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EXPERIMENTAL INVESTIGATION OF CONCRETE INCORPORATING MARBLE POWDER, RICE HUSK ASH, AND STEEL SLAG

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ABSTRACT

This study investigates the mechanical and durability properties of concrete incorporating sustainable agricultural and industrial by-products as partial replacements for conventional constituents. Fine aggregate was partially substituted with marble powder to utilize waste from the marble industry, thereby improving particle packing and reducing disposal concerns. Rice husk ash, a pozzolanic material, was employed as a supplementary cementitious replacement to enhance long-term strength and durability. Steel slag was introduced as a partial replacement for coarse aggregate to improve toughness and load-bearing capacity. Concrete specimens with varying replacement levels were cast, cured, and tested, with results compared against control mixes. Compressive and split tensile strengths were evaluated at 28, 56, and 90 days. The results indicated that optimized proportions of marble powder, rice husk ash, and steel slag enhanced mechanical performance, reduced porosity, and improved durability. Overall, the findings highlight that the combined use of these materials supports sustainable construction by reducing natural resource consumption, minimizing environmental impact, and producing eco-friendly concrete suitable for structural applications.

KEYWORDS: Marble powder, Rice husk ash, Steel slag, Sustainable concrete, Waste utilization, Compressive strength, Partial replacement, Durability.

1. INTRODUCTION

Concrete is the most widely used construction material worldwide due to its versatility, high strength, and durability. Comprising cement, fine aggregate, coarse aggregate, and water, it undergoes hydration to form a hard, stone-like mass capable of bearing structural loads. With rapid urbanization and infrastructure growth, the demand for concrete continues to rise. However, the extensive use of cement and natural aggregates has raised concerns about resource depletion, greenhouse gas emissions, and waste generation, underscoring the need for sustainable alternatives that maintain performance while reducing environmental impact.

A promising strategy for sustainable construction is the partial replacement of conventional concrete constituents with industrial and agricultural by-products. This approach not only reduces waste disposal challenges but also conserves natural resources and lowers construction costs. Marble powder, a waste product from the marble industry rich in calcium carbonate, serves as a suitable partial replacement for fine aggregate. Its fine particle size enhances particle packing, reduces voids, and improves strength and durability when used in optimal amounts.

Rice husk ash, an agricultural by-product obtained from controlled burning of rice husks, has emerged as an effective supplementary cementitious material. Its high amorphous silica content provides pozzolanic reactivity, enabling it to react with calcium hydroxide during hydration and form additional calcium silicate hydrate (C-S-H) gel. This contributes to long-term strength and durability while reducing cement consumption and addressing agro-waste management.

Steel slag, a by-product of the steel industry, offers another sustainable alternative as a partial replacement for coarse aggregate. Its high density and mechanical strength enhance toughness, abrasion resistance, and load-bearing capacity of concrete. By integrating marble powder, rice husk ash, and steel slag, a composite eco-friendly concrete can be developed that balances environmental responsibility with structural performance, thereby advancing the concept of green and sustainable infrastructure.

2. OBJECTIVES

1. To evaluate the effect of partially replacing fine aggregate with marble powder on the mechanical properties of concrete, with emphasis on compressive and split tensile strengths.
2. To assess the performance of rice husk ash as a partial replacement for cement and its contribution to strength development and durability.
3. To investigate the influence of steel slag as a partial replacement for coarse aggregate on the toughness and load-bearing capacity of concrete.
4. To determine the optimum combination of marble powder, rice husk ash, and steel slag that yields maximum compressive and split tensile strengths at 28, 56, and 90 days in comparison with conventional concrete.

3. MATERIALS

3.1 Cement: A finely ground binding material, commonly produced from limestone and clay, that hardens in the presence of water. Through the hydration process, it develops a stone-like mass and serves as the primary source of strength in concrete.

3.2 Fine Aggregate: Naturally occurring sand or crushed stone that passes through a 4.75 mm sieve. It fills voids between coarse aggregates, improves workability, and contributes to the overall density of concrete.

3.3 Coarse Aggregate: Gravel or crushed stone retained on a 4.75 mm sieve. It provides bulk, strength, and structural stability to concrete mixtures.

3.4 Water: An essential ingredient that chemically reacts with cement to produce hydration products. It also imparts workability to fresh concrete, ensuring proper placement, compaction, and curing.

3.5 Marble Powder: A waste by-product generated during the cutting and polishing of marble stones. Rich in calcium carbonate and characterized by its fine particle size, it can partially replace fine aggregate, enhancing particle packing and reducing voids in the concrete mix.

3.6 Rice Husk Ash (RHA): An agricultural by-product obtained from the controlled burning of rice husks. Containing high amounts of amorphous silica, it exhibits strong pozzolanic properties, making it an effective partial replacement for cement that improves long-term strength and durability.

3.7 Steel Slag: A dense, durable by-product produced during steel manufacturing in blast furnaces. With high mechanical strength, it is suitable as a partial replacement for coarse aggregate, improving toughness, abrasion resistance, and load-bearing capacity of concrete.

4. EXPERIMENTAL RESULTS

4.1 Compressive strength:-In this test, standard concrete cubes measuring 150 mm × 150 mm × 150 mm are cast and properly cured. After 28, 56 and 90 days of curing, the cubes are placed in a compression testing machine, where a gradually increasing load is applied until failure occurs. The maximum load at failure is then used to calculate the compressive strength of the concrete.

Table 1: Compressive strength results of concrete marble powder as partial replacement of fine aggregate.

Sl.no	% of marble powder	Compressive Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	27.88	30.15	32.46
2	5%	28.99	31.38	33.62
3	10%	30.12	32.53	34.94
4	15%	31.51	34.09	36.55
5	20%	30.45	32.87	35.32

Table 2: Compressive strength results of concrete rice husk ash as partial replacement of cement.

Sl.no	% of rice husk ash	Compressive Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	27.88	30.15	32.46
2	2.5%	28.17	30.42	32.68
3	5%	28.48	30.75	33.04
4	7.5%	28.42	30.69	32.96

Table 3: Compressive strength results of concrete steel slag as partial replacement of coarse aggregate

Sl.no	% of steel slag	Compressive Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	27.88	30.15	32.46
2	20%	30.75	33.21	35.67
3	40%	32.62	35.39	37.83
4	60%	30.11	32.52	34.96

Table 4: Compressive strength results of combined replacement of % of MP+% of RHA+% of SG in concrete.

Sl.no	% of MP+% of RHA+% of SG	Compressive Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	27.88	30.15	32.46
2	% of MP+% of RHA+% of SG	34.74	37.53	40.29

4.2 Split tensile strength: - Split tensile strength is an indirect method used to assess the tensile capacity of concrete, as concrete is naturally weak in direct tension. In this test, a cylindrical specimen is positioned horizontally, and a compressive load is applied along its diameter. The applied load generates tensile stresses within the cylinder, causing it to split along the line of loading. Tests are performed at 28, 56 and 90 days of curing to evaluate the development of tensile strength and observe the cracking behavior of the concrete.

Table 5: Split tensile strength results of concrete marble powder as partial replacement of fine aggregate.

Sl.no	% of marble powder	Split tensile Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	2.75	2.98	3.21
2	5%	2.83	3.05	3.34
3	10%	2.97	3.24	3.46
4	15%	3.18	3.43	3.67
5	20%	3.02	3.28	3.52

Table 6: Split tensile strength results of concrete rice husk ash as partial replacement of cement.

Sl.no	% of rice husk ash	Split tensile Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	2.75	2.98	3.21
2	2.5%	2.89	3.12	3.35
3	5%	3.01	3.24	3.49
4	7.5%	2.82	3.05	3.27

Table 7: Split tensile strength results of concrete steel slag as partial replacement of coarse aggregate

Sl.no	% of steel slag	Split tensile Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	2.75	2.98	3.21
2	20%	3.05	3.29	3.53
3	40%	3.29	3.58	3.81
4	60%	3.01	3.25	3.49

Table 8: Split tensile strength results of combined replacement of % of MP+% of RHA+% of SG in concrete.

Sl.no	% of MP+% of RHA+% of SG	Split tensile Strength Results, N/mm ²		
		28 days	56 days	90 days
1	0%	2.75	2.98	3.21
2	% of MP+% of RHA+% of SG	3.63	3.92	4.37

5. CONCLUSION

1. The **normal concrete without any replacement** achieved a compressive strength of 27.88, 30.15 and 32.46 N/mm² at 28, 56 and 90 days.
2. **Marble powder replacement** showed an increase in compressive strength up to 15% replacement, where the concrete achieved 31.51, 34.09 and 36.55 N/mm² at 28, 56 and 90 days. Beyond 15%, strength slightly decreased.
3. **Rice husk ash replacement** exhibited a marginal improvement at 5% replacement, with compressive strengths of 28.48, 30.75 and 33.04 N/mm² at 28, 56 and 90 days.
4. **Steel slag replacement** improved strength significantly at 40% replacement, achieving 27.88, 30.15 and 32.46 N/mm² at 28, 56 and 90 days.
5. **Combined replacement of MP, RHA, and SG** resulted in the highest compressive strength, with 34.74, 37.53 and 40.29 N/mm² at 28, 56 and 90 days.

6. **The normal concrete without any replacement** achieved a split tensile strength of 2.75, 2.98 and 3.21 N/mm² at 28, 56 and 90 days.
7. **Marble powder replacement** showed an increase in split tensile strength up to 15% replacement, achieving 3.18, 3.43 and 3.67 N/mm² at 28, 56 and 90 days. Beyond 15%, the strength slightly decreased.
8. **Rice husk ash replacement** improved tensile strength at 5% replacement, with values of 3.01, 3.24 and 3.49 N/mm² at 28, 56 and 90 days.
9. **Steel slag replacement** enhanced tensile strength significantly at 40% replacement, achieving 3.29, 3.58 and 3.81 N/mm² at 28, 56 and 90 days.
10. **Combined replacement of MP, RHA, and SG** produced the highest split tensile strength, with 3.63, 3.92 and 4.37 N/mm² at 28, 56 and 90 days.

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