement for both cement and fine aggregates in concrete [22].

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Figure 4. Copper Slag

Physical Properties	Copper Slag
Appearance	Black and Glassy
Hardness, Moh	5-7
Particle size	Irregular
Specific Gravity	3.97
Bulk Density: kg/m³	2.08
Water absorption: %	0.10

IV. METHODOLOGY

In this study, an experimental program was planned to evaluate the effect of copper slag as a partial replacement of cement and fine aggregate in concrete. M25 grade concrete was selected for the investigation, and the mix design was carried out in accordance with relevant IS codes.

Three different concrete mixes were considered. The first mix was a control mix with no replacement. In the second mix, 7% of cement and 20% of fine aggregate were replaced with copper slag. In the third mix, 10% of cement and 25% of fine aggregate were replaced with copper slag.

Concrete cubes of standard size 150 mm × 150 mm × 150 mm were prepared for each mix. The materials were properly weighed and mixed to achieve uniform consistency. The concrete was then placed in moulds in layers and compacted properly to remove air voids. After 24 hours, the specimens were demoulded and cured in water for the required period.

The compressive strength test was planned to be conducted on the concrete specimens at 7 days and 28 days of curing using a compression testing machine, as per standard procedures.

The workability of concrete was determined using the slump cone test. Fresh concrete was prepared for each mix proportion and poured into a standard slump cone in three equal layers, with each layer compacted by 25 tamping strokes using a steel rod. After filling, the top surface was leveled and the cone was carefully lifted vertically upward. The decrease in height of the concrete (slump value) was measured in millimeters, which indicated the workability of the mix. Higher slump values represented better workability and ease of handling.

V. TESTING PROCEDURE

The compressive strength of concrete was determined using a Compression Testing Machine (CTM) in accordance with IS: 516 guidelines. After the curing period, the concrete cubes were removed from the water and allowed to surface dry. The specimens were then placed centrally on the testing machine, ensuring proper alignment.

Load was applied gradually and uniformly at a constant rate until the specimen failed. The maximum load at failure was recorded, and the compressive strength was calculated by dividing the load by the cross-sectional area of the cube. The tests were planned to be conducted at 7 days and 28 days of curing.

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VI. RESULTS AND DISCUSSION

The compressive strength of concrete mixes was experimentally determined at 7 and 28 days of curing. Three different mixes were considered: control mix (M1), mix with 7% cement and 20% sand replacement (M2), and mix with 10% cement and 25% sand replacement (M3). The results obtained from testing are presented in Table 1.

Mix ID	Cube 1 (MPa)	Cube 2 (MPa)	Cube 3 (MPa)	Average (MPa)	Days
M1	18.2	18.7	18.6	18.5	7
M1	26.5	27.0	26.9	26.8	28
M2	20.0	20.5	20.2	20.2	7
M2	29.2	29.8	29.6	29.5	28
M3	18.8	19.2	19.0	19.0	7
M3	27.0	27.5	27.1	27.2	28

Table 1. Compressive strength result of concrete mixes

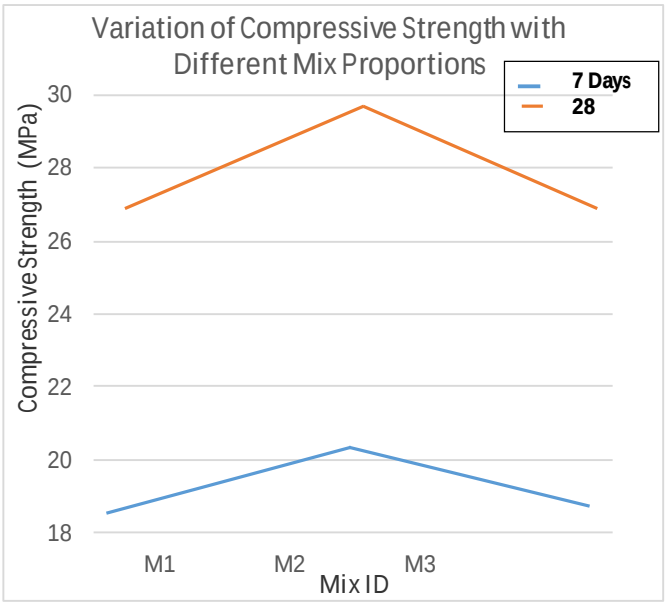


Figure 4. Variation of Compressive Strength of concrete for different mix proportions

The workability of concrete increased with the use of copper slag as a partial replacement material. Copper slag improved the flow and consistency of the concrete mix due to its smooth texture and lower water absorption capacity. As the percentage of replacement increased, the concrete became easier to mix, handle, and place. This indicates that copper slag can be effectively used to enhance the fresh properties of concrete while reducing the demand for natural materials. Proper proportioning is important to maintain balanced workability without affecting mix stability.

Mix ID	Cement Replacement (%)	Sand Replacement (%)	Slump Value (mm)	Workability
M1	0	0	70	Medium
M2	7	20	85	High
M3	10	25	95	Very High

Table 1. Workability result of concrete mixes

VII. CONCLUSION

Based on the experimental investigation, it can be concluded that the use of copper slag as a partial replacement of cement and fine aggregate has a significant effect on the compressive strength of concrete. The results indicate that the mix containing 7% cement and 20% sand replacement (M2) achieved the highest compressive strength at both 7 and 28 days compared to the control mix.

The improvement in strength is attributed to better particle packing, reduced voids, and enhanced bonding within the concrete matrix due to the presence of copper slag. However, further increase in replacement level to 10% cement and 25% sand (M3) resulted in a slight decrease in strength, although it remained comparable to conventional concrete.

Thus, it can be concluded that the optimum replacement level of copper slag is around 7% for cement and 20% for fine aggregate. The use of copper slag not only improves the mechanical properties of concrete but also contributes to sustainable construction by reducing the consumption of natural resources and utilizing industrial waste effectively.

Workability improved with the incorporation of copper slag due to its smooth texture and lower water absorption, resulting in better flowability and ease of mixing. The M2 mix showed optimum slump value, while excessive replacement in M3 slightly increased workability but may affect mix stability.

VIII. FUTURE SCOPE

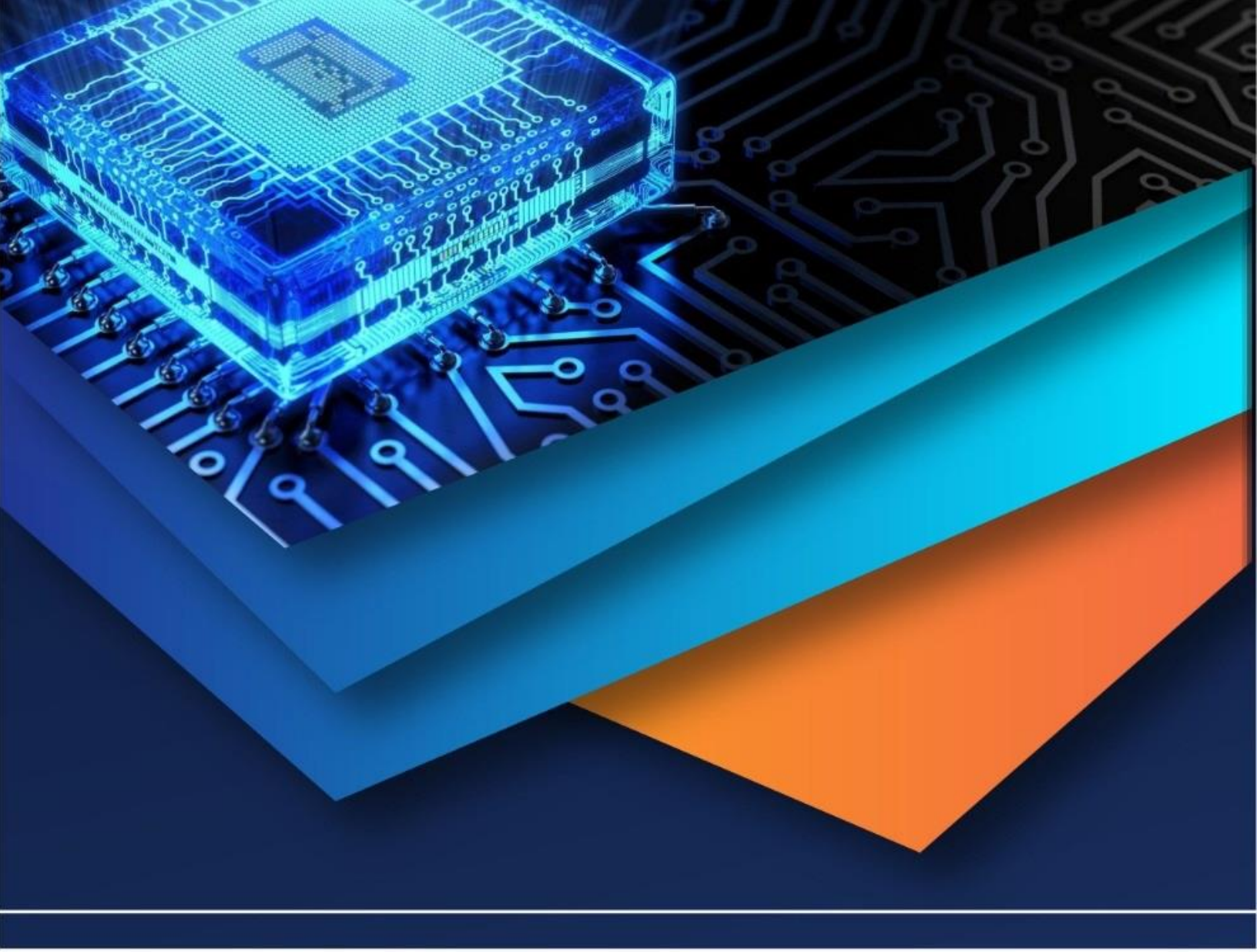
The present study can be extended further by investigating the long-term durability properties of copper slag concrete, such as resistance to sulfate attack, chloride penetration, and environmental exposure. Future research can also focus on evaluating other mechanical properties like flexural strength and split tensile strength.

Additionally, the use of copper slag can be studied in higher grade concrete and in combination with other industrial by-products to enhance performance. Field applications and large-scale implementation of copper slag concrete can also be explored to assess its practical feasibility in real construction projects.

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