



(RESEARCH ARTICLE)



Experimental studies on replacement of the fine aggregate with copper slag and cement with marble powder

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World Journal of Advanced Engineering Technology and Sciences, 2026, 19(01), 237-244

Publication history: Received on 13 March 2026; revised on 25 April 2026; accepted on 27 April 2026

Article DOI: <https://doi.org/10.30574/wjaets.2026.19.1.0218>

Abstract

Concrete is one of the most widely used construction materials due to its strength, durability, and versatility. Rapid urbanization and infrastructure development have significantly increased the demand for natural resources such as cement and fine aggregates. Continuous extraction of these materials results in depletion of natural resources and creates environmental concerns. Therefore, the use of industrial waste and by-products in concrete has gained considerable attention as a sustainable alternative. This study investigates the partial replacement of cement with marble powder and fine aggregate with copper slag in concrete. Marble powder is a waste product generated during the cutting and polishing of marble stones, while copper slag is a by-product obtained during the smelting process of copper production. The utilization of these materials in concrete not only reduces environmental pollution but also helps in conserving natural resources. In this experimental investigation, cement is partially replaced with marble powder at proportions of 5%, 10%, 15%, and 20%, while fine aggregate is replaced with copper slag at proportions of 5%, 10%, 15%, and 20%. Concrete specimens are prepared and tested to evaluate their mechanical properties, including compressive strength, split tensile strength, and flexural strength. The study also aims to determine the optimum replacement level that provides improved performance and sustainability.

Keywords: Concrete; Marble Powder; Copper Slag; Mechanical Properties; Sustainable Construction

1. Introduction

A French gardener named Joseph Monier first invented reinforced concrete in 1849. Without this reinforced concrete, most modern buildings would not be standing today. Reinforced concrete can be used to make frames, columns, foundations, beams, etc. The reinforcing material used should have excellent bonding properties, high tensile strength and good thermal compatibility. Reinforcement requires a smooth transfer of load from the concrete to the interface between the concrete and the reinforcing material and then to the reinforcing material. Therefore, the concrete and the reinforced material must have the same stress. Concrete is a composite material which is most widely used and is a key structural element for development of global infrastructure. It comprises three components namely water, aggregate which consists of coarse aggregate (CA) and fine aggregate and cement. Cement in its powder form is used as a binder when mixed with water and aggregate. The worldwide usage of concrete in construction is twice the total of all different building materials used. Today concrete is the most consumed material, with three tons per year used for every person in the world. Plain concrete is good in compression but weak in tensile strength with very limited ductility and little resistance to cracking. The production of concrete is said to be responsible for 8% of the world's carbon dioxide with Portland cement being a major contributor. The cement or particularly Portland cement in concrete, releases concrete dust when building is demolished or by the action of natural disasters, this is a major source of air pollution. The workers who cut and grind or polish the concrete are at risk of inhaling airborne silica, which can cause silicosis after a long period of time. Hence a solution to partially replace cement can reduce its effect.

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Concrete is the largest used material worldwide. With the increasing rate of population growth, infrastructure too needs to be developed rapidly to fulfill the needs of the people and for all these a huge amount of resources are required. The major one of them is cement and sand. But the excessive consumption of these resources will create environmental imbalance. Therefore, we have decided to replace these two major ingredients of the construction industry with marble dust and copper slag respectively.

1.1. Marble Powder

Marble Powder can be used as a partial replacement of cement in concrete mixes. The use of marble powder in concrete can improve the workability, compressive strength, and durability of the concrete. Marble Powder has high calcium content, which can act as a nucleation site for cement hydration and improve the strength of the concrete. It also has a lower water demand than cement.

Table 1 Properties of Marble Powder and Cement

Properties	Marble Powder	Cement
Bulk density (kg/m ³)	1118.01	1440
Specific gravity	2.5	3.15

1.2. Copper Slag

The slag structure is stabilized with the addition of lime and alumina. The molten slag is discharged from the furnace at 1000–1300 °C. When liquid slag is cooled slowly, it forms a dense, hard crystalline product, while as quick solidification by pouring molten slag into water gives granulated amorphous slag.

Table 2 Properties of Copper Slag and Sand

Properties	Copper Slag	Sand
Particle shape	Irregular	Irregular
Density (kg/m ³)	3016–3870	1602
Specific gravity	3.40	2.63-2.67

2. Materials and Methods

The present study focuses on evaluating the mechanical properties of concrete by partially replacing cement with marble powder and fine aggregate with copper slag. The experimental program was designed to determine the suitability of these alternative materials and to identify the optimum replacement percentage that provides satisfactory strength characteristics. The methodology adopted for this research consists of material collection, mix design, preparation of concrete specimens, curing, and testing of specimens for various mechanical properties.

2.1. Mix Proportions.

Concrete mixes were prepared with different proportions of marble powder and copper slag. Marble powder replaced cement at percentages of 5%, 10%, 15%, and 20%, and copper slag replaced fine aggregate at 5%, 10%, 15%, and 20%. A control mix with conventional materials was also prepared for comparison.

Four types of mixes were prepared for the experimental investigation:

- Mix A: Plain Concrete (Control Mix)
- Mix B: Plain Concrete + Marble Powder (5%, 10%, 15%, 20% replacement of cement)
- Mix C: Plain Concrete + Copper Slag (5%, 10%, 15%, 20% replacement of fine aggregate)
- Mix D: Plain Concrete + Marble Powder + Copper Slag (combined replacement)

The cured specimens were tested to determine their mechanical properties, including:

- Compressive Strength Test

- Split Tensile Strength Test

The test results were compared with the control mix to analyze the effect of marble powder and copper slag on concrete performance and to determine the optimum replacement percentage.



Figure 1 Cube Casting



Figure 2 Cylinder Casting

3. Results and Discussion

3.1. Results for Marble Powder

Table 3 Compressive Strength (Marble Powder)

Compressive Strength (Marble Powder)			
Percentage	7 Days	14 Days	28 Days
0%	18.20	26.13	30.806
5%	19.83	26.81	31.783
10%	20.67	28.82	35.075
15%	24.17	30.84	36.887
20%	20.16	27.72	32.762

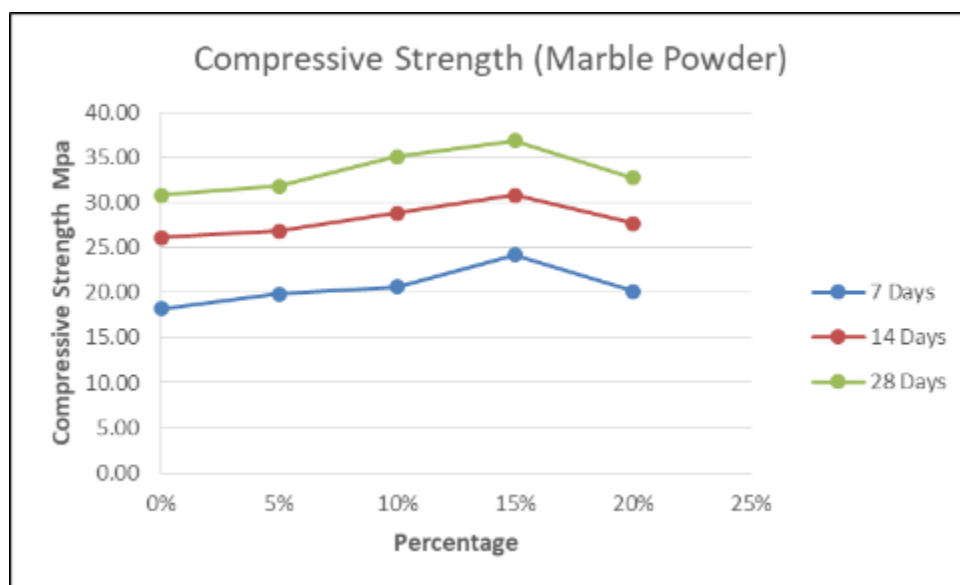


Figure 3 Compressive Strength (Marble Powder)

Table 3 shows the compressive strength of concrete with partial replacement of cement by marble powder at different curing ages. The control mix (0%) achieved compressive strengths of 18.20 MPa, 26.13 MPa, and 30.80 MPa at 7, 14, and 28 days, respectively. With the addition of marble powder at 5% and 10%, the compressive strength gradually increased due to the filler effect, which improves particle packing and bonding in the concrete matrix. The maximum compressive strength was observed at 15% replacement, reaching 24.17 MPa, 30.84 MPa, and 36.88 MPa at 7, 14, and 28 days. However, when the replacement level increased to 20%, the compressive strength slightly decreased because higher marble powder content reduces the effective cementitious material in the mix. Therefore, 15% marble powder replacement gives the optimum compressive strength compared to the control concrete.

Table 4 Split Tensile Strength (Marble Powder)

Split Tensile Strength (Marble Powder)					
%	0%	5%	10%	15%	20%
7 Days	3.31	3.71	3.86	4.23	3.75
	3.47	3.72	3.89	4.18	3.79
	3.39	3.78	3.86	4.25	3.71
14 Days	3.75	3.81	4.25	4.71	4.01
	3.73	3.83	4.44	4.78	3.99
	3.81	3.8	4.37	4.68	4.07
28 days	4.55	4.71	4.98	5.2	4.83
	4.51	4.69	4.91	5.18	4.86
	4.59	4.66	4.95	5.24	4.88

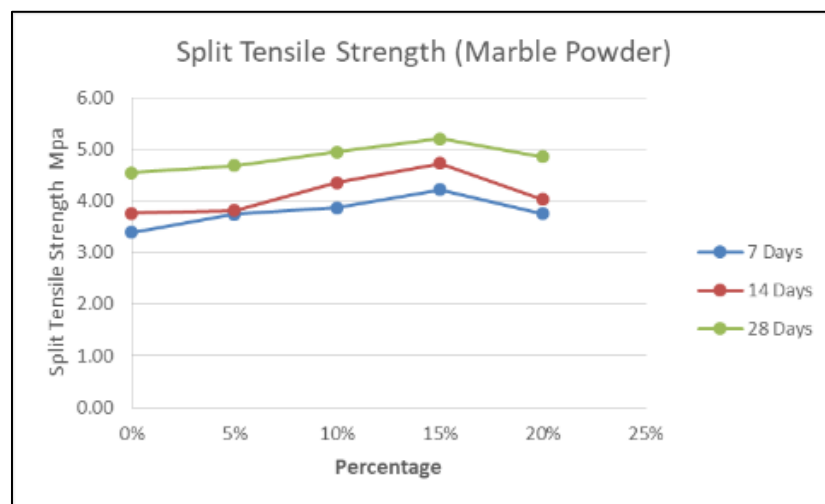


Figure 4 Split Tensile Strength (Marble Powder)

Split tensile strength of concrete with partial replacement of cement by marble powder at different curing periods. The results show that the split tensile strength increases with the increase in marble powder content up to 15% replacement for 7, 14, and 28 days curing. The control mix (0%) shows comparatively lower strength values, while mixes with 5% and 10% marble powder exhibit gradual improvement due to better particle packing and filler effect. The maximum split tensile strength is observed at 15% marble powder, indicating improved bonding between the cement paste and aggregates. However, at 20% replacement, the tensile strength slightly decreases due to the reduction in effective cement content. Therefore, the results indicate that 15% marble powder replacement provides the optimum split tensile strength compared to the conventional concrete mix.

3.2. Results For Copper Slag

Table 5 Compressive Strength (Copper Slag)

Compressive Strength (Copper Slag)			
Percentage	7 Days	14 Days	28 Days
0%	19.36	25.41	31.39
5%	20.90	26.44	31.933
10%	21.54	27.83	32.437
15%	22.66	28.01	35.293
20%	19.13	27.66	31.96

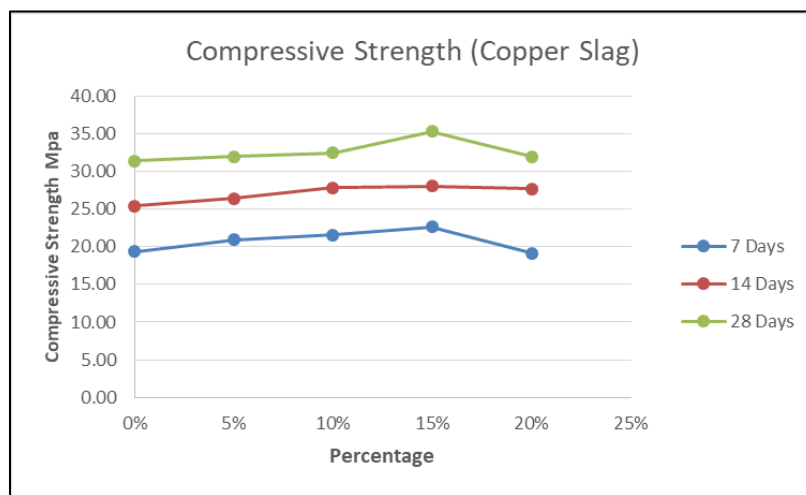


Figure 5 Compressive Strength (Copper Slag)

Compressive strength of concrete with partial replacement of fine aggregate by copper slag at different curing periods. The control mix (0%) achieved compressive strengths of 19.36 MPa, 25.41 MPa, and 31.39 MPa at 7, 14, and 28 days, respectively. With the addition of copper slag at 5% and 10%, the compressive strength gradually increased due to better particle packing and improved density of the concrete mix. The maximum compressive strength was observed at 15% copper slag replacement, reaching 22.66 MPa, 28.01 MPa, and 35.29 MPa at 7, 14, and 28 days. However, when the replacement level increased to 20%, the compressive strength slightly decreased due to excess copper slag affecting the bonding and workability of the concrete. Therefore, 15% copper slag replacement provides the optimum compressive strength compared to conventional concrete

Table 6 Split Tensile Strength (Copper Slag)

Split Tensile Strength (Copper Slag)			
Percentage	7 Days	14 Days	28 Days
0%	2.40	3.06	3.98
5%	2.56	3.57	4.067
10%	2.69	3.81	4.317
15%	2.97	3.99	4.517
20%	2.69	3.78	4.36

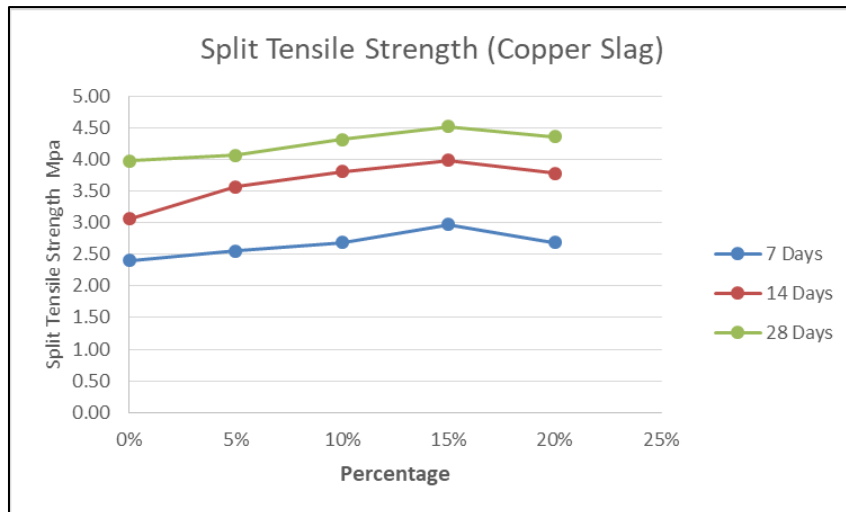


Figure 6 Split Tensile Strength (Copper Slag)

Split tensile strength of concrete with partial replacement of fine aggregate by copper slag at different curing ages. The control mix (0%) recorded split tensile strengths of 2.40 MPa, 3.06 MPa, and 3.98 MPa at 7, 14, and 28 days, respectively. With the addition of copper slag at 5% and 10%, the tensile strength gradually increased due to improved particle packing and better bonding within the concrete matrix. The maximum split tensile strength was observed at 15% copper slag replacement, with values of 2.97 MPa, 3.99 MPa, and 4.51 MPa at 7, 14, and 28 days. However, when the replacement level increased to 20%, the tensile strength slightly decreased due to excess copper slag affecting the cohesion of the mix. Therefore, 15% copper slag replacement provides the optimum split tensile strength compared to the control concrete mix.

3.3. Results For Marble Powder + Copper Slag

Table 7 Compressive Strength (Marble Powder + Copper Slag)

Compressive Strength (Marble Powder + Copper Slag)			
Percentage	7 Days	14 Days	28 Days
0%	22.14	26.94	32.81
5%	25.05	29.01	33.293
10%	27.27	30.89	35.650
15%	29.62	36.74	40.117
20%	26.03	29.94	34.15

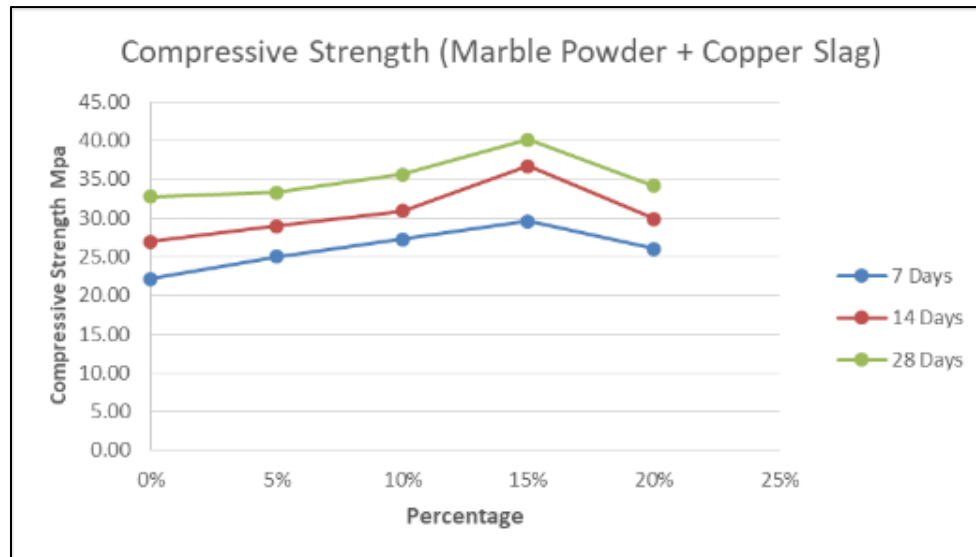


Figure 7 Compressive Strength (Marble Powder + Copper Slag)

Compressive strength of concrete with combined replacement of cement by marble powder and fine aggregate by copper slag at different curing periods. The control mix (0%) recorded compressive strengths of 22.14 MPa, 26.94 MPa, and 32.81 MPa at 7, 14, and 28 days, respectively. With the addition of 5% and 10% replacement, the compressive strength gradually increased due to improved particle packing and better bonding in the concrete matrix. The maximum compressive strength was observed at 15% replacement, achieving 29.62 MPa, 36.74 MPa, and 40.11 MPa at 7, 14, and 28 days, respectively. However, when the replacement increased to 20%, the compressive strength slightly decreased due to the reduction in effective cement content and excess replacement materials. Therefore, the results indicate that 15% combined replacement of marble powder and copper slag provides the optimum compressive strength compared to the conventional concrete mix

4. Conclusion

A detailed study has been carried out on the Compressive and tensile strength of concrete with varying the various percentage of Marble Powder and Copper Slag. Experimental investigation was carried out to check suitability and veracity of the Plain concrete mix with marble powder for 5, 10, 15, 20% with cement and copper slag for 5, 10, 15, and 20% with fine aggregate on performance of concrete. Inclusion of marble powder for cement performs better up to 15%, and similarly, inclusion of copper slag for fine aggregate also performs better up to 15%, but adding both together gives excellent performance results up to 15% of replacement. Hence the following conclusion is considered based on the results and observations are following.

- Inclusion of Marble Powder and Copper Slag for cement and fine aggregate reduces the slump values. This is due to the resistance for the free flow of concrete.
- From the test results obtained during the experiment work it is clear that the strength of Marble Powder and Copper Slag concrete significantly higher than the normal concrete. The crack formation is also very small in mix specimen compared to normal specimen
- There is a marginal increase in Compressive strength in replacement of Marble Powder + Copper Slag up to 15% at the age of 7, 14, 28 days and gets slightly decreased at the 20%.
- There is a marginal increase in Split Tensile Strength in replacement of Marble Powder + Copper Slag up to 15% at the age of 7, 14, 28 days and gets slightly decreased at the 20%.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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IS Codes

- **IS 456:2000** Code of Practice for Plain and Reinforced Concrete.
- **IS 10262:2019** – Guidelines for Concrete Mix Design Proportioning.
- **IS 383:2016** – Specification for Coarse and Fine Aggregates from Natural Sources for Concrete.
- **IS 12269:2013** – Specification for Ordinary Portland Cement (OPC 53 Grade).