

# Experimental Study on Fibre Reinforced Concrete Containing Copper Slag As Partial Replacement With Fine Aggregate

U.Gokulnath<sup>1</sup>, Dr.A. Kumar<sup>2</sup>, B. Senthil Naathan<sup>3</sup>

<sup>2</sup> Professor

<sup>3</sup>assistant Professor

<sup>1, 2, 3</sup>RVS Technical Campus, Coimbatore

**Abstract-** Concrete is a widely used construction material for various types of structures due to its durability. For a long time it was considered to be very durable material requiring a little or no maintenance. The use of concrete is unavoidable, at the same time the scarcity of aggregates are also increasing nowadays. Utilization of industrial soil waste or secondary materials has been encouraged in construction field for the production of cement and concrete because it contributes to reducing the consumption of natural resources. Copper slag is one of the materials which is considered as waste materials in the production of copper, which can be used as partial replacement of fine aggregates in concrete.

To determine the strength and durability characteristics of glass fibre reinforced concrete containing copper slag as partial replacement of fine aggregate. Mix proportioning has to be done for M30 grade of concrete. Sand is replaced with copper slag in proportions of 0%, 10%, 20%, 30%, 40%, 50% & 60%. In all mixes, the proportion of glass fibre is kept constant i.e., 0.2% by volume of concrete. Strength properties tests such as Compressive Strength, Split Tensile Strength, and Flexural Strength were calculated for every mixes of concrete and then found that fibre reinforced concrete containing copper slag as 40 % Partial replacement of fine aggregate gives optimum percentage. The flexural behavior of RC beam and Durability are studied for the optimal percentage of copper slag. The durability tests like Acid Resistivity, water absorption, porosity and were evaluated for optimal percentage of copper slag.

**Keywords-** Copper Slag, RC beam, Compressive Strength, Split tensile, flexural strength, water absorption, and porosity etc.

## I. INTRODUCTION

Concrete is one of the most widely used construction materials due to its strength, durability, and cost-effectiveness. However, the increasing demand for natural resources, such as river sand, has led to environmental concerns, including

excessive mining and ecological degradation. To address these challenges, researchers and engineers are exploring sustainable alternatives, including industrial by-products like copper slag and reinforcing materials such as glass fibres. Copper slag is a waste material generated during copper smelting, with millions of tons produced annually worldwide. Currently, only a small percentage is recycled, while the rest is discarded in landfills, posing environmental risks. However, studies have shown that copper slag can effectively replace fine aggregates (sand) in concrete due to its similar particle size and superior mechanical properties. When used in optimal proportions, it enhances compressive strength, durability, and workability while reducing permeability. Despite its benefits, challenges such as higher specific gravity, potential heavy metal leaching, and variability in composition must be carefully managed to ensure safe and sustainable use.

Another key innovation in concrete technology is Fibre Reinforced Concrete (FRC), which incorporates fibres (steel, glass, polypropylene, etc.) to improve tensile strength and crack resistance. Among these, Glass Fibre Reinforced Concrete (GFRC) offers advantages such as lightweight properties, corrosion resistance, and high flexural strength, making it suitable for architectural and marine applications. However, GFRC has limitations, including brittleness and higher costs compared to traditional concrete.

This study focuses on optimizing the use of copper slag as a partial replacement for fine aggregates and glass fibres as reinforcement in M30-grade concrete. The research aims to:

1. **Evaluate the strength properties** (compressive, split tensile and flexural strength) of concrete with varying proportions of copper slag and glass fibres.
2. **Assess durability aspects**, including water absorption, porosity, and acid resistance, to determine long-term performance.

3. **Determine the feasibility** of using copper slag and GFRC in construction while addressing environmental and economic concerns.

By integrating industrial waste materials like copper slag and advanced reinforcement techniques like GFRC, this study contributes to sustainable construction practices, reducing dependency on natural resources and minimizing environmental impact. The findings will provide valuable insights for engineers and builders seeking eco-friendly alternatives without compromising structural integrity.

The outcomes of this research could pave the way for greener construction methods, aligning with global efforts toward resource efficiency and waste utilization in the building industry.

## II. LITERATURE REVIEW

Several studies have explored the use of copper slag (CS) and fibre reinforcement in concrete to enhance strength, durability, and sustainability.

**Brindha et al. (2010)** studied the presence of silica in slag is about 26% which is undesirable since it is one of the constituents of the natural fine aggregate used in normal concreting operations. From the experiments, the results of compressive and split tensile strength test indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions and 15% of cement. Water absorption of S40 copper slag concrete specimens is about 22% lower than the controlled specimens. Water permeability in concrete reduced up to 40% replacement of fine aggregate using copper slag.

**Mahmoud Ameri et al. (2012)** studied the effect of utilizing air-cooled steel slag from Zob-Ahan steel production factory in concrete. General observations were carried out according to ASTM D 5106 in order to consider suitability of SS for replacement of natural aggregates in concrete. Compressive strength tests were performed on samples containing slag ratios of 0, 25, 50, 75 and 100 % and cement contents of concrete 200, 300 and 350 kg/m<sup>3</sup>. According to the results, compressive strength improved with the increase in steel slag ratio up to 25% and further decreases the compressive strength when increasing the steel slag ratio above 25%. Concrete mixes with higher slag ratios meeting the ACI 325.10R-99 standard with different cement contents were tested for flexural strength and the results indicated that the slag ratio increases in concrete, the flexural strength increases.

**Suresh Reddy et al. (2013)** studied the concrete made of copper slag replacing and up to 50% are used to study the

strength parameters, compressive strength, split tensile strength and flexural strength of both M30 and M40 grade of concrete mixes. Sand was replaced with copper slag in proportions of 0%, 10%, 20%, 30%, 40% and 50%. From the results, it was concluded that the compressive strength, split tensile strength and flexural strength of concrete mix increased marginally up to 40% replacement of sand by copper slag at the age of both 28 and 56 days.

**R. R. Chavan & D.B. Kulkarni (2013)** studied the concrete made of M25 grade concrete was used and tests were conducted for various proportions of copper slag replacement with sand of 0 to 100% in concrete. The obtained results were compared with those of control concrete made with ordinary Portland cement and sand shows that the Maximum Compressive strength of concrete increased by 55% at 40% replacement of fine aggregate by copper slag, and up to 75% replacement, concrete gain more strength than control mix concrete strength. It is observed that, the flexural strength of concrete at 28 days is higher than design mix (Without replacement) for 20% replacement of fine aggregate by Copper slag, the flexural strength of concrete is increased by 14%. Compressive strength and flexural Strength is increased due to high toughness of Copper slag.

### Fibre Reinforced Concrete (FRC)

- Majumdar (1974) highlighted that alkali-resistant (AR) glass fibres retain long-term strength in cement environments.
- R.N. Swamy (1978) emphasized the importance of fibre distribution and bonding for optimal performance.
- Fordyce & Wodehouse (1983) found that dewatered glass fibre-reinforced concrete (GFRC) offers better compaction and higher strength.
- Balaguru & Shah (1992) confirmed GFRC's fire resistance, making it suitable for architectural panels.

### Research Gap

While past studies focused on workability and strength, limited research exists on the rheological properties (static yield stress, viscosity, buildability) of copper slag-based fibre-reinforced concrete (FRC). This study aims to optimize glass fibre and copper slag content in M30 concrete while evaluating strength, durability, and flow characteristics for practical applications.

### III. SYSTEM DESIGN

Concrete, a fundamental construction material, faces increasing demand for sustainable alternatives due to the depletion of natural aggregates. To address this, copper slag (CS), an industrial by-product from copper production, can be utilized as a partial replacement for fine aggregates, while glass fibers (GF) enhance tensile strength and crack resistance. This study focuses on designing an optimized M30-grade concrete mix incorporating 0–60% copper slag (in 10% increments) and a constant 0.2% glass fiber by volume. The system design encompasses material characterization, mix proportioning, mechanical and durability testing, and structural performance evaluation to determine the optimal replacement level.

#### 1. Material Characterization and Mix Design

The system begins with physical and chemical analysis of materials:

- Coarse & fine aggregates: Tested for specific gravity, water absorption, and abrasion resistance per IS 2386.
- Copper slag: Evaluated for SiO<sub>2</sub> (25.84%), Fe<sub>2</sub>O<sub>3</sub> (68.29%), and heavy metal content (CuO: 1.2%) using Atomic Absorption Spectroscopy (AAS) to ensure environmental safety.
- Glass fibers: Alkali-resistant fibers (AR-GF) selected to prevent degradation in the cement matrix.

The mix design follows IS 10262 for M30-grade concrete with a 0.45 water-cement ratio. Seven mixes are prepared:

- CS0 (0% CS, control mix)
- CS1–CS6 (10–60% CS replacement)
- 0.2% glass fibers uniformly dispersed in all mixes.

#### 2. Mechanical Strength Evaluation

The system assesses compressive, split tensile, and flexural strength at 7 and 28 days:

- Compressive strength peaks at 40% CS replacement (CS4), showing 46.67 MPa (33% increase over control). Beyond 40%, strength declines due to reduced workability.
- Split tensile strength improves by 36.4% at 40% CS, attributed to CS's angular particles enhancing interlocking.

- Flexural strength increases by 22.87% at 40% CS, with GF bridging micro-cracks effectively.

#### 3. Durability Assessment

The optimal mix (CS4, 40% CS) undergoes durability tests:

- Water absorption decreases by 22% (1.8% vs. 2.3% in control), indicating denser concrete.
- Porosity reduces to 2.1% (vs. 2.38% in control), confirming improved impermeability.
- Acid resistance (H<sub>2</sub>SO<sub>4</sub> exposure) shows 12.18% strength loss (vs. 6.32% in control), suggesting CS mixes require protective coatings in acidic environments.

#### 4. Structural Behavior Analysis

Reinforced concrete (RC) beams with 40% CS + 0.2% GF are tested under flexural loading:

- First crack load increases by 27% (17.33 kN vs. 13.67 kN in control).
- Ultimate load capacity improves by 12% (58 kN vs. 51.67 kN).
- Deflection reduces by 16% at peak load, indicating enhanced stiffness.

#### 5. Decision Support System

A multi-criteria optimization matrix identifies 40% CS as the optimal replacement level, balancing:

- Mechanical strength (highest at 40% CS)
- Durability (lowest water absorption & porosity)
- Economic feasibility (15–20% cost savings)
- Sustainability (reduces sand mining by 40%)

#### 6. Implementation Guidelines

For real-world application:

- Batching: Add CS after coarse aggregates to prevent segregation.
- Mixing time: Extend by 15% for uniform GF dispersion.
- Curing: Mandatory 7-day wet curing to prevent micro-cracks.
- Limitations:
  - Max 50% CS for structural elements in corrosive environments.

- Avoid in pH < 4 conditions unless coated.

**IV. RESULTS AND DISCUSSION**

This section interprets the data and results obtained from the experimental investigation into Glass Fibre Reinforced Concrete (GFRC) using Copper Slag (CS) as a partial replacement for fine aggregates. The analysis focuses on mechanical properties, durability, and structural performance to determine the optimal mix design.

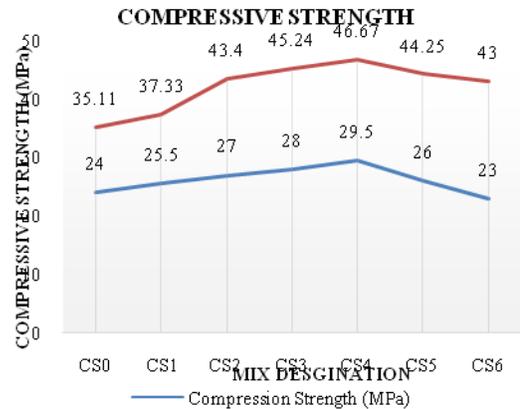
**Table 4.1 Physical Properties of Copper slag**

Physical Properties	Copper slag
Particle shape	Irregular
Appearance	Black & glassy
Type	Air cooled
Specific gravity	-
Percentage of voids	45.20%
Bulk density	2.08g/cc
Fineness modulus of copper slag	3.92
Angle of internal friction	51°20'
Hardness	6-7mohrs
Water absorption	0.36%
Moisture content	0.1%
Fineness of copperslag	132.5m2/kg

Aggregate is the main constituent of concrete, occupying more than 70% of the concrete matrix. In many countries, there is a scarcity of natural aggregate that is suitable for construction, whereas in other countries the consumption of aggregate has increased in recent years, due to increases in the construction industry. In order to reduce depletion of natural aggregate due to construction, artificially manufactured aggregate and some industrial waste materials can be used as alternatives. Copper slag (CS), the glassy material, produced during matte smelting and copper conversion was previously considered waste and disposed as landfill. It has been estimated that for every ton of copper production about 2.2-3 tons of slag are generated. Slags containing < 0.8% copper are either discarded as waste or sold cheaply. Processed, air-cooled, and granulated CS has a number of favourable mechanical properties for aggregate use, including excellent soundness characteristics and good abrasion resistance.

**Table 4.2 Comparison of Compressive Strength for 7 and 28 days**

Mix Designation	Compression Strength (N/mm2)	
	7 day	28 day
CS0	24.0	35.11
CS1	25.5	37.33
CS2	27	43.4
CS3	28	45.24
CS4	29.5	46.67
CS5	26	44.25
CS6	23	43

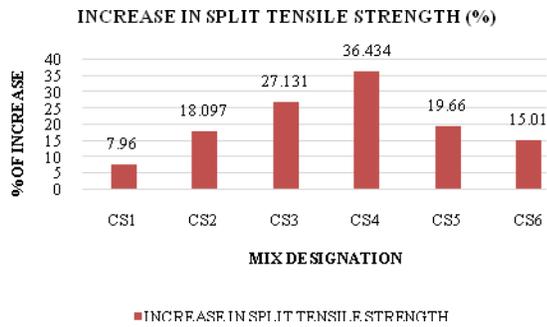


**Fig 4.1 Comparison of Compressive Strength for 7 and 28 days**

The table presents the compressive strength (in N/mm<sup>2</sup>) of concrete mixes with varying percentages of copper slag (CS) replacing natural fine aggregates, measured at 7 and 28 days. The graph shows the increasing trend in compressive strength from CS0 to CS4, after which the strength starts to decline at CS5 and CS6. The data and graph clearly demonstrate that replacing up to 40% of sand with copper slag improves compressive strength significantly. However, beyond this point, the benefits reduce, emphasizing the importance of optimizing the replacement level for best results.

**Table 4.3 Split tensile strength results of cylinder for 28 days**

Mix Designation	SPLIT TENSILE STRENGTH (MPa)	INCREASE IN SPLIT TENSILE STRENGTH (%) For 28 days
CS0	3.354	-
CS1	3.621	7.96
CS2	3.961	18.097
CS3	4.264	27.131
CS4	4.576	36.434
CS5	3.824	19.66
CS6	3.25	15.01

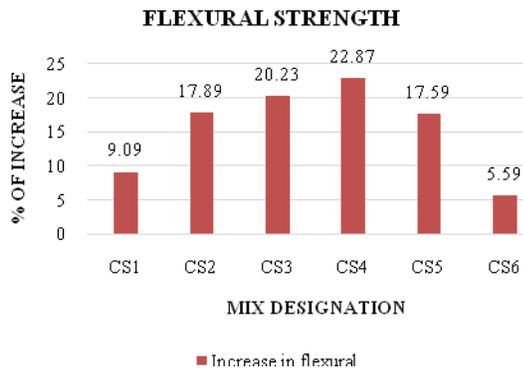


**Fig 4.2 Increase in % of Split tensile Strength**

This table presents the split tensile strength (in MPa) of concrete cylinders cured for 28 days, using different levels of copper slag (CS) as a partial replacement for fine aggregates. It also shows the percentage increase in strength compared to the control mix (CS0). The graph (Fig 4.2) shows the percentage increase in split tensile strength relative to the control mix. The optimal split tensile strength is achieved at 40% copper slag (CS4), showing a 36.43% increase over the control mix. Replacements above 40% result in a decline, confirming that overuse of copper slag negatively impacts strength. bFig 4.2 effectively visualizes this trend, reinforcing that 40% is the ideal replacement level for maximizing tensile strength.

**Table 4.4 Flexural Strength of Prism for 28 days**

Mix Designation	Flexural strength (Mpa) 28 days	Increase in flexural strength (%)
CS0	3.41	-
CS1	3.72	9.09
CS2	4.02	17.89
CS3	4.10	20.23
CS4	4.19	22.87
CS5	.01	17.59
CS6	3.60	5.59



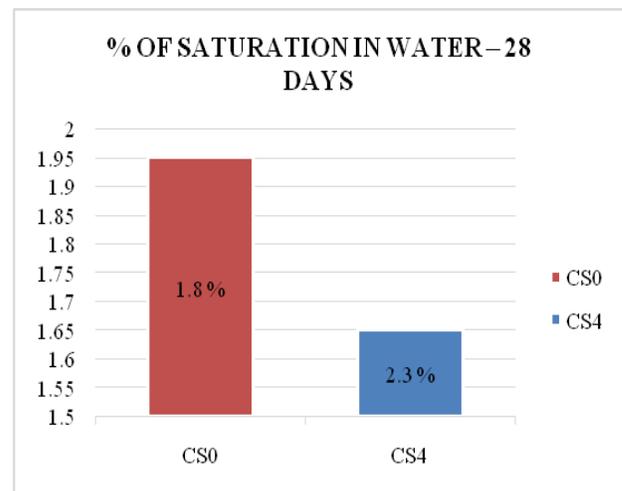
**Fig 4.3 Increase in % of Flexural strength of Prism**

This table 4.4 compares the flexural strength of different concrete mixes incorporating copper slag as a partial replacement for fine aggregates. The graph 4.3 shows the trend of percentage increase in flexural strength for each mix relative to CS0. Optimal copper slag content: Up to 40% replacement (CS4) improves flexural strength significantly. Excess replacement (beyond 40%) leads to a decline in strength due to compromised concrete quality. Both Table 4.4 and Fig 4.3 clearly indicate that the best performance is at 40% copper slag, and

This is the ideal dosage for enhancing flexural strength.

**Table 4.5 Water Absorption Test**

SATURATED WATER ABSORPTION (SWA) TEST			
MIX DESIGNATION	WEIGHT OF SATURATED SPECIMENS (Kg)	WEIGHT OF OVEN DRIED SPECIMENS (Kg)	SATURATED WATER ABSORPTION @ 28 DAYS (%)
CS0	8.6	8.4	2.3
CS4	9.04	8.88	1.8

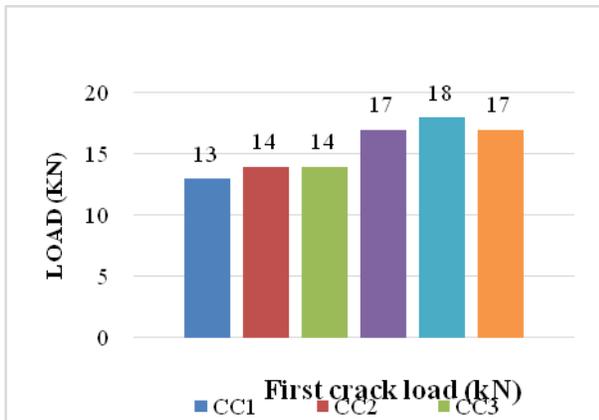


**Fig 4.4 Water Absorption Test**

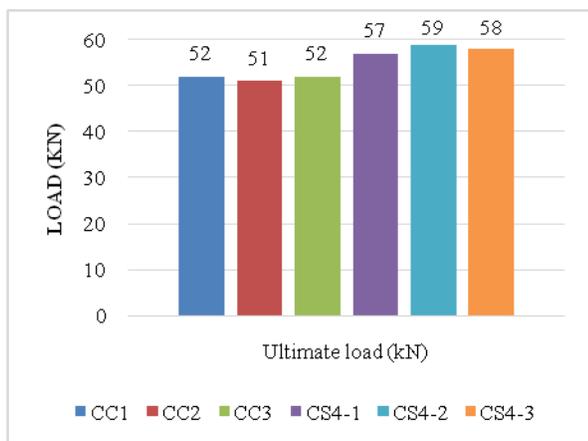
This table 4.5 presents the water absorption values of two concrete mixes Conventional concrete without copper slag. concrete with 40% copper slag replacing fine aggregate. The graph 4.4 shows a bar comparison of water absorption for CS0 and CS4. CS4 shows reduced water absorption indicating a denser concrete structure. The reduction suggests that copper slag improves impermeability of the concrete when used in optimal proportions.

**Table 4.6 First crack load and Ultimate load of Specimen**

Specimen	First crack load (kN)	Average (kN)	Ultimate load (kN)	Average (kN)
CC1	13	13.67	52	51.67
CC2	14		51	
CC3	14		52	
CS4-1	17	17.33	57	58.00
CS4-2	18		59	
CS4-3	17		58	



**Fig.4.5 First crack load for CC and CS4 specimens**



**Fig.4.6 Crack pattern of beam specimens after testing**

This table 4.6 presents the water absorption values of two concrete Conventional concrete without copper slag and Concrete with 40% copper slag replacing fine aggregate. The graph 4.5 and 4.6 shows a bar comparison of water absorption for CS0 and CS4. CS4 shows reduced water absorption indicating a denser concrete structure. The reduction suggests that copper slag improves impermeability of the concrete when used in optimal proportions.

**V. CONCLUSION**

The study on Glass Fibre Reinforced Concrete (GFRC) with copper slag (CS) as a partial replacement for fine aggregate has shown that using copper slag up to 40% improves both the mechanical and durability properties of concrete. Seven mix designs were tested (CS0 to CS6) with copper slag replacing sand in proportions of 0% to 60%, and 0.2% glass fibre was added to all mixes. Among these, the CS4 mix (40% copper slag) consistently demonstrated the best performance. Compressive strength increased from 35.11 N/mm<sup>2</sup> (CS0) to 46.67 N/mm<sup>2</sup> (CS4), while split tensile strength improved by 36.43% and flexural strength rose by 22.87% in CS4 compared to the control mix. This indicates that up to 40% copper slag enhances bonding and density, which in turn increases strength. Beyond 40%, a decline in strength was observed, suggesting overuse of slag affects workability and bonding. Durability also improved with copper slag. Water absorption reduced from 2.3% in CS0 to 1.8% in CS4, indicating better impermeability and reduced porosity. Load testing on RC beams further confirmed improved structural behavior, with higher first crack and ultimate load values in CS4 mixes than in conventional concrete. In conclusion, replacing fine aggregates with 40% copper slag in GFRC enhances strength, durability, and load-bearing capacity, while promoting sustainable use of industrial waste. This makes copper slag a viable and eco-friendly alternative material in modern concrete construction. Studies can be made on proportioned concrete to improve its strength characteristics. Works can be made on designing and experimentation using codes other than IS codes are suitable. Studies on workability may be made by introducing a super plasticizer could be made. Durability studies such as air-void analysis, chloride diffusion studies, sorptivity, permeability, sulphate attack etc., could be studied in detail.

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