International Journal of Emerging Trends in Science and Technology
11 (1) June 2025, 11-17
www.publishingindia.com/ijetst

Potential Pathway of using Marble Powder as a Fine Aggregates in Manufacture of Self Compacting Concrete

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Abstract: This research delves into enhancing concrete strength through innovative approaches, particularly the substitution of traditional components with alternative materials like silica fumes, GGBS, fly ash, granite, and marble powder. The study specifically investigates the use of marble powder in self-compacting concrete, aiming to repurpose industry waste and minimize environmental impact. Focusing on M-40 concrete, the project replaces fine aggregate with varying proportions of marble powder (0%, 5%, 10%, 15%, 20%). The research explores the feasibility of this substitution by assessing the fresh and hardened properties, including self-compaction through tests like slump flow, V-funnel, and L-box. Additionally, beams are fabricated using TMT and HYBRID rods to evaluate structural behavior under diverse loading conditions. The experiment emphasizes the practical application of marble dust, considering its impact on flow properties and structural integrity. Multiple trial mixtures undergo testing, ensuring compliance with permissible limits for slump flow, V-funnel, and L-box. The structural behavior of beams, incorporating TMT and HYBRID bars, is thoroughly examined to ascertain the effectiveness of marble dust in enhancing concrete performance. In summary, this research offers valuable insights into the sustainable integration of marble powder in self-compacting concrete, addressing both environmental concerns and structural considerations.

Keywords: Alternative materials, Marble powder, Self-compacting concrete, Sustainable construction.

I. Introduction

The field of material science has witnessed rapid advancements, particularly in the last three decades, with global research dedicated to enhancing concrete performance in terms of strength and durability [1]. Concrete has evolved from a simple mix of cement, aggregate, and water into an engineered custom material, incorporating various constituents to meet specific construction industry needs. The increased use of concrete in specialized architectural configurations and structures with closely spaced reinforcing bars underscores the importance of ensuring proper filling ability, structural performance, and durability [2].

In the contemporary landscape of construction materials, the pursuit of sustainability has become a paramount objective. As the construction industry grapples with the challenge of minimizing its environmental footprint, innovative approaches that repurpose waste materials for concrete production are gaining significant attention. One such promising avenue is the utilization of marble waste powder as a replacement for fine aggregate in the manufacturing of Self-Compacting Concrete (SCC). This research not only addresses the critical issue of waste management in the marble industry but also seeks to unlock the potential of marble waste powder in creating a more sustainable and environmentally friendly concrete.

Marble waste powder, a by-product derived from the sawing and shaping processes within the marble industry, has long been regarded as a disposal challenge. However, recent advancements in concrete technology and a growing commitment to sustainable practices have prompted a reevaluation of such waste materials [3, 4]. This research is poised at the forefront of this reevaluation, exploring the transformative role that marble waste powder can play in the realm of concrete production.

The adoption of marble waste powder in SCC introduces a groundbreaking approach to sustainable construction practices. The primary advantage lies in the dual-purpose nature of this utilization - not only does it alleviate the environmental burden associated with marble waste disposal, but it also enhances the properties of concrete [5, 6]. By replacing traditional fine aggregate with marble waste powder, this research seeks to contribute to a circular economy model, where waste materials are repurposed in a manner that aligns with environmental stewardship.

The significance of this research extends beyond waste management; it delves into the core attributes of SCC, with a specific focus on fresh concrete properties. Workability, a pivotal aspect of SCC, is thoroughly examined through a battery of tests. These tests assess the concrete's flowability and its resistance to segregation, crucial factors in determining the practical applicability of SCC in construction projects [7]. Understanding how the introduction of marble waste powder influences these fresh concrete properties is central to unlocking the full potential of this sustainable concrete variant.

Furthermore, the research undertakes a comprehensive analysis of the mechanical properties of SCC. This includes scrutinizing the compressive strength, flexural strength, and split tensile strength of the concrete. By evaluating these mechanical attributes, the research aims to ascertain how the incorporation of marble waste powder influences the structural performance and durability of SCC. The outcomes of these analyses are expected not only to provide valuable insights into the material's behavior but also to establish its credibility as a sustainable alternative in the construction sector.

In essence, this research stands as a beacon in the journey towards sustainable construction practices. By harnessing the latent potential of marble waste powder in SCC, it not only addresses a pressing waste management issue but also lays the groundwork for a more sustainable and environmentally conscious future in the construction sector. The investigation into fresh concrete properties and mechanical characteristics further underscores the commitment to ensuring that sustainability in construction is not just a concept but a tangible reality, paving the way for a more responsible and resilient built environment.

II. Materials Used

A. Cement

The cement used in the production of these hollow blocks is a locally available ordinary Portland cement (OPC). OPC are classified into three types, namely grades 33, 43, and 53, depending upon the strength they achieve at the end of 28 days. In this experimental analysis, grade 53 cement is used. The cement was tested to match the properties proposed by the Indian Standards, IS: 4031 (1988) and IS: 12269 (1987). Table I displays the results of the various property tests.

Table I: Physical Properties of Cement

Properties	Value
Specific gravity (g)	3.25
Fineness (f)	2%
Standard consistency (s)	34%
Initial setting time (I)	35 min
Final setting time (F)	6 hours

B. Marble Powder

Marble powder, a by-product of marble sawing and shaping, was utilized in the study. With a specific gravity of 2.55 kg/m^3 and a Blaine fineness value of 1.50 m^2/g, the marble powder exhibited a notably high specific surface area. This characteristic suggests that the inclusion of marble powder in mortars and concretes may enhance their cohesiveness. The physical and chemical properties of marble powder are tabulated in Table II and Table III respectively. Fig. 1 illustrates the marble powder used for this study.

Table II: Physical Properties of Marble Powder

Physical Properties	Values
Moisture	0.30%
Loose Bulk Density	44.83 lb/ft^3
Tapped Bulk Density	77.30 lb/ft^3

Table III: Chemical Properties of Marble Powder

Chemical Compounds	Composition (in wt%)
$Mg(OH)^2$	35.7%
SiO_2	0.17%
$CaCO_3$	63.4%
Al_2O_3	0.11%
Fe_2O_3	0.14%
Heavy Metals	>0.002%
LOI (1000°C)	36.5%

Fig. 1: Marble Powder

C. Aggregates

Aggregates, regarded as an inert material, plays a pivotal role in forming a robust mass through a mechanical bond with cement paste in concrete. Constituting 70 to 80% of the concrete volume, it represents a major and essential component. In the context of this study, the maximum size of coarse aggregate employed is 20 mm with a specific gravity of 2.68. Various types of sands commonly used in conventional concrete are equally suitable for Self-Compacting Concrete (SCC) [8]. This includes both crushed and rounded sands, whether they are siliceous or calcareous. In SCC, the fines content, referring to particles less than 0.125 mm, is crucial, and it includes the powder component. It is essential to attain a minimum number of fines, originating from binders and sand, to prevent segregation in SCC mixes [9].

The use of aggregates not only ensures structural integrity but also contributes to economic efficiency, as they are more cost-effective than cement [10]. This strategic utilization helps minimize shrinkage, demonstrating the multifaceted importance of aggregates in concrete construction, aligning with IS standards for optimal performance.

III. Mix Design

This research explores the integration of marble powder waste into Self-Compacting Concrete (SCC) with a mix proportion of 1:2.2:3.4 (cement: sand: coarse aggregate) and a water-to-cement (w/c) ratio of 0.95. The study investigates the impact of replacing fine aggregate with varying percentages (0-20 wt%) of marble powder waste. The chosen mix proportion serves as a baseline for evaluating the concrete properties Table IV shows the various mix proportions for different percentages of replacement of marble powder.

Table IV: Mix Proportion for Various Percentage of Replacement of Tyre

Ingredients	Mix Proportion (%)				
Fine aggregate	55	50	45	40	35
Coarse aggregate	35	35	35	35	35
Cement	10	10	10	10	10
Marble powder	0	5	10	15	20

Primarily, the fine aggregate, coarse aggregate, marble powder, and cement are mixed together with the preferred water-cement ratio. The varying ratio of marble powder used in this mix design is shown in Table V.

Table V: Ratio for the Replacement of the Fine Aggregates

Percentage of Marble Powder Replaced on Fine Aggregate	Volume of Marble Powder (kg/m^3)	Volume of Fine Aggregate (kg/m^3)	Volume of Coarse Aggregate (kg/m^3)	Volume of Cement (kg/m^3)
0	-	0.450	2.140	1
5	0.02	0.430	2.140	1
10	0.04	0.410	2.140	1
15	0.06	0.390	2.140	1
20	0.08	0.350	2.140	1

IV. Results and Discussion

A. Workability Tests

The investigation involves varying marble dust content by substituting sand and adjusting super plasticizer dosage. The initial investigation maintains constant cement content of 508 kg/m^3, testing five mixes to achieve self-compacting concrete characteristics. The mix compositions, along with different plasticizer dosages used in the investigation, are provided in Table VI. Fig. 2 shows the slump flow test done on fresh concrete.

Table VI: Mix Compositions along with Different Plasticizer Dosages

Description	0%	5%	10%	15%	20%	Suggested Value as Per Code
Slump flow (mm)	675	700	690	660	620	600-800
v-funnel (sec)	8	10	12	14	15	8-12
l-box (mm)	0.82	0.91	1	0.28	0.25	0.8-1
u-box (mm)	28	26	27	33	34	0-30
j-ring (mm)	9	9	10	11	10	0-10

Fig. 2: Slump Flow Test Done on Fresh Concrete

B. Hardened Concrete Tests

This compressive strength of the concrete is determined by using the compressive testing machine, which has a capacity of 2000 kN. The rate of loading used for a concrete specimen is 315 kN/min (5 kN/sec) as per IS 516. The machine applies a constant rate of loads to until failure occurs. Scrutinize the loads and note the maximum load at failure. The compressive strength of bricks is equal to the maximum load (N) divided by the average area of the samples (mm^2). The concrete cubes of 150x150x150 are casted and they are tested for compressive strength that has undergone curing for 7 days, and 28 days to record the strength at different curing stages. Tables VII and VIII show the compressive strength of the concrete cubes with a varied ratio of marble powder replacement at the end of 7 days, and 28 days, respectively. Fig. 3 shows the compressive strength test of concrete cube.

Table VII: Compressive Strength Test Results for Various Percentage of Replacement of Marble Powder after 7 days

Specimen Index	Marble Powder	Compressive Strength in 7 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	37.5	37.5	37.5
B5	5	38	40	39
C10	10	35.25	36.75	36
D15	15	28	30	29
E20	20	23	25	24

Table VIII: Compressive Strength Test Results for Various Percentage of Replacement of Marble Powder after 28 Days

Specimen Index	Marble Powder	Compressive Strength in 28 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	55.3	55.4	55.35
B5	5	56.98	60.60	58.79
C10	10	54.45	55.78	55.10
D15	15	40.3	43.71	43.5
E20	20	37.80	39.70	38.76

Fig. 3: Concrete Cubes Undergoing Compressive Strength Test

The flexural strength test on hardened concrete is a crucial assessment of the material's ability to withstand bending forces. This test involves subjecting a prismatic or cylindrical concrete specimen to a bending moment until failure occurs. The specimen is typically supported at its ends and loaded at the center. The goal is to measure the maximum stress the concrete can endure before developing cracks or failing in flexure. As per the Indian Standard (IS 516:1959) for the Method of Tests for Strength of Concrete, the recommended size for a standard beam used in the flexural strength test is 150 mm x 150 mm x 700 mm. Tables IX and X show the flexural strength of the concrete cubes with a varied ratio of marble powder replacement at the end of 7 days, and 28 days, respectively.

Table IX: Flexural Strength Test Results for Various Percentage of Replacement of Marble Powder after 7 Days

Specimen Index	Marble Powder	Flexural Strength in 7 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	3	3.4	3.2
B5	5	3.1	3.3	3.2
C10	10	2.2	2.6	2.4
D15	15	2	2	2
E20	20	2.4	2.10	2.24

Table X: Flexural Strength Test Results for Various Percentage of Replacement of Marble Powder after 28 Days

Specimen Index	Marble Powder	Flexural Strength in 28 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	5.40	5.39	5.3
B5	5	5.84	5.36	5.6
C10	10	4.69	3.90	4.3
D15	15	3.1	3.70	3.4
E20	20	3.10	3.50	3.3

The split tensile strength test is conducted to evaluate the tensile strength of concrete. According to Indian Standard IS 516:1959, the recommended size of cylindrical specimens for the split tensile strength test is 150 mm diameter and 300 mm height. In this test, a cylindrical concrete specimen is subjected to diametrical compression, creating a tensile stress across the diameter. The force required to split the specimen is then measured, and the split tensile strength is calculated. This property is important in assessing the ability of concrete to resist tensile forces. Tables XI and XII show the Split tensile strength of the concrete cubes with a varied ratio of marble powder replacement at the end of 7 days, and 28 days, respectively. Tables XIII and XIV gives a detailed comparison of compressive, flexural and split tensile strength at the end of 7 days and 28 days respectively.

Table XI: Split Tensile Strength Test Results for Various Percentage of Replacement of Marble Powder after 7 Days

Specimen Index	Marble Powder	Split Tensile Strength in 7 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	3.92	3.88	3.78
B5	5	3.81	4.10	3.96
C10	10	3.15	3.65	3.4
D15	15	3.15	3.40	3.28
E20	20	3.15	3.52	3.33

Table XII: Split Tensile Strength Test Results for Various Percentage of Replacement of Marble Powder after 28 Days

Specimen Index	Marble Powder	Split Tensile Strength in 28 Days (MPa)		
		Specimen 1	Specimen 2	Average
A0	0	4.58	5.10	4.82
B5	5	4.61	3.91	4.9
C10	10	4.42	4.42	4.42
D15	15	3	3.26	4.9
E20	20	5	5.10	5.05

The Tables XIII and XIV presents the compressive strength, flexural strength, and split tensile strength of concrete samples with varying percentages of marble powder replacement at different curing periods, 7 days and 28 days respectively. After 7 days, the compressive strength slightly increased from 37.5 MPa (0% replacement) to 39 MPa (5% replacement), then decreased at higher replacement percentages. Flexural strength remained relatively constant, while split tensile strength showed some variations.

Table XIII: Comparison of Various Tests at Various Percentage of Replacement of Marble Powder after 7 Days

Specimen Index	Marble Powder	Compression Strength	Flexural Strength	Split Tensile Strength
A0	0	37.5	3.2	3.78
B5	5	39	3.2	3.4
C10	10	36	2.4	3.4
D15	15	29	2	3.28
E20	20	24	2.4	3.33

Table XIV: Comparison of Various Tests at Various Percentage of Replacement of Marble Powder after 28 Days

Specimen Index	Marble Powder	Compression Strength	Flexural Strength	Split Tensile Strength
A0	0	55.35	5.3	4.82
B5	5	46.5	4.3	3.83
C10	10	43.5	2.6	4.42
D15	15	38.75	2.7	3.13
E20	20	36.4	2.4	5.05

At 28 days, the compressive strength exhibited a substantial increase for the 0% replacement (55.35 MPa) compared to 7 days. However, as the replacement percentage increased, compressive strength decreased. Flexural strength followed a similar trend, with a notable reduction at higher replacement percentages. Split tensile strength displayed a varied pattern, with fluctuations in values at different replacement percentages.

Overall, the results indicate that incorporating marble powder up to a certain percentage can enhance early compressive strength. However, for later ages and as the replacement percentage increases, a decline in compressive, flexural, and split tensile strength is observed, suggesting a careful consideration of the optimum replacement level for achieving the desired concrete properties. Further analysis and optimization may be required to balance the trade-offs between marble powder utilization and maintaining key mechanical properties in the concrete. Fig. 4 and 5 show the variation of tests at various percentage of replacement of marble powder after 7 days and 28 days.

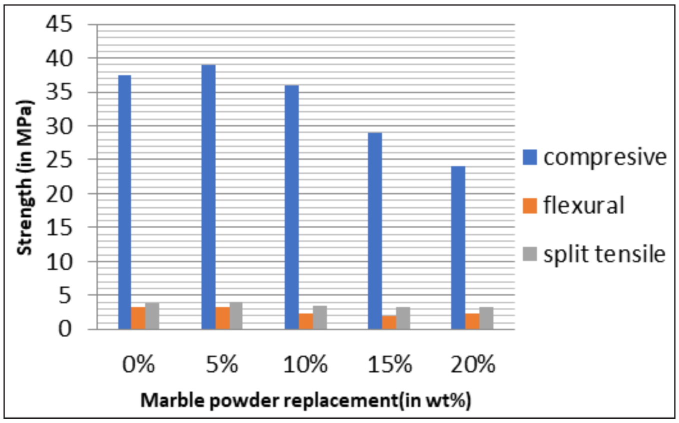

Fig. 4: Graph Showing the Variation of Compressive Strength after 7 Days of Curing

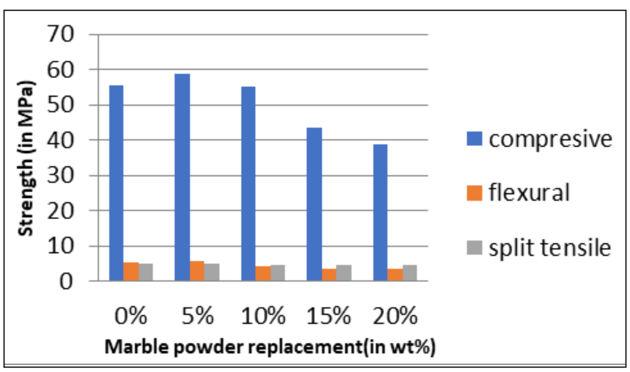

Fig. 5: Graph Showing the Variation of Strengths after 28 Days of Curing

V. Conclusion

The results emphasize the effective integration of marble powder in concrete, improving workability and showcasing varied mechanical properties. From achieving favorable fresh concrete characteristics to confirming structural efficacy in beams, the study contributes insights for sustainable construction. The following conclusions were drawn from the analysis of test results, shedding light on potential advancements across concrete grades and structural elements:

- *Workability Assessment (Fresh Concrete)*
    - Slump values (500-800 mm) meet satisfaction criteria for replacements of 0%, 5%, 10%, 15%, and 20% of sand with marble powder.
    - V-funnel test (8-12 sec) yields satisfactory results for the same replacement percentages.
    - L-box test (0.8-1 mm), U-box test (0-30 mm), and J-ring tests (0-10 mm) also meet criteria with varied percentages of replacement.
- *Hardened Concrete Properties*
    - Compressive strength of hardened concrete is 55.35 MPa and 43.5 MPa for 5% replacement in self-compaction concrete, decreasing with higher marble powder percentages.
    - Flexural strength is 5.3 MPa for 5%, decreasing with increased marble powder content.
    - Split tensile strength is 4.9 MPa for 5%, reducing with higher marble powder percentages.
    - Optimal performance is noted at 5% replacement, guiding the selection for beam casting.
- *Future Scope:* Suggested future work includes exploring various concrete grades and extending the application to other structural members like columns, prefabricated structures, pavers, flooring, and roof slabs.

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