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METAKAOLIN AND MARBLE POWDER EFFICACY ON THE MECHANICAL STRENGTH OF TRIPLE-BLENDED HIGH PERFORMANCE CONCRETE

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Abstract
Rapid urbanization and industrialization have significantly boosted cement production, which has resulted in significant environmental contamination. The control of the significant carbon footprints has been the major worldwide concern in relation to the production of cement. Utilizing ecofriendly cementitious substances in design of structures has proven to be a practical solution to this environmental issue. Through use of cementitious substances, which, albeit partially, can substitute cement, must therefore be further examined. In this research, two of these cement replacement materials, namely, Meta-kaolin (MK) and Marble-Powder (MP) - have been examined. In this work, Meta-kaolin (MK) and Marble-Powder (MP)have been prepared as partial substitutes for cement in M65 grade High Performance Concrete. To improve the workability, a polycarboxylate-ether-based superplasticizer has been utilized. The mechanical strength (compressive, split tensile and flexural strength) of the test material, which was casted and allowed to be cured for 7, 28, and 56 days at room temperature, was determined in accordance with Indian guidelines. The ideal mixture of high-performance-concrete created in this way complied with Indian regulations, and the blend of cement + 12.5% Marble Powder + 7.5% Metakaolin showed the best compressive strength and flexural strength and 0 % Marble Powder + 20 % Metakaolin showed the best split tensile strength after 56 days of curing. Metakaolin (MK) and Marble Powder (MP) are suggested as partial cementitious materials since their usage in lesser amounts has boosted the strength of concrete.

Keywords: Metakaolin, Marble Powder, Compressive strength, Split tensile strength, Flexural strength, High Performance Concrete, Ternary concrete.

I. INTRODUCTION
Concrete is a highly popular construction material that is widely used around the world [1]. Cement, water, fine aggregates, and coarse aggregates are the main ingredients in concrete [8]. Since the cement is the major construction material used in the construction sector and that its demand is rapidly rising due to its enormous environmental consequences [6]. During the cement manufacturing, a carbon dioxide is produced on a large scale, it is imperative to switch to sustainable techniques and resources. Due to the enormous need for concrete, architects and engineers are carrying out research on substituting cement with various waste materials that are more sustainable [16]. To reduce CO_2 emissions, partial exclusion of cement substituted by supplementary cementitious substances or industrial by – products [2]. Meta-kaolin (MK) and

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Marble-Powder (MP) materials enhance the compressive strength of concretely blocking the pore sizes and decreasing permeability and porosity of the concrete without compromising the necessary properties. The aspect of sustainability improves human quality of life while without compromising it by meeting both present and future demands.

A. Metakaolin in Concrete

Fig. 1 Metakaolin

Metakaolin (MK), a de-hydroxylated kind of the kaolinite clay mineral, is heated to produce this disinfect or modified kaolinite clay to a temperature between 650^{o}cto 850^{o}c, then calcining it at that temperature while grinding it to a fineness of 750 to 900 m2 per kg [1]. Metakaolin (MK) resembles a fine powder with a light grey colour. Metakaolin is frequently employed in the manufacture of ceramics, but it is also utilised in concrete in replacement of cement. Metakaolin has smaller particles (1-2 m) and a larger surface area than Portland cement [4]. Although its particles are bigger than those of SF. Metakaolin undergoes a pozzolanic reaction when incorporated into concrete, which improves the microstructure of the hydrated cement paste [5]. It can urbanise the microstructure, enhancing the concrete's durability and mechanical qualities. It has been discovered that using MK helps to accelerate the cement's hydration. However, adding MK might make a fresh mixture less workable and require more time to combine. Thus, by partially substituting Metakaolin for Portland cement, carbon dioxide emissions are decreased while simultaneously extending the useful life of structures. Metakaolin has a similar chemical makeup as portland cement.

B. Marble-Powder in Concrete

Fig. 2 Marble Powder Sample

Since antiquity, Marble has traditionally been a prevalent choice for construction purposes. Marble-powder is a byproduct generated during the manufacturing process of marble. A substantial amount of powder is produced during the process of trimming of marble.The Chinchpura region in Vadodara district and the Ambaji region in Banaskantha district are the principal marble-producing

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centers in the state of Gujarat. India produces around 90% of the marble used worldwide, with Rajasthan and Banaskantha, Gujarat, contributing about 85% of the country's overall production [6]. Around 259.60 million tons of marble are thought to be present in the districts of Vadodara and Banaskantha with 250+ marble mines. There are 257.90 million tons in the district of Banaskantha and the remaining 1.7 million tons in the district of Vadodara [6].

As a result, around 25% of the initial marble mass is lost as dust or powder. Leaving these waste products in the environment might result in environmental problems such as increased soil alkalinity, effects on plants, effects on the human body, and so on. Also, the productivity of marble powder decreases as it is deposited on open land; it also lessens porosity and interferes with ground water recharge.

A number of countries have experienced challenges in satisfying the growing demand for cement due to its expanded use in the manufacturing of concrete. Because marble is strong, beautiful, and fireproof, it is frequently employed in construction. The emergence of concrete technology has the potential to decrease energy and natural resource use, hence reducing the environmental impact of pollutants. Conventional concrete's mechanical and physical qualities can be enhanced by adding waste marble powder. The prospect of using discarded marble-powder as an alternative cement in the manufacturing of concrete will also result in waste disposal difficulties being alleviated.

1) Ternary Blended Concrete:

Ordinary concrete has only one cementitious substance, namely cement. A binary concrete blend has cement as the binding material and a pozzolanic material. A ternary mixture is the one where the binder comprises portland cement and two diverse SCMs (supplementary cementitious materials) include fly ash, metakaolin, silica fume, marble powder, GGBS, etc…that are combined either at the cement plant or at the batch plant [3]. Common combinations for ternary blended concretes include fly ash-metakaolin, fly ash-silica fume, fly ash-marble powder, and metakaolin-marble powder, among others [1]. Compared to conventional portland cement combinations, ternary blended cement concrete compositions emit less carbon dioxide.

II. MATERIALS AND METHODS

A. Materials

1) Cement:

This research paper delves into the properties, applications, and advancements in HPC utilizing Ultratech's OPC 53 grade cement is used for this investigation in accordance with Indian Standard specifications.

2) Metakaolin:

The metakaolin used in this investigation has a specific gravity of 2.28 and is supplied as a grey powder by Contech Chemicals Pvt. Ltd. in Ahmedabad, Gujarat, India. It was gradually added to the concrete mixtures under evaluation in increments ranging from 0% to 30%.

TABLE I CHEMICAL ANALYSIS OF META-KAOLIN

Chemicals	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**SO_3**	**K_2O**	**Na_2O_3**	**C_3A**	**CL**	**LOI**
Percentage (%)	53.9	42.80	0.41	0.025	0.03	0.20	0.25	9.5	0.004	0.48

TABLE 2 PHYSICAL ANALYSIS OF META-KAOLIN

Property	**Specific-Gravity**	**Bulk-Density (g/cm3)**	**Physical-Form**	**Color**
Value	2.28	0.32	Powder	Grey

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3) Marble Powder:

Marble powder, obtained from Jay Gajanand Pvt. Ltd. in Visnagar, is essential to this study project. This fine powder is a crucial ingredient of the experimental formulations, with a particle size of 90 microns flowing through it. With a specific gravity measuring 2.73, it possesses distinctive physical properties that contribute to its effectiveness as a supplementary material in concrete mixtures. Throughout the investigation, the marble powder is systematically introduced into the mixtures, gradually increasing in percentage from 0% to 30%.

TABLE 3 CHEMICAL ANALYSIS OF MARBLE POWDER

Chemicals	SiO_2	Al_2O_3	Fe_2O_3	MgO	C_3A	CL	LOI
Percentage (%)	0.6	0.35	0.17	0.110	6.5	0.004	0.43

TABLE 4 PHYSICAL ANALYSIS OF MARBLE POWDER

Property	Specific-Gravity	Bulk-Density (g/cm3)	Physical- Form	Color
Value	2.73	0.81	Powder	White

4) Super plasticizer:

A polycarboxylate-based superplasticizer called CONFLOW - CP, which was obtained from Contech Chemicals (India) Pvt. Ltd. in Ahmedabad, was used in this study. Because of its high-performance qualities, this superplasticizer helps concrete mixtures have better workability and flow characteristics. This addition uses Polycarboxylate ether's sophisticated composition to improve cement particle dispersion, which lowers the water content of the mix and increases fluidity.

5) Coarse aggregate:

The VSI aggregate which is retained on 4.75 mm maximum size of 20 mm is used in this experimental investigation.

6) Fine aggregate:

Aggregate gradation is defined as the dispersion of particle sizes. In this study, the aggregate that is passing through a 4.75 mm screen is utilized. Sand from Zone II is utilized.

7) Water:

For mixing and curing concrete, fresh portable water which is free from acid and organic component concentration is selected for study.

B. Mixture Proportion and Specimen Preparation

The mechanical strength of high-performance concrete of grade M65, which was designed based on IS 10262-2019, was studied experimentally. Metakaolin and Marble Powder were added upto 30 % weight of cementitious material. The goal of this study was to find out what the split tensile strength, flexural strength, and compressive strength were. The mix proportion for M65 grade high performance concert, based on IS 10262-2019 is shown in Table 5.

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TABLE 5 DIFFERENT MIX PROPORTION FOR REPLACEMENT OF MK & MP WITH CEMENT

Mix	Cementitious Content Kg/m^3	Total Replacement (%)	OPC (%)	MK (%)	MP (%)	MK Kg/m^3	MP Kg/m^3	Powder Content Kg/m^3
1	540	0	100	0	0	0	0	504
2	540	10	90	100	0	54	0	558
3	540			75	25	40.5	13.5	558
4	540			50	50	27	27	558
5	540			25	75	13.5	40.5	558
6	540			0	100	0	54	558
7	529	20	80	100	0	106	0	578
8	529			75	25	79.5	26.5	578
9	529			62.5	37.5	66.25	39.75	578
10	529			50	50	53	53	578
11	529			37.5	62.5	39.75	66.25	578
12	529			25	75	26.5	79.5	578
13	529			0	100	0	106	578
14	524	30	70	100	0	157	0	572
15	524			75	25	117.75	39.25	572
16	524			50	50	78.5	78.5	572
17	524			25	75	39.25	117.75	572
18	524			0	100	0	157	572

TABLE 6 MIX DESIGN PROPORTIONS FOR VARIOUS MIX

Mix	Total Replacement	OPC	MK	MP	W/C Ratio	Water Content	Admix.	OPC	MK	MP	CA	FA
	(%)					(Kg/m^3)						
1	0	100	0	0	0.30	162	7.938	450	0	0	1237.71	675
2	10	90	10	0	0.30	162	7.938	450	54	0	1169.27	675
3	10	90	7.5	2.5	0.30	162	7.938	450	40.5	13.5	1172.09	675
4	10	90	5	5	0.30	162	7.938	450	27	27	1174.91	675
5	10	90	2.5	7.5	0.30	162	7.938	450	13.5	40.5	1177.73	675
6	10	90	0	10	0.30	162	7.938	450	0	54	1180.55	675
7	20	80	20	0	0.325	172	7.756	423	106	0	1167.86	612.5
8	20	80	15	5	0.325	172	7.756	423	79.5	26.5	1173.40	612.5
9	20	80	12.5	7.5	0.325	172	7.756	423	66.25	39.75	1176.16	612.5
10	20	80	7.5	12.5	0.325	172	7.756	423	53	53	1178.93	612.5
11	20	80	10	10	0.325	172	7.756	423	39.75	66.25	1181.70	612.5
12	20	80	5	15	0.325	172	7.756	423	26.5	79.5	1184.47	612.5
13	20	80	0	20	0.325	172	7.756	423	0	106	1190.00	612.5
14	30	70	30	0	0.33	173	6.813	367	162	0	1167.79	600
15	30	70	22.5	7.5	0.33	173	6.813	367	117.75	39.25	1182.5	600
16	30	70	15	15	0.33	173	6.813	367	78.5	78.5	1184.19	600
17	30	70	7.5	22.5	0.33	173	6.813	367	39.25	117.75	1192.39	600
18	30	70	0	30	0.33	173	6.813	367	0	157	1200.59	600

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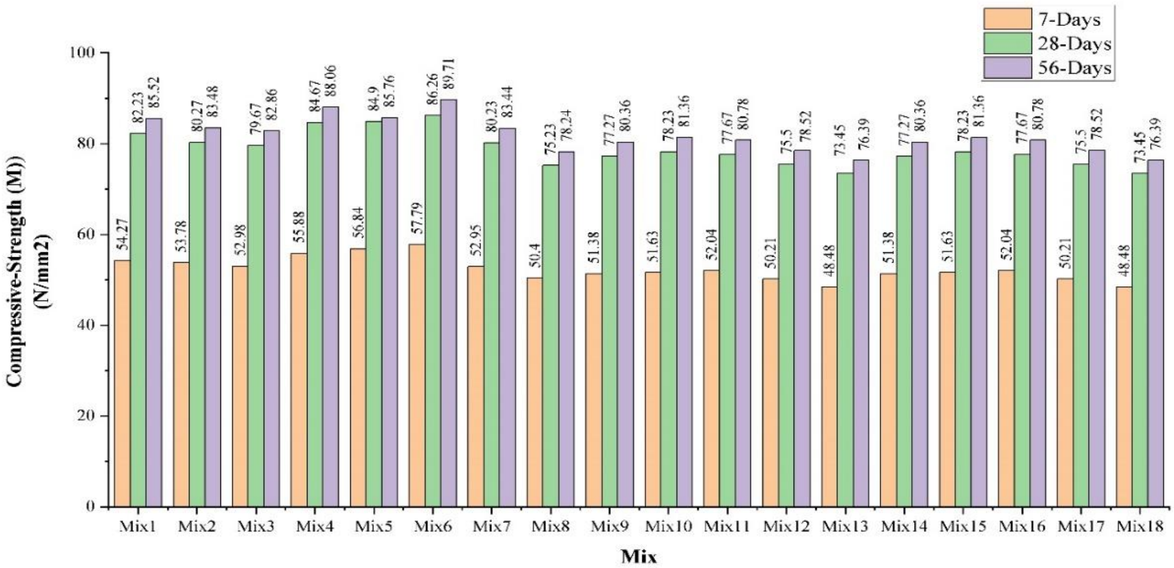
Specimens are prepared according to the IS: 10086-1982 standard by selecting materials, measuring their weight, and casting them into cube, cylinder, and beam shapes. For the compressive strength test, cube-specimens measuring 150 mm x 150 mm x 150 mm were cast; cylinder-specimens measuring 150 mm x 30 mm were cast for the split tensile strength; and prism-specimens measuring 100 mm x 100 mm x 500 mm were cast for the flexural strength [15]. The mixing, compacting, and curing processes are carried out in accordance with IS: 516-1959 [17]. The specimens were extracted from the molds and placed in a curing tank for 7, 28, and 56 days, following a 24-hour casting process, at room temperature. M65 grade concrete are formulated and the amount of material needed per meter cube of concrete is determined.

III. FINDINGS AND ANALYSIS

The compressive strength, split tensile strength, and flexural strength results for Mix-1 to Mix-18, with varying proportions of cement replacement using marble powder and metakaolin, after 7 days, 28 days, and 56 days of curing, are shown in Graph 1, 2, and 3 accordingly.



Graph 1 Compressive-Strength results

From Graph 1, we can see that the compressive strength increases up to Mix-11, and then it decreases. Mix-11, which contains 7.5% MK and 12.5% MP with 20% cement replacement, reaches its maximum compressive strength at 57.79 N/mm2 after 7 days, 86.26 N/mm2 after 28 days, and 89.71 N/mm2 after 56 days.

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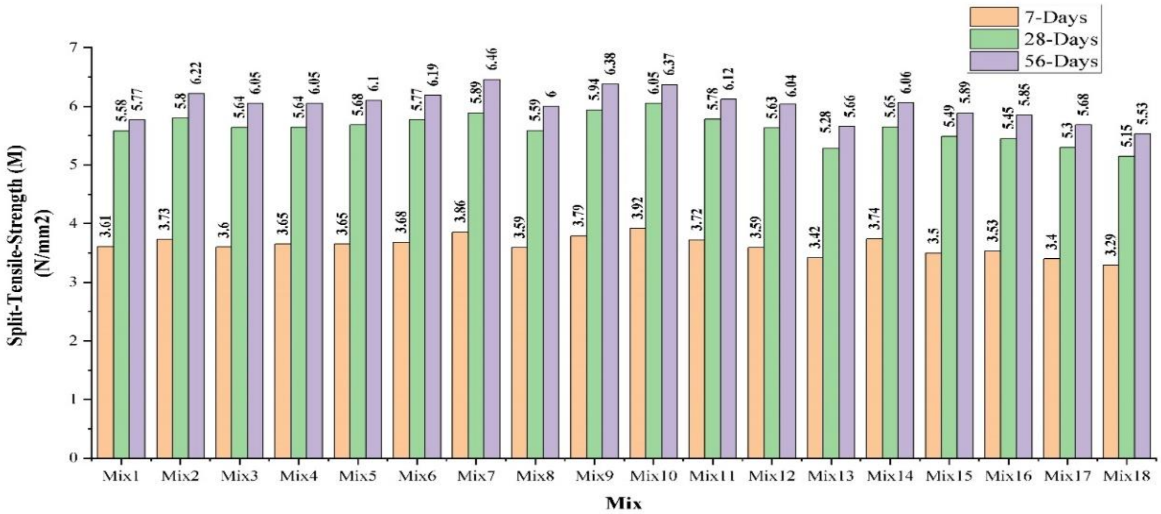
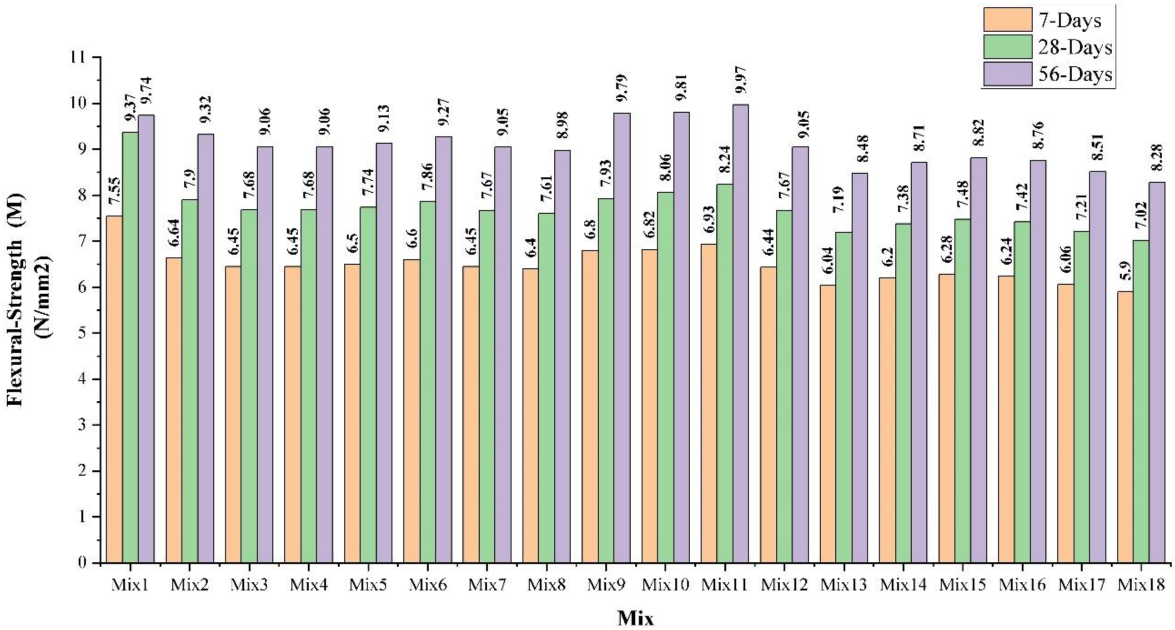


Graph 2 Split-Tensile-Strength results

It can be shown from Graph 2 that the split tensile strength increases up to Mix-7, beyond which it decreases. For Mix-7 (20% MK and 0% MP of 20% cement replacement), the maximum slit tensile strengths after 7 days, 28 days, and 56 days are 3.86 N/mm2, 5.89 N/mm2, and 6.46 N/mm2, respectively.



Graph 3 Flexural-Strength Results

The flexural strength is found increased till Mix-11 and then goes decreasing that is represented in Graph 3. The maximum flexural strength is available for Mix-11 (7.5 % MK and 12.5 % MP of 20 % cement replacement) as 6.93 N/mm^2, 8.24 N/mm^2 and 9.97 N/mm^2 for 7 days, 28 days and 56 days respectively.

IV. CONCLUSION

The experimental findings led to prove that this optimal blends of High performance concrete created in this way complied with Indian regulations, and the blend of cement + 12.5% Marble

Powder + 7.5% Metakaolin of 20 % cement replacement for Mix-11 showed the optimum compressive strengths and flexural strength as 57.79 N/mm^2, 86.26 N/mm^2, 89.71 N/mm^2 and 6.93 N/mm^2, 8.24 N/mm^2 and 9.97 N/mm^2 for 7 days, 28 days and 56 days respectively and optimum split tensile strengths at the blend of cement 0 % Marble Powder + 20 % Metakaolin of 20 % cement replacement for Mix-7 as 3.86 N/mm^2, 5.89 N/mm^2 and 6.46 N/mm^2 for 7 days, 28 days and 56 days respectively. Metakaolin (MK) and Marble Powder (MK) are suggested as partial cementitious materials since their usage in lesser amounts has boosted the strength of concrete.

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