



## Experimental Review on the Use of Copper Slag as a Partial Replacement for Fine Aggregate in Concrete

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**Abstract:** The depletion of natural river sand due to its extensive use in concrete and pavement construction has raised environmental and economic concerns across India. Copper slag, a by-product of copper smelting, has emerged as a promising alternative to fine aggregates. This review compiles experimental findings on copper slag's influence on concrete properties such as strength, workability, and durability. Studies consistently suggest that replacement levels between 30–50% yield optimal performance. The paper also explores environmental implications and life-cycle benefits, positioning copper slag as a viable material for sustainable construction.

**Keywords:** Copper slag, fine aggregate replacement, sustainable concrete, industrial waste, durability.

### 1. INTRODUCTION:

Concrete is the most widely used construction material globally, yet its production heavily depends on non-renewable resources like river sand. The environmental consequences of excessive sand mining have prompted researchers to explore industrial by-products as substitutes. Copper slag, generated during copper refining, has gained attention for its potential as a fine aggregate replacement B. Gorai, and Shi, Caijun & Meyer, [1], [2].

M. P. Chockalingam [8]. Its angular shape, high density, and chemical composition—rich in iron, silica, and alumina—contribute to improved mechanical strength and durability. Incorporating copper slag supports sustainable development by promoting waste recycling and reducing the carbon footprint of construction

### 2. MATERIAL CHARACTERISTICS AND ENGINEERING BEHAVIOR

Copper slag is a dense, glassy material with low water absorption. Al-Nuami [3] found that 40% replacement in reinforced concrete columns increased load-bearing capacity, while 80% led to early failure. Wu et al. [4] reported optimal compressive strength and workability at 40% replacement, with higher levels increasing porosity.

Brindha et al. [5] demonstrated improved corrosion resistance and reduced chloride penetration when copper slag was used as both fine aggregate and cement replacement. Najimi et al. [6] observed enhanced sulphate resistance due to suppression of ettringite formation. Khalifa et al. [7] confirmed better density and reduced permeability at 50% replacement.

### **3. MECHANICAL PERFORMANCE AND DURABILITY**

Selvi et al. [9] validated mechanical improvements in M40-grade mixes using non-destructive testing. Madheswaran et al. [10] applied copper slag in masonry and plastering, achieving denser matrices and higher strength. Al-Jabri and Shoukry [11] used nano copper slag to enhance compressive strength and reduce sorptivity.

Ambily et al. [12] incorporated copper slag in ultra-high-performance concrete, achieving strengths above 190 MPa, though complete replacement led to slight performance decline. Velumani and Meenambal [13], and Saxena and Simalti [14], found that 40–50% replacement improved strength, workability, and durability when combined with fly ash.

Mithun and Narasimhan [15] studied alkali-activated slag concrete and found that copper slag improved early strength and reduced porosity. Patil et al. [16] reported a 32% increase in compressive strength with 40% slag replacement. Dash and Mullick [17] emphasized the role of industrial by-products in enhancing freeze–thaw resistance.

Sharma et al. [18] identified 20% as optimal for self-compacting concrete, beyond which performance declined. Geetha and Madhavan [19] demonstrated that combining copper slag with fly ash and silica fume improved both strength and durability. Mavroulidou [20] confirmed that water-cooled copper slag concrete performed comparably to conventional mixes.

Dos Anjos et al. [21] and Vijayaraghavan and Raja [22] showed that copper slag combined with recycled aggregates reduced water absorption and improved mechanical properties. Sumathy Raju and Brindha Dharmar [23] supported its use for enhanced structural capacity and corrosion resistance.

### **4. RECENT REVIEWS AND EMERGING APPLICATIONS**

Gurevitch et al. [24] summarized copper slag's benefits in cement-based materials. Singh et al. [25] highlighted its role in green construction. Whiting et al. [26] emphasized its contribution to recycling industrial by-products.

Guedes de Paiva et al. [27] discussed recent advances in copper slag composites. Ahmad et al. [28] provided a comprehensive overview of its environmental and structural benefits. Upadhyay et al. [29] reported strengths up to 50 MPa with 30–50% replacement, confirming environmental safety.

Ajith Kumar and Pavan [30] achieved a 28-day strength of 30.6 MPa using 30% copper slag and 40% cement replacement with bagasse and rice husk ash, demonstrating good workability and sustainable synergy.

### **5. OPTIMAL REPLACEMENT RANGE AND PRACTICAL CONSIDERATIONS**

Across studies, the optimal copper slag replacement range is consistently reported between 30–50%. Excessive replacement may lead to segregation and reduced bonding [3], [4].

#### **Implementation guidelines include:**

- Conducting trial mixes to assess compatibility [9], [10]
- Using admixtures to control bleeding [17]
- Ensuring proper curing to enhance strength [12]
- Monitoring long-term durability [21], [22]

## 6. ENVIRONMENTAL AND ECONOMIC IMPLICATIONS

Copper slag utilization supports circular economy principles by diverting waste from landfills and reducing reliance on natural sand [24], [25]. Life-cycle assessments show lower embodied energy and carbon emissions [28], [29].

Its encapsulation in concrete ensures environmental safety, with low leachability confirmed by Shi et al. [2]. Economic benefits include reduced material costs and improved performance, making copper slag attractive for large-scale infrastructure projects [30].

## 7. CONCLUSION

Copper slag is a sustainable and technically viable partial replacement for fine aggregates in concrete. When used within optimal limits, it enhances strength, workability, and durability while supporting environmental goals. Its integration into concrete technology promotes eco-efficient construction and resource conservation. Future research should explore long-term field performance, compatibility with emerging binders, and scalability in precast and pavement applications.

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