



# Sustainable Development Of Pavement Quality Concrete Utilising Copper Slag

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**Abstract:** This study explores the use of copper slag as a partial replacement for fine aggregate in Pavement Quality Concrete (PQC) to achieve sustainable construction. With increasing environmental concerns due to excessive use of natural resources like river sand and cement, the incorporation of industrial by-products such as copper slag provides an eco-friendly alternative. Concrete mixes were prepared with 0%, 20%, 40%, and 60% replacement levels and tested for workability using slump, compaction factor, and Vee-Bee tests.

The results indicate that copper slag significantly improves the workability of concrete and enhances compressive strength up to an optimum replacement level of around 60%. Beyond this level, a slight reduction in strength is observed. The study concludes that copper slag can be effectively used in PQC as a sustainable material, reducing environmental impact while maintaining satisfactory performance.

## I. INTRODUCTION

The construction industry is among the largest consumers of natural resources worldwide and is also a significant contributor to environmental pollution and carbon emissions. In building construction, concrete plays a vital role as the most commonly used material for structural components such as foundations, columns, beams, slabs, and floors due to its strength, durability, and versatility. However, conventional concrete relies heavily on materials like Portland Pozzolana Cement (PPC) and natural river sand [1].

The production of cement is energy-intensive and releases a large amount of carbon dioxide, contributing to global warming, while excessive extraction of river sand leads to depletion of natural resources, riverbank erosion, and ecological imbalance. These issues have raised serious environmental concerns and highlight the urgent need for sustainable alternatives. As a result, modern civil engineering is increasingly focused on developing eco-friendly concrete by incorporating industrial by-products and reducing dependency on natural materials, thereby promoting sustainability without compromising performance [2].

The incorporation of copper slag in pavement quality concrete aligns with the principles of sustainable development by promoting waste recycling, conserving natural resources, and potentially improving material performance. Studies have indicated that copper slag can enhance workability, compressive strength, and resistance to abrasion—key properties required for pavement applications. Additionally, its use can contribute to cost efficiency and reduce the overall environmental footprint of construction projects [3].

This study focuses on the sustainable development of pavement quality concrete through the utilization of copper slag. It aims to evaluate the mechanical and durability characteristics of concrete with varying

proportions of copper slag, and to assess its feasibility as an eco-friendly alternative to conventional materials in pavement construction [4].

## 2. MATERIALS USED

### 2.1. Portland Pozzolana Cement (PPC)

Portland Pozzolana Cement is a blended cement produced by intergrading ordinary Portland cement clinker with pozzolanic materials such as fly ash. The presence of pozzolana enhances long-term strength and significantly improves the durability of concrete. PPC generates less heat of hydration compared to ordinary cement, making it suitable for mass concreting works like pavements. It also offers better resistance to chemical attacks, sulphates, and environmental degradation. Additionally, PPC contributes to sustainability by utilizing industrial by-products and reducing carbon emissions.

### 2.2. Fine Aggregate (River Sand)

Fine aggregate, commonly known as river sand, is a naturally occurring granular material collected from riverbeds. It plays a crucial role in filling the voids between coarse aggregate particles, thereby increasing the density and strength of concrete. River sand improves the workability and finishability of the concrete mix, making it easier to place and compact. It also helps in reducing segregation and bleeding when properly graded. However, excessive extraction of river sand has led to environmental concerns, encouraging the use of alternative materials like copper slag [5].

### 2.3. Coarse Aggregate

Coarse aggregate consists of crushed stone or gravel particles that form the major portion of the concrete mix. These aggregates provide bulk, strength, and structural stability to the concrete. They help in reducing shrinkage and minimize the amount of cement paste required, making the mix more economical. The size, shape, and grading of coarse aggregates significantly influence the strength and durability of concrete. Well-graded aggregates ensure better interlocking and load distribution, which is essential for pavement quality concrete.

### 2.4. Copper Slag

Copper slag is an industrial by-product obtained during the smelting and refining of copper. It is a dense, glassy material with high strength and low water absorption characteristics, making it suitable as a partial replacement for fine aggregate. The use of copper slag in concrete improves mechanical properties such as compressive strength and abrasion resistance. It also enhances durability by reducing permeability. Moreover, incorporating copper slag helps in effective waste management and supports sustainable construction practices by reducing the need for natural sand [6].

### 2.5. Water

Water is a vital component in concrete as it initiates the hydration process of cement, leading to the formation of a strong binding matrix. The quality and quantity of water directly influence the strength, durability, and workability of concrete. Clean, potable water is generally recommended to avoid impurities that may affect the chemical reactions. Proper water-cement ratio is essential to achieve the desired consistency and strength. Excess water can reduce strength and cause segregation, while insufficient water may lead to poor workability and incomplete hydration.

## 3. METHODS OF WORKING

### 3.1 Test Performed

**3.1.1 Slump Test:** The slump test is one of the most commonly used methods to determine the workability and consistency of fresh concrete. It provides a quick and simple way to assess how easily concrete can be mixed, placed, and compacted, which is especially important for Pavement Quality Concrete (PQC). The slump value is measured as the vertical difference between the height of the cone and the highest point of the slumped concrete. This value indicates the workability of the mix:

Low slump (0–25 mm): Indicates stiff concrete, suitable for pavements and roads.

Medium slump (25–75 mm): Indicates moderate workability.

High slump (75–150 mm): Indicates high workability, used for heavily reinforced sections.



Figure 1: Slump test

### 3.1.2 Compressive Strength Test:

The compressive strength test measures the maximum load concrete can withstand before failure. Concrete cubes are cast, cured (usually 7 and 28 days), and tested in a compression testing machine (CTM) by applying load until they break.

The strength is calculated as load divided by area. Higher values indicate stronger and more durable concrete. This test helps evaluate the effect of copper slag on concrete strength.



Figure 2: Compressive Strength test

### 3.1.3 Compaction Factor Test:

The compaction factor test is used to measure the workability of concrete, especially for stiff mixes where the slump test is less effective. It indicates how easily concrete can be compacted under standard conditions.

In this test, concrete is allowed to fall through two hoppers into a cylinder, and the weights of partially and fully compacted concrete are compared. The compaction factor is calculated as the ratio of these two weights.

A higher value of compaction factor means better workability and easier compaction. This test is useful for evaluating concrete used in Pavement Quality Concrete (PQC), especially when materials like copper slag are added, as they can improve the flow characteristics of the mix.



Figure 3: Compaction Factor test

### 3.1.4. Vee Bee Test:

The Vee-Bee test is used to determine the workability and consistency of fresh concrete, especially for stiff or low-workability concrete mixes. In this test, concrete is placed in a cylindrical container and subjected to vibration until it changes from a conical shape to a fully compacted cylindrical shape. The time required for this remolding process, known as the Vee-Bee time, indicates the degree of workability of the concrete mix.



Figure 4: VEE BEE Test

## 3.2 Observation

### 3.2.1 Slump Test:

The slump cone test was conducted for concrete mixes with 0%, 20%, 40%, and 60% replacement of sand by copper slag. The observed slump values were 72 mm, 130 mm, 90 mm, and 100 mm respectively. The control mix (0%) showed a slump of 72 mm, indicating moderate workability. At 20% replacement, the slump increased significantly to 130 mm, showing improved workability due to the addition of copper slag. At 40%, the slump decreased to 90 mm, indicating reduced flowability compared to the 20% mix. At 60% replacement, the slump slightly increased to 100 mm, showing moderate workability. Overall, the results indicate that copper slag improves the workability of concrete compared to the control mix, with the highest slump observed at 20% replacement.

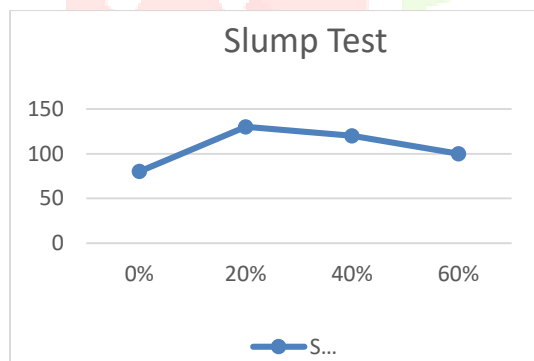


Figure 5: Slump Test

Copper slag replaced	Slump Value (mm)
0%	80
20%	130
40%	120
60%	100

Table 1: Slump Test

### 3.2.2 Compressive Strength Test:

Results of Compressive Strength Test conducted by replacing 0%, 20%, 40% and 60% sand with copper slag.

Test conducted for 0%, 20%, 40%, and 60% replacement of sand with copper slag.

Strength increases at 20% due to better particle packing.

At 40%, strength is nearly similar or slightly reduced.

At 60%, strength decreases due to excess copper slag.

Overall, 60% replacement gives the best compressive strength.

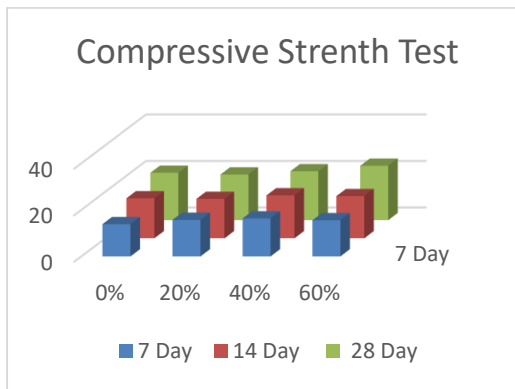


Figure 6: Compressive Strength Test

Copper Slag	Vee Bee
0%	21.6
20%	15.7
40%	11.2
60%	12.6

Table 2: Compressive Strength Test

### 3.2.3 Compaction Factor Test:

Results of Compaction Factor Test conducted by replacing 0%, 20%, 40% and 60% sand with copper slag.

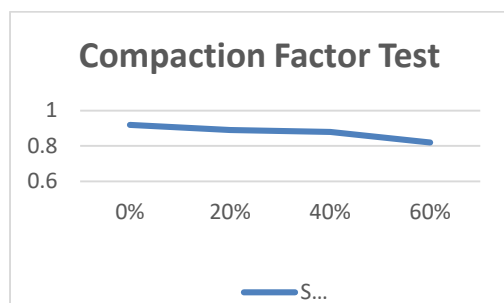


Figure 7: Compaction Factor Test

Copper Slag was Replaced	Compaction Factor [wp/wf]
0%	0.92
20%	0.89
40%	0.88
60%	0.82

Table 3: Compaction Factor Test

Test

### 3.2.4. Vee Bee Test:

The Vee-Bee test is a method used to determine the workability (consistency) of fresh concrete, especially for stiff or dry mixes where a slump test is not suitable.

It measures the time (in seconds) required for concrete to change from a conical shape (like in a slump test) into a cylindrical shape under vibration. This time is called the Vee-Bee time.

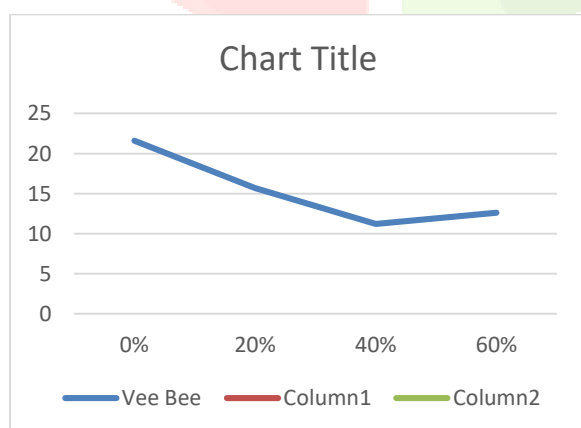


Figure 8: VEE BEE Test

Copper slag was replaced	Compressive Strength (N/mm <sup>2</sup> )		
	7 Day	14 Day	28 Day
0%	13.83	17.16	20.35
20%	15.68	16.93	19.62
40%	16.31	18.44	21
60%	15.55	18.12	23.37

Table 4: VEE BEE Test

## 4. Result & Conclusion

### 4.1. Result

The experimental study was carried out to evaluate the effect of replacing fine aggregate with Copper Slag in concrete. Different percentages of copper slag such as 0%, 20%, 40%, and 60% were used, and the properties of fresh and hardened concrete were studied through slump test, compressive strength test,

compaction factor test, and Vee-Bee consistometer test. In the slump test, the slump value increased from 80 mm for conventional concrete to 130 mm at 20% replacement of copper slag. At 40% and 60% replacement, the slump values were 120 mm and 100 mm respectively. The increase in slump value indicates that copper slag improved the workability of concrete due to its smooth texture and lower water absorption capacity. The compressive strength test showed that the strength of concrete increased with the increase in copper slag content. The 28-day compressive strength for conventional concrete was 20.35 N/mm<sup>2</sup>, whereas the concrete with 60% copper slag achieved the maximum strength of 23.37 N/mm<sup>2</sup>. The improvement in strength may be due to better particle packing and denser concrete structure produced by copper slag.

In the compaction factor test, the compaction factor values gradually decreased from 0.92 for normal concrete to 0.82 at 60% replacement. Although the compactability reduced slightly at higher replacement levels, all mixes showed acceptable workability for practical use.

The Vee-Bee consistometer test indicated that the Vee-Bee time decreased from 21.6 seconds for conventional concrete to 11.2 seconds at 40% replacement, showing improved consistency and ease of compaction. At 60% replacement, the Vee-Bee time slightly increased to 12.6 seconds, indicating a minor reduction in workability compared to 40% replacement.

#### 4.2. Conclusion:

From the overall investigation, it can be concluded that Copper Slag can effectively be used as a partial replacement for fine aggregate in concrete. The use of copper slag improved the workability and compressive strength of concrete while also promoting sustainable construction by reducing the consumption of natural sand. The optimum replacement level varied depending on the property considered, with 20% giving maximum slump, 40% showing the best Vee-Bee performance, and 60% producing the highest compressive strength. Therefore, copper slag is a suitable and eco-friendly alternative material for concrete production.

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