Workability Behaviour of High Performance Concrete with Metakaolin and Marble Powder

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High-Performance Concrete (HPC) is a relatively novel concrete variant that provides numerous economic and technical advantages; the incorporation of by-products enhances its potential when paired with HPC. This research paper investigates the effects of incorporating metakaolin and marble powder as supplementary cementitious materials on the workabilityproperties of high-performance concrete.In this study, cement was partially replaced with different proportions of Metakaolin and Marble Powder, ranging from 0% to 30% by weight. The workability of the HPC mixtures was assessed using a comprehensive suite of tests, including the J-ring, slump flow, U-box, V-funnel and L-box tests. These tests were specifically chosen to evaluate the filling ability and passing ability of the concrete, providing a thorough understanding of how the additions of Metakaolin and Marble Powder affect these crucial workability parameters.

Keywords: High-Performance concrete, Metakaolin, Marble Powder, Workability.

1. Introduction

Modern concrete technology has the potential to alleviate environmental pollution by cutting down on the use of energy and natural resources [7]. High Performance Concrete is a specialized form of concrete that exhibits enhanced mechanical strength, durability, and workability compared to traditional concrete mixes [2, 3]. These enhanced properties make HPC a preferred choice for demanding construction projects. The incorporation of supplementary cementitious materials, such as metakaolin and marble powder, has been explored to improve the performance of high performance concrete. Metakaolin is a pozzolanic material derived from the calcination of kaolinitic clay, while Marble powder is a byproduct of the marble manufacturing industry that adversely impacts the environment and poses health risks [7]. The production involves a series of processes including sawing, shaping, and polishing. The disposal of marble powder generated by the marble industry presents a significant environmental challenge globally today [5,6,7].

This project examines the feasibility of utilising marble dust as a partial substitute for cement in concrete production. In India, the processing of marble powder represents a significant industry. The impact of varying marble powder content on the physical and workability properties, which are critical to concrete performance, influences the ease of placement, consolidation, and finishing of both fresh and hardened concrete. These aspects have been thoroughly investigated.

This research delves into the impact of partially replacing cement with Metakaolin and Marble Powder, as supplementary cementitious materials, on the workability properties of HPC, at levels ranging from 0% to 30% by weight. This approach facilitates the reduction of construction costs and addresses disposal issues, including the environmental challenges faced by the region. To comprehensively assess the workability parameters, a series of tests were conducted, including:

- J-ring: Evaluates the passing ability of concrete, particularly in congested reinforcement conditions [4].
- Slump flow: Measures the flowability and spreading ability of concrete [4].
- U-box: Assesses the filling ability and passing ability of concrete through narrow sections [4].
- V-funnel: Determines the flowability and resistance to segregation of concrete [4].
- L-box: Evaluates the flowability and passing ability of concrete through obstacles [4].

By employing these tests, this research aims to provide a comprehensive understanding of how the inclusion of Metakaolin and Marble Powder affects the filling ability and passing ability of HPC, ultimately influencing its overall workability.

2. EXPERIMENTAL METHODOLOGY

2.1. Material

s Cement

This research utilises Ordinary Portland cement (OPC) - 53 grade from Ultratech, adhering to Indian Standard specifications [1].

Metakaolin

Metakaolin available in the Grey powder form used in this research was obtained from the Contech Chemicals Pvt. Ltd., Ahmedabad having specific gravity of 2.28 and is replaced in increasing percentage from 0 % to 30 % [1].

Table 1: Chemical Analysis of Meta-kaolin [1]

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 [1]

Property	Specific- Gravity	Bulk-Density (g/cm^3)	Physical- Form	Color
Value	2.28	0.32	Powder	Grey

Marble Powder

Marble powder of 90 micron passing used in this research was obtained from Jay Ganpati Marble Pvt. Ltd., Visnagar having specific gravity of 2.73 and is replaced in increasing percentage from 0 % to 30 % [1].

Table 3: Chemical Analysis of Marble Powder [1]

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 [1]

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

Super plasticizer

Polycarboxylate either based CONFLOW – CP superplasticizer acquired from Contech Chemicals (India) Pvt. Ltd., Ahmedabad was utilized [1]

Coarse aggregate

The VSI aggregate which is retained on 4.75 mm maximum size of 20 mm is used in this experimental investigation [1].

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 [1].

Water

For mixing and curing concrete, fresh portable water that is devoid of acid and organic component concentration is required [1].

2.2. Mixture Proportion and Experimental Tests

This study evaluates the workability of M65 grade High-performance concrete, which was designed based on IS 10262-2019, with varying proportions of metakaolin and marble powder, upto 30 % by weight of cementitious material.. A total of Eighteen concrete mixes were prepared, including one control mixes without any supplementary materials, and the remaining seventeen mixes containing different percentages of metakaolin (and marble powder by weight of cement. For each mix, the fresh characteristics of workability were assessed based on four primary measurements: passing ability, flowability, viscosity, and segregation resistance. The characteristics were measured using the following tests: J-ring Test (ASTM C1621), Slump flow, V-funnel, L-box, and U-box. The mix proportions for M65 grade High performance concrete, based on IS 10262-2019 are shown in Table 5 [1].

Table 5: Different Mix proportion for Replacement of MK & MP with cement [1]

Mix	Cementitious Content Kg/m^3	Total Replacement (%)	Cement (%)	Metakaolin (%)	Marble Powder (%)	MK Kg/m^3	MP Kg/m^3	Powder Content
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 mixes [1]

Mix	Total Replacement (%)	Cement (%)	MK (%)	MP (%)	W/C Ratio	Water (Kg/m^3)	Admix. (Kg/m^3)	OPC (Kg/m^3)	MK (Kg/m^3)	MP (Kg/m^3)	FA (Kg/m^3)	CA (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

3. RESULTS AND DISCUSSION

Table 7: Workability tests results for all mix

Mix	Replacement	Cement (%)	MK (%)	MP (%)	L-Box H_2/H_1)	Slump Flow (mm)	V-Funnel (Sec.)	U-Box (H_2 -H_1) (mm)
1	0	100	0	0	0.81	680	11.5	19
2	10	90	10	0	0.84	691	11.3	22
3	10	90	7.5	2.5	0.83	687	11.3	20
4	10	90	5	5	0.73	683	11.5	21
5	10	90	2.5	7.5	0.80	674	11.6	23
6	10	90	0	10	0.81	669	11.7	24
7	20	80	20	0	0.86	701	10.8	21
8	20	80	15	5	0.85	695	11.0	21
9	20	80	12.5	7.5	0.83	692	11.1	20
10	20	80	10	10	0.81	683	11.5	23
11	20	80	7.5	12.5	0.82	685	11.8	22
12	20	80	5	15	0.82	678	11.8	24
13	20	80	0	20	0.84	681	12.0	25
14	30	70	30	0	0.84	703	11.4	23
15	30	70	22.5	7.5	0.88	712	11.3	22
16	30	70	15	15	0.83	693	11.5	23
17	30	70	7.5	22.5	0.81	677	11.7	26
18	30	70	0	30	0.83	668	12.0	26

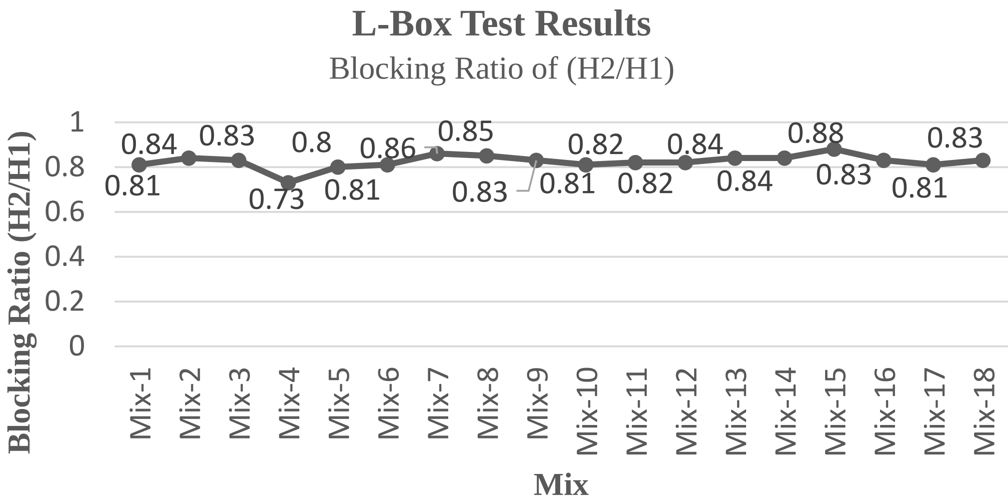

Fig. 1.: L-box Test Results (mm)

The blocking ratio (H_2/H_1) for various concrete mixes is measured using the L-Box Test, and the findings are shown in Fig. 1. Self-compacting concrete's (SCC) ability to pass the L-Box Test with reinforcement without blocking is frequently assessed. The ratios mostly range from 0.73 to 0.88, indicating differences in the concrete mixes' performance. The blocking ratio varies somewhat across mixes, with Mix-4 having the lowest value at 0.73 and Mix-14 having the highest at 0.88.

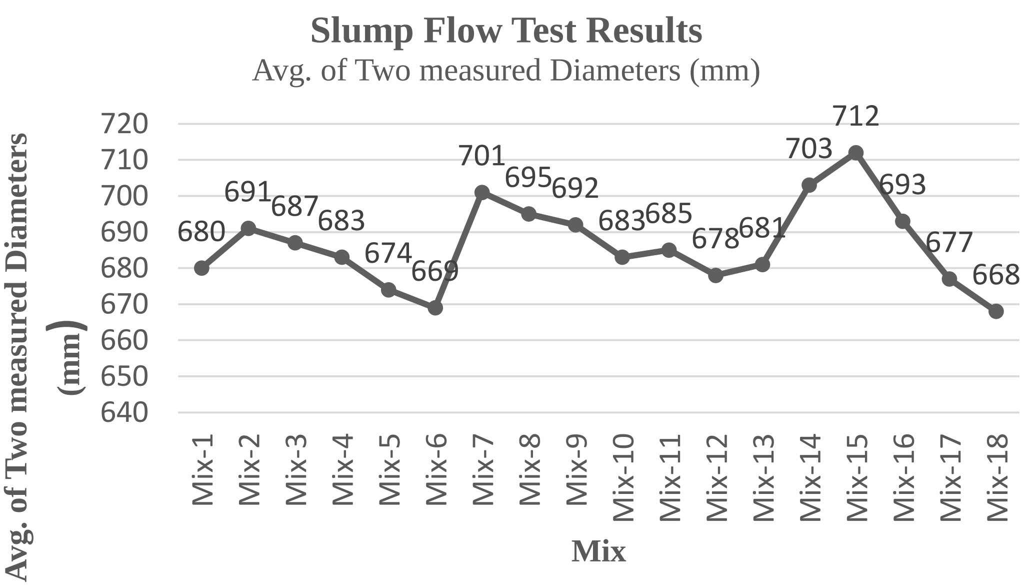

Fig. 2: Slump Flow Test Results (mm)

The Slump Flow Test Results, which calculate the average of two measured diameters (mm) for various concrete mixes (Mix-1 to Mix-18), are displayed in Fig. 2. One important technique for assessing the workability and flowability of concrete is the Slump Flow Test. For SCC/HPC applications, Mix-15's greatest average diameter (712 mm) indicates exceptional flowability. The lowest average diameter (666 mm) is shown by Mix-6, suggesting worse flowability, increased viscosity, and decreased workability.

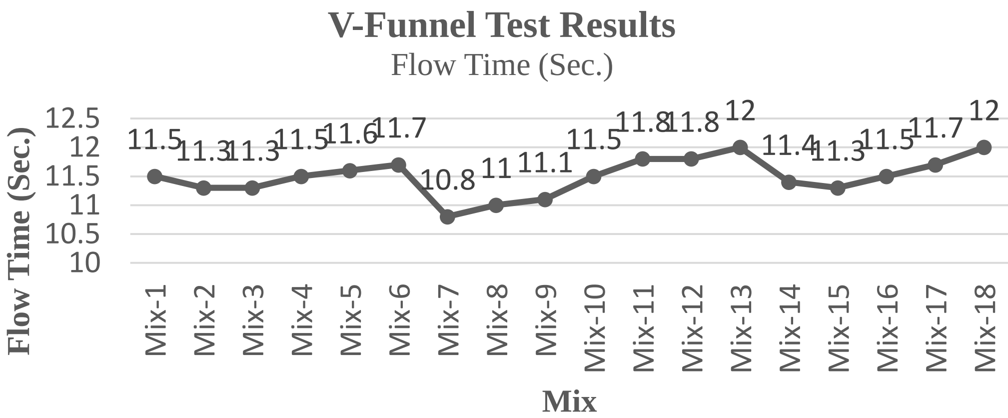

Fig. 3: V-Funnel Test Results (Sec.)

The flow time (in seconds) for the various concrete mixes (Mix-1 to Mix-18) is displayed in this graph, which displays the results of the V-Funnel Test. Concrete's viscosity and flowability are assessed using the V-Funnel test. Mix-7 has a flow time of 10.8 seconds, whereas Mix-13, Mix-14, and Mix-18 have flow times of 12 seconds. Mix-7 appears to have the highest flowability and the least viscosity since it has the lowest flow time (10.8 seconds). The longest flow times (12 seconds) are found in Mixes 13, 14, and 18, which suggests comparatively increased viscosity and decreased flowability.

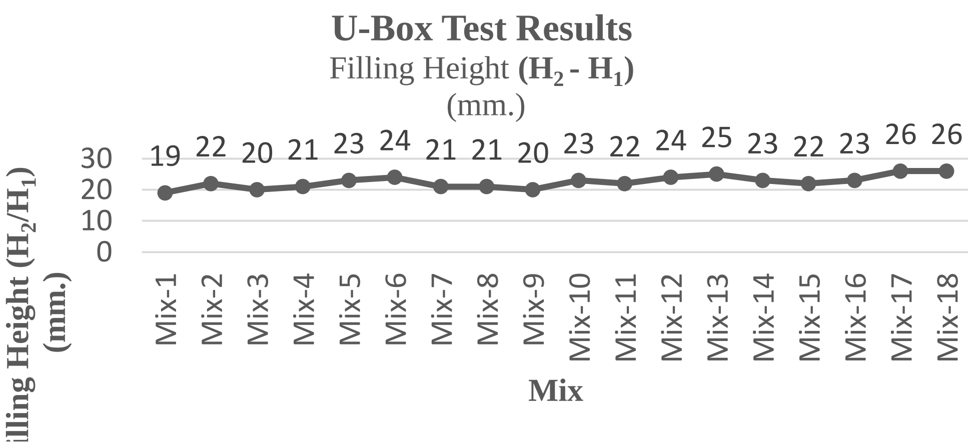

Fig. 4: U-Box Test Results (mm.)

The concrete may pass through obstructions (reinforcement bars in the U-Box test) without experiencing a substantial loss of height or blockage, according to the results (Fig. 4). This illustrates how well the mix design balances admixtures, coarse aggregates, and fine aggregates. Mix 1 has outstanding flowability. Mix 18 is appropriate for the majority of SCC/HPC applications since it has a little reduced flowability but still shows adequate flowability.The findings reveal that the inclusion of metakaolin up to 10% by weight of cement enhanced the workability of the concrete, whereas higher replacement levels resulted in a decrease in workability. The addition of marble powder also influenced the workability, with optimal replacement levels contributing to improved concrete performance.

Overall, the use of metakaolin and marble powder as partial replacements for cement in high-performance concrete mixtures can be an effective strategy to improve the workability and other key properties of the concrete.

4. CONLCUSION

The present study investigates the workability behavior of high-performance concrete incorporating metakaolin and marble powder as supplementary cementitious materials. The concrete may pass through obstructions (reinforcement bars in the U-Box test) without experiencing a substantial loss of height or blockage, according to the results (Fig. 4). This illustrates how well the mix design balances admixtures, coarse aggregates, and fine aggregates. Mix 1 has outstanding flowability. Mix 18 is appropriate for the majority of SCC/HPC applications since it has a little reduced flowability but still shows adequate flowability.

The test findings show notable differences in the performance of the 18 concrete mixes that were assessed using a variety of tests, such as the L-Box, Slump Flow, V-Funnel, and U-Box tests. Mix-14 (0.88) has the highest passing ability, while Mix-4 (0.73) has the lowest, according to the blocking ratio from the L-Box test. Mix-15 had the largest average diameter (712 mm) in the Slump Flow test, demonstrating remarkable flowability, whereas Mix-6 has the lowest (666 mm), suggesting poor workability. In a similar vein, Mix-7's outstanding flowability and low viscosity are demonstrated by its shortest flow time of 10.8 seconds in the V-Funnel test, whereas Mixes 13, 14, and 18 had somewhat higher viscosities with flow durations of 12 seconds. All mixes have sufficient passing ability, according to the U-Box test findings, with Mix-1 showing exceptional flowability and Mix-18, while having somewhat lower flowability, being appropriate for the majority of SCC/HPC applications. The workability and performance of the mixtures are greatly enhanced by the addition of up to 10% metakaolin and the ideal amounts of marble powder. Mix-15 is recommended as the best mix based on the overall test results because of its balanced viscosity, excellent flowability, and passing ability.

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