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An Experimental Study on Partial Replacement of Coarse Aggregate with Mangalore Tiles in Self-Compacting Concrete.

Ms. Rupali Balu Bisale [1], Prof. A. S. Sajane [2]

[1-2] Department of Civil Engineering & Dr. J. J. Magdum college of engineering, Jaysingpur.

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Abstract - For sustainable building, this research explores the creation and functionality of self-compacting concrete (SCC) that uses recycled materials and industrial waste. The study focuses on creating SCC mixes with Mangalore tiles as a partial substitute for traditional coarse aggregates and fly ash and ground granulated blast furnace slag (GGBS) as partial substitutes for cement. To assess the impact of these components on the workability and strength properties of SCC, several mix amounts were created. Based on slump flow, V-funnel and L-box experiments, the best mix of fly ash, GGBS and Mangalore tiles was identified to provide sufficient self-compaction qualities.

To find the mix design that provides the optimum mechanical performance without reducing workability, compressive strength tests were performed. Concrete cubes were submerged in water to test their durability and long-term performance in simulated environmental settings. To assess the modified SCC mix's economic viability in comparison to traditional concrete, a cost analysis was also conducted. In order to retain performance and cost-effectiveness, the findings seek to encourage the use of locally accessible and sustainable materials in the manufacturing of concrete.

Key Words: **Ground Granulated Blast Furnace Slag (GGBS), Fly Ash, Mangalore tiles, Self-compacting concrete (SCC) and Mix Design.**

1. INTRODUCTION

Concrete is the most widely used construction material in the world due to its versatility, high compressive strength, durability and ability to be molded into various shapes and sizes. It plays a vital role in the development of infrastructure such as residential buildings, bridges, dams, roads and industrial structures. Two prominent industrial by-products that have gained widespread acceptance are Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash.

1. GGBS is obtained as a by-product during the manufacture of iron in a blast furnace. It has excellent cementitious properties when ground finely and when used in concrete, it enhances workability, improves resistance to aggressive chemicals and significantly increases the long-term strength and durability. GGBS also reduces the heat of hydration, making it suitable for mass concrete works.
2. Fly Ash is a finely divided residue resulting from the combustion of pulverized coal in thermal power plants. It acts as a pozzolanic material, reacting with calcium hydroxide in concrete to form additional cementitious compounds. Fly Ash improves the workability of fresh concrete, enhances strength development at later ages, reduces permeability and improves resistance to sulfate attack.
3. Mangalore tiles when crushed into suitable sizes, possess properties like good hardness, rough texture and durability that make them a potential replacement for natural coarse aggregates in concrete. Utilizing crushed tile waste can reduce dependency on virgin aggregates, minimize environmental damage and promote a circular economy in the construction sector.

In parallel with these developments, advancements in concrete technology have lead to the emergence of Self-Compacting Concrete (SCC) a highly flowable and non-segregating concrete that can spread under its own weight and completely fill formworks and tightly packed reinforcements without the need for mechanical vibration.

- SCC advantages:

1. Improved surface finish,
2. Reduced labor costs and construction time,
3. Better quality of concrete with fewer voids,
4. Enhanced durability due to denser packing.

SCC requires careful mix proportioning and the use of supplementary cementitious materials and fine aggregates to achieve the desired flowability without segregation. The use of GGBS and Fly Ash further improves the flow properties and workability of SCC while simultaneously enhancing its strength and durability characteristics.

Integrating sustainable waste management with modern concrete technologies, this study focuses on the partial replacement of natural coarse aggregates with crushed Mangalore tile waste and the partial replacement of cement with GGBS and Fly Ash in the production of Self-Compacting Concrete.

The idea is to evaluate the fresh and hardened properties of SCC made with these substitutions, ensuring that the performance of concrete is not compromised while achieving environmental and economic benefits.

1.1 PURPOSE

To investigate the feasibility and effectiveness of partially replacing coarse aggregate with Mangalore tile waste in Self-Compacting Concrete (SCC).

1. Utilize waste Mangalore tiles (a common construction debris) as an alternative aggregate, promoting sustainable construction and waste recycling.
2. Evaluate the impact of tile replacement on the fresh properties of SCC (such as slump flow, V-funnel flow time, L-box passing ability).
3. Assess the mechanical properties like compressive strength, split tensile strength and flexural strength of SCC containing tile aggregates.
4. Compare the performance of SCC with and without tile aggregates to determine the optimal replacement percentage for maintaining or improving strength and workability.
5. Contribute to eco-friendly construction practices by reducing dependence on natural aggregates and minimizing construction waste.

2. MATERIALS AND EXPERIMENTAL INVESTIGATIONS

The primary materials used in concrete include cement, fine aggregate, coarse aggregate, water and admixtures or mineral additives such as fly ash, GGBS or silica fume.

2.1 CEMENT: Ordinary Portland Cement (OPC)

A. Specific Gravity Test: 3.15

B. Standard Consistency Test: 31.93%

C. Initial and Final Setting Time:

Table -1: Initial and Final Setting Time

Trial No	Initial setting time (mins)	Final setting time (mins)
1	75	427
2	79	451
3	72	435

2.2 COARSE AGGREGATE

Naturally occurring or crushed stones retained on a 4.75 mm sieve, usually ranging from 10 mm to 20 mm

A. Specific Gravity test: 2.81

B. Water Absorption :1 %

C. Aggregate Crushing Value Test: 17.14%.

D. Sieve Analysis of Coarse Aggregate:

Fineness modulus= 6.99

2.3 FINE AGGREGATE (SAND)

Passes through a 4.75 mm sieve.

A. Sieve analysis:

Fineness modulus= 2.35

% of fine aggregate passing through 0.125mm sieve is found to be 7.5%.

B. Specific gravity test:2.74

2.4 MANGALORE TILES

A. Specific gravity test:2.37

B. Water absorption: 2.74%

C. Aggregate Crushing value:24.10

D. Sieve analysis of Mangalore Tiles:

Fineness modulus = 6.90

3 MIX DESIGN OF CONCRETE (IS 10262-2019)

3.1 DATA FOR MIX PROPORTION

1. Grade of designation: M40
2. Type of cement : OPC 53 grade
3. Maximum nominal size of Aggregate: 20 mm
4. Exposure condition: Severe
5. Workability :
   i. Slump flow: 760-850mm
   ii. Passing ability by L-box: 0.9 (h2/h1)
   iii. V-funnel flow time: Class V1 (Flow time <8s)
6. Degree of site control: good
7. Maximum cement content: 450kg/m3
8. Type of aggregate: Angular crushed
9. Chemical admixture: Super plasticizer (Polycarboxylate ether- PCE)

3.2 TEST DATA FOR MATERIALS

a) **Specific gravity of cement** : 3.15
b) **Specific gravity of coarse aggregate** : 2.81
c) **Specific gravity of fine aggregate** : 2.74
d) **Specific gravity of admixture** : 1.1
(Polycarboxylate ether- PCE)
e) **Water absorption**
i) **Fine aggregate** : 0.5%
ii) **Coarse aggregate** : 1.0%
f) **Fine aggregate** : Zone II

3.3 QUANTITIES OF MATERIALS (IN kg) REQUIRED FOR 1m^3 OF CONCRETE

Table 2: Quantities of materials

Mix Number	Cement	Fly Ash	GGBS	Fine Aggregate	Coarse aggregate	Mangalore Tiles
1	324	216	0	533.33kg	1124.84	0
2	324	162	54	533.33kg	1124.84	0
3	324	108	108	533.33kg	1124.84	0
4	324	54	162	533.33kg	1124.84	0
5	324	0	216	533.33kg	1124.84	0
6	324	0	216	533.33kg	1012.36	112.49
7	324	0	216	533.33kg	899.87	224.97
8	324	0	216	533.33kg	787.39	337.35
9	324	0	216	533.33kg	674.90	449.94
10	324	0	216	533.33kg	562.42	562.42

4. RESULTS AND DISCUSSIONS

4.1 Mix 1: cement -60%, fly ash 40% and GGBS 0%
Mix 2: cement -60%, fly ash 30% and GGBS 10%
Mix 3: cement -60%, fly ash 20% and GGBS 20%
Mix 4: cement -60%, fly ash 10% and GGBS 30%
Mix 5: cement -60%, fly ash 0% and GGBS 40%

Table 3: Workability Testing

Test	Range as per IS10262:2019	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Slump flow (mm)	760-850	785	795	810	820	830
Passing ability by L-box	0.9 (h_2/h_1)	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
V-funnel flow time (s)	8	7.5	7.2	7.1	6.8	6.5

Table 4: 28 Days Compressive Strength

Mix Number	Average compressive strength (N/mm^2)
Mix 1	43.29
Mix 2	44.19
Mix 3	44.98
Mix 4	48.22
Mix 5	48.59

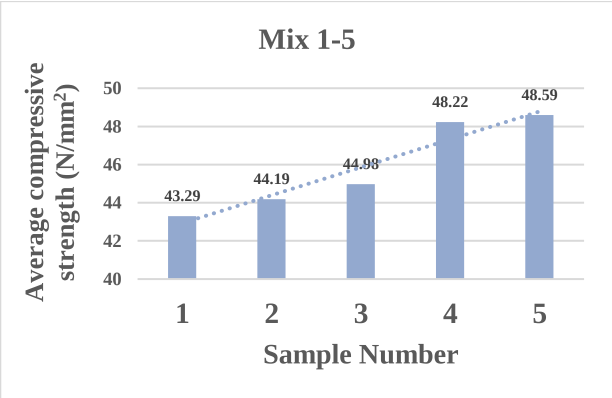

Fig. 1: Average compressive strength (N/mm^2)

4.2 Mix 6: Cement- 60%, GGBS- 40%, Mangalore tiles-10% replacement for coarse aggregate
Mix 7: Cement- 60%, GGBS- 40%, Mangalore tiles-20% replacement for coarse aggregate
Mix 8: Cement- 60%, GGBS- 40%, Mangalore tiles-30% replacement for coarse aggregate
Mix 9: Cement- 60%, GGBS- 40%, Mangalore tiles-40% replacement for coarse aggregate
Mix 10: Cement- 60%, GGBS- 40%, Mangalore tiles-50% replacement for coarse aggregate

Table 5: Workability Testing

Test	Range as per IS10262:2019	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10
Slump flow (mm)	760-850	815	810	785	760	725
Passing ability by L-box	0.9 (h_2/h_1)	Satisfied	Satisfied	Satisfied	Satisfied	Satisfied
V-funnel flow time (s)	8	6.8	7.3	7.8	8.1	8.5

Table 6: 7 Days Compressive Strength

Mix Number	Average compressive strength (N/mm^2)
Mix 6	36.15
Mix 7	35.19
Mix 8	32.96
Mix 9	29.70
Mix 10	28.07

Table 7: 28 Days Compressive Strength

Mix Number	Average compressive strength (N/mm^2)
Mix 6	53.48
Mix 7	52.81
Mix 8	49.19
Mix 9	44.30
Mix 10	43.04

Table 8: 28 days Split tensile strength

Mix Number	Average split tensile strength (N/mm^2)
Mix 6	6.13
Mix 7	5.94
Mix 8	5.54
Mix 9	5.47
Mix 10	5.16

Table 9: 28 days Flexural strength

Mix Number	Average split tensile strength (N/mm^2)
Mix 6	6.93
Mix 7	6.67
Mix 8	6.27
Mix 9	5.87
Mix 10	5.47

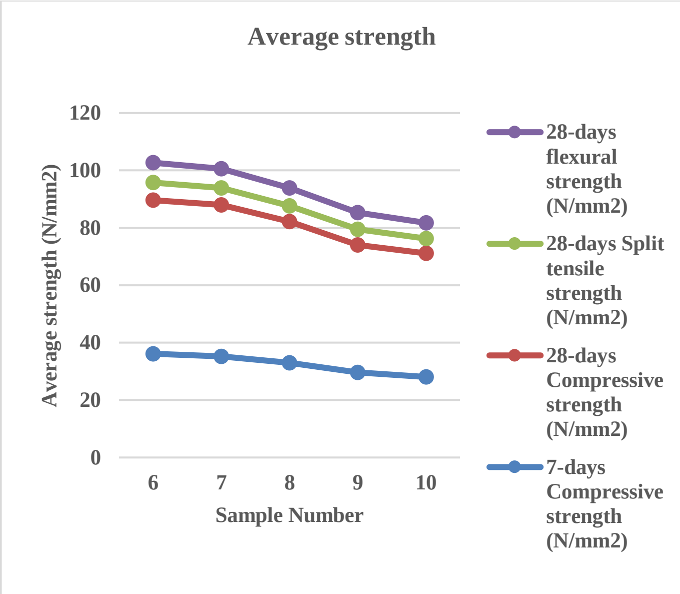

Fig. 2: Average Strength (N/mm^2)

4.3 DURABILITY STUDIES

A. Acid Resistance Test:

Table 10: Acid Resistance Test

Mix	Curing under 5% H2SO4			Curing under 5% H2SO4		
	% wt loss after 14days	% wt loss after 28days	% wt loss after 90 days	% strength loss after 14days	% strength loss after 28 days	% strength loss after 90 days
M5	0.94	1.45	2.40	4.75	10.12	25.62
M6	1.03	1.65	2.76	5.70	12.95	29.46
M7	1.16	1.92	3.26	7.07	16.45	35.94

M8	1.32	2.26	3.88	9.05	22.04	40.98
M9	1.53	2.74	4.92	11.94	30.20	50.81
M10	1.79	3.50	6.35	16.48	36.24	63.51

B. WATER ABSORPTION TEST

Table 11: Water Absorption Test

Mix	% Water Absorption			
	Cube 1	Cube 2	Cube 3	Average
M5	1.27	1.54	1.47	1.43
M6	1.48	1.69	1.94	1.70
M7	2.16	2.45	2.27	2.29
M8	3.42	3.76	3.94	3.71
M9	4.18	4.56	4.89	4.54
M10	6.12	6.54	6.28	6.31

4.5 MATERIAL QUANTITIES AND UNIT RATES

The optimized SCC mix was designed using 60% cement and 40% GGBS as the binder, with 10% partial replacement of coarse aggregate by Mangalore tile waste. The following materials were used in the mix:

For 1m3 of concrete

Table 12: Material Quantities and Unit Rates

No.	Material	Quantity (kg)	Rate (Rs. Per kg)	Cost (Rs)
1.	Cement	324	6.81	2206.44
2.	GGBS	216	4.5	972.00
3.	Super Plasticizer (Polycarboxylate Ether)	6.48	90	583.20
4.	Fine Aggregate	533.33	0.92	490.66
5.	Coarse aggregate	1012.36	0.86	870.63
6.	Mangalore Tiles	112.49	1	112.49
		Total Material cost		**5235.42**

(From all the studies M6 is considered as optimum)

5.CONCLUSIONS

Based on the detailed experimental investigation carried out on various self-compacting concrete (SCC) mixes incorporating GGBS and partial replacement of coarse aggregates with Mangalore tiles, several observations and insights were drawn. The tests were conducted to evaluate the workability, compressive strength, split tensile strength and flexural strength of different concrete mixes. The study aimed to assess the feasibility and effectiveness of using industrial by-products and recycled materials in sustainable concrete production. The following specific conclusions were derived from the experimental results:

1.Optimal Binder Combination: Among the mixes with varying fly ash and GGBS proportions, Mix 5 (60% cement + 40% GGBS) showed the best overall performance in terms of workability and compressive strength, making it the ideal reference mix for further modification.

2.Workability Standards: All SCC mixes up to 30% Mangalore tile replacement met the slump flow, V-funnel and L-box criteria as per IS 10262:2019, indicating adequate flowability and passing ability for practical applications.

3.Compressive Strength Performance: The highest 28-day compressive strength of 53.48 N/mm² was achieved by Mix 6 (10% Mangalore tile replacement), demonstrating that partial replacement can enhance strength up to an optimal level.

4.Strength Degradation with Increased Replacement: As Mangalore tile content increased beyond 30%, a gradual reduction in compressive, tensile and flexural strength was observed due to the rough texture and angularity of the tiles affecting the concrete matrix.

5.Passing Ability Limitations: Mixes with 40% and 50% tile replacement failed the L-box test, indicating unsatisfactory passing ability and reduced suitability for sections with dense reinforcement.

6.Tensile and Flexural Strength Trends: The best tensile and flexural strength values were recorded in Mix 6, while Mix 10 showed the lowest, confirming that 10–

20% replacement offers the best structural performance in terms of crack resistance and load distribution.

7.Early Strength Development: Mixes with up to 30% tile replacement exhibited satisfactory 7-day compressive strengths, supporting their use in time-sensitive construction without compromising early-age performance.

8.Sustainability with Performance: The study confirms that up to 30% replacement of coarse aggregate with Mangalore tiles, along with GGBS as a supplementary cementitious material, offers a sustainable and performance-efficient SCC solution for structural applications.

9.Acid Resistance: The acid resistance of the concrete mixes decreased with increasing Mangalore tile replacement. Mix 5 (0% tile replacement) showed the lowest weight and strength loss over 90 days (2.40% and 25.62%, respectively), while Mix 10 (50% replacement) exhibited the highest degradation (6.35% weight loss and 63.51% strength loss). This indicates that higher tile content adversely affects the long-term chemical durability of SCC in aggressive environments.

10.Water Absorption Behavior: Water absorption increased steadily with the rise in Mangalore tile content, reflecting higher porosity in the concrete matrix. Mix 5 recorded the lowest average water absorption (1.43%), while Mix 10 showed the highest (6.31%), confirming that excessive replacement compromises the concrete's impermeability and durability.

11.Durability Threshold: Up to 20% replacement (Mix 7), the mixes maintained acceptable performance in both acid resistance and water absorption. Beyond this point, especially in Mixes 8 to 10, the deterioration in durability properties was significant, suggesting that 20% is the practical upper limit for Mangalore tile usage in structural applications exposed to aggressive environments.

12.Cost Efficiency: The cost analysis revealed that the optimized M40 grade self-compacting concrete mix, incorporating 40% GGBS as cement replacement and partial substitution of coarse aggregate with Mangalore tile waste, results in a total material cost of Rs. 5235.42 per m^3. This demonstrates that the use of sustainable and recycled materials can produce high-performance concrete while maintaining economic viability, making it suitable for large-scale structural applications with enhanced durability and workability requirements.

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