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EXPERIMENTAL STUDIES ON STEEL FIBER REINFORCED SELF COMPACTING CONCRETE BY PARTIAL REPLACEMENT OF CEMENT WITH MARBLE DUST

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ABSTRACT

This study investigates the performance of steel fiber-reinforced self-compacting concrete (SCC) with partial replacement of cement by marble dust, aiming to enhance both mechanical properties and sustainability. Self-compacting concrete, known for its high fluidity and ability to fill complex molds without external vibration, faces challenges related to the high consumption of cement, contributing to environmental concerns such as carbon emissions. To address these issues, marble dust, a by-product of the marble industry, is explored as a partial cement substitute, promoting sustainable waste management. Additionally, steel fibers are incorporated to improve the tensile strength, toughness, and crack resistance of the concrete.

Concrete mixes were prepared by replacing cement with varying percentages of marble dust (5%, 10%, 15%, and 20%) and adding steel fibers in controlled proportions. The workability, compressive strength, splitting tensile strength, flexural strength, and durability of the modified SCC were evaluated.

The experimental results show that the inclusion of marble dust up to an optimal level (10-15%) leads to satisfactory mechanical performance without compromising the self-compacting properties. Moreover, the addition of steel fibers significantly enhances the tensile and flexural strength, improving the concrete's resistance to cracking and increasing its load-bearing capacity. However, higher percentages of marble dust replacement resulted in reduced compressive strength, indicating the need for careful mix design.

This study concludes that marble dust can be effectively used as a partial cement replacement in SCC, contributing to sustainable construction practices by reducing cement consumption and recycling industrial waste. The synergy between steel fibers and marble dust ensures improved mechanical performance and durability, making this composite concrete a promising material for modern construction.

I.INTRODUCTION

In modern construction, self-compacting concrete (SCC) has emerged as an innovative material, known for its excellent flowability and ability to fill complex molds without the need for vibration. SCC offers benefits such as improved surface finish, faster placement, and reduced labor requirements. However, the high amount of cement used in SCC increases the environmental impact due to the energy-intensive cement production process, which contributes significantly to carbon emissions. To mitigate these environmental challenges, researchers and engineers are exploring sustainable alternatives through partial replacement of cement with industrial waste products.

Marble dust, a by-product generated during the cutting and polishing of marble, is often disposed of in landfills, leading to environmental hazards such as air and water pollution. However, marble dust contains a significant amount of calcium carbonate, which makes it a potential candidate for use as a partial cement replacement in concrete. Utilizing marble dust not only reduces cement consumption but also promotes waste recycling, aligning with the principles of sustainable construction and circular economy.

In addition to addressing sustainability, this study also focuses on steel fiber reinforcement to improve the mechanical properties of SCC. While SCC offers excellent workability, it is inherently more prone to shrinkage and cracking due to its high paste content. Steel fibers, when added to SCC, enhance its tensile and flexural strength, improve toughness, and provide greater resistance to cracking, making it more suitable for structural applications.

This research aims to evaluate the combined effect of marble dust and steel fibers on the performance of SCC. The primary objectives of the study are:

To assess the impact of partial cement replacement with marble dust on the workability and strength properties of SCC.

To investigate the role of steel fibers in improving the tensile strength, flexural strength, and crack resistance of the concrete.

To determine the optimal replacement level of cement with marble dust for maintaining a balance between strength and sustainability.

The findings from this study will contribute to the development of eco-friendly high-performance concrete that leverages industrial waste for sustainable construction. The use of steel fiber-reinforced SCC with marble dust will not only enhance the mechanical properties of concrete but also address environmental concerns by reducing cement usage and promoting waste management.

II.MATERIALS

The following are some of the materials that were utilised to complete this project:

2.1 Cement

In this job, ordinary Portland cement of grade 53 was utilised. Because of its optimal particle size distribution and excellent crystalline structure, 53 Grade OPC offers exceptional strength and durability to constructions. As a high-strength cement, it offers a number of benefits in applications where high-strength concrete is needed, such as skyscrapers, bridges, flyovers, chimneys, runways, concrete highways, and other heavy-load-bearing constructions. This kind of cement is not only stronger but also more durable than other varieties. Furthermore, by replacing OPC 53 for lower-grade cement, total savings may be realised due to the decreased amount of cement needed. When 53 Grade OPC is used instead of any other grade, a savings of 8-10% may be realised.

2.2 Fine aggregate

In this project, manufactured sand was utilised in lieu of fine aggregate. Crushed hard granite stone is used to make manufactured sand. Crushed sand is cubical in form with grounded edges, cleaned, and graded for use as a building material. It's more angular than river sand, and it has somewhat different characteristics. Manufactured sand may be manufactured in locations closer to building sites, lowering transportation costs and ensuring a constant supply. Natural sand contains silt and clay particles, while manufactured sand has a denser particle packing than natural sand. It also has a greater flexural strength, superior abrasion resistance, a lower permeability, and a larger unit weight

Figure 2.1 Manufactured sand

2.3 Coarse aggregate

The coarse aggregate in this research was crushed granite stone chips (angular) with a diameter of 12.5mm. The more coarse the aggregate, the more cost-effective the mixture. Larger chunks have less surface area of the particles than smaller ones of the same volume. The use of coarse aggregate with the highest permitted maximum size allows for a decrease in cement and water use. When coarse aggregates are used in excess of the maximum size allowed, they may interlock and create arches or obstacles inside the concrete form. As a consequence, the region below becomes a vacuum, or at most, only fills with finer sand and cement particles, resulting in a weaker area.

Figure 2.2 coarse aggregate

2.4 Super plasticizer

In the combination, Conplast SP 430 was employed as a super plasticizer. Conplast SP430 is a superplasticizing admixture made from sulphonated naphthalene polymers that is chloride-free. It comes as a dark solution that dissolves quickly in water. Conplast SP430 disperses tiny particles in the concrete mix, allowing the concrete's water content to function better. The very high levels of water reduction achievable allow for significant strength gains. The admixture will enable water to be removed from the mix while preserving its workability.

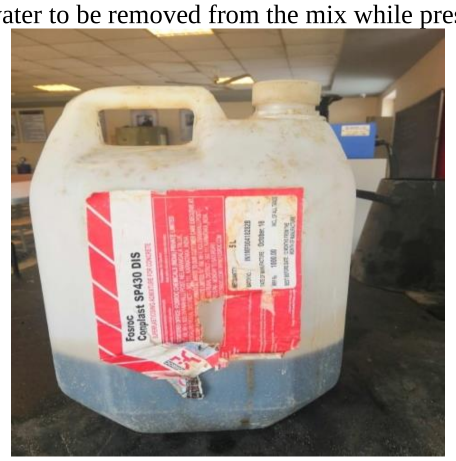

Figure 2.3 Conplast SP430 super plasticizer

2.5 Steel fibers

Steel fibres with hooks were included in the mix. Steel fibre is a discrete short length of steel with a length-to-diameter ratio (i.e. aspect ratio) ranging from 20 to 100. The random distribution reduces efficiency, improves concrete toughness and tensile characteristics, and aids crack management. Further research and development showed that adding SFs to concrete improves its flexural toughness considerably.

Figure 2.4 steel fibers

2.6 Marble dust

Marble Dust Powder is a metamorphic rock composed of recrystallized carbonate minerals, most commonly calcite or dolomite. Marble may be foliated. Marble is commonly used for sculpture and as a building material.

Figure 2. 5 Marble Dust

III. METHODOLOGY

3.1 Mix Design

Mix design using Nan-Su method: Nan Su and colleagues suggested a simple mix design method for SCC, with the primary goal of using binder paste to fill gaps in weakly packed aggregate. For aggregate, they developed a factor called Packing Factor (PF). It's the mass of aggregates in a densely packed state divided by the mass of aggregates in a loosely packed state. The process is completely reliant on the Packing Factor (PF). A greater PF number implies that the aggregate content is bigger, requiring less binder and having less flow ability. The packing factor, it was determined, affects the aggregate content and influences characteristics such as flow ability, self-consolidation ability, and strength. The volume of FA to mortar in his mix design was in the range of 54–60 percent, and he discovered that the PF value would be the regulating element for the U– box test.

Self-compacting concrete (SCC) has been dubbed "concrete's most significant breakthrough in decades." The most significant benefit of self-compacting concrete is that it reduces construction time and ensures compacting inside buildings, especially in restricted areas where vibration and compaction are problematic. Professor Hajime Okamura of Japan invented the self-compacting concrete in 1986, while the prototype was first constructed in 1988 in Japan by Professor Ozawa of the University of Tokyo. The standards and instructions for testing fresh compacting concrete included within this document are derived from “Specification and guidelines for Self-compacting concrete” issued by EFNARC in February 2002. The European Organization for Specialist Construction Chemicals and Concrete Systems (EFNARC) is a federation devoted to specialist construction chemicals and concrete systems. High quality cementitious material, mineral admixtures such as ash, silicon oxide fume, GGBFS, stone powder, and chemical admixtures such as high vary water reducers (HRWR or super plasticizer) and consistency modifying admixtures are required to induce engineering characteristics and smart performance (VMA). It requires concrete with a limited aggregate concentration of around 59 percent by volume. The following are the functions of those additives:

• It fills and shuts holes or changes the kind of pore structure, in addition to the filling action of micro aggregate.

Marble Dust Replacement with cement for cubes

Table:3.1

Opc 53 grade (100%)	**MD(0%)**	2.26 kg	2.26kg
Opc 53 grade (95%)	**MD(5%)**	2.26x5%	113gm
Opc 53 grade (90%)	**MD(10%)**	2.26x10%	226gm
Opc 53 grade (85%)	**MD(15%)**	2.26x15%	339gm
Opc 53 grade (80%)	**MD(20%)**	2.26x20%	452gm

Marble Dust Replacement with cement for cylinder

Table:3.2

Opc 53 grade (100%)	**MD(0%)**	3.47kg	3.47kg
Opc 53 grade (95%)	**MD(5%)**	3.47x5%	173gm
Opc 53 grade (90%)	**MD(10%)**	3.47x10%	347gm
Opc 53 grade (85%)	**MD(15%)**	3.47x15%	520gm
Opc 53 grade (80%)	**MD(20%)**	3.47x20%	694gm

Marble Dust Replacement with cement for prism

Table:3.3

Opc 53 grade (100%)	**MD(0%)**	3.47kg	3.47kg
Opc 53 grade (95%)	**MD(5%)**	3.47x5%	173gm
Opc 53 grade (90%)	**MD(10%)**	3.47x10%	347gm

Opc 53 grade (85%)	**MD(15%)**	3.47x15%	520gm
Opc 53 grade (80%)	**MD(20%)**	3.47x20%	694gm

3.3 Casting and curing of test specimens
The specimens of standard cubes (150mm x 150mmx 150mm), Standard prisms (100mm x 100mm x500mm) and standard cylinders (150mm diameter x300mm height) were casted.

3.4 Mixing of concrete
On an impermeable concrete floor, measured amounts of coarse aggregate, fine aggregate, and cement were laid out. Steel fibres are thrown in at random while the concrete is being mixed. Repeat the process until the colour is consistent; the mixing time should be between 10-15 minutes.

Figure 3.1 concrete mixing

3.5 Placing and compacting
To guarantee that no water escapes during the filling, the mould sections were coated with mould oil, and a similar layer of mould oil was placed between the contact surfaces of the bottom of the moulds and the base plate. The concrete is then poured into the moulds, layer by layer, and compacted properly. Finally, after the moulds have been completely filled, they are levelled.

Figure 3.2 Compaction of prism mould

3.6 Workability Tests
To examine the SCC fresh properties, recent properties such as the slump flow test, the L-box test, J ring test, V-funnel test were carried out. For better flowability super plastisizers was added to the mix.

Description of Mix	Slump flow (mm)	T50 Slump flow(sec)	v-funnel test (sec)	J-ring test H1-H2(mm))	L-box test H1/H2
Opc 53 grade (80%) MD(20%)	796	2.57	8.2	4	0.93
Opc 53 grade (80%) MD(20%) S.F(0.2%) Admixture (0.6%)	645	6.6	13.9	18	1.55

3.7 Curing
The test specimen cubes, prisms, and cylinders were kept in a vibration-free environment with 90% relative humidity and a temperature of 27°C for 24 hours 12 hours after water was added to the dry components. The

concrete cubes, prisms, and cylinders are then taken from the moulds and put for 3 days, 7 days, or 28 days of curing.

Figure 3.3 Test specimens kept for curing

IV. TESTING AND RESULTS

4.1 Compression strength test on concrete cubes

Compressive Strength Definition

The capacity of a material or structure to bear stresses on its surface without cracking or deflection is known as compressive strength. When a substance is compressed, it shrinks, while when it is stretched, it lengthens.

Compressive Strength Formula

The load applied at the point of failure to the cross-section area of the face on which the load was applied is the compressive strength formula for any material.

Compressive Strength = Load / Cross-sectional Area

Apparatus for Concrete Cube Test

Compression testing machine

Sampling of Cubes for Test

1. Oil the moulds after cleaning them.

2. Pour about 5 cm thick layers of concrete into the moulds.

1. Using a tamping rod, compact each layer with at least 35 strokes each layer (steel bar 16mm diameter and 60cm long, bullet pointed at lower end)
2. Using a trowel, level and polish the top surface.

Procedure for Concrete Cube Test

1. After the required curing time has passed, remove the specimen from the water and wipe away any excess water from the surface.
2. Round the specimen's size to the closest 0.2m.
3. Clean the testing machine's bearing surface.
4. Place the specimen in the machine in such a way that the load is given to the cube cast's opposing sides.
5. Place the specimen in the centre of the machine's base plate.
6. Gently rotate the moveable part so that it contacts the specimen's top surface.
7. Gradually increase the weight without causing shock until the specimen fails.
8. Make a note of the maximum load and any unique characteristics in the kind of failure.

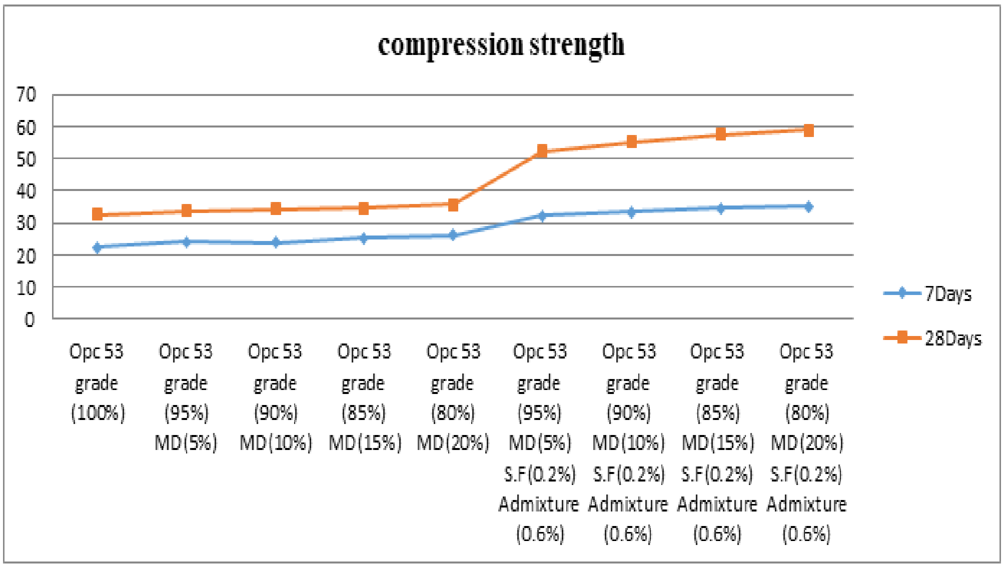

Figure 4.1 compression test of cubes

Compression Test results

Table: 4.1

SI.NO	Mix	Description of Mix	7Days	28Days
1.	M1	**Opc 53 grade (100%)**	22.4	32.5
2.	M2	**Opc 53 grade (95%) MD(5%)**	24.2	33.8
3.	M3	**Opc 53 grade (90%) MD(10%)**	23.8	34.2
4.	M4	**Opc 53 grade (85%) MD(15%)**	25.4	34.6
5.	M5	**Opc 53 grade (80%) MD(20%)**	26.2	35.8
6.	MD5	**Opc 53 grade (95%) MD(5%) S.F(0.2%) Admixture (0.6%)**	32.2	52.4
7.	MD10	**Opc 53 grade (90%) MD(10%) S.F(0.2%) Admixture (0.6%)**	33.4	55.2
8.	MD15	**Opc 53 grade (85%) MD(15%) S.F(0.2%) Admixture (0.6%)**	34.5	57.4
9.	MD20	**Opc 53 grade (80%) MD(20%) S.F(0.2%) Admixture (0.6%)**	35.2	59.1

4.2 Split tensile test on concrete cylinders

One of the most fundamental and essential characteristics of concrete is its tensile strength, which has a significant impact on the amount and size of cracking in buildings. Furthermore, owing to its brittle nature, the concrete is extremely weak in tension. As a result, it is unlikely to withstand direct strain. As a result, when tensile pressures surpass the concrete's tensile strength, fractures appear. As a result, the tensile strength of concrete must be determined in order to calculate the load at which the concrete members may fracture.

Now **split tensile strength = 2P/πLD**

Where P = load , L = length of the cylinder

D = diameter of cylinder

Procedure of Splitting Tensile Test

1. After 7, 28, or any appropriate age at which tensile strength is to be measured, remove the wet specimen from the water.
2. Wipe the water from the specimen's surface.
3. Then, on both ends of the specimen, draw diametrical lines to verify that they are in the same axial position.
4. Next, note the specimen's weight and dimensions.
5. Adjust the compression testing machine's range to the necessary value.
6. Place the specimen on the plywood strip on the bottom plate.
7. Center the specimen over the bottom plate with the lines indicated on the ends vertical and centred.
8. Place the second piece of plywood on top of the specimen.
9. Lower the top plate until it touches the plywood strip.
10.Continue to apply the load without becoming shocked.

Finally, make a note of the breaking load (P).

Figure 4.2 Split tensile test on concrete cylinder

Split Tensile Test results

Table:4.2

SI.NO	Mix	Description of Mix	7 Days	28Days
1.	**M1**	**Opc 53 grade (100%)**	2.52	3.63
2.	**M2**	**Opc 53 grade (95%) MD(5%)**	3.17	3.48
3.	**M3**	**Opc 53 grade (90%) MD(10%)**	3.32	3.72
4.	**M4**	**Opc 53 grade (85%) MD(15%)**	3.28	3.84
5.	**M5**	**Opc 53 grade (80%) MD(20%)**	3.36	3.96
6.	**MD5**	**Opc 53 grade (95%) MD(5%) S.F(0.2%) Admixture (0.6%)**	3.70	4.05
7.	**MD10**	**Opc 53 grade (90%) MD(10%) S.F(0.2%) Admixture (0.6%)**	3.81	4.26
8.	**MD15**	**Opc 53 grade (85%) MD(15%) S.F(0.2%) Admixture (0.6%)**	3.94	4.34
9.	**MD20**	**Opc 53 grade (80%) MD(20%) S.F(0.2%) Admixture (0.6%)**	4.09	4.47

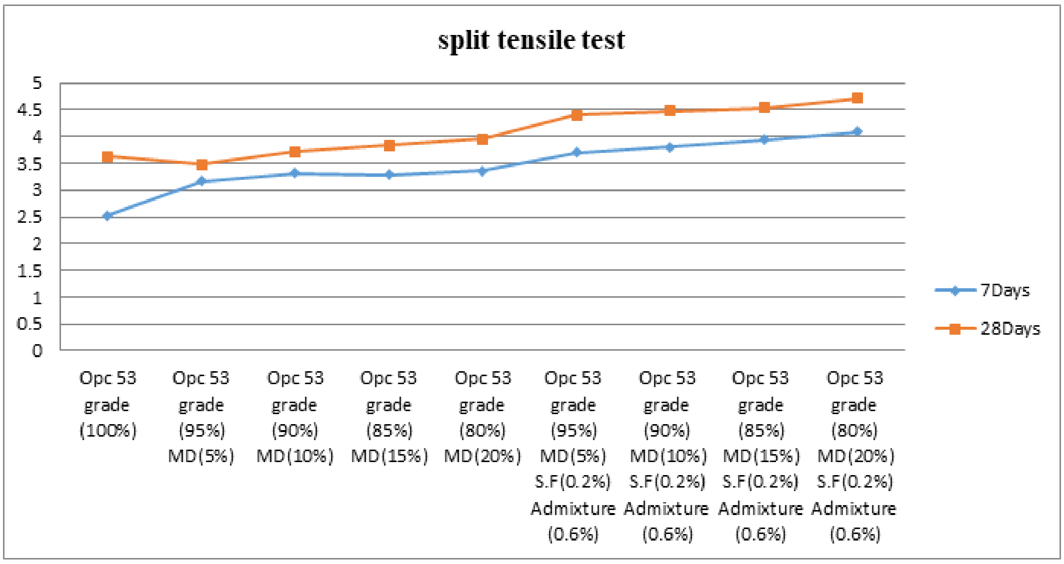

Figure 4.3 Graphical Representation for tensile strength of cylinders

V.CONCLUSION

This study demonstrates that partial replacement of cement with marble dust in steel fiber-reinforced self-compacting concrete (SCC) can be an effective approach to improve sustainability without significantly compromising performance. The experimental results indicate that replacing cement with 10-15% marble dust offers optimal results, maintaining good compressive strength and workability while reducing the environmental impact associated with cement production. However, higher replacement levels (beyond 15%) resulted in a decline in compressive strength, highlighting the need for careful mix design.

The addition of steel fibers enhanced the tensile and flexural strength of the SCC, improving its crack resistance, toughness, and durability. Steel fibers effectively compensated for the higher shrinkage tendency in SCC, making the concrete suitable for structural applications that demand high strength and resistance to deformation. The study confirms that the synergy between steel fibers and marble dust can result in high-performance concrete with improved mechanical properties and eco-friendly characteristics.

In summary, this research shows that marble dust can be used as a sustainable partial cement replacement, reducing cement consumption and promoting the recycling of industrial waste. The use of steel fibers ensures that the mechanical performance of the SCC is not compromised, even with the introduction of marble dust. This approach aligns with sustainable construction practices by minimizing environmental impact, supporting circular economy goals, and offering practical solutions for resource-efficient construction.

Future studies are recommended to investigate the long-term durability of this composite concrete under various environmental conditions and to explore its application in large-scale construction projects. With optimized design, steel fiber-reinforced SCC incorporating marble dust can become a reliable and sustainable building material for the construction industry

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