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Mechanical and durability characteristics of marble-powder-based high-strength concrete

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KEYWORDS
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Abstract. Concrete is a construction material consisting of cementitious material, fine aggregate, coarse aggregate, and water. Nowadays, the cost of this material is increasing. We need to look for a way to reduce the cost of building materials, especially cement. One of the recent advancements in construction industry is the replacement of cement with waste materials in concrete. This replacement offers cost reduction, energy saving, and protection of the environment. In this study, to achieve the above objectives, an attempt was made to replace cement with the Waste Marble Powder (WMP) produced by the marble industries. The present investigation aimed to study the mechanical and durability properties of High-Strength Concrete (HSC) with cement partially replaced by waste marble powder. Cement was replaced with marble powder at 0%, 5%, 10%, 15%, and 20%. The properties, such as compressive strength, modulus of elasticity, and flexural strength, as well as durability characteristics, such as water absorption, acid resistance, and rapid chloride permeability, of concrete were determined.

1. Introduction

With a view to conserving the natural resources, reuse of waste materials is being attempted by the engineering fraternity. Marble powder has been identified as a viable material for use in concrete [1-3]. Large volumes of marble powder are disposed of in stone handling plants. Improper and unplanned disposal may have negative effect on the environment and people [3]. Marble dust is essentially made by cutting and sawing of marbles. Huge amounts of marble waste are being generated in marble cutting plants and mineral industries. As these wastes have adverse effect on the environment, it is very essential to find a safe disposal method for this type of waste or a proper solution to its re-utilization [1,4]. This research presents an eco-friendly solution to the utilization of marble powder and helps in preserving the ecosystem.

Siva and Mallika [3] studied the possibility of utilizing marble dust in high-strength concrete mix. It was observed that maximum compressive strength would be achieved by 10% marble replacement. It was reported that replacement of cement and sand by marble powder up to 10% could increase the compressive strength, split tensile strength, and durability characteristics of concrete specimens. Latha et al. [5] conducted an experimental investigation into strength characteristics of concrete with waste marble powder as cementitious material. It was observed that workability of M20-, M30-, and M40-grade concrete increased with increase in replacement of cement with waste marble powder up to 20%. Also, optimum replacement level of marble powder with cement ranged from 10% to 15%. The test results showed that waste marble powder had the capability to improve the performance of hardened

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concrete. Nitisha and Kumar [6] examined the use of marble powder as partial replacement in cement concrete. They used 10% marble powder as replacement for cement and reported that increase in marble powder would significantly decrease the workability of concrete. Replacement of cement and sand with marble powder at 10% has been found to improve the mechanical and durability characteristics of concrete. Shirule et al. [7] conducted a study in which cement was replaced with marble dust powder. It was observed that compressive strength, flexural strength, and split tensile strength of concrete increased with the addition of marble dust up to 15% replacement level in comparison with the conventional concrete specimen. Thereafter, a sudden decrease occurred in the strength at 20% replacement level. Accordingly, they reported that the optimum percentage of replacement was 15% of the total cement content.

This study has been conducted to identify the suitability of marble powder for replacing cement in high-strength concrete. The objective of the study is to assess the impact of replacing cement with marble powder in HSC on its mechanical properties and durability characteristics.

2. Materials and methods

2.1. Test materials

2.1.1. Cement

Ordinary Portland cement of grade 53 available in the local market was used in this study. The cement used for all the tests was from the same batch. Various properties of the cement were obtained from IS: 456-2000 and IS: 12269-2013 [8,9]. The specific gravity, fineness, initial setting time, and final setting time were 3.14, 379 m^3/kg, 190 min, and 290 min, respectively.

2.1.2. Coarse aggregate

Crushed angular granite from local quarry was used as coarse aggregate. The size of the aggregate used was 10 to 20 mm. The physical characteristics of coarse aggregate were tested in accordance with IS: 2386-1963 [10]. These physical properties are presented in Table 1.

2.1.3. Fine aggregate

Natural river sand was used as fine aggregate. It was tested for various properties such as specific gravity, sieve analysis, and fineness modulus according to IS: 2386-1963 [10]. The physical properties of fine aggregate are presented in Table 2.

2.1.4. Water

The water used for mixing and curing was fresh potable water conforming to IS: 456-2000 [8].

2.1.5. Chemical admixture

GLENIUM B233 was used as hyper plasticizer to reduce the water content. Its specific gravity was 1.08.

2.1.6. Marble powder

Marble powder was collected from the local market. It was sieved in IS-90-micron sieve before mixing in concrete. Tests were carried out in order to find out the properties of waste marble powder. The specific gravity of marble powder used was 2.4. The chemical compositions of cement and marble powder are presented in Table 3. Marble powder was used at replacement levels of 0%, 5%, 10%, 15%, and 20%. For all the replacement levels of marble powder, control specimens were cast and tested.

2.2. Mix proportion

The designed mix proportion with a water-binder ratio of 0.36 was used for all the test specimens; the details are presented in Table 4 [11]. The constituent materials required for making one cubic meter of concrete are presented in the first line and the corresponding mix ratio is presented in the second line of Table 4. A slump of 75 mm was obtained for the above mix proportion.

2.3. Test specimens

2.3.1. Test plan

A total of 180 concrete specimens were cast and tested in this study. Forty-five cube specimens (150 × 150 × 150 mm) were used to determine the compressive strength. Fifteen cylindrical specimens (150 × 300 mm) were used to determine the elasticity modulus and forty-five prism specimens (100 × 100 × 500 mm) were used to determine the rupture modulus. Forty-five cube specimens (100 × 100 × 100 mm) were cast to determine the durability characteristics such as acid resistance, water absorption, and sulphate resistance. Also, thirty cylindrical specimens (100 × 50 mm) were

Table 1. Physical properties of coarse aggregate.

Sl. no.	Characteristics	Experimental results
1	Specific gravity	2.7
2	Water absorption	0.5%
3	Fineness modulus	2.58
4	Crushing strength	13.80 MPa
5	Impact strength	15.55 MPa

Table 2. Physical properties of fine aggregate.

Sl. no.	Characteristics	Experimental results
1	Specific gravity	2.6
2	Fineness modulus	3.2
3	Grading zone	Zone III
4	Water absorption	0.944 %

Table 3. Chemical compositions of cement and marble powder[a].

Sl. no	Chemical compounds	Cement	Marble powder
1	Lime (CaO)	60-67%	50.10%
2	Alumina (Al_2O_3)	3-8%	1.38%
3	Silica (SiO_2)	17-25%	1.28%
4	Magnesia (MgO)	0.1-0.4%	1.72%
5	Iron oxide (Fe_2O_3)	0.5-0.6%	0.54%
6	Sulphur trioxide (SO_3)	1.3-3%	0.21%
7	Alkaline (Na_2O)	0.4-1.3%	0.29%
8	Calcium carbonate ($CaCO_3$)	–	94.30%
9	Loss of ignition	3-4%	0.39%

[a]**Source:** Chennai Testing Laboratory Pvt. Ltd, Chennai.

Table 4. Mix proportion.

Cement kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Water l/m^3	Silica fume kg/m^3	Hyper plasticizer l/m^3
445	736	1120	160	25	3.6
Mix ratio					
1	1.65	2.52	0.36	0.056	0.008

Table 5. Nomenclature of test specimens.

Test specimens	Description
S1	Control specimen
S2	Specimen with 5% replacement level of marble powder
S3	Specimen with 10% replacement level of marble powder
S4	Specimen with 15% replacement level of marble powder
S5	Specimen with 20% replacement level of marble powder

cast to conduct sulphate attack and rapid chloride penetration test. The nomenclature of all the test specimens is presented in Table 5.

2.3.2. Preparation of test specimens

A tiling-type drum mixer was used for preparing fresh concrete. The cement, sand, marble powder, and coarse aggregate were placed inside the drum and dry mixed. Then, water was added slowly and mixed thoroughly. The specimens were cast in batches. They were cast in steel moulds and compacted using needle vibrator. All the specimens were de-moulded after 24 hours of casting and then, cured for 28 days before being tested.

3. Results and discussion

3.1. Mechanical properties of test specimens

3.1.1. Compressive strength

Strength is the most important property of structural concrete, because it displays an overall picture of its quality. High compressive strength of concrete indicates better quality, while poor quality of concrete is the result of its inadequate compressive strength. The compressive strengths of all the test specimens are presented in Figure 1. Compressive strengths of 64 MPa, 65.22 MPa, 69.91 MPa, 67.77 MPa, and 61.97 MPa were obtained for the specimens S1, S2, S3, S4, and S5, respectively. Specimen S2 exhibited an increase by 1.90% in compressive strength compared to the control specimen (S1). Increases by 9.23% and 7.19% in compressive strength were observed for the specimen S3 compared to S1 and S2, respectively. The specimen S4 exhibited an increase by 5.89% in compressive strength in comparison with the control specimen (S1) and a decrease by 3.06% compared to S3. Decreases by 4.68% and 11.35% in compressive strength were observed for the specimen S5 in comparison with S1 and S3, respectively. The experimental results showed that replacement of cement with marble powder (5%, 10%, and 15%) would improve the compressive strength of concrete. The interfacial transition

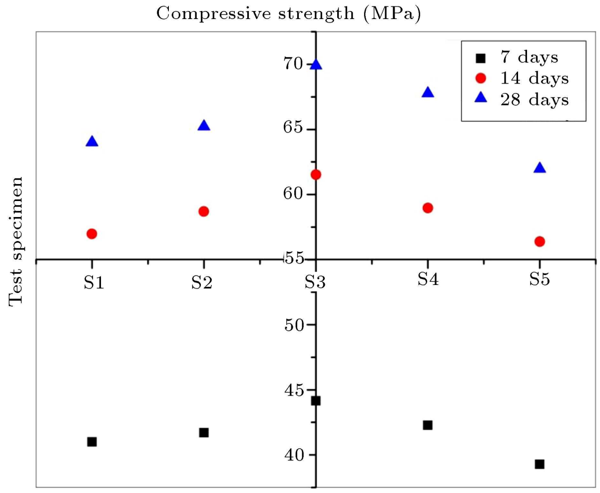

Figure 1. Compressive strength of test specimen.

zone was strengthened by the finer marble waste. It is quite natural to expect such a development in concrete with low w/b ratio [12]. These results are in agreement with those reported by Shirule et al. [7]. Replacement of cement with marble waste beyond 15% was found to reduce the compressive strength marginally. This might be due to reduction in the quantum of the available cementing material [12].

3.1.2. Flexural strength

The flexural strengths of all the test specimens are presented in Figure 2. Flexural strengths of 5.7 MPa, 6.1 MPa, 6.8 MPa, 6.2 MPa, and 5.5 MPa were obtained for the specimens S1, S2, S3, S4, and S5. The specimen S2 exhibited an increase by 7.01% in flexural strength compared to control specimen (S1). Increases by 19.29% and 11.47% in flexural strength were observed for the specimen S3 compared to S1 and S2, respectively. The specimen S4 exhibited an increase by 8.77% in flexural strength compared to the control specimen (S1) and a decrease by 8.82% compared to S3. Decreases by 3.50% and 19.11% in flexural strength were observed for the specimen S5 in comparison with S1 and S3, respectively. The experimental results showed that replacement of cement with marble powder (5%, 10%, and 15%) improved the flexural strength of concrete. Beyond 15% level of replacement, the concrete flexural strength was found to decrease slightly. This might be attributed to reduction in the quantum of the available cementing material [12].

3.1.3. Modulus of elasticity

The elasticity moduli of all the test specimens are presented in Figure 3. The moduli of elasticity of 40.62 GPa, 43.54 GPa, and 49.36 GPa were obtained for the specimens S1, S2, and S3. The specimen S2 exhibited an increase by 7.16% in modulus of elasticity compared to control specimen (S1). Increases by 21.51% and 13.36% in modulus of elasticity were observed for the specimen S3 compared to S1 and S2. The specimen S4 exhibited an increase by 3.79% in modulus of elasticity compared to control specimen (S1) and decrease by 14.58% compared to S3. Decreases by 3.27% and 20.40% in modulus of elasticity were observed for the specimen S5 in comparison with S1 and S3. The experimental results showed that replacement of cement with marble powder (5%, 10%, and 15%) improved the elasticity modulus of concrete. Normally, the elasticity modulus of concrete is directly proportional to the compressive strength. Thus, increase in compressive strength results in increase in elasticity modulus.

3.2. Durability properties of test specimens

3.2.1. Acid attack

The acid solution was prepared by mixing 3% sulphuric acid (H_2SO_4) and 2% hydrochloric acid (HCl) in

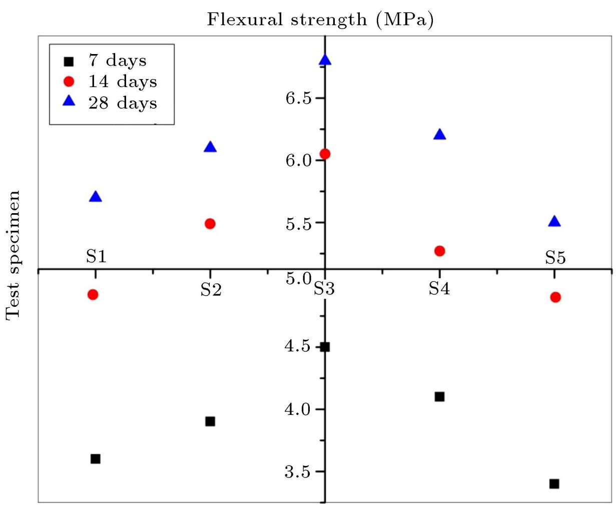

Figure 2. Flexural strength of test specimen.

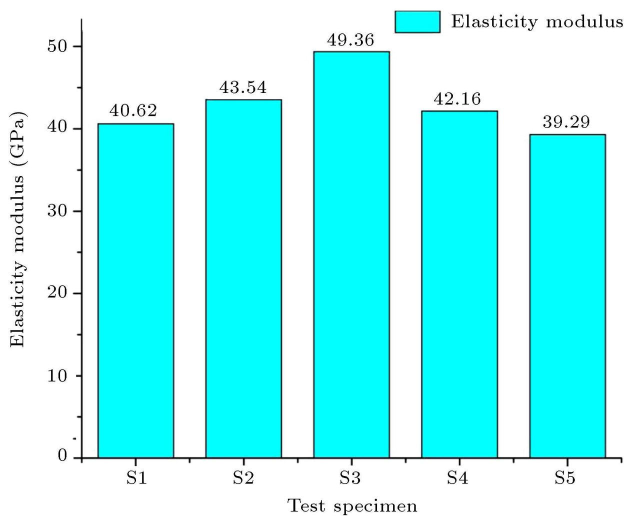

Figure 3. Elasticity modulus of test specimen.

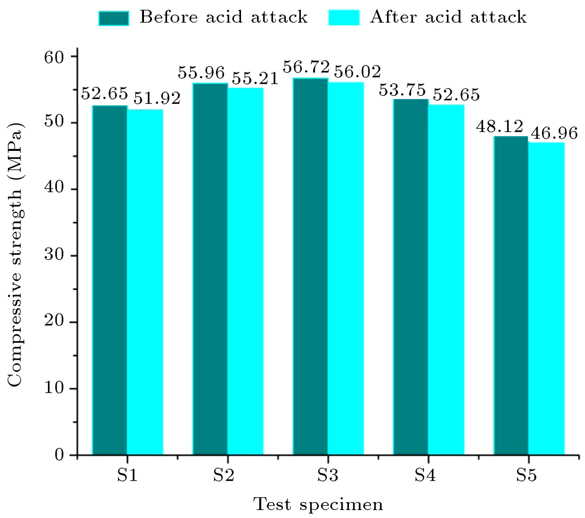

Figure 4. Acid attack test results.

distilled water. At the end of 28 days of curing period, the specimens were air dried, cooled at room temperature, weighed using an electronic balance, and then immersed into an acid bath. The initial weights of all the specimens were found and recorded before immersion. After immersion for 15 days in acid, the losses in weights and compressive strengths of conventional and marble powder concrete specimens were measured, which are presented in Figure 4. There was no significant reduction in the observed weights for all the test specimens. However, there were reductions in compressive strengths, as presented in Figure 4.

3.2.2. Rapid chloride penetration test

The chloride penetration for conventional and marble powder concrete slices at 28 days is presented in Table 6 [13]. It was observed that with the addition of marble powder, significant decrease occurred in chloride penetration, which showed that the marble powdered concrete was densely packed.

3.2.3. Water absorption test

The percentages of water absorption for conventional and marble powdered concrete cubes are presented in Table 7 [14]. There was no significant difference between conventional and marble powdered concrete cubes in terms of water absorption.

Table 7. Water absorption test results.

Nature of specimen	Test specimen	Volume fraction (%)	Water absorption (%)
Cube	S1	0	0.65
	S2	5	0.97
	S3	10	1.42
	S4	15	1.58
	S5	20	1.86

4. Conclusions

The main aim of this study was to investigate the effect of MP replacement on the mechanical and durability properties of high-strength concrete. Based on the experimental results, the following conclusions were drawn:

- The test specimen S3 (10% replacement of marble powder) exhibited increases by 9.23%, 19.29%, and 21.51% in compressive strength, flexural strength, and elasticity modulus, respectively, compared to the control specimen (S1);
- Slight reductions in weight and compressive strength (1.25% to 2.47%) were observed in the test specimens with and without addition of marble powder when subjected to acid attack;
- Very low penetration of chloride ion was observed in the test specimens with 0%, 5%, 10% and 15% replacement levels of marble powder;
- The marble powdered concrete and the conventional

Table 6. Rapid chloride penetration test results.

Nature of specimen	Test specimen	Volume fraction (%)	Charge passed (Q) in coulombs	Value range	Remarks
Cylinder	S1	0	986	100-1000	Very low penetration
	S2	5	929	100-1000	Very low penetration
	S3	10	936	100-1000	Very low penetration
	S4	15	993	1000-2000	Very low penetration
	S5	20	1012	1000-2000	Low penetration

concrete exhibited the same water absorption capacity.

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Biographies

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