

Experimental Study on Replacement of Cement and Fine Aggregate with Marble Dust and Copper Slag

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Abstract

With the ever-growing challenge of managing escalating waste materials globally, this paper explores sustainable solutions in construction through the utilization of marble dust and copper slag. The rapid generation of waste poses severe environmental and health threats, necessitating innovative strategies for responsible waste management. Local availability and the potential to enhance concrete strength make marble dust and copper slag attractive candidates for the partial replacement of cement and fine aggregate. Initial investigations suggest that a 30% replacement ratio offers optimal strength, with a slight decrease noted beyond this threshold. In this experimental study, M30 Grade concrete is employed, and equal percentages of 0%, 10%, 20%, 30%, 40%, and 50% of cement and fine aggregate are replaced with marble dust and copper slag. Cubes, cylinders, and prisms are cast to undergo comprehensive strength and durability tests at 7, 14, 28, and 56 days. The primary goal is to assess the long-term performance of concrete with varied proportions of marble dust and copper slag replacements. By providing insightful information on the potential of waste materials to improve concrete's characteristics, this research enhances environmentally friendly solutions for the building sector and fosters sustainable construction practices.

Keywords: Aggregate, cement, concrete, copper slag, durability, marble dust, strength

INTRODUCTION

Concrete, a key material in building, is well-known for its flexibility, ability to handle heavy loads, and capability to adapt to various constructions. Concrete, which comprises cement, water, and aggregates, is of utmost importance in civil engineering [1]. Nevertheless, the increasing build-up of waste materials from many businesses presents immediate risks of environmental degradation and negative health consequences. This study discusses the urgent concerns about waste management and the ecological repercussions linked to concrete manufacturing. It specifically examines the feasibility of employing marble dust and copper slag as cement and fine aggregate alternatives [2].

The evolution of concrete technology, while yielding advancements, has concurrently given rise to detrimental pollutants. This study underscores the urgency for sustainable practices within the concrete industry [11]. Emphasis is placed on recycling waste materials to alleviate conventional waste disposal methods' environmental and health repercussions. To mitigate construction costs and reduce cement consumption, the study introduces marble dust as a partial replacement for cement [3].

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The investigation extends to copper slag, a by-product of copper production, explored as a viable alternative for fine aggregate [5]. Utilizing copper slag addresses the concern of waste recycling and promotes proper waste disposal. The study

highlights the significant volume of copper slag generated during copper production, emphasizing its pozzolanic characteristics and potential as a substitute for Portland cement [8].

Marble dust, a by-product of marble processing, is a valuable waste material for concrete production. The paper accentuates the considerable amount of waste marble often improperly disposed of in open areas and advocates for its integration into concrete manufacturing processes to enhance hardening [9]. [10].

The metamorphic nature of marble is discussed, underscoring the importance of proper disposal methods to circumvent environmental issues [4].

Within civil engineering, there is a compelling need for sustainable construction practices. The paper posits that challenges associated with waste materials and environmental impact can be mitigated by replacing industrial wastes with marble dust and copper slag [7]. This introduction lays the foundation for a deeper exploration of subsequent studies that delve into specific aspects of waste utilization and material substitution in concrete mixes [6].

Drawing from a rich tapestry of research, the subsequent sections briefly introduce fundamental studies, each contributing to a nuanced understanding of sustainable construction practices [12]. [13]. [14]. [15]. [16]. [17]. [18]. These studies look at various materials, including bagasse ash, fly ash-based geo-polymer concrete, sugarcane bagasse ash, ceramic aggregate, palm oil fuel ash, and ground-granulated blast furnace slag. They stress how important these materials are for making concrete better while having the most minor adverse effects on the environment.

Exploring alternative materials, like bagasse ash and fly ash-based geo-polymer concrete, reflects a paradigm shift in the construction industry [12]. [13]. Using sugarcane bagasse ash as a supplementary material showcases the potential of agricultural waste in the construction sector [14]. Meanwhile, experimenting with ceramic aggregate demonstrates a novel approach to resource conservation and waste reduction [16]. The studies examining palm oil fuel ash and ground-granulated blast furnace slag highlight the industry's quest for diverse and optimized materials that contribute to the long-term sustainability of construction practices [17]. and [18].

These investigations collectively underscore the dynamic and evolving research landscape in sustainable construction practices. They illuminate the potential benefits and challenges of integrating alternative materials, reinforcing the necessity of a balanced approach to infrastructure development. As civil engineering progresses, these studies offer a roadmap for incorporating environmentally conscious methodologies into construction practices, contributing to a more sustainable and resilient built environment.

MATERIALS AND METHOD

Materials

The use of OPC 53 grade in this investigation yields more strength compared to 43 grades. The fine aggregate and coarse aggregate (10mm and 20mm) are obtained from a nearby supplier. The copper slag shown in Fig. 4 is used for this study, is sourced from Ganesh Groups in Hyderabad. It is often employed for sandblasting purposes. The copper slag particles used in this experiment have a size range of 4.75mm to 300 μ , with particles less than 4.75 mm and more significant than 300 μ being excluded. The marble dust shown in Figure. 5 is obtained from a supplier located in Vijayawada and is mixed with drinking water for this task.

Physical Properties

The physical properties of cement, aggregates, copper slag and marble dust are shown below. The Sieve analysis also done for each material and shown in the Table 1, 2, 3

Table 1. Properties of cement

S.NO.	Properties	Values
1.	Cement Grade	53
2.	Specific Gravity	3.14
3.	Normal Consistency	34%
4.	(a) Initial Setting Time(b) Final Setting Time	50 min480 min

Table 2. Properties of aggregate

S.NO.	Properties	Values
1.	Specific Gravity of Fine Aggregate	2.71
2.	Fineness Modulus of Fine Aggregate	3.17
3.	Specific Gravity of Coarse Aggregate	2.73
4.	Fineness Modulus of Coarse Aggregate	7.94

Table 3. Properties of copper slag & marble dust

SI.NO.	Properties	Values
1.	Specific Gravity of Marble Dust	3.00
2.	Specific Gravity of Copper Slag	3.470
3.	Fineness Modulus of Copper Slag	3.36
4.	Physical Form of Marble Dust	White Powder
5.	Physical Form of Copper Slag	Dull Black Colour & Glassy Appearance

METHODOLOGY

Experimental Work

Mix Design and Proportion

In this paper, M30 grade concrete was prepared as per IS 10262:2019 and IS 456: 2000. The water cement ratio 0.45 was used throughout the mix.

Mix Design

Design Constraints

Mix design was done as per IS specifications 10262:2019 and 456:2000 for M30 is 1:1.46:2.51 and water content is 0.45.

Materials Calculation for 1m³

Volume of concrete	=	1m ³
Cement	=	438.2kg/m ³
Fine aggregate	=	641.24kg/m ³
Coarse aggregate	=	1104.21kg/m ³
Water	=	197.16kg/m ³

Sample Mix Preparation

For testing compression strength of cubes, mould size of 150×150×150mm was used and for split tensile strength the size used is 300mm×150mm and for flexural test the size is used 100×100×500mm and also for concrete permeability test cubes were used with the size of 150×150×150mm. The samples were tested at 7, 14, 28 and 56 days. Total 168 samples were casted for testing, out of which 72 samples of cubes, 48 samples of cylinders and 48 samples of prisms of cement and fine aggregate when partially substituted by both marble dust and copper slag. For each test two trails were done for 7, 14, 28 and 56 days. The replacements were done starting from 0 % to 50% with equal percentages of marble dust and copper slag.

Workability Test The workability test was done, for the replacement of cement and fine aggregate with marble dust and copper slag. Table-4 shows the slump values.

RESULT AND DISCUSSION

Compressive Strength

The Compressive strength test was carried out as per IS specification 516-1959, Table 5 shows the result of compressive strength for 7, 14, 28 and 56 days. Fig. 1 clearly shows that compressive strength increases up to 30% as the marble dust and copper slag increases and above that, it decreases. The nominal concrete values of compressive strength for 7, 14, 28 and 56 days are 23.55, 30.22, 36.44, and 40 respectively.

Split Tensile Strength

The split tensile test was carried out as per IS specification 516-1959, Table 6 shows the result of split tensile strength for 7, 14, 28 and 56 days. Fig. 2 clearly show that split tensile strength increases up to 30% as the marble dust and copper slag increases and above that, it decreases. The nominal concrete values of split tensile strength for 7, 14, 28 and 56 days are 2.26, 2.54, 2.83, and 3.04 respectively.

Flexural Strength

The Flexural strength test was carried out as per IS specification 516-1959, Table 7 shows the result of flexural strength for 7, 14, 28, 56 days. Fig. 3 clearly show that flexural strength increases up to 30% as the marble dust and copper slag increases and above that, it decreases. The nominal concrete values of flexural strength for 7, 14, 28, 56 days are 2.45, 3.3, 4.16, and 6.12 respectively.

Concrete Permeability

The concrete permeability test was carried out as per IS specification 516-2018, Table-8 shows the result of concrete permeability for 28 and 56 days. The specimens are tested to its water permeability in terms of water penetration depth. After 72 hours the samples were removed and split into two halves and measured the depth of water penetrated into the specimen.

Table 4. Workability test

Mix	Water Cement Ratio	Slump (mm)
Nominal Concrete	0.45	120
5(MD)+5(CS)%	0.45	70
10(MD)+10(CS)%	0.45	60
15(MD)+15(CS)%	0.45	45
20(MD)+20(CS)%	0.45	70
25(MD)+25(CS)%	0.45	80

Table 5. Compressive strength

Materials	Percentage Replacement (%)	Compressive Strength Results (N/mm ²)			
		7 Days	14 Days	28 Days	56 Days
Marble Dust+ Copper Slag	0(MD)+0(CS)	23.55	30.22	36.44	40
	5(MD)+5(CS)	30	34.77	39.55	41.77
	10(MD)+10(CS)	30.88	36.32	41.77	42.22
	15(MD)+15(CS)	31.33	37.66	44	48.88
	20(MD)+20(CS)	28.66	30.33	32	40
	25(MD)+25(CS)	22.22	26.66	31.11	38.22

Table 6. Split Tensile strength.

Materials	Percentage Replacement (%)	Split Tensile Strength Results (N/mm ²)			
		7 Days	14 Days	28 Days	56 Days
Marble Dust+ Copper Slag	0(MD)+0(CS)	2.26	2.54	2.83	3.04
	5(MD)+5(CS)	2.33	2.61	2.9	2.97

	10(MD)+10(CS)	2.4	2.67	2.97	3.11
	15(MD)+15(CS)	2.47	2.79	3.11	3.25
	20(MD)+20(CS)	2.12	2.43	2.54	2.75
	25(MD)+25(CS)	1.41	1.69	1.97	2.12

Table 7. Flexural strength

Materials	Percentage Replacement (%)	Flexural Strength Results (N/mm ²)			
		7 Days	14 Days	28 Days	56 Days
Marble Dust +Copper Slag	0(MD)+0(CS)	2.45	3.30	4.16	6.12
	5(MD)+5(CS)	2.94	4.41	5.88	6.61
	10(MD)+10(CS)	3.06	4.59	6.12	6.74
	15(MD)+15(CS)	3.18	4.77	6.37	6.86
	20(MD)+20(CS)	2.91	4.27	5.63	6.71
	25(MD)+25(CS)	2.84	4.11	5.39	6.61

Table 8. Concrete permeability

Materials	Percentage Replacement (%)	Water Permeability Result (m/s)	
		28 Days	56 Days
Marble Dust +Copper Slag	0(MD)+0(CS)	1.98x10 ⁻¹²	2.24x10 ⁻¹²
	5(MD)+5(CS)	2.51x10 ⁻¹²	3.10x10 ⁻¹²
	10(MD)+10(CS)	3.10x10 ⁻¹²	3.76x10 ⁻¹²
	15(MD)+15(CS)	4.47x10 ⁻¹²	4.47x10 ⁻¹²
	20(MD)+20(CS)	3.10x10 ⁻¹²	2.80x10 ⁻¹²
	25(MD)+25(CS)	1.98x10 ⁻¹²	2.24x10 ⁻¹²

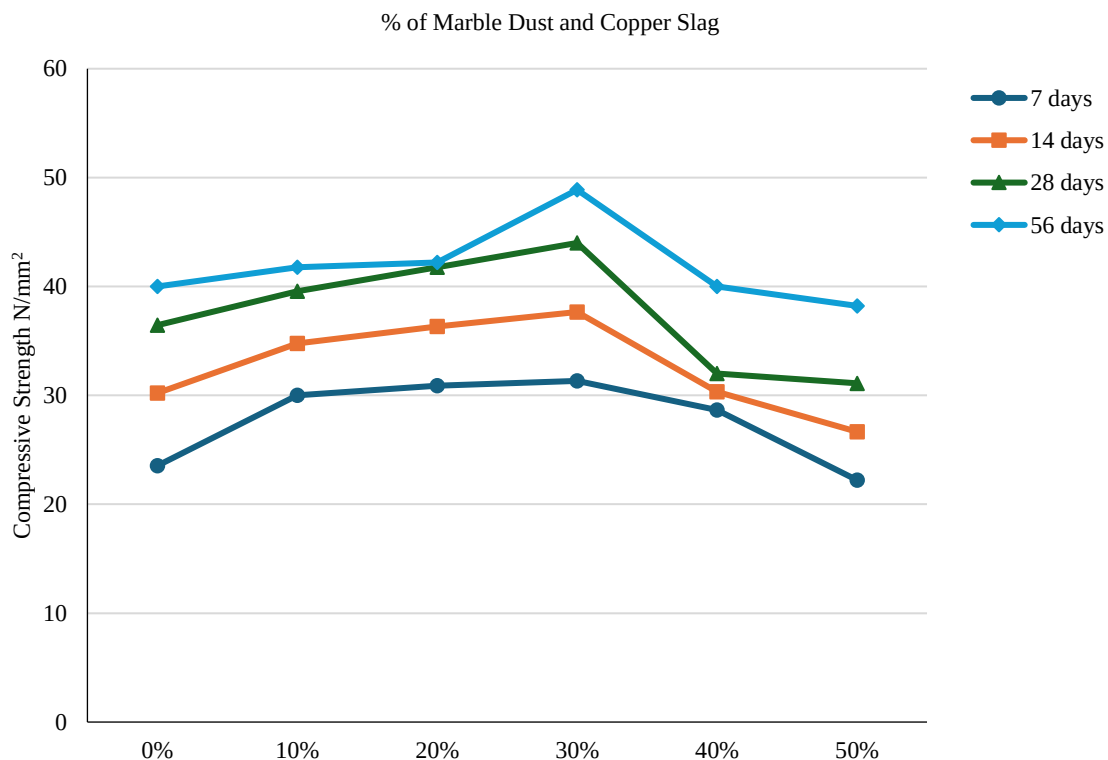


Figure 1. Compressive strength

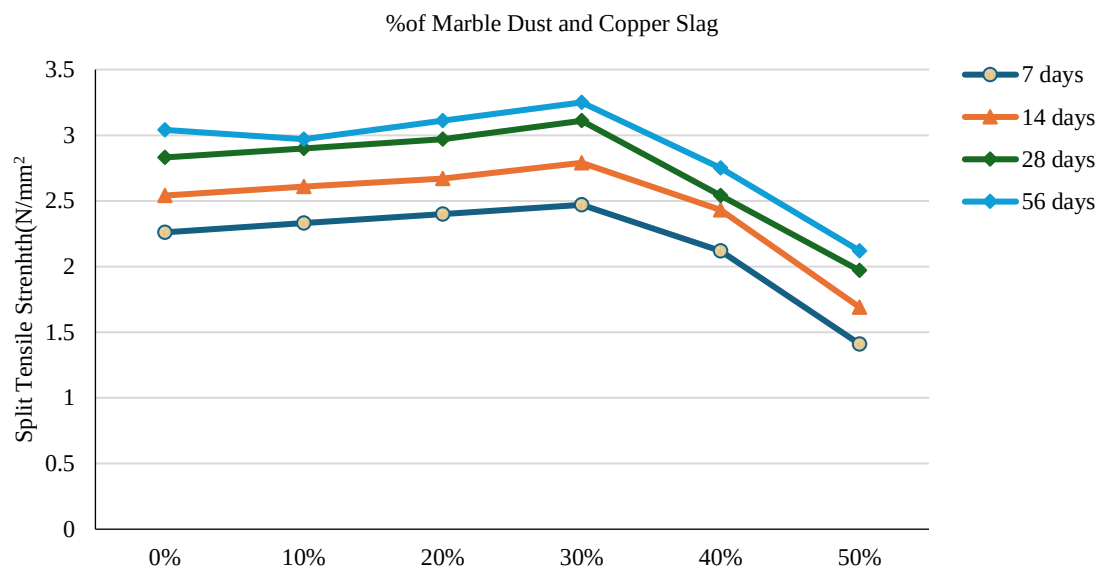
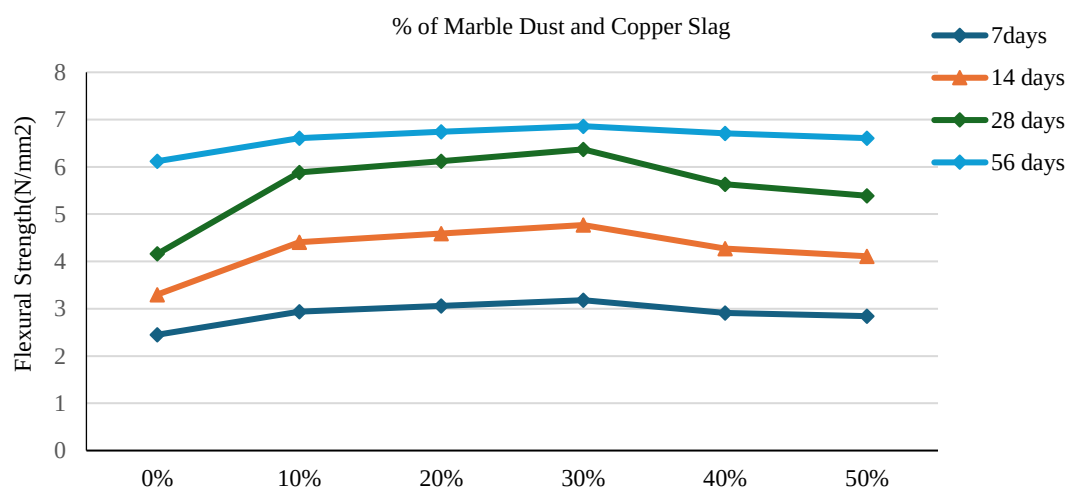
**Figure 2.** Split Tensile**Figure 3.** Flexural Strength**Figure 4.** Copper slag



Figure 5. Marble dust

CONCLUSIONS

1. The endeavor to introduce more sustainable and environmentally friendly building practices has led to a strategic decision to substitute traditional construction materials with alternative substances such as copper slag and marble dust. These materials, derived as byproducts from the copper extraction process and marble processing, respectively, serve a dual purpose: reducing overall waste and repurposing materials that would otherwise be discarded. This intentional choice aligns with the principles of circular economy and resource optimization, reflecting a broader commitment to responsible environmental practices.
2. To identify the most effective substitution strategy, the study meticulously examined various percentages of replacement. Notably, the research identified that an equal partial substitution of 30% for cement and fine aggregate with marble dust and copper slag resulted in the highest strength. This optimal percentage represents a delicate balance between incorporating alternative materials and maintaining structural integrity, showcasing the potential for sustainable construction practices to achieve harmony between environmental considerations and structural robustness.
3. A critical observation from the study is the discernible increase in strength at the 30% replacement level. This finding suggests that the combination of marble dust and copper slag positively influences the overall strength of the construction material. The exploration into strength variation at different substitution levels enriches our understanding of the material's performance and provides valuable insights into how these alternative materials respond under diverse conditions. This nuanced understanding contributes significantly to the evolving knowledge base of sustainable construction practices.
4. The study's absence of a superplasticizer in its initial results is another remarkable feature. Superplasticizers, renowned for enhancing the workability and performance of concrete mixes, emerge as a potential avenue for further exploration. The statement suggesting that up to 30% replacement can be done without superplasticizer prompts curiosity about the possible effects of superplasticizer beyond this threshold. This aspect opens a new dimension in understanding how additives may contribute to optimizing the material's characteristics, warranting further investigation into this influential factor.
5. At the 30% replacement level, the material exhibits commendable results in compression, tension, and bending tests. This comprehensive evaluation across different types of stress affirms the material's overall strength and provides a holistic perspective on its performance characteristics. The positive outcomes at this substitution level underscore the practical viability of this approach in construction projects, emphasizing the importance of finding alternative materials and identifying alternatives that demonstrate commendable performance under diverse stress conditions. To sum up, a close study of material substitution levels, finding the best percentages, looking at the effect of superplasticizers, and thorough strength testing all help us get a better idea of whether and how using copper slag and marble dust as replacements in building materials might work and what benefits they might have. These findings lay the

groundwork for further research, refining our understanding and potentially facilitating broader applications in sustainable construction practices.

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