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Optimizing Concrete Strength and Sustainability: Quarry Dust and Copper Slag Powder Additives

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Abstract

This research investigates the potential of quarry dust and copper slag powder additives to enhance the strength and performance of concrete. Compressive strength tests were conducted on mortar cubes at 7 and 28 days to evaluate the effects of these additives. The results indicate significant improvements in compressive strength over time, with Mix A4 achieving a remarkable 43.42% increase in strength at 28 days. Other mixes also demonstrated substantial strength gains, highlighting the effectiveness of quarry dust and copper slag powder additives in promoting both early and long-term strength development. These findings contribute to the advancement of sustainable and high-performance concrete materials, offering insights into their practical application in construction projects.

Keywords: Quarry dust, copper slag powder, concrete additives, compressive strength, sustainable concrete, high-performance concrete

INTRODUCTION

Concrete, a vital construction material, continuously undergoes research and development to enhance its strength and performance while aligning with sustainability objectives. One promising avenue is the incorporation of supplementary cementitious materials, such as quarry dust and copper slag powder, as additives in concrete mixtures. These additives offer potential benefits in terms of improved mechanical properties, sustainability, and waste reduction [1–15].

Quarry dust, a byproduct of the crushing process in quarrying activities, has gained attention as a viable material for enhancing concrete strength. It possesses pozzolanic properties, contributing to the hydration process and improving the microstructure of concrete. Copper slag, a byproduct of copper production, is another material with latent potential. Its use in concrete can lead to reduced environmental impact and less dependence on traditional cementitious materials [16–22].

Compressive strength is a fundamental parameter to assess concrete performance. The evaluation of strength gain in concrete mixtures containing quarry dust and copper slag powder additives is the primary focus of this research. Understanding how these additives influence both the early-age and long-term strength development of concrete is critical for informed decision-making in construction projects [23–40].

OBJECTIVES

The objective of this study is to investigate the effects of quarry dust and copper slag powder additives on the compressive strength of concrete. Compressive strength tests were conducted on

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mortar cubes at 7 and 28 days to assess the influence of these additives over time. The results will provide valuable insights into the potential of quarry dust and copper slag powder as sustainable additives to enhance concrete strength and performance. This research aims to contribute to the growing body of knowledge on sustainable construction materials and support the development of concrete mix designs that balance environmental considerations with the need for high-performance concrete in modern construction practices.

MATERIALS

Cement

In this investigation, we utilized Ordinary Portland Cement 43 Grade Ramco cement. The required quantity was carefully determined, procured, and stored appropriately at the casting yard Subsequently Table 1, we conducted the following tests in accordance with IS codes:

Table 1. Examinations conducted on Cement.

S.N.	Particular	Test Results	IS Code Limits
1	Specific Gravity	3.07	3.15
2	Standard Consistency	31.5%	25-35
3	Setting Time (i) InitialSetting Time (ii) Final Setting Time	27 minutes 4 hours	<30 minutes 10 hours
4	Soundness Test	9.5 mm	<10 mm

Specific Gravity (IS:1727-1967)
Standard Consistency (IS:4031(Part4)–1988)
Initial Setting Time (IS:4031(Part5) –1988)
Final Setting Time (IS: 4031(Part5)–1988)

Copper Slag (CS)

Copper slag is a residual material generated during the copper production process. When copper is extracted, it settles due to its greater density in the smelting process. Impurities, on the other hand, remain in the upper layer and are subsequently conveyed to a low-temperature water basin where they solidify. The resulting material is a firm, solid substance that is further processed after being sent to a crusher. The copper slag utilized in this study was procured from Sterlite Industries (India) Ltd., located in Tuticorin, Tamil Nadu, India.

Fine Aggregate

Fine aggregate employed in this study comprises clean river sand. Various tests, including Specific Gravity, Water Absorption, and Fineness Modulus, are conducted on the sand in accordance with IS: 2386-1963 (III) standards. The test results for the sand are presented in Table 2.

Table 2. Test results for Fine Aggregate.

S.N.	Descriptions	Test Results
1.	Specific gravity	2.56
2.	Percentage of voids	33.00%
3.	Fineness modulus	2.39
4.	Water absorption	1.5%
5.	Bulk density in Kg/m^3	1720
6.	Sieve analysis	ZONEII

Quarry Dust (QD)

Naturally washed quarried pit sand, as recommended by the Public Works Department (PWD), has been sourced for this study. The sand particles typically have a sub-angular and flaky shape. You can find the test results for this sand in Table 3, and the physical appearance of the quarried pit sand is illustrated in Figure 1.

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Table 3. Outcomes of the tests conducted on QD.

S.N.	Descriptions	Test Results
1.	Specific Gravity	2.45
2.	Percentage of Voids	26.00%
3.	Fine Particles < 0.075mmin%	12–15
4.	Fineness Modulus	2.61
5.	Water Absorption	1.2%
6.	Bulk Density in Kg/m^3	1860
7.	Sieve Analysis	ZONEII

Figure 1. Samples of QD.

Coarse Aggregate (C.A)

In this study, we have utilized locally sourced crushed stone aggregates with a size ranging from 20 mm down. These aggregates have undergone various tests including Specific Gravity, Bulk Density, Sieve Analysis, Fineness Modulus (following IS: 2386–1968 Part 3), and Crushing Value (following IS: 2386-1968 Part 4).

Water

For this work, we utilize potable water.

RESULTS

Compressive Strength Test

The main focus of compressive strength measurements involves evaluating the concrete's strength. Compression testing is conducted on mortar and concrete cube specimens using a Compression Testing Machine.

Compressive Strength Results for Cement Mortar Cubes

This machine meets all the requirements for compression testing according to IS: 516–1959. Cube specimens are positioned at the center of the machine to ensure that the load is applied perpendicular to the casting faces. The load is applied steadily and uniformly without sudden impact. During this test, the maximum load sustained by each specimen is recorded. Compressive strength is calculated by dividing the maximum load by the cross-sectional area of the specimen. The average value of three specimens is used to determine the compressive strength Table 4.

A total of 78 cement mortar cube specimens (three samples for each mix) are cast and tested for strength at 7 days and 28 days. The measured compressive strength values are provided in Table 1. The impact of substituting CS and QD for cement and F.A on the strength of cement mortar is illustrated in Figure 2.

Table 4. Compressive strength testing of mortar cubes.

Mixed	Average Ultimate Load kN		Compressive Strength N/mm^2		% Increase in Streng that 28 Days
	7days	*28days*	*7days*	*28days*	
A0	176	210.34	35.21	42.08	----
A1	190.64	214.64	38.14	42.94	2.04
A2	202.29	226.63	40.47	45.34	7.75
A3	222.33	266.67	44.48	53.35	26.78
A4	238.32	301.66	47.68	60.35	43.42
A5	191.24	239.98	38.26	48.01	14.09
A6	196.14	232.33	39.24	46.48	10.46
A7	219.93	251.37	44.00	50.35	19.65
A8	219.28	231.18	43.87	46.25	9.91
A9	202.74	219.18	40.56	43.85	4.21
A10	192.19	218.18	38.45	43.65	3.73
A11	186.14	212.53	37.24	42.58	1.19
A12	180.64	212.04	36.14	42.42	0.81

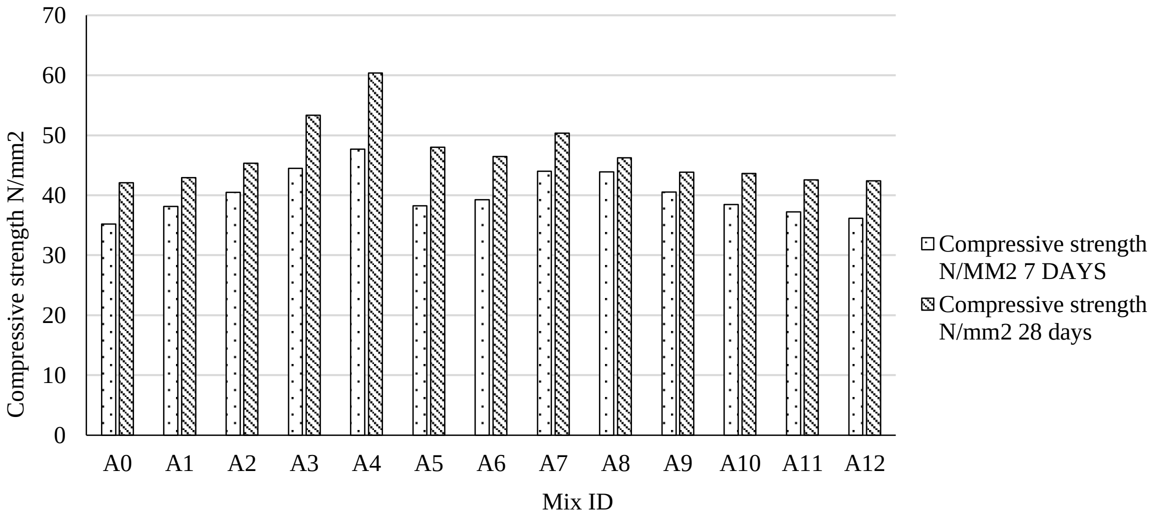

Figure 2. Compressive strength testing on mortar cubes.

Results and Discussion on Mortar Cubes

The results showed that all the combinations produced consistently higher compressive strength compared to the control concrete mixture across all curing durations. Additionally, as the CS and QD content increased, the compressive strength of cement and sand mortars increased up to the A4 mix. After that point, the compressive strength decreased as CS and QD content increased. The A4 mix exhibited the highest average 28-day compressive strength, measuring 60.35 N/mm2, which was nearly 43.42% higher than the A0 mix. While all mixtures outperformed the control mix in terms of compressive strength, it can be concluded that substituting 10% of CS for cement and 80% of QD for sand will result in the highest compressive strength, representing a 40% improvement over the strength of the control concrete.

CONCLUSION

In this experimental investigation involving the use of quarry dust and copper slag powder additives, the compressive strength testing of mortar cubes provided valuable insights into the enhancement of concrete strength and performance. The results in Table 1 demonstrate a significant improvement in compressive strength over time (from 7 to 28 days) for all mixes. Notably, Mix A4 achieved the highest compressive strength of 60.35 N/mm2 at 28 days, representing a remarkable 43.42% increase compared to the initial 7-day strength. This finding suggests the potential of quarry dust and copper slag powder additives to enhance the long-term strength development of concrete.

Mixes A3, A5, A7, and A9 also exhibited substantial strength gains, with percentage increases ranging from 19.65% to 26.78% at 28 days. These results highlight the effectiveness of these additives in promoting the early and long-term compressive strength of concrete.

Overall, the experimental findings support the conclusion that the incorporation of quarry dust and copper slag powder additives has a positive impact on concrete strength and performance. This research contributes to the growing body of knowledge on sustainable and high-performance concrete materials and can inform future construction practices aiming for enhanced strength and durability. Further studies and optimization efforts are recommended to fully harness the potential of these additives in concrete mix design.

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