As per UGC guidelines an electronic bar code is provided to secure your paper

International Journal for Modern Trends in Science and Technology
Volume 11, Issue 10, pages 74-80.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol11issue10.html
DOI: https://doi.org/10.5281/zenodo.17489435

Mechanical Performance of Concrete Modified with Metakaolin and Marble Dust

Shaikh Mohd Zubair[1] | Raut Ashok[2]

[1]*Assistant Professor, Deogiri Institute of Engineering and Management Studies, Aurangabad, Maharashtra, India.*
E-mail: zubairshaikh@dietms.org
[2]*P.G. Scholar, Deogiri Institute of Engineering and Management Studies, Aurangabad, Maharashtra, India.*

To Cite this Article
Shaikh Mohd Zubair & Raut Ashok (2025). Mechanical Performance of Concrete Modified with Metakaolin and Marble Dust. International Journal for Modern Trends in Science and Technology, 11(10), 74-80. https://doi.org/10.5281/zenodo.17489435

Article Info
Received: 11 September 2025; Accepted: 18 October 2025.; Published: 31 October 2025.

KEYWORDS

Metakaolin, Marble dust, Compressive Strength, Split Tensile Strength, Flexural Strength, Workability

ABSTRACT

The rapid growth of infrastructure development has significantly increased the demand for standard grade concrete, prompting a need for more sustainable and performance-enhancing alternatives. This study investigates the mechanical behavior of concrete incorporating varying proportions of metakaolin and marble dust as partial replacements for cement. Metakaolin was substituted at 10%, 15%, 20%, and 25%, while marble dust was added at 5%, 10%, 15%, and 20% by weight of cement. The mechanical properties assessed include compressive strength, split tensile strength, and flexural strength, following relevant Indian standards. Compressive strength was evaluated using 150 mm cube specimens as per IS 516, and split tensile strength was tested using 150 mm diameter cylindrical specimens. The experimental results reveal that a combination of 15% metakaolin and 10% marble dust yields the most favorable mechanical performance, demonstrating enhanced strength of concrete. This combination offers a promising approach for improving concrete performance while promoting the sustainable utilization of industrial by products.

1. INTRODUCTION

The increasing demand for standard grade concrete and environmentally sustainable construction materials has led to a growing interest in the use of Supplementary Cementing Materials (SCMs) in concrete production. SCMs are materials that are used to partially replace ordinary Portland cement (OPC) in concrete, enhancing both its performance and sustainability. Commonly used SCMs include fly ash, ground granulated blast-furnace slag (GGBS), silica fume, Alccofine [4] and natural pozzolans such as metakaolin. These materials not only improve the mechanical and durability properties of concrete but also contribute to significant reductions in carbon emissions and energy consumption associated with cement production. Given these advantages, the incorporation of SCMs has become a vital component in the development of durable, efficient, and eco-friendly concrete. This study focuses on evaluating the mechanical behavior of concrete incorporating metakaolin and marble dust, two potential Supplementary Cementing Materials by analyzing their effects on compressive strength, split tensile strength, and flexural strength in accordance with Indian standards.

2. EXPERIMENTAL PROGRAM:

Following materials are used for the experiment: For the study, ordinary Portland cement (OPC) of grade 53was used. [09] As fine aggregate and coarse aggregate, respectively, natural sand with a fineness modulus of 2.62 and natural gravel with a fineness modulus of 3.2 are employed.

The specific gravities of fine and coarse aggregates were 2.72 and 2.84, respectively and Potable Water pH value vary from 7 to 7.9. The Indian standards were followed or testing of the materials.

Metakaolin: The Metakaolin used in the experimental work is having the following properties.

Table- I: Chemical composition of Metakaolin [5]

Chemical Elements	% By mass
SiO2	51.62
Al2O3	40.31
Fe2O	3 1.49
CaO	2.01
MgO	0.15
K2O	0.72
SO3	0.008
TiO2	2.32
Na2O	0.04
L.O.I	2.07

Table-I I: Physical Properties of Metakaolin [5]

Specific gravity	2.1 to 2.4
Bulk density (g/cm3)	0.31 to 0.42
Water absorption	0.31 to .9%
pH	7.7 to 7.9
Physical form	Powder
Color	white
GE Brightness	72 to 81

Marble Dust: Marble is formed through the metamorphic transformation of pure limestone. The color of marble often indicates its level of purity. Since ancient times, marble has been widely used for decorative purposes in monuments and historic structures. In India, the marble industry generates tons of waste material. Therefore, utilizing this marble waste in concrete presents a sustainable and effective solution.

Figure 01: Marble Dust

Superplastisizer- super plasticizer used was a new generation Polycarboxyle base super plasticizer containing carboxylic (COOH) group instead of sulphonic (SO3H) as in case of Melamine or naphthalene formaldehyde sulphonate. The super plasticizer was added in all mixes and the quantity was kept constant throughout the study as 1.03% by weight of total cementitious material [4].

Experimental Work: In this experiment, concrete specimens were cast for M40 grade concrete. The specimens included cube samples of size 150 mm × 150 mm × 150 mm, cylindrical specimens with a diameter of 150 mm and a length of 300 mm, and beam specimens measuring 100 mm × 100 mm × 500 mm. The concrete mix design was prepared in accordance with Indian Standard guidelines for M40 grade as per IS 10262:2009, using a water–cement ratio of 0.3.

Following proportions are used for all the tests [5]

1. 10% MK, 5% Marble dust, 85% OPC, Fine Aggregate, Coarse Aggregate
2. 15% MK, 10% Marble dust, 75% OPC, Fine Aggregate, Coarse Aggregate
3. 20% MK, 15% Marble dust,, 65% OPC, Fine Aggregate, Coarse Aggregate
4. 25% MK, 15% Marble dust,, 60% OPC, Fine Aggregate, Coarse Aggregate

Test Performed: Compressive strength - Concrete cubes of size 150 mm × 150 mm × 150 mm were cast for compressive strength testing. After water curing for 7, 14, and 28 days, the compressive strength of the specimens was evaluated. For each curing age, three specimens were tested, and the average of their compressive strength values was reported.

Compressive strength results for cubes with (MD1)

Table:III 10% MK, 5 % marble powder 85%OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cube No.	Cube Weight After Unmolding	Cube weight after removing from curing(kg)	Curing Days	Peak Load (Kn)	Compressive Strength
1	C.no 1	8.401	8.357	7	510	22.67
2	C.no 2	8.101	8.241	7	470	20.89
3	C.no 3	8. 633	8.711	7	479	21.29
4	C.no 4	8.299	8.268	14	730	32.44
5	C.no 5	8.611	8.425	14	765	34
6	C.no 6	8.697	8.442	14	751	33.88
7	C.no 7	8.101	8.390	28	804	35.73
8	C.no 8	8.399	8.302	28	863	38.36
9	C.no 9	8.807	8.504	28	790	35.11

Compressive strength results for cubes with (MD2)

Table IV: 15% MK, 10 % marble powder, 75%OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cube No.	Cube Weight After Unmolding	Cube weight after removing from curing(kg)	Curing Days	Peak Load (Kn)	Compressive Strength
1	C.no 1	8.740	8.860	7	523	23.24
2	C.no 2	8.602	8.795	7	504	22.40
3	C.no 3	8.613	8.719	7	508	22.58
4	C.no 4	8.533	8.693	14	774	34.40
5	C.no 5	8.567	8.678	14	763	33.91
6	C.no 6	8.503	8.670	14	790	35.11
7	C.no 7	8.640	8.785	28	904	40.18
8	C.no 8	8.513	8.629	28	956	42.49
9	C.no 9	8.645	8.772	28	945	42.00

Compressive strength results for cubes with (MD3)

Table V: 20% MK, 15 % marble powder, 65%OPC, Fine Aggregate, Coarse Aggregate

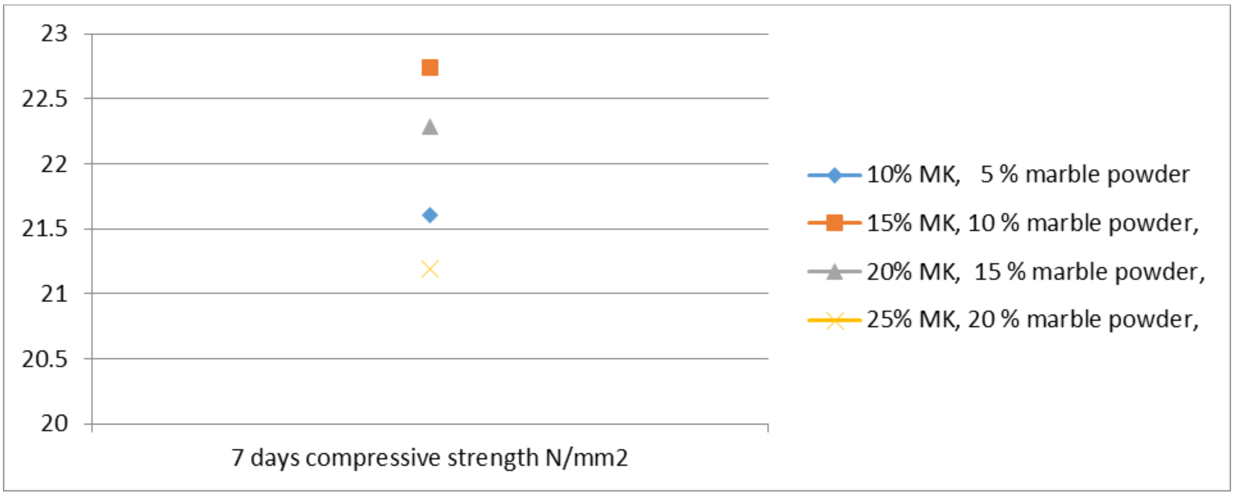
Sr. No.	Cube No.	Cube Weight After Unmolding	Cube weight after removing from curing(kg)	Curing Days	Peak Load (Kn)	Compressive Strength
1	C.no 1	8.413	8.583	7	514	22.84
2	C.no 2	8.465	8.653	7	511	22.71
3	C.no 3	8.621	8.761	7	493	21.91
4	C.no 4	8.543	8.696	14	743	33.02
5	C.no 5	8.911	9.060	14	741	32.93
6	C.no 6	8.765	8.862	14	737	32.76
7	C.no 7	8.512	8.674	28	890	39.56
8	C.no 8	8.499	8.692	28	885	39.33
9	C.no 9	8.844	8.611	28	903	40.13

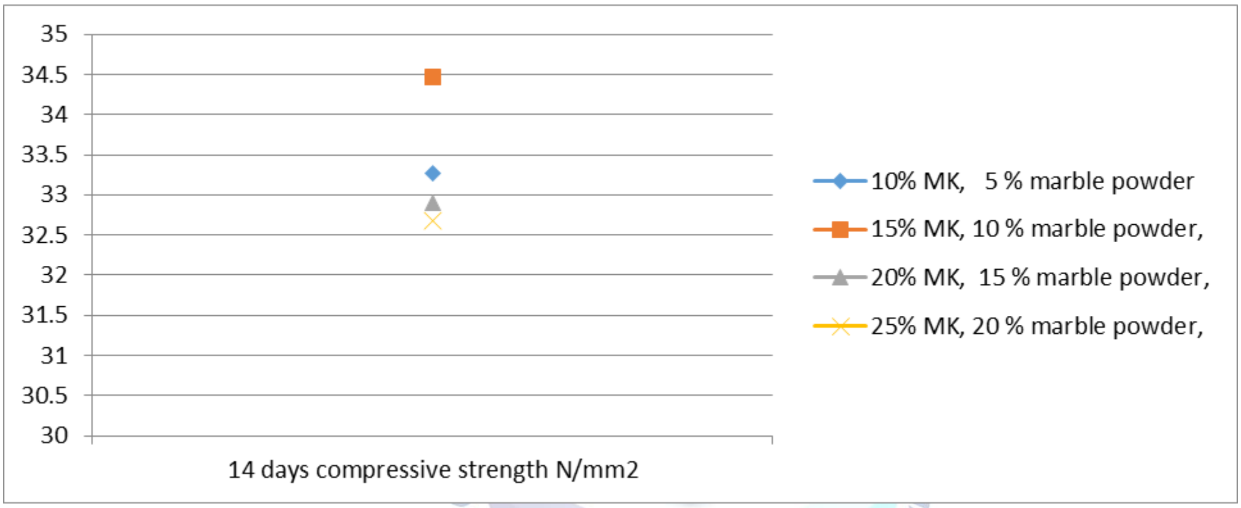
Compressive strength results for cubes with (MD4)

Table VI: 25% MK, 20 % marble powder, 55% OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cube No.	Cube Weight After Unmolding	Cube weight after removing from curing(kg)	Curing Days	Peak Load (Kn)	Compressive Strength
1	C.no 1	8.213	8.394	7	513	22.80
2	C.no 2	8.413	8.546	7	462	20.53
3	C.no 3	8.322	8.652	7	455	20.22
4	C.no 4	8.345	8.495	14	702	31.20
5	C.no 5	8.432	8.525	14	742	32.98
6	C.no 6	8.501	8.587	14	761	33.82
7	C.no 7	8.211	8.366	28	792	35.20
8	C.no 8	8.399	8.521	28	846	37.60
9	C.no 9	8.541	8.636	28	853	**37.91**

Graphical Presentation of compressive strength:





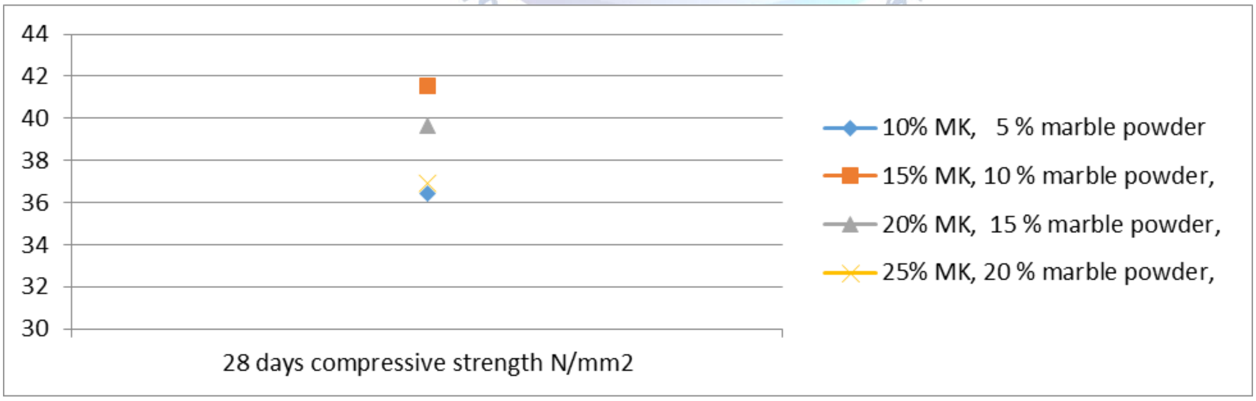


Figure – 02 Failure pattern of cube

Split Tensile Test: The results obtained from the split tensile strength test according to IS 5816:1999. Are presented in the following table.

Table VII: Split tensile strength results for Cylinders with (MD1)

10% MK, 5 % marble powder 85%OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cylinder No.	Cylinder Weight After Unmolding	Cylinder weight after removing from curing(Kg)	Curing Days	Peak Load (KN)	Compressive Strength(MPA)
1	Cy.no 1	13.094	13.232	28	278.70	3.94
2	Cy.no 2	13.495	13.640	28	266.50	3.77
3	Cy.no 3	13.210	13.360	28	272.6	3.86

Table VIII: Split tensile strength results for Cylinders with (MD2)

15% MK, 10 % marble powder, 75%OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	CylinderNo.	Cylinder Weight After Unmolding	Cylinder weight after removing from curing(Kg)	Curing Days	PeakLoad (KN)	Compressive Strength(MPA)
1	Cy.no 1	13.354	13.496	28	334.9	4.74
2	Cy.no 2	12.611	12.772	28	311.5	4.41
3	Cy.no 3	13.012	13.182	28	323.2	4.57

Table IX: Split tensile strength results for Cylinders with (MD3)

20% MK, 15 % marble powder, 65%OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cylinder No.	Cylinder Weight After Unmolding	Cylinder weight after removing from curing(Kg)	Curing Days	PeakLoad (KN)	Compressive Strength(MPA)
1	Cy.no 1	13.089	13.140	28	197.50	2.80
2	Cy.no 2	12.901	13.008	28	186.60	2.64

3	Cy.no 3	13.112	13.282	28	192.05	2.72

Table X: Split tensile strength results for Cylinders with (MD4)
25% MK, 20 % marble powder, 55% OPC, Fine Aggregate, Coarse Aggregate

Sr. No.	Cylinder No.	Cylinder Weight After Unmolding	Cylinder weight after removing from curing(Kg)	Curing Days	PeakLoad (KN)	Compressive Strength(MPA)
1	Cy.no 1	13.314	13.512	28	199.80	2.83
2	Cy.no 2	13.101	13.252	28	209.80	2.97
3	Cy.no 3	12.892	13.069	28	204.8	2.90

Figure 03 – Split Tensile Test

Flexural Strength Test Results: The results obtained from the flexural strength test, conducted as per IS 5816:1999, are presented in the following table.

Sr. No.	Mix Proportions	Beam No.	Beam Weight After Unmolding	Beam weight after removing from curing(Kg)	Curing Days	Peak Load (kN)	Compressive Strength(MPA)
1	MD1	B.no 1	11.600	11.857	28	18.90	7.56
2	MD1	B.no 2	11.740	11.986	28	18.50	7.40
3	MD2	B.no 3	12.076	12.212	28	17.50	7.00
4	MD2	B.no 4	12.156	12.114	28	17.90	7.30
5	MD3	B.no 5	12.290	13.332	28	16.70	6.68
6	MD3	B.no 6	12.360	13.440	28	15.10	6.04
7	MD4	B.no 7	12.414	12.660	28	8.90	3.56
8	MD4	B.no 8	12.468	12.584	28	13.80	5.52

CONCLUSION FROM RESULTS:

Following are the conclusions obtain from test results:

1. Slump cone test

a) For concrete mix proportion 10% MK, 5% Marble dust, 85% OPC, Fine Aggregate, Coarse Aggregate give us medium workability and measured slump 84mm. 15% MK, 10% Marble dust, 75% OPC, Fine Aggregate, Coarse Aggregate gives slump 95mm

b) Whereas for mix proportion 20% MK, 15% Marble dust,, 65% OPC, Fine Aggregate, Coarse Aggregate concrete slump was 110 whereas . 25% MK, 15% Marble dust,, 60% OPC, Fine Aggregate, Coarse Aggregate give us low workability and measured slump 98mm.

c) This indicates that the as percentage of metakaoline and marble dust addition increases which reduced workability of concrete.

2. Compressive strength Test

The experimental investigation evaluated the effects of varying proportions of **Metakaolin (MK)** and **Marble Powder (MP)** as partial replacements for **Ordinary Portland Cement (OPC)** in concrete mixes. The compressive strength of concrete cubes was tested at 7, 14, and 28 days for the following mixes:

Mix	OPC (%)	MK (%)	MP (%)	Cement Replacement (%)
MD1	85	10	5	15
MD2	75	15	10	25
MD3	65	20	15	35
MD4	55	25	20	45

All mixes showed acceptable early strength at 7 days. Mix M1 (85% OPC) had the highest 7-day strength 21.62 MPa. Mix M4 (55% OPC) had the lowest 21.18 MPa but still adequate for general use.

Mix M2 (15% MK, 10% MP) showed the highest 14-day strength 34.47 MPa. All mixes reached compressive strengths above 35 MPa, confirming their suitability for structural applications. Mix M2 (75% OPC, 15% MK, 10% MP) had the highest 28-day strength 41.56 MPa. Even the most cement-reduced mix, M4 (55% OPC), achieved a solid 28-day strength of 36.90 MPa, showing the effectiveness of MK and MP in maintaining performance.

Concrete mixes with partial replacement of OPC using Metakaolin and Marble Powder showed excellent performance in terms of compressive strength. The optimal mix based on strength results appears to be M2 (75% OPC, 15% MK, 10% MP), offering the best balance between sustainability and mechanical performance. However, even higher replacement mixes (M3, M4) are viable for structural applications, demonstrating that sustainable concrete can be achieved without significant loss in strength.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] Zaid Ali Hasan Et.Al. (2021) Properties of reactive powder concrete containing different combinations of fly ash and metakaolin.

[2] Jun Xie Et.Al. (2020) Effect of nano metakaolin on compressive strength of recycled concrete.

[3] P. Dinakar Et.Al. (2014) Concrete Mix Design for High Strength Self-compacting Concrete using Metakaolin

[4] Shaikh Mohd Zubair, Dr. S.S. Jamkar, Experimental Investigation on Effect of Mineral Admixtures on High Performance Concrete with various W/B ratios, International Journal of Research in Engineering and Technology,(2015).

[5] Shaikh Mohd Zubair, S.R. Pakhare, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878 (Online), Volume-11 Issue-3, September 2022

[6] Indian Standards 10262 – 2009: Recommended Guidelines for Concrete Mix Design.

[7] Indian Standards 456 – 2000: Plain and Reinforced Concrete Code of Practice.

[8] Indian Standards 516 – 1959: Method of Tests for Strength of concrete.

[9] Indian Standards 12269-1987: Specification for 53 Grade Ordinary Portland cement.

[10] Indian Standards 2386-1963 (Part I, II, III, IV, V, VI, VII): Methods of Test for aggregates for Concrete.

[11] Sandip Kumar Nayaka, Alok Satapathya, Sisir Mantry Et all, Use of waste marble and granite dust in structural applications: A review, Journal of Building Engineering 46 (2022)