



International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 9, Issue 3, March 2026



Experimental Investigation on Partial Replacement of Fine Aggregate with Copper Slag and Optimum Usage of Dolomite Powder as a Cement Replacement in Concrete

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ABSTRACT: The experimental investigation is aimed at utilizing low-cost material dolomite powder and waste material copper slag as partial replacement of cement and sand in concrete. This experimental investigation is carried out in two stages. The 1st stage, M30 grade of concrete is produced by replacing cement by 0%, 10% and 15% of Dolomite Powder (DP). The 2nd Stage, concrete is produced by keeping the optimum 10% of dolomite powder as constant, and sand is replaced by copper slag (CS) in the percentage of 0%, 10%, 20%, 30%, 40% and 50%. The concrete cubes were produced using different amounts of copper slag and dolomite powder. The test specimens were cured and tested for compressive strength, split tensile strength and flexural strength in 7 days and 28 days for concrete. It is found that the concrete made of low-cost material dolomite powder and waste material copper slag increases the compressive strength, split tensile strength and flexural strength of concrete when compared to that of normal concrete. From study, it is concluded that the low-cost material Dolomite powder & copper slag can be used in construction works, which results in construction cost. By using natural resources, the environment is protected.

KEYWORDS: Compressive strength, Split tensile strength, Flexural strength, Dolomite powder, Copper slag.

I. INTRODUCTION

Concrete is one of the world's most widely used construction materials, but its production has significant environmental and resource costs. Natural river sand is increasingly scarce, and cement manufacture generates large amounts of CO₂. In this context, the valorisation of industrial by-products and mineral wastes can promote more sustainable concrete production. Copper slag, a by-product of copper smelting, has been widely studied as a partial replacement for fine aggregate. It offers high density and angularity, low water absorption, and improved mechanical performance—some studies report enhanced compressive and tensile strength when replacing sand up to 30-50 % by volume or weight, though higher replacement levels may adversely affect durability or workability.

Equally, promising is the use of dolomite powder—finely ground dolostone—as a partial substitute for Portland cement. Dolomite powder can function as a filler and micro-aggregate, refining the concrete microstructure, reducing voids, and contributing to compressive and tensile strength gains when used up to moderate replacement percentages. Several investigations indicate that replacement of cement by 5–20 % dolomite powder can improve mechanical and durability properties while lowering material cost and CO₂ emissions.

This experimental investigation aims to combine these two sustainable strategies: partial replacement of fine aggregate with copper slag, and optimal substitution of cement with dolomite powder. The objective is to identify a concrete mix with the best trade-off between strength, workability, density, durability, cost, and environmental impact. By systematically varying



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both copper slag and dolomite powder levels, casting and testing concrete specimens, and comparing them to a conventional control mix, the study seeks to define the optimum usage levels of these alternative materials to produce a greener, high-performance concrete.

II. OBJECTIVES

The objectives of the study are;

- To investigate the optimum percentage of dolomite powder as a partial replacement of cement on the compressive strength of concrete.
- To evaluate the fresh concrete properties such as workability with different replacement levels.
- To evaluate the mechanical properties of the modified concrete mixes, including compressive strength and split tensile strength, at different curing ages 7 and 28 days.
- To determine the optimum percentage of DP and CS in concrete. (10% DP, (0, 10, 20, 30, 40, 50) % CS)

III. MATERIALS AND PROPERTIES

- **Cement:** Cement is a binding material, when chemical reaction between cement water to form C-S-H gel which gives strength for the concrete and makes fire and weather resistant. Locally available Nagarjuna OPC 53 grade was used.

Table 1:- Properties of cement

Si.No	Properties of Cement	Result
1.	Specific Gravity	3.15
2.	Standard Consistency	27.5%
3.	Initial Setting Time	80 min
4.	Final Setting Time	180 min
5.	Fineness	8%
6.	density	1440 kg/m ³

- **Dolomite powder (DP):** Dolomite powder is a mineral composed of calcium magnesium carbonate. The chemical composition and physical properties of dolomite powder are

Table- 2: Physical properties of dolomite powder

SI.NO.	Property	Description
1	Formula	(CaMg(CO ₃) ₂)
2	Colour	White
3	Moisture content	0.02%
4	PH on 10%	8
5	Fineness modulus (325#)	2.5%



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Table- 3: Chemical composition of dolomite powder

SI. No.	Constituent	% weight
1	SiO ₂	0.32%
2	Al ₂ O ₃	0.05%
3	Fe ₂ O ₃	0.11%
4	CaO	32.28%
5	MgO	22.90%
6	Lol @ 1000C	46.32%

- **Fine aggregate:** Locally available river sand Zone II is used in this project work. A sand's fineness modulus (FM) is a numerical index of its fineness.
- **Coarse aggregate (CA):** Crushed stones of size below 10 to 20mm are used.

Table- 4: Physical Properties of Fine Aggregate And Coarse Aggregate

Properties	Sand (FA)	Range	Coarse aggregate	Range
Specific gravity (Pycnometer)	2.51	IS 2386 (Part 3), 2.60 to 2.75	2.54	IS 2386 (Part 3), 2.6 to 2.9
Fineness (sieve analysis)	2.79	IS 383, zone II, 2.6 to 2.9	6.51	6.0 to 6.9.
Water absorption	1%	1 - 2%	1.1%	< 2%
Bulk density	1563kg/m ³	1450 to 1750 kg/m ³	1500.74 kg/m ³	1200 to 1750 kg/m ³

- **Copper slag:** Copper slag is an industrial by-product generated during copper smelting and refining. It is a dark, glassy, granular material rich in iron, silica, and alumina, making it suitable for construction use. Due to the physical chemical properties of copper slag.

Table- 5: Physical properties of copper slag

SI. No.	Property	Typical value
1	Granules size	0.5 to 2.5mm
2	Particle shape	Angular granules
3	Type	Air cooled
4	hardness	6 – 7 Mohs
5	Specific gravity	2.8 – 3.8
6	Bulk density	1.87 tones/m ³
7	Fineness modulus of copper slag	3.92
8	Colour	Black, glassy
9	Moisture content	<0.1%



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Table- 6: Chemical composition of copper slag

Sl. No.	Constituent	% weight
1	Silica SiO ₂	26 – 30%
2	Free silica	<0.5%
3	Iron oxide, Fe ₂ O ₃	42 – 48%
4	Alumina, Al ₂ O ₃	1 – 3%
5	Calcium oxide, CaO	1 – 2%
6	Magnesium oxide, MgO	0.8 – 1.5%
7	Copper Oxide, CuO	0.60 – 0.70%
8	Sulphates	0.02 – 0.3%
9	Chlorides	0.001 – 0.002%

➤ **Admixture:** Conplast SP 430 is a high-range water-reducing superplasticizer used to improve the workability and strength of concrete. It allows significant water reduction while maintaining good flow, making it ideal for high-strength and pumped concrete. Being chloride-free, it enhances durability, reduces permeability, and provides a smooth, cohesive mix.

➤ **Selection of Mix Ratio for M30 Grade Concrete:** This experiment's goal is to assess the characteristics of concrete made with dolomite powder and copper slag, as well as a number of other factors like the concrete's compressive strength, flexural strength, and split tensile strength. The mix design is made to achieve M30 grade concrete with coded provisions of IS 10262-2009. In compliance with IS 456: 2000 and IS 10262: 2009.

Table- 7: Mix Proportion

Cement (Kg/m ³)	fine aggregate (Kg/m ³)	Coarse aggregate (Kg/m ³)	Water (L/m ³)
412.32	625.607	1096.655	177.3
1	1.51	2.65	0.43

IV. TESTS ON CONCRETE

Table- 8: Fresh And Hardened Concrete Properties

Concrete Properties	Tests	Specimen Dimensions (mm)	Formula	Uses
Fresh concrete	Slump cone	30cm height, 20 cm base, and 10cm top	-	It is commonly assessed using test for medium workability.
Hardened concrete	Compressive strength	150×150×150	f_{ck} = load/Area	Representing its ability to resist crushing under applied loads. (load carrying capacity of concrete)
	Split tensile strength	150×300	f_{ct} = 2P/πLD	It is an indirect measure of the tensile capacity of concrete.
	Flexural	150×150×700	f_{cr} = PL/bd²	Concrete's ability to resist bending stresses



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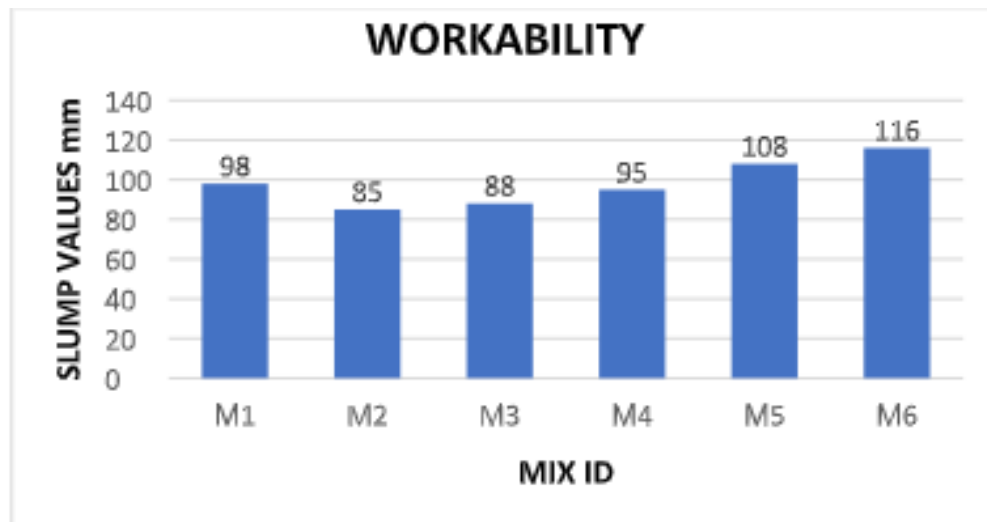
	strength			on its tension face (modulus of rupture).
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V. RESULTS AND DISCUSSIONS

1. WORKABILITY

Table 9:- Slump Values for the mix

Mix Id	Percentage replacement		Slump (mm)
	Dolomite powder (%)	Copper slag (%)	
M1	0	0	98
M2	10	10	85
M3		20	88
M4		30	95
M5		40	108
M6		50	116



Graph 1: Workability of Concrete

The slump values of the mixes show that workability is initially reduced due to the presence of DP, whose fine particles and higher water demand lower the free water available in the mix. As CS content increases, however, the slump gradually rises because CS has a smooth, dense, and non-porous texture that does not absorb water, allowing more free water to improve flow. Thus, lower replacement levels show reduced workability due to DP, while higher levels show increased workability as the effects of CS become dominant, resulting in smoother flow and higher slump values.

2. COMPRESSIVE STRENGTH TEST

M1 = Conventional Concrete, **M2** = 10% DP & 10% of CS, **M3** = 10% DP & 20% of CS, **M4** = 10% DP & 30% of CS, **M5** = 10% DP & 40% of CS, **M6** = 10% DP & 50% of CS.



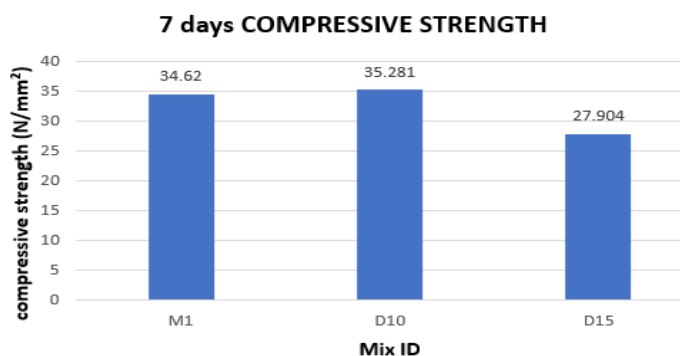
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Stage I — Determine optimum dolomite powder percentage

Table 10:- Compressive strength results for DP concrete (N/mm²)

Mix Id	% Replacement of cement with DP	7 days Compressive strength (N/mm ²)
M1	0	34.62
D10	10	35.281
D15	15	27.904



Graph 2: Optimum dolomite powder percentage

The 7-day compressive strength results show that replacing cement with DP slightly reduces early strength. The M1 mix achieved the strength of 34.62 N/mm², while the mix with 10% replacement showed a small increase to 35.281 N/mm², indicating that dolomite at this level has minimal impact on early performance. However, when the replacement level decreased to 15%, the strength dropped more noticeably to 27.904 N/mm². Higher percentages lead to a dilution effect, reducing the cementitious material needed for proper hydration and strength development.

Stage II — Copper slag replacement and optimum dolomite

Table 11:- Compressive strength results for DP+CS concrete (N/mm²)

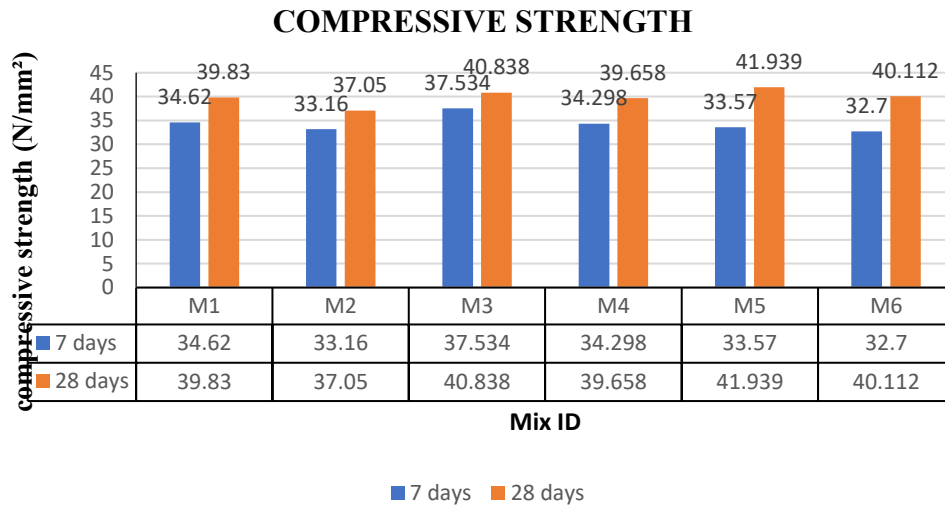
Mix Id	Percentage replacement		Compressive strength (N/mm ²)	
	Dolomite powder (%)	Copper slag (%)	7 days	28 days
M1	0	0	34.62	39.83
M2	10	10	33.16	37.05
M3		20	37.534	40.838
M4		30	34.298	39.658
M5		40	33.57	41.939
M6		50	32.7	40.112

The control mix is serving as the reference. When M2, the strength slightly decreased indicating that small quantities of CS may have slightly reduced early strength due to the inert nature of slag particles. With M3, compressive strength improve. The M4 maintained good strength compared to the control. At M5, increased significantly. the highest strength among all mixes, showing that this proportion provides optimum pozzolanic reaction and compact microstructure due to proper balance between binder and filler materials. However, at M6, dropped strength remained fairly high, indicating delayed strength gain.



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Graph 3: Compressive strength for (DP+CS)



Fig 1: cube specimens



Fig 2: Compression test for cube specimens

3. SPLIT TENSILE STRENGTH

Table 12:- Split Tensile Strength Results For DP+CS concrete (N/mm²)

Mix Id	Percentage replacement		Split tensile strength (N/mm ²)	
	(DP) (%)	(CS) (%)	7 days	28 days
M1	0	0	2.01	2.3
M2	10	10	2.174	2.459
M3		20	2.22	2.613
M4		30	2.358	2.88
M5		40	2.914	3.22

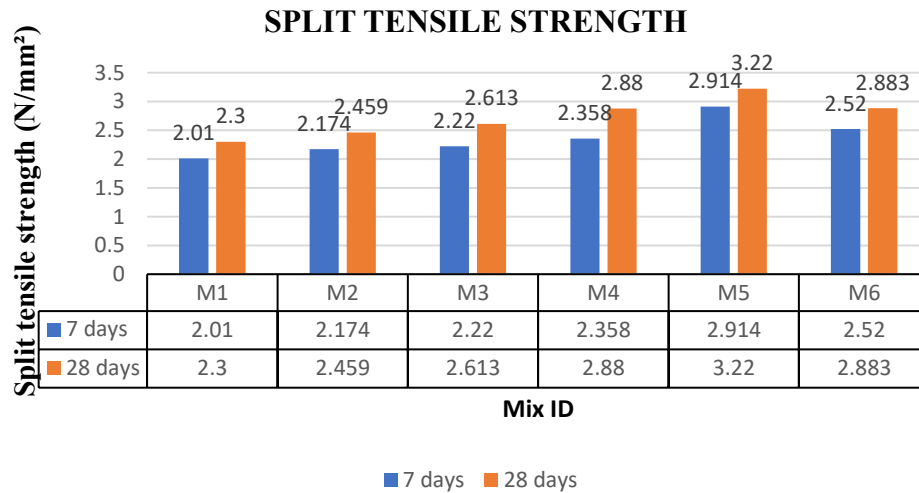


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M6	50	2.52	2.883
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The M1, representing the baseline strength of control mix. When M2, the strength slightly increased. Further increase to M3 slightly improved strength, showing that moderate replacement still contributes positively due to the dense microstructure formed. At M4, the tensile strength reached, reflecting better bond strength between aggregates. The maximum strength was obtained at M5, the DP enhanced the hydration reaction, while CS acted as a dense filler, improving both the tensile resistance and overall cohesion of the concrete. M6, strength dropped slightly.



Graph 4: Split Tensile Strength For (DP+CS)



Fig 3: Cylinder specim



Fig 4: Split Tensile Strength test for cylinder specimens



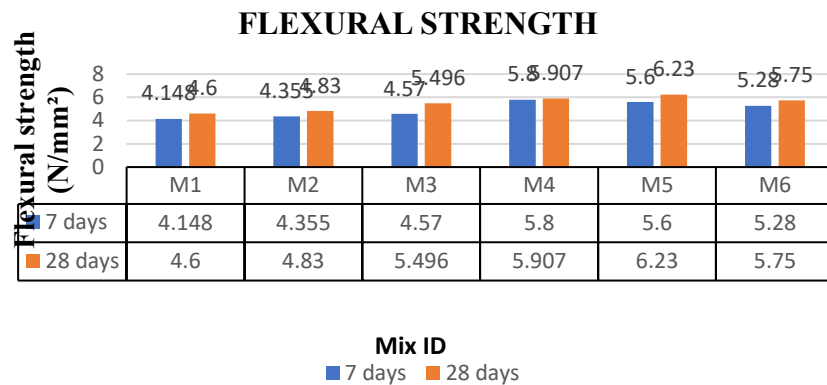
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4. FLEXURAL STRENGTH

Table 13:- Flexural Strength Results for (DP+CS) Concrete (N/mm²)

Mix Id	Percentage replacement		Flexural strength (N/mm ²)	
	Dolomite powder (%)	Copper slag (%)	7 days	28 days
M1	0	0	4.148	4.6
M2	10	10	4.355	4.83
M3		20	4.57	5.496
M4		30	5.8	5.907
M5		40	5.6	6.23
M6		50	5.28	5.75



Graph 5: Flexural Strength For (DP+CS)

The M1 serves as the reference for comparison. When M2, M3, M4, the strength increased slightly, indicating a refined pore structure, the combined filler and pozzolanic effects, producing dense and strong matrix formation. When the M5, strength again increased to 5.6 and 6.23 MPa— the highest recorded strength, suggesting this as the optimum level. The improvement is attributed to improved particle packing, enhanced load transfer between the matrix and aggregates, and sufficient cementitious content for strong bonding. However, beyond this, at M6, the strength dropped.





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Fig 5: Testing of beams

The experimental investigation on the mechanical properties of concrete incorporating dolomite powder and copper slag reveals that both materials can be effectively used as partial replacements to enhance the performance of conventional concrete within certain limits.

- The compressive strength results, the control mix attained 39.83 MPa at 28 days, while the mix with 10% dolomite powder and 40% copper slag recorded the highest compressive strength of 41.93 MPa, representing a noticeable increase. The improvement is attributed to the filler effect of dolomite powder, which the dense packing and pozzolanic nature of copper slag. However, beyond 40% replacement, the strength slightly decreased due to excessive slag causing cement dilution and reduced hydration.
 - The split tensile strength also followed a similar trend. The control mix achieved 2.3 MPa at 28 days, while the mix with 40% copper slag reached the maximum of 3.22 MPa. The increase in tensile strength is due to improved bonding between the cement matrix and aggregates, finer particle distribution, and enhanced microstructural compactness. A further increase to 50% copper slag led to a slight reduction in tensile strength, indicating loss of cohesion and weaker paste-aggregate interface at higher replacement levels.
 - Flexural strength results also demonstrated an increasing pattern up to the optimum mix. The control mix had 4.6 MPa at 28 days, whereas the 10% DP + 40% CS mix achieved 6.23 MPa. This improvement is due to enhanced stress distribution, denser matrix, and better interlocking between aggregate particles. However, at 50% replacement, flexural strength slightly decreased to 5.75 MPa, likely due to reduced cement paste content and excessive slag leading to lower workability and segregation.
 - Overall findings confirm that 10% DP combined with 40% CS provides the optimum mix, delivering maximum improvements in compressive, split tensile, and flexural strengths at both early and later ages.
- The results reaffirm that integrating industrial waste materials into concrete is a viable pathway for developing more sustainable and high-performing construction materials. Future investigations involving durability, microstructural characterization, and long-term performance would further strengthen the understanding of this composite system and support its broader implementation in structural applications.

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